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BULLETIN 99A

GEOLOGY OF NORTHERN NYE COUNTY, NEVADA

(Prepared cooperatively by the United States Geological Survey)

FRANK J. KLEINHAMPL
JOSEPH I. ZIONY

UNIVERSITY OF NEVADA RENO

1985

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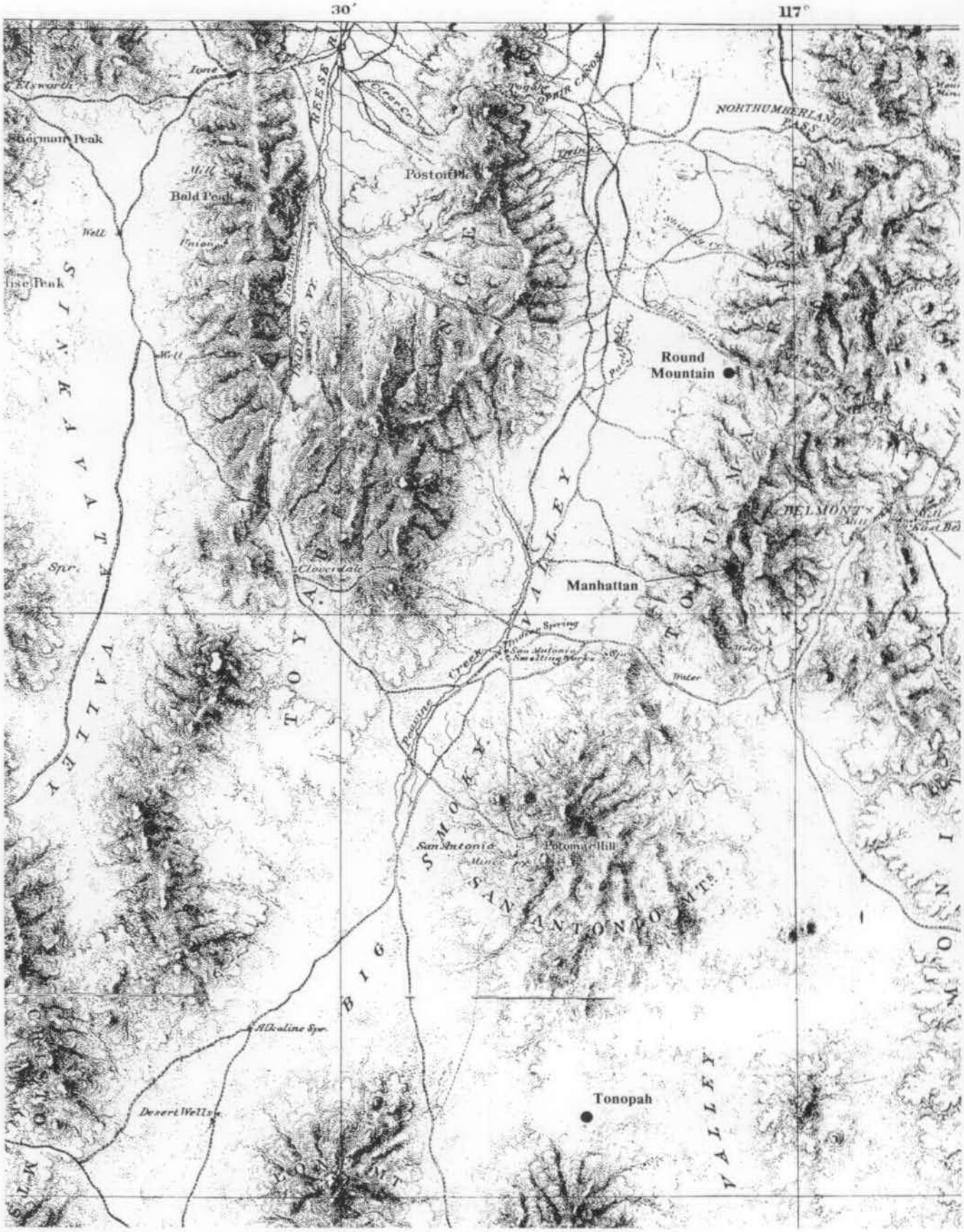

A portion of the map of the Wheeler Survey 1871 expedition, depicting the region of the Utah Territory later occupied by the great mining camps of Manhattan, Round Mountain, and Tonopah, and now encompassed by Nye County, Nevada. Demographic changes in the region since the time of Lt. Wheeler's map chiefly reflect the contribution of mining, a continuing major factor for change and for economic viability. The 38° N Lat parallel lies near the bottom of the illustration and 39° N Lat near the top.

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ABSTRACT

Northern Nye County, that part of Nye County north of 38° N. lat, occupies nearly 11,000 square miles in central Nevada, a region characterized by alternate north-trending bedrock ranges and alluvial valleys. A varied and economically significant suite of mineral occurrences is associated with the complex stratigraphic and structural elements of the area.

Pre-Tertiary rocks of diverse lithologies crop out across the region. Paleozoic marine sedimentary strata predominate in the east and central parts, whereas in the far western part late Paleozoic and Mesozoic marine sedimentary strata interbedded with metavolcanic rocks occur. Most of the Paleozoic strata change in facies from east to west, grading from a mainly carbonate assemblage (platform facies) westward to a mixed carbonate-shale transitional assemblage possibly of back-arc origin. A volcanic-detrital assemblage with near-shore elements dominates the late Paleozoic(?) and Mesozoic sections in the extreme western part of northern Nye County and is possibly of island-arc or back-arc basin origin.

Plutonic rocks crop out in small, widely scattered bodies in the western half and the far eastern part of the area. Most of the plutons are pre-Cenozoic and Cretaceous; however, at least one, in the Toquima Range, is Jurassic, and hypabyssal granitic plutonic masses exposed in the White Pine Range and in the Toiyabe Range and a dioritic body in the Monitor Range have been dated radiometrically as Tertiary.

Tertiary rocks in northern Nye County consist chiefly of widespread and thick pyroclastic material in ash-flow tuff sheets of silicic to intermediate composition. The older tuff sheets, early to middle Oligocene in age, are generally confined to the central and eastern parts of the mapped region. Subordinate andesitic to dacitic lavas and associated intrusive and extrusive masses are intercalated with the tuff sheets near the base of the volcanic section, particularly in the western and northern parts of the mapped region. Mafic lavas also form a thin cap to the volcanic section in large parts of the western region. Less abundant rhyolitic extrusive and intrusive bodies are widely scattered areally and stratigraphically and locally compose the basal rocks. Tertiary sedimentary units representing deposition into small lakes are locally interbedded within the volcanic rocks.

The intermontane valleys generally are filled with Pleistocene alluvial fill locally as thick as a few thousand feet, and are covered with a veneer of Holocene sediments.

A succession of late Paleozoic, Mesozoic, and Cenozoic compressional tectonic events have affected the region. The two oldest recognized events, the late Paleozoic Antler and the early Mesozoic Sonoma orogenies, are characterized by large-scale eastward-directed low-angle faulting. Both events led to the juxtaposition of the diverse Paleozoic facies in the region of the Monitor, Toquima, and Toiyabe Ranges. The western part of the mapped region was imprinted in the late Early Jurassic by the effects of the Nevadan orogeny; folding and thrusting associated with the latter event was directed southward and eastward and was concluded with episodes of high-angle faulting and widespread plutonism. The eastern part of northern Nye County experienced major deformation during Laramide time (Sevier orogeny) in the late Mesozoic. Eastward-directed overturned folds and thrusts that emplace chiefly younger strata on older characterize this event.

Early and Middle Tertiary tectonism is distinguished by widespread volcanism throughout the county that mainly preceded basin-and-range normal faulting. Pulses of volcanism in the Oligocene and Miocene led to the formation of numerous calderas, shield domes, and other constructional volcanic features. The caldera complexes were the sources for the enormous volumes of widespread ash-flow tuffs. Some of the calderas commonly impinge and coalesce with one another to form diversely aged complexes. The later calderas in these places partly obliterate or conceal earlier ones. Scattered west-to northwest-striking faults form lineaments that could represent left-lateral slip during early Tertiary time. The locations and shapes of some calderas appear to be controlled by some of these lineaments. One system of arcuate northwesterly trending strike-slip faults may have sheared apart prior to 19 m.y. ago an inferred major late Oligocene caldron in the northern Reveille Range.

Basin-and-range normal faults, which generally strike north to northeast, represent the latest stage of structural development and account for the present topography. These faults apparently were initiated in the middle Miocene, had major movement in the Pliocene, and have been recurrently active to the present. Uplift of the ranges may have locally generated gravity slides and low-angle faults that place pre-Tertiary bedrock on Tertiary and Quaternary deposits.

The principal metallic and nonmetallic commodities produced in northern Nye County have been gold, silver, lead, molybdenum, tungsten, mercury, petroleum, barite, and magnesite. The volume of magnesite production far exceeds that of any of the other commodities, and its total dollar value ranks among the highest of all the commodities. Copper, zinc, antimony, arsenic, gemstones (chiefly turquoise), brines, talcose minerals, sand and gravel, clay, and dimension stone have been produced in minor quantities. Occurrences of some commodities for which there is no reported production include uranium, vanadium, selenium, manganese, nickel, glass (perlite and pumice), silica, and zeolites. Past fluorspar production has been moderate, but the future is bright for additional discoveries. Large resources of this mineral may exist in at least two areas within northern Nye County, including the Union and Willow Creek mining districts. Large-scale mining of molybdenum by the open-cast mining method has been conducted during the past several years near the Liberty camp, San Antone mining district (Hall property). Similarly, gold and silver is mined from large low-grade bulk-tonnage deposits at Manhattan, Northumberland, and Round Mountain. There is reason to believe that these or similar deposits shall yield considerably more ore than that produced to date. Resources of clay, perlite, pumice, silica, dolomite,

limestone, and dimension stone are extremely large, but are far from potential markets.

Host rocks for the ore deposits in the region are diverse in age and type. Molybdenum has been produced from a Cretaceous alaskitic body, but a large low-grade resource also occurs in Paleozoic strata. Silver, mercury, and lead production has come chiefly from Tertiary rocks, and gold from both Tertiary and Paleozoic rocks. Much gold production has been from deposits formed during Tertiary volcanism, although many other gold deposits are genetically or spatially related to Mesozoic intrusive rocks. Placer gold deposits of Tertiary age yielded much gold at Manhattan and Round Mountain. Fluorspar is most generally spatially associated with Tertiary volcanic rocks, and probably everywhere in northern Nye County is genetically related to Tertiary volcanism. However, exploration may reveal large deposits hosted by underlying Paleozoic carbonate rocks. Magnesite at Gabbs is in a Triassic dolomite host rock.

Nevada's two producing oil fields lie within Railroad Valley. Petroleum production and the known petroleum reserves are small compared to total current production in the United States; however their dollar value is large compared to the dollar value of ore recovered from many mining districts of northern Nye County. Total reserves of about 35 million barrels have been assigned to the Eagle Springs and Trap Spring fields, with that of the Trap Spring field about seven times greater than the other. Unlike the Trap Spring field, production of nearly four million barrels exhausted the ultimate primary reserves, as published, at Eagle Springs. The Eagle Springs field is a complex trap formed through a combination of folding, faulting, truncation, and overlap. Reservoir rocks consist of several units of diverse age and lithology, with lacustrine limestone of the early Tertiary Sheep Pass Formation the most important and representing the source rock as well. Updip truncated parts of Tertiary welded tuff form the reservoir rock at the Trap Spring field, where the oil generally fills fractures. The source of this oil was the Late Mississippian Chainman Shale. The potential for discovery of additional fields in the eastern part of northern Nye County, especially in Railroad, Garden, and White River Valleys, remains good because the same source rocks exist throughout the region. Complex structure will complicate the search, although the conditions for entrapment of oil are more likely to exist under these circumstances.

Although undiscovered metallic and nonmetallic ore bodies probably remain in the mountainous areas, the greatest potential for future large discoveries are possible deposits hidden beneath the alluvial valleys. Sophisticated geophysical, geologic, and geochemical methods will be needed to identify and evaluate potential mineral resources that may be concealed beneath these valleys.

INTRODUCTION

Purpose

This volume, bulletin 99A, summarizes the geology of the northern part of Nye County, an area of approximately 11,000 square miles (28,500 km^2) lying north of lat 38° N. (fig. A1). The southern part of Nye County, an area of about 7000 square miles (18,000 km^2) south of lat 38°, was studied by H. R. Cornwall (1972). Bulletin 99A and a companion volume, bulletin 99B published in 1984, are intended to furnish a base for more detailed geologic studies, which will ultimately benefit the economic growth of the region. Part A contains a geologic map (pl. A1) of northern Nye County as well as an abstract for both volumes. Part B describes the economic geology by focusing on the mineral commodities of the region and the mining districts there. Part B is intended for use with part A—the summary descriptions of geologic settings of mining districts in part B are elaborated upon in part A.

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Appreciation is extended to those residents of northern Nye County who made our work easier and more pleasant by furnishing information, logistical aid, and friendship. Included are Mr. and Mrs. Ollie Simpson, formerly of Adaven; Earl Matney and Mrs. Jean Duhme of Big Smoky Valley; Mr. and Mrs. Lamar Cobb, formerly of Tonopah; John and Eugene Titus, the former a past foreman of the Hot Creek Ranch; Mr. and Mrs. Madison Locke, originally of Lockes Station, on U.S. Highway 6 in Railroad Valley; and V. J. Barndt of Tybo. Specific acknowledgments in appropriate places throughout the text are accorded the various people who have supplied data used in the report.

J. S. Pomeroy and Ronald Willden of the U.S. Geological Survey were briefly assigned to the project in 1960 and their mapping efforts in the Grant and Pancake ranges are gratefully acknowledged.

Other acknowledgments of geologists whose maps we used appear on plate A1. Discussions and correspondence with most of these people sharpened our geologic insight and led to a better product.

Finally, thanks are extended to numerous colleagues in the U.S. Geological Survey, geologists and support personnel (chemists and administrators), who contributed to this project. Special thanks are due H. R. Boyd, who initially collated and tabulated production data for many of the mining districts.

Geography

POLITICAL GEOGRAPHY AND HISTORY

Nye County encompasses approximately 18,000 square miles (46,600 km^2). Until at least 1960 Nye County had the lowest population density of any county in the nation and in 1975, with an estimated population of 5000 (Rand, McNally and Co., 1975), may still retain this position. The county was carved from Esmeralda County in 1864 after a petition, drawn up by residents of the then-thriving mining camp of Ione (Union district), was submitted to Governor Nye, who obviously looked with favor upon a suggestion according honor and a sense of history to his name. Six changes in Nye County's boundaries subsequently occurred from 1865 to 1875 to accommodate developing political interests (Thompson and West, 1881, p. 513).

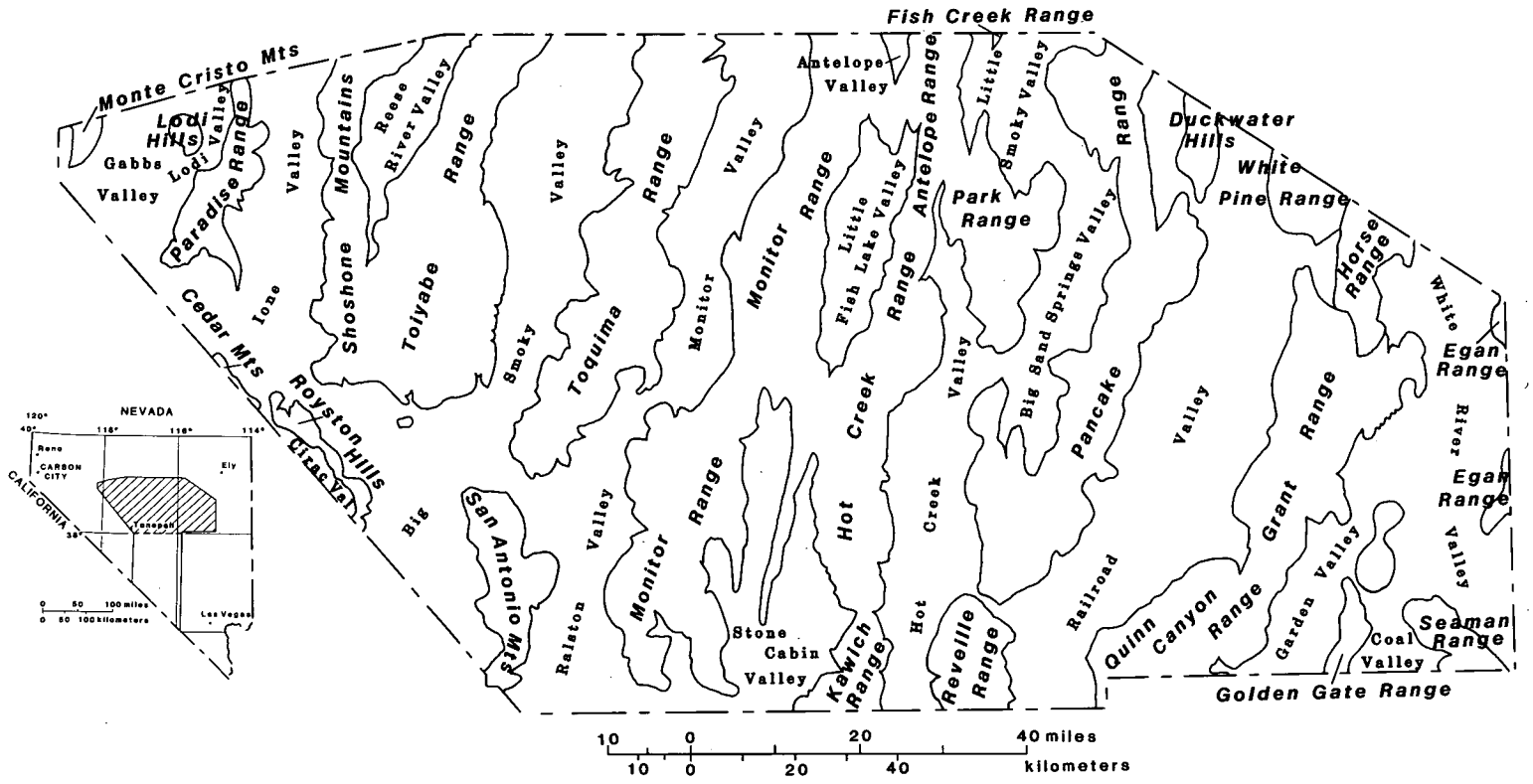


FIGURE A1. Northern and southern parts of Nye County; northern part (hachured) described in this bulletin.

In northern Nye County nearly all the towns and townsites started as mining camps; consequently, many are removed from the principal modern highways along easy travel routes within valleys. This region has only six towns today, which are listed here with their estimated 1975 populations: Tonopah (1716), Gabbs (874), Round Mountain (125), Manhattan (30), Ione (15), and Belmont (about 10). Only Tonopah and Gabbs are on present-day main highways. Tonopah is a regional farming supply center as well as the main stopover point within about 100 miles (~160 km) for highway travelers. Gabbs started in 1941 as a residence for workers of the nearby magnesite mine and remains as such. Even smaller populations than the smallest given above, ranging from a few to a score, intermittently inhabit other old mining camps, including Berlin, Quartz Mountain, Reveille, Troy, and Tybo. Abandoned major townsites include, among others, Morey, Northumberland, Ophir, Grantsville, Pactolis, Downeyville, and Quartz Mountain.

The Duckwater and Yomba Indian reservations (pl. B1) are homes for a few to several hundred Indians (Rand, McNally and Co., 1973, p. 347-348), and numerous ranches lie adjacent to the reservations. Roadside businesses serving travelers outside the major towns are scarce and include Carvers Station, Currant, and Warm Springs.

Numerous forage crop and cattle ranches are strung out along some of the major valleys, as in Reese River and Big Smoky Valleys in the western part of the county and in Duckwater, Railroad, and White River Valleys in the eastern part. All of the spreads are located where water is available. Other more isolated ranches, small and large, are scattered through the region where sufficient water permits some form of agriculture; the largest of the isolated ranches are listed in table A1.

TABLE A1. Main operating solitary ranches in northern Nye County (not including clusters of ranches).[1]

Ranch	Location
Forest Moon (Moon River)	White River Valley
Pine Creek	Garden Valley
Twin Springs	Hot Creek Valley
Hot Creek	Hot Creek Valley
Indian Spring	Little Smoky Valley
Snowball	Little Smoky Valley
Fish Lake	Little Fish Lake Valley
Segura	Antelope Valley
Stone Cabin	Stone Cabin Valley
Hunts	Hunts Canyon, south-central Monitor Range
Pine Creek	Monitor Valley
Barley Creek	Monitor Valley
Wilson (Stoneberger Creek)	Monitor Valley
San Antonio	Big Smoky Valley
Cornell (Moores Creek)	Big Smoky Valley
Peavine	Peavine Creek, Toiyabe Range
Cloverdale	Cloverdale Creek, Toiyabe Range
Nyala	Railroad Valley
Manzoni	Railroad Valley
Currant	Railroad Valley
Uhalde	Quinn Canyon Range

[1]Clusters are chiefly in Reese River and Big Smoky Valleys, along east sides of Railroad and White River Valleys, and in vicinity of Duckwater.

The region is also dotted with numerous cultivated areas and ranch buildings without permanent residents; many of these buildings are parts of larger spreads and serve as temporary quarters for seasonal workers. These ranches included, among others in the 1980's, Clear Creek, Tulle Creek, Potts, Mosquito, Moores Station, and Bellehelen. Many spreads were homesteaded in meadowland areas prior to 1900 or just after World War I; original log, stone, or frame buildings still exist at some of them, such as at Stoneberger Creek (formerly Wilson Creek in Toquima Range), Clear and Tulle Creeks (Monitor Range), Hot Creek (Hot Creek Range), and in Little Fish Lake Valley. Although many of the homesteads are no longer being worked as individual enterprises, most have been patented and the deeded lands are parts of large cattle ranches. Other former homesteads include, in the Monitor Range, those of Daugherty, Wagon Johnnie, and one in Butler Creek whose name is unknown to us; others in the Toquima Range (Meadow and Stoneberger Creeks and Ikes Canyon); and several unnamed places in the Toiyabe and Shoshone Ranges. The residents livelihood has always centered on mining, agriculture, and furnishing hospitality to travelers. Tourism is increasingly beneficial to the region but remains relatively unimportant compared with areas to the north, because only two highways (U.S. 6 and 95) transect the county (fig. A1). In recent years governmental rocket test facilities (Sandia Test Range) have employed people living in Tonopah. General population pressures and land development are changing the economic and social life of the region—the major factor for change is the extensive construction of and plans for electric power transmission grids across the region.

Although overshadowed at times by more recent activities in the county, mining, ranching, and farming remain vital to the economy and continue to develop. Agriculture evolves steadily and strongly, and mining evolves erratically in a manner dictated by commodity prices and national interests.

Since 1960 alfalfa and other forage crops have been intensely cultivated in Big Smoky Valley near Round Mountain (pl. B1). More intensive agriculture is being attempted in Stone Cabin and Railroad Valleys (pl. B1). Mining interest since 1970 is mostly in old mining districts of past importance, such as Ione, Manhattan, Northumberland, Round Mountain, Royston, San Antone, Tybo, and districts in the Paradise Range (pl. B1). In almost all cases, interest centers on copper, gold, silver, molybdenum, tungsten, mercury, diatomite, and magnesite. Additional localities with these metals and a host of other commodities, including nonmetallic materials, receive intermittent attention by claim holders doing annual assessment work, lessees, and speculators. The earliest commercial oil field in Nevada, the Eagle Springs in Railroad Valley, has been supplanted in importance by the nearby newly discovered Trap Springs field. The latter find has led to increased exploration in and around Railroad Valley.

The road net in northern Nye County is considerably more extensive than that shown on the best of Nevada highway maps. Old supply routes, once regularly travelled by freight wagons, pack strings, and possibly stages, include the one between Eureka and Tonopah

extending south through Little Smoky and Hot Creek Valleys. Stops along the way were at Hicks, Pritchards, and Moores Stations. Many of the present-day access roads to mining camps, ranches, or townsites follow the original routes to or through the same places, such as the road across the Toquima Range linking Manhattan with Belmont and that through the Paradise Range linking Downeyville and Ellsworth Station with Ione (now partly rerouted away from Craig Canyon). Except for rugged mountainous parts of the Grant, Quinn Canyon, Monitor, and Toiyabe Ranges, vehicular accessibility to the region is good, especially with four-wheel drive. All roads, including major highways, are subject to washouts that commonly occur during late summer storms. The roads, however, are well maintained and the county highway department deserves commendation for its efforts. Many other roads, built during the mining boom days of the late 1800's, have undergone little or no repair except by an occasional claimant to mining property. Severe storms such as those that occurred in the autumn of 1961 and again in 1983–84 made some canyon-bottom roads impassable for ordinary four-wheeled vehicles.

The actual and potential land uses, such as mining, farming, camping, and hunting, have led to massive efforts in the 1970's to consider environmental protection. It has been proposed, for example, that the Arc Dome area, Toiyabe Range, be placed within the Federal Wilderness system. We do not evaluate the merits of this and similar proposals in this report; however, it seems wise to protect some parts of the mapped region. Numerous very beautiful but fragile mountain and valley environments are so unique or scenic that their preservation may well outweigh their utilization for other purposes.

PHYSICAL GEOGRAPHY

Northern Nye County undergoes four well-defined seasonal changes. Widespread heavy rainstorms are prevalent during late spring (May–June) and late summer (August); intermittent thundershowers are common during the other summer months. Sleety rain (snow in the higher elevations) is not uncommon in early June. Following a cold rain, a hot dry period may last for many weeks. Relief then occurs from scattered afternoon thundershowers that alternate with periods of clear weather. Temperatures in the lower valleys commonly range from about −10°F in many winters (particularly in January) to about 100°F in some summers (particularly in July). In the highest mountainous regions during an average year, snow may last well into July. Such high areas occur in the White Pine, Monitor, Antelope, Toquima, Toiyabe, and Shoshone Ranges. Less commonly, snow may remain throughout the summer in a few ranges, particularly in the Toiyabe Range. Regional snowstorms commonly occur in October, at which time many of the valleys may be blanketed. At this time of year, however, the snow seldom lasts more than a few days at the valley elevations. More generally, October is a very pleasant cool month and an ideal month for geologic field activities in the region.

Chiefly because of the extreme differences in elevation throughout northern Nye County, temperature and precipitation vary widely at any one time within any weather pattern. These localized climatic variations are characterized by much higher rainfall and snowfall (figs. A2 and A3) and lower temperatures in the mountains than in the valleys. Vegetation zones bear this out and, for the mapped region, indicate an annual precipitation in the higher mountains of at least 20 inches (51 cm) per year. Unfortunately, the several climatological recording stations in northern Nye County are mostly in the valleys, and their temperature and precipitation data (table A2) characterize only the lower elevations. Belmont, the highest station at about 7400 feet (2250 m), had 8.53 inches (22 cm) of annual precipitation during the period from 1889 to 1916 (U.S. Weather Bureau records, *in* Eakin, 1962a, p. 4). Maxey and Eakin (1949, p. 18–25) describe variations of temperature and precipitation as a function of elevation for a part of east-central Nevada. In Nye County winter temperatures commonly range from −20°F to 50°F in the intermontane valleys; temperatures at higher elevations can be as much as 20°F–30°F lower. Summer temperatures range from 55°F to 115°F at valley level

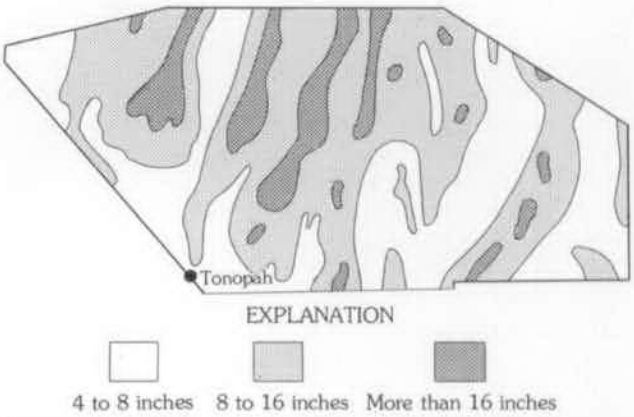


FIGURE A2. Average annual precipitation in northern Nye County. From Houghton, Sakamoto, and Gifford (1975, fig. 40).

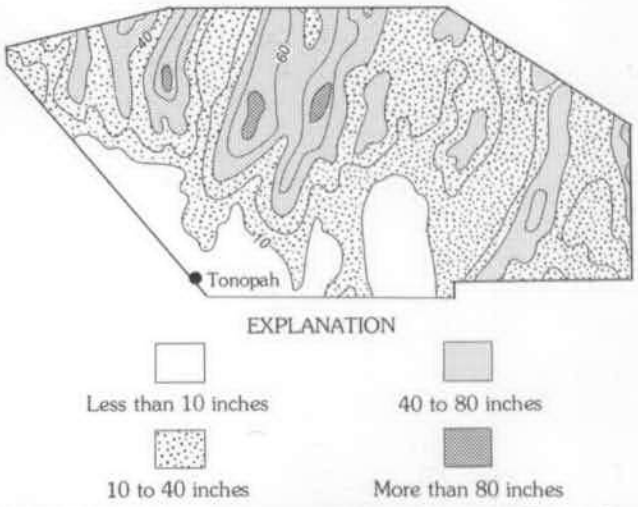


FIGURE A3. Mean annual snowfall in northern Nye County, from 1939 to 1968. From Houghton and others (1975, fig. 52).

TABLE A2. Climatological data from the main recording stations in northern Nye County for selected periods.[1]

Location	Elevation (ft)	Precipitation (normal)[2] (inches) Month Min. (month)	Max. (month)	Annual Range[4]	Normal	Temperature (°F) Normal mean[3] Month Min. (month)	Max. (month)	Annual	Amount and month of highest and lowest mean daily maximum and minimum[5]	
SITES IN VALLEYS										
Big Smoky	(5625)	.3 (Oct.)	.8 (Jan.)	2.5–11.7	5.9	28.9 (Jan.)	71.8 (July)	49.2	90.3 (July)	16.3 (Jan.)
Rattlesnake	(5913)	.3 (June)	.5 (May, Nov.)	2.0–10.8	4.8	29.5 (Jan.)	75 (July)	51.3	90.2 (July)	17.6 (Jan.)
Tonopah[3]	(5426)	.07 (June)	.6 (May, July)	2.5–4.1	3.6					
LOW AREAS IN MOUNTAINS										
Adavan	(6250)	.5 (June)	1.6 (Jan.)	4.4–19.0	12.8	29 (Jan.)	70.2 (July)	48.6	87.4 (July)	18.6 (Jan.)
Snowball Ranch	(7160)	.0 (Oct.)	2.4 (Sept.)	—	[6]11.2	21.3 (Dec.)	64.9 (Aug.)[7]	—		

[1]Except for Snowball Ranch locality, data are from U.S. Weather Bureau.
[2]Climatological standard normals based on period from 1931 to 1960, unless noted otherwise.
[3]For period from 1955 to 1960.
[4]Range is for period from 1951 to 1960, the years for which are not complete at some localities.
[5]Number of years for records vary by location.
[6]1967 only.
[7]July missing; probably warmer in July.

and are as much as 15°F to 55°F less at high elevations. Although verification is difficult, Gabbs and Lodi Valleys, in the western part of the region, are thought to be the warmest and to receive the least precipitation or the least rainfall of any area in northern Nye (see Maxey and Eakin, 1949, p. 22; Eakin and others, 1951, p. 135; and Eakin, 1962b, p. 3, 5). This low precipitation has two basic causes: one, the area lies within the rain shadow of the Sierra Nevada and two, the nearly 5000-foot (1500-m) average elevation of the two valleys is about 500 feet (150 m) less than that of other intermontane basins, except for Railroad Valley (table A3). The absence of high topography in an arc swinging from west to north of the Gabbs and Lodi Valleys probably also aids in effecting warmer summers and winters there than elsewhere.

Houghton and others (1975, p. 27) have noted a more regional pronounced topographical effect on temperatures in Nevada (fig. A4) due to the general rise in elevations of intermontane valleys from southern Nevada to about the latitude of Tonopah (38° N.). These authors indicate that farther north the temperature decline is more gradual and irregular because the valleys exhibit no such regular change as those to the south.

Microclimates, or localized climates, are common in the region and may occur at any elevation. They are a

TABLE A3. Approximate elevation of bottoms of major intermontane valleys, northern Nye County, Nevada.[1]

Valley	Bottom elevation(s) (ft) (approximate average) Overall	South end	North end
Antelope		6800	
Big Smoky		4900	5500
Gabbs	4500		
Garden	5100		
Hot Creek		5200	
Ione		5600	6500
Little Fish Lake		6500	7000
Little Smoky		5900	6800
Lodi	5000		
Monitor		7000	6600
Railroad		4900	5400
Ralston		5300	6400
Reese River	6600		
Reveille	5700		
Stone Cabin	5600		
White River	5200		

[1]Where bottom elevations differ drastically along some long valleys, the extremes are noted.

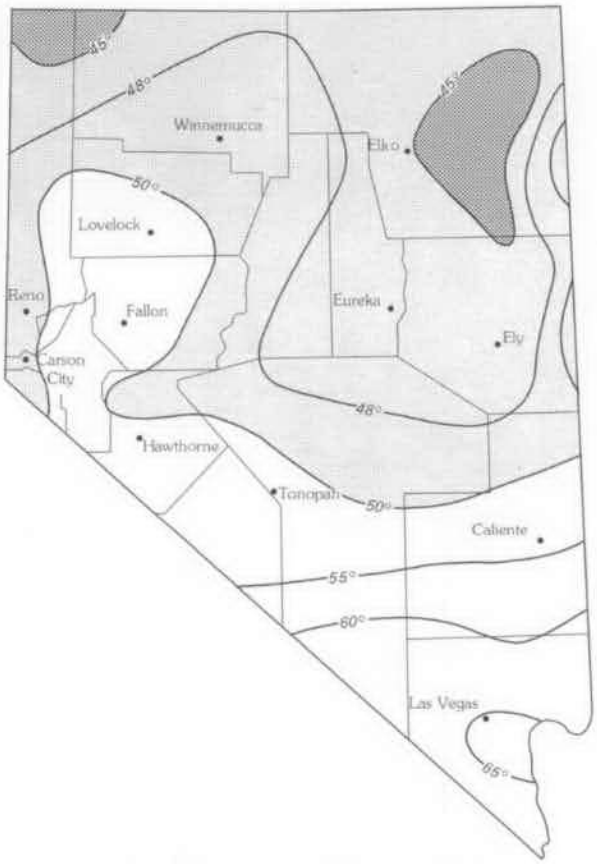


FIGURE A4. Mean annual temperatures in Nevada. From Houghton, Sakamoto, and Gifford (1975).

function of topography but are not necessarily due entirely to elevation. The major influence on microclimates is a combination of sun and slope-facing direction, which control the degree of insolation. Nighttime cold-air drainage commonly creates a microclimate different from that on the surrounding slopes, even though elevations are the same. In the higher, more massive mountains, persistent winds of high velocities during the daytime characterize the area from the crest to somewhat below the crest on the western slope. Primarily by its desiccating action, the wind contributes significantly to localized climates. The microclimates affect vegetation because of their attendant temperature and moisture conditions. The changes wrought on flora by microclimates and differences in elevation are described in the following section.

BIOLOGICAL GEOGRAPHY

Biological geography of the mapped region is incidental to this bulletin; however, because some biological features may be related to the geology, a brief summary follows. For example, plant descriptions and lists (tables A4 and A5) may be a useful guide to the selection of species for geochemical sampling programs. Plants may also be a clue to the kinds of rocks in the subsurface. There is no intent here to describe all aspects of the biological geography of the region.

Vegetation

The following brief summary of vegetation in the mapped region may be augmented by contacting the U.S. Forest Service, an agency of the U.S. Department of Agriculture, whose field personnel are extremely knowledgeable. U.S.D.A. personnel supplied some information used in this bulletin; also, Lindsdale (1952, p. 129–200) provided data concerning the plants of the Toiyabe Range.

A pigmy forest of pinyon pine (*Pinus monophylla*) and juniper (*Juniperus monosperma*) blankets most of the mountainous areas of intermediate elevations in northern Nye County. The forest is absent or only weakly developed along an 80-mile (129-km)-long belt extending northwest from Tonopah parallel to and roughly coincident with the mapped region's western boundary (fig. A1). Paucity of forest here and in the southern parts of the Pancake and Monitor Ranges correlates with areas of low elevation and, presumably, less precipitation and higher average temperatures. Similar conditions exist in the intermontane valleys, which are nonwooded or lightly forested only in their higher parts.

TABLE A4. Plants common to the Grant and White Pine Ranges and adjacent Railroad Valley.

Typical desert vegetation in elevations below 5000 feet (1500 m)	
Atriplex canescens	Fourwing saltbush
Atriplex confertifolia	Shadscale saltbush
Eurotia lanata	Winterfat
Hilaria jamesii	Galleta grass
Species found in foothills and low mountain areas from 5000 to 8000 feet (1500 to 2400 m)	
Ephedra nevadensis	Mormon tea
Pinus monophylla	Single leaf Pinyon pine
Juniperus osteosperma	Utah juniper
Artemisia tridentata	Tall sagebrush
Artemisia arbuscula	Low sagebrush
Chrysothamnus nauseosus	Rabbitbrush
Purshia tridentata	Bitterbrush
Cowania stansburiana	Cliffrose
Wyethia amplexicaulus	Mulesears
Zigadenus elegans	Deathcamus
Prunus virginiana	Chokecherry
Eriogonum heracleoidis	Buckwheat
Balsamorhiza sagittata	Arrowleaf balsamroot
Stypa comata	Needle and thread grass
Sitanion histrix	Squirreltail
Sporobolus airoides	Alkali sacatan
Oryzopsis hymenoides	Indian ricegrass
Cercocarpus ledifolius	Curlleaf mountain mahogany
Species found at elevations above 8000 feet (2400 m)	
Abies concolor	White fir
Pinus aristata	Bristlecone pine
Populus tremuloides	Quaking aspen
Argropyron spicatum	Bluebunch wheatgrass

List prepared by G. E. Baxter, District Ranger, Humboldt National Forest, Ely, Nevada, 1973. Plant list incomplete but representative of designated elevation zones.

TABLE A5. Plants common to the Monitor and Toiyabe Ranges and adjacent Big Smoky and Ralston Valleys.[1]

Common name	Scientific name	Use
	Mountain range plant species	
	Mountain Brush Community (occurs above 8500-ft [2600-m] elevation)	
	Grasses	
Wheatgrass	*Agropyron trachycaulum*	Forage for livestock
	Agropyron subsecundum	Forage for livestock
Lettermans needlegrass	*Stipa lettermani*	Forage for livestock
Needle and thread grass	*Stipa columbiana*	Forage for livestock
Bluegrass	*Poa nevadensis*	Forage for livestock
	Poa secunda	Forage for livestock
	Poa pratensis	Forage for livestock
Spike fescue	*Leucopoa kingii*	Forage for livestock
Brome	*Bromus marginatus*	Forage for livestock
	Bromus porteri	Forage for livestock
Squirreltail	*Sitanion hystrix*	Forage for livestock
Junegrass	*Koeleria cristata*	Forage for livestock
	Shrubs	
Sagebrush	*Artemisia tridentata*	Forage for deer
	Artemisia arbuscula nova	Forage for deer
Curlleaf mountain mahogany	*Cercocarpus ledifolius*	Forage for deer and livestock
Antelope bitterbrush	*Purshia tridentata*	Forage for deer and livestock
Chokecherry	*Prunus virginiana melanocarpa*	(Fruit is edible for man)
Snowberry	*Symphoricarpos oreophilus*	Forage for deer and livestock
Elderberry	*Sambucus gluaca*	Food and cover for wildlife (Fruit is edible for man)
	Forbs	
Lupine	*Lupinus* species	Forage use negligible
Milkvetch	*Astragalus* species	Forage for deer and livestock
Groundsel	*Senecio* species	Forage for deer and livestock
Aster	*Aster* species	Forage for deer and livestock
Bluebells	*Mertensia* species	Forage for deer and livestock
	Trees	
Quaking aspen	*Populus tremuloides*	Poles and fuel
Limber pine	*Pinus flexilus*	Cover and food for wildlife
	Pinyon-Juniper Community (occurs between 6500- and 8500-ft (2000- and 2600-m elevation)[2]	
	Grasses	
Squirreltail	*Sitanion hystrix*	Forage for livestock
Needle and thread grass	*Stipa comata*	Forage for livestock
Indian ricegrass	*Oryzopsis* hymenoides	Forage for livestock
	Shrubs	
Antelope bitterbrush	*Purshia tridentata*	Forage for deer and livestock
Sagebrush	*Artemisia tridentata*	Forage for deer and livestock
	Artemisia nova	Forage for deer and livestock
Cliffrose	*Cowania stansburiana*	Forage for deer and livestock
Rabbitbrush	*Chrysothamnus* species	Forage for deer and livestock
	Forbs	
Lupine	*Lupinus* species	Forage use is negligible
Milkvetch	*Astragalus* species	Forage for deer and livestock
Aster	*Aster* species	Forage for deer and livestock
	Trees	
Pinyon pine	*Pinus monophylla*	Fuelwood, posts, edible fruit
Juniper	*Juniperus osteosperma*	Fuelwood, posts

TABLE A5. Plants common to the Monitor and Toiyabe Ranges and adjacent Big Smoky and Ralston Valleys (continued).[1]

Common name	Scientific name	Use
Valley plant community (Northern Desert Shrub)[3]		
	Grasses	
Galeta grass	*Hilaria jamesii*	Forage for livestock
Squirreltail	*Sitanion hystrix*	Forage for livestock
Indian ricegrass	*Oryzopsis hymenoides*	Forage for livestock
	Shrubs	
Sagebrush	*Artemisia tridentata*	Forage for deer
	Artemisia nova	Forage for deer and livestock
Four-winged salt bush	*Atriplex canescens*	Forage for antelope and livestock
Shadscale	*Atriplex confertifolia*	Forage for antelope and livestock
Bud sagebrush	*Artemisia spinescens*	Forage for antelope and livestock
Rabbitbrush	*Chrysothamnus*	Forage for antelope and livestock
Spiny hopsage	*Grayia spinosa*	No forage value
Horsebrush	*Tetradymia* species	No forage value
Winterfat	*Erotia lanata*	Forage for antelope and livestock
	Forbs	
Globe mallow	*Sphaeralcea coccinea*	Forage for wildlife and livestock
Lupine	*Lupinus* species	Forage use is negligible
Aster	*Aster* species	Forage for wildlife and livestock
Weedy plant species which have invaded disturbed sites in the valleys and foothills		
	Grasses	
Cheatgrass	*Bromus tectorum*	No forage value
	Forbs	
Russian thistle	*Salsola kali tenuifolia*	No forage value
Halogeton	*Halogeton glomeratus*	Poisonous to stock
Important trees and shrubs growing along the stream channels throughout all of the above plant communities		
	Trees	
Birch	*Betula*	Firewood
Cottonwood	*Populus augustifolia*	Firewood
	Shrubs	
Willow	*Salix* species	Holds soil
Rose	*Rosa* species	Holds soil; forage

[1]List prepared by W. E. Hanks, District Ranger, Toiyabe National Forest, Tonopah, Nev., June 1973. Plant list incomplete but representative of designated zones. Includes the more abundant species and those useful to man. The same plants probably are found in the Toquima and Shoshone Ranges and adjacent valleys. Except for the absence of the Mountain Brush Community, the same may be said for the San Antonio Mountains.

[2]Limits of elevation may locally differ from those given.

[3]Primarily refers to the intermontane valleys. Trees are virtually absent; those growing include poplar and apple and were introduced by man.

Other conifers (*Pinus aristata* [bristlecone pine] and *Abies concolor* [white fir]) appear in small concentrations above the pinyon-juniper zone in some of the higher ranges, such as the Grant and White Pine Ranges. *Bristlecone pine* is fairly common in scattered localities high in the Hot Creek, Toiyabe, and White Pine Ranges.

Quaking aspen (*Populus tremuloides*) forms thick stands of large trees in secluded well-watered mountain valleys and forms dense thickets of stunted trees in the higher exposed parts of ranges, as in the Monitor Range above about 9000 feet (2700 m). Locally, large conspicuous stands of aspen appear to be anomalously stunted; for example, a stand at about 8000 feet (2400 m) in the Toquima Range (S12,T11N,R44E and S7,T11N,R45E). Forests such as this and the one on the north flank of Mount Jefferson probably reflect harsh microclimates. Mountain mahogany (*Cercocarpus ledifolius* in the Grant and White Pine Ranges) grows in many of the higher ranges, and especially fine stands may be seen on and west of Morey Peak (Hot Creek Range) and in the Monitor and Shoshone Ranges. Luxuriant stands in and adjacent to North Sixmile Canyon, Hot Creek Range, grow at contrasting elevations; the site at low elevation in the canyon must have a microclimate similar to those at the higher site along the rim of the canyon. Mountain mahogany stands are bordered with and locally intermixed with pinyon pine of the underlying pinyon pine and juniper zone; mountain mahogany vies with aspen as the major tree type just below the timberline. Oak (*Quercus*) is noteworthy for its absence.

A common shrub within the upper vegetation zones of the high ranges is the mountain snowberry (*Symphoricarpos*). Sagebrush (*Artemisia*) is most common in the lower more arid parts of the mountains, and bitterbrush (*Purshia*) and cliffrose (*Cowania*) are present locally. In and adjacent to the mountains, creek bottoms are commonly densely overgrown with quaking aspen, willow (*Salix*), roses (*Rosaceae*), and, locally, chokecherry (*Prunus*). Rabbitbrush (*Chrysothamnus*) fringes these wetter parts of stream bottom lands.

Vegetation types change transitionally from the foothills of the mountains downward across the alluvial fans to the bottoms of the intermontane valleys. Dense to open stands of pinyon pine and juniper fringe many of the valleys, and the trees become more scattered and finally disappear toward the centers of the valleys. Scattered rows and clumps of two kinds of poplar (*Populus*), one the spreading Fremont cottonwood (*P. fremonti*) and the other a tall compact variety similar to the eastern or European poplar, dot the valley bottoms adjacent to ranches and cultivated fields. Except for these and very rare, small deciduous orchards, the broad central parts of the intermontane valleys are largely devoid of trees, and the vegetative cover consists of low shrubs, herbaceous plants, and grasses. Contrary to popular belief, sagebrush is not everywhere the main cover in the intermontane valleys. Sagebrush is commonly, but not invariably, dominant on the slopes and low hills fringing the main valleys and throughout large parts of some of the higher valleys such as the Antelope, Little Fish Lake, and probably Monitor Valley and Reese River Valleys. But in Big Smoky, Ione, Gabbs, and Ralston Valleys and probably Garden, Stone Cabin, and Railroad Valleys, other xeric plants such as blackbrush (*Coleogyne ramosissima*), horsebrush(?) (*Tetradymia*), and several varieties of saltbush (*Atriplex canescens* and *A. confertifolia*, among others) dominate the shrub cover. Here, sagebrush may be conspicuous by its absence, as in Gabbs Valley and the lower reaches of Big Smoky Valley. At the latter place, Indian ricegrass (*Oryzopsis hymenoides*) is an important part of the plant cover.

White sage (*Salvia* sp.) is widely scattered in some of the valleys and on the lower slopes of mountains in the north-central part of the mapped region, for example between the Monitor and Pancake Ranges. Locally, it is the dominant species in Little Smoky and Antelope Valleys. This low, silvery-gray plant is conspicuous by virtue of its color and appears to grow on relatively undissected flat and gently sloping surfaces. Elsewhere in northern Nye County, the sagebrush is more typical and consists mainly of big sage (*Artemisia tridentata*) and perhaps other varieties with the familiar grayish-green color, such as *A. arbuscula*. Mature sagebrush ranges in height from about 1 foot (.3 m) under poor growing conditions to as much as about 8 feet (2 m) under ideal growing conditions (nearer water).

Playas are commonly barren of vegetation but are rimmed successively outward with pickleweed (*Allenrolfea*) and saltgrass (*Distichlis*). The saltbush (*Atriplex*), shrubby phreatophytes greasewood (*Sarcobatus vermiculatus*), and rabbitbrush (*Chrysothamnus*) may also form partial zones around the playas and are very common elsewhere around springs.

Herbaceous plants and grasses of many different kinds are abundant in the valleys and mountains. Tables A4 and A5, prepared in 1973 by district rangers Garth E. Baxter (Humboldt National Forest) and W. E. Hanks (Toiyabe National Forest) (oral commun., June 1973), list some of the representative species of grasses as well as other kinds of vegetation for various altitude zones in the eastern and western parts of the mapped region.

Mammals, Birds, and Fish

Mammals and birds in northern Nye County are typical of the Great Basin deserts and mountains. Of special note are antelope, which were introduced into the region and are seen (rarely) in foothills bordering Railroad Valley and in Little Fish Lake Valley. Mountain lion probably inhabit all the major ranges and have been seen in the Grant, Quinn Canyon, and Hot Creek Ranges. The chukar partridge is scattered throughout the region, whereas sage hen commonly exists only in the high mountains and valleys in and west of the Monitor Range. Golden eagles are especially prevalent in the northwestern region, particularly in the Big Smoky and Reese River Valleys, where there is extensive cultivation. Beaver were abundant in years past, as evidenced by old ponds, dams, and downed trees along aspen-forested perennial streams in the Hot Creek, Monitor, and Toquima Ranges. One old, large beaver,

still living in an extensive system of ponds in Clear Creek, Monitor Range, was last observed in the mid-1960's. Trout are present in most of the permanent streams of the region and are stocked in some that are within popular camping areas, such as Clear Creek and Peavine Creek. Dace, relict fish of the Pleistocene, were recently discovered and described by E. H. McKee and Robert Brown (oral commun., Sept. 3, 1975) in the waters adjacent to Dianas Punch Bowl, Monitor Valley.

GEOMORPHOLOGY

The northern part of Nye County lies near the center of the Great Basin section of the Basin and Range physiographic province. Within this section, subparallel north-trending elongate mountain ranges rise abruptly from and are separated by broad intermontane valleys. The ranges and intervening valleys of northern Nye County exhibit what may be the most regular repetitive topographic pattern in all of the Great Basin, with a slightly east of north trend to the major topographic elements.

The relative uplift of the present-day ranges above the intermontane valleys was caused by Cenozoic basin-and-range faulting that attained great magnitude in the middle to late Tertiary and has not yet ended. The general form of the present-day ranges had already been established by the Pleistocene, and especially by the late Pleistocene, as determined from the disruption of once-continuous Tertiary volcanic rock units, late glaciation in a few of the highest ranges, and the confinement of late Pleistocene lakes to intermontane valleys. The geographic discontinuities in the form of the ranges appear to be a function of the basin-and-range structure as well as of Tertiary cauldron boundaries, and perhaps even of deep-seated pre-Tertiary structures. Proposed lateral movement in the Tertiary along east- to northwest-striking lineaments (Ekren, Quinlivan, and Marvin, 1974; Ekren, Rogers, and Dixon, 1973; Lumsden, 1964, p. 156, 159–163) may also account for some of the discontinuities.

Water Erosion Features

DRAINAGE

Interior drainage characterizes most of northern Nye County (fig. A5). Only the White River Valley in the east exhibits exterior drainage, and that is southward to the Colorado River via the Muddy River. The main drainage in many of the intermontane valleys parallels the north-striking valleys and is commonly ephemeral and partly submerged. Major downcutting of Hot Creek across the Hot Creek Range is probably mainly Pliocene, as is the major downcutting of streams across indurated fanglomerate and pre-Quaternary bedrock in the lower reaches of major canyons in the Grant, Quinn Canyon, White Pine, Toquima, and Toiyabe Ranges. Pleistocene erosion and canyon formation is discussed in the section on Glacial Geology. Incised gorges are typified in the Toquima Range (fig. A6), where gorge depth and width average about 75 and 100 feet (23 and 30 m), respectively, with a maximum width of about 400 feet (120 m). Moores Creek Canyon and the unnamed canyon with several branches about 4 miles (6 km) north in the Toquima Range are excellent examples. The gorges in the Grant and White Pine Ranges have somewhat smaller dimensions (pl. A1). The morphology of the canyons identified above in the Toquima Range follows.

The extreme headwaters of these canyons are in a steep, V-shaped, youthful stage of development. Mid-reaches are impressively broad and well incised down through gravels into bedrock and yield downstream to a progressively broader valley bottom. At some point, out into where the fanglomerate and gravel apron envelopes the bedrock of the range, the broad form of the canyon abruptly ends in a minor incised V-shaped gorge or a shallow braided pattern on a large gravel fan. The deep broad reaches of channels cut in fans composing the upper parts of alluvial slopes in Big Smoky Valley were termed "trenched streamways" by Meinzer (1917, p. 45–47). Some of the best examples of major deep canyons that pass outward from the ranges into broad gorges, cut in part into bordering fanglomerate and alluvium, include several canyons along the east side of Reese River Valley; the upper 10–12 miles (16–19 km) of the Reese River, and Peavine Creek, Toiyabe Range; Ikes, Jefferson, and Moores Creek Canyons, Manhattan Gulch, and several other unnamed canyons on the west side of the Toquima Range; Big Spring, Sherwood, and Ox Spring Washes, and Rimrock and Scofield Canyons, Grant Range; many canyons in the Quinn Canyon Range, and Broom Canyon, White Pine Range. These canyons range in length from about 3 to 12 miles (5 to 19 km). In some canyons, broad terrace remnants of alluvial gravels (including fanglomerates) are preserved. A few Pleistocene vertebrate fossil localities in the gravels attest to the longevity of at least some of the stream systems. This is not to imply that the present Holocene systems have precisely retained their ancestral forms from the Pleistocene. The modern, largely intermittent streams have contributed debris not only to present stream courses but also to what we believe are long-lived fans whose ancestral forms may date from the Pleistocene. The older gravels (including the pre-Pleistocene fanglomerate of the Broom Canyon area, White Pine Range) commonly cap pedimented Paleozoic rocks, tending to fill old topographic lows and to smooth out the topography. Many of the canyons mentioned above dissect the older gravels and the old pediment surfaces; rejuvenation is a result of changes in base level (see the section of this bulletin on Manhattan District and Adjoining Areas—Geologic Setting). Other major long and deep canyons comparable in magnitude to those mentioned above are cut in some of the ranges, but gravel terraces are absent, perhaps because steep gradients, high relief on canyon walls, and heavy precipitation would have destroyed them even if any were originally deposited.

Hot Creek (a major incised stream whose headwaters lie in Little Fish Lake Valley) flows southward through

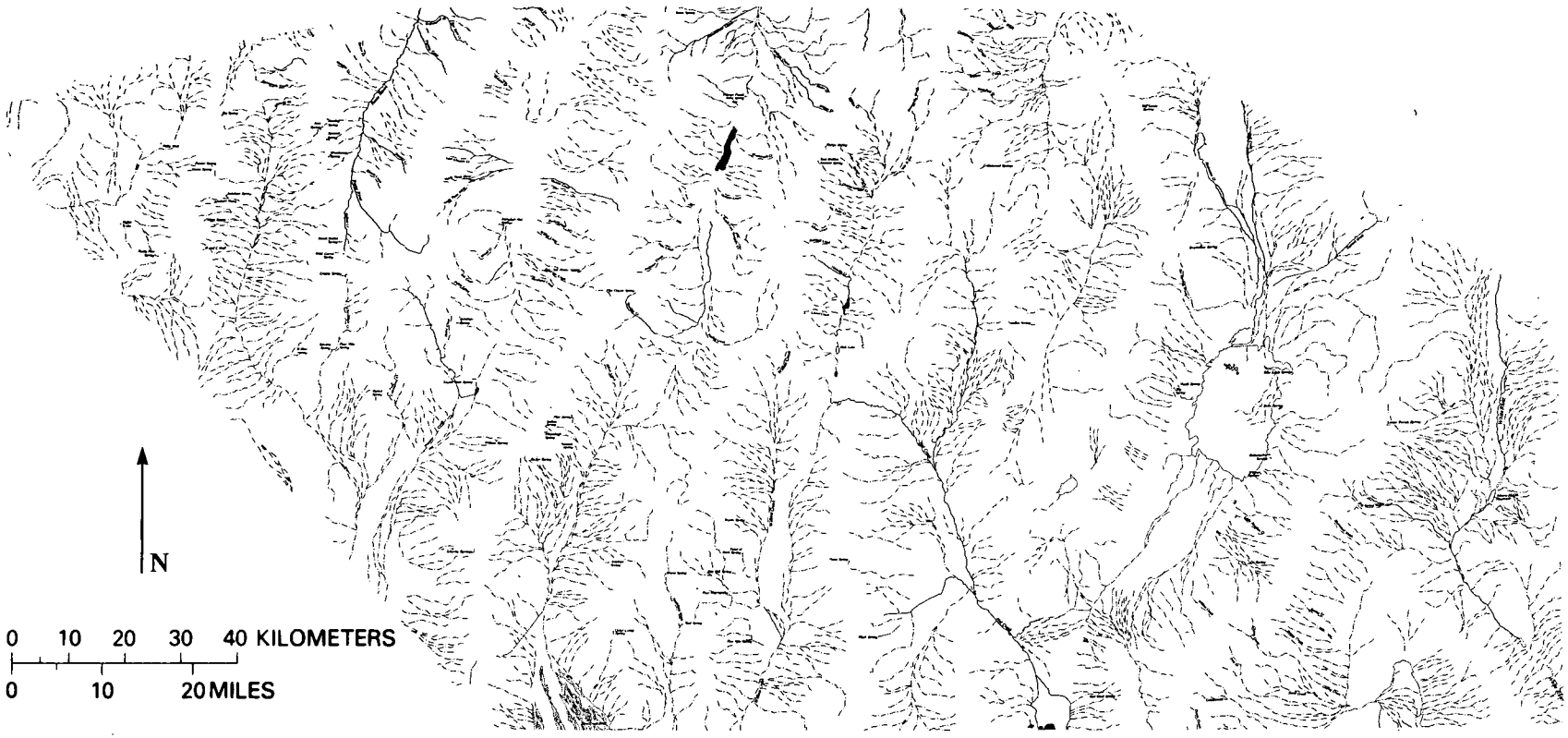


FIGURE A5. Pattern of major drainage in northern Nye County.

FIGURE A6. Incised gorges along west side of Toquima Range, south of West Northumberland Canyon, Nye County. U.S. Geological Survey photograph no. 13369, Western U.S. Project 109, strip 79, roll 106.

a 100-foot (30-m)-deep, 4-mile (6-km)-long gorge (Little Fish Gorge) cut in dense welded tuff; it then abruptly turns eastward and flows transversely across the Hot Creek Range for 7 miles (11 km). Upon emerging, it becomes ephemeral and partly submerged in its passage across Hot Creek Valley to near the topographic break between the Reveille and Pancake Ranges, before sinking into the alluviated Railroad Valley. In crossing the Hot Creek Range, the stream flows through a 1000-foot (300-m)-deep canyon that exposes the major north-trending structural grain in the Paleozoic rocks. It is doubtful that the present volume of water, even in flood, could have scoured the stream's course through the incised gorges. In fact, the stream appears to be aggrading locally; in its upper reaches, in Little Fish Gorge and Little Fish Lake Valley, are several lakes, in part ponded by gravel fans issuing from side canyons.

One aspect of the drainage pattern in northern Nye County holds special interest. A west-northwest-trending straight line, about 50 miles (80 km) long and transverse to trends of valleys and ranges, demarcates the approximate drainage divide in several intermontane valleys, including Stone Cabin, Little Fish Lake, Monitor, and Big Smoky (fig. A5).

TABLE A6. Major streams in northern Nye County, Nevada. Listed within each group in order of declining water volume unless otherwise noted.

Perennial throughout most of stream course
North Twin and South Twin Rivers
Peavine Creek
Ophir Creek
Currant and Duckwater Creeks[1]

Perennial throughout in most years[2]
Jett Creek
Indian Creek?
Cottonwood, San Juan, Washington, and Tierney Creeks
Pine Creek (Toquima Range)
Stoneberger Creek
Barley Creek?
Pine and Cottonwood Creeks (Quinn Canyon Range)
Bowman Creek
Jefferson, Meadow, Moore, and Shoshone Creeks
Creek in Hunts Canyon? (Monitor Range)
Barker Creek?
Clear Creek (Monitor Range)
Danville Creek
Mosquito Creek

Streams intermittent in part of course in many years[3]
Butler and Willow Creeks (northern Monitor Range)
Copenhagen Creek
Cottonwood, Snowball, and Willow Creeks (Antelope Range)
Cloverdale Creek
Andrews Creek
Corcoran Creek
Creek in Sixmile Canyon (Hot Creek Range)
Creeks in Grant, Irwin, and Troy Canyons (Grant Range)
Cherry Creek?
Big, Deep, Hooper, Willow, and Ox Spring Creeks (Quinn Canyon Range)
Creek in Water Canyon (Quinn Canyon Range)
Willow Creek (southern Monitor Range)
Creeks in McCann, White Rock, and Wildcat Canyons (Monitor Range)
Clover, Dobbin Summit, Savory, and Stargo Creeks
Creek in Manhattan Gulch (Toquima Range)

Perennial streams in upper part of courses; submerge, becoming intermittent, in valley-fill deposits along part of course (lack of flow due in part to local withdrawals of water for irrigation)—special class of major streams
Reese River
White River[4]
Hot Creek

Streams with largest discharges in the region, listed in approximately declining volume[5]
Reese River
North Twin and South Twin Rivers
Peavine Creek
White River?[6]
Ophir and Jett Creeks?[6]
Hot Creek
Currant and Duckwater Creeks?[6]

[1]Measurements given (Maxey and Eakin, 1951, p. 142–147) indicate that these streams may have similar discharges: 4650 and 5430 acre-feet for 1914–1915 and 1916–1917 years, respectively, for Currant Creek and 5700 acre-feet (1915–1916 year) for Duckwater Creek. Flow of latter, however, is much more regular and in some high runoff years may be less than that of Currant Creek.

[2]Order of declining volume is less certain in this list. Queries mark the streams with most seriously questioned position.

[3]Magnitudes of discharge not known to the authors, so only a crude order of declining volumes is implied. Streams believed to be smaller in general than those in preceding lists.

[4]Average flow near Preston is about 2 second-feet, and measured flows below the confluence with Ellison Creek near U.S. Highway 6 include a 44.0 second-foot maximum in 1914 and a 1.85 second-foot minimum in 1937 (Maxey and Eakin, 1949, p. 15).

[5]List includes only those whose positions in list are least questionable.

[6]Position very uncertain.

Streams in northern Nye County are chiefly intermittent and some are ephemeral, as is common in semiarid regions; however, some water courses out of the higher ranges contain perennial streams (table A6). Even some of the streams listed as intermittent are permanent in parts of their courses, especially toward their headwaters.

Streams with the largest drainage basins are approximately the same ones listed in table A6 as having the largest volumes of water, such as the Reese and White Rivers in intermontane valleys and Peavine Creek and Twin Rivers in the mountains. All the largest streams are fed by mountain waters. In some streams, a few springs contribute most of the water; the best example of this is Duckwater Creek, fed mainly by the large flow of Big Warm Spring (14 second-feet discharge; Maxey and Eakin, 1951, p. 134).

The mountain streams commonly disappear into the alluvium (fanglomerate) near the edges of the valleys, but during storms and the spring thaw, many of the larger streams carry water their full length, dumping it into playa lakes in the valleys.

PLAYAS AND ASSOCIATED LAKES

Single and multiple playa lakes lie in low parts of most of the large intermontane valleys. The lakes are commonly ephemeral and dry up during normal summers, but occasionally vestiges remain year round, especially in Little Fish Lake Valley and Moore Lake (Meinzer, 1917, p. 41, 43, and pl. 2) about 6 miles (10 km) northeast of Darroughs Hot Springs in Big Smoky Valley. Moore Lake, a Holocene ephemeral (playa) lake, is a relict of Pleistocene Lake Toiyabe and may be alternately wet or dry for many years. The ephemeral and permanent lakes that are strung out northward like beads on a string in Little Fish Lake Valley are especially interesting because the valley lacks interior drainage and drains southward through Hot Creek. Little Fish Lake, the middle of three lakes, clearly owes its presence to a small alluvial fan that dams the lake and blocks the narrow main drainage gorge at the south end of Little Fish Lake Valley. The alluvial fan originates mainly from Horse Canyon on the west side of the narrow main gorge. The two other lakes, including one to the south at Squaw Flat (Morey Peak

15-minute topographic quadrangle) and Upper Fish Lake to the north, also probably owe their existence to similar but broader and less obvious obstructions on the south sides of the lakes. Shoreline features are not well developed because these lakes are small and, when reduced further in size by climatic conditions, shoreline and bottom structures are obliterated by grazing cattle. The presence of at least two terrace levels in the area suggests that relict shoreline features of any Pleistocene lake that might have existed here have been partly removed by erosion. The three lakes themselves are believed to be relicts of a larger Pleistocene lake.

Pluvial lakes, once present in Railroad and Big Smoky Valleys, left wave-cut features, hooked spits, bars, and numerous beaches that are still well preserved (fig. A7). The lakes are briefly described in the section of this bulletin on Glacial Geology.

ALLUVIAL FANS

The intermontane valleys of northern Nye County are currently receiving detritus from talus and from fans built by streams disgorging from canyons in the surrounding mountains. Encroachment of the fans in some of the valleys, especially Little Fish Lake Valley, has obliterated nearly all the flat areas that are typically central to intermontane valleys and in which the finer grained alluvium and lacustrine material were deposited. A similar convergence of fans has taken place on a grand scale throughout much of Garden Valley and has affected large parts of some of the other valleys, including Hot Creek, Ione, and Reese River Valleys. Meinzer (1917, p. 24–29) described some of the fans in Big Smoky Valley.

The fans range from less than 400 feet (120 m) to about 2000 feet (600 m) in height. Except for the correlation of some of the very high large fans with the position of range-front faults, the height of fans generally has not been related to the presence or absence of such faults in the fans' vicinity. The extreme bulk of some fans, such as the 1200-foot (360-m)-high fan off Broom Canyon, White Pine Range, and the one off Kingston Canyon, Toiyabe Range, can be attributed partly to their longevity. These fans undoubtedly include several ages of gravels and thereby reflect several stages of development.

The size of the greater than 1200-foot (360-m)-high fan near Park Canyon, Toiyabe Range, may not indicate great age, but rather that the source area was able to yield vast amounts of debris. The relief here is extreme and precipitation is heavy. Other fans as much as 2000 feet (600 m) high (the highest known in the mapped region, located off the southern Grant Range) and several as much as 1200 feet (360 m) high probably owe their enormous size to a combination of age and (or) abundantly available debris. Included in this group are fans off the Cedar Mountains and the Toiyabe, Toquima, and Hot Creek Ranges. These large fans and another group about 800 feet (240 m) high commonly lie off those parts of ranges demarcated by basin-and-range normal faults along the range front.

Numerous fans in the 800-foot (240-m) category lie along the east side of Railroad Valley and off the flank of Morey Peak, Hot Creek Range. They are believed to be chiefly Quaternary; others elsewhere probably have composite ages that encompass the late Tertiary and Quaternary. Some of those in Little Fish Lake Valley may intertongue with Tertiary tuffs and fossil-mammal-bearing tuffaceous sedimentary strata.

Wind Deposition and Erosion Features

Wind action has affected all the intermontane valleys of northern Nye County to differing degrees. Deflated areas are perhaps best developed and can be readily seen in parts of Gabbs, Big Smoky, Railroad, and Ralston Valleys, where there are minor local deflation basins (blowouts) and accumulations of sand in solitary dunes and dune fields (fig. A8), as well as high on the flanks of mountains. Desert pavements are well developed locally, as along U.S. Highway 6 east of Tonopah in Ralston Valley.

There are several types of sand dunes in the valleys, and most may be seen in the dune field 12 miles (19 km) north-northwest of Tonopah (area labelled "Crescent dunes," pl. A1; fig. A8). The only stationary dunes known in the mapped region are found here. They range in height from about 80 to 240 feet (24 to 73 m) and are clustered in a 2-square-mile (5 km^2) dune field chiefly composed of much lower transverse dunes. Travel here, as in other sandy areas, is especially difficult, if not hazardous. Another dune locality with barchanlike and transverse dunes lies 13 miles (21 km) north of the crescent dunes area at the San Antonio Ranch (fig. A8). Vast sandy tracts of dunes in western Gabbs Valley, southern Ralston Valley, and parts of Railroad Valley also make travel difficult. Parts of the Monte Cristo Mountains, Lodi Hills, extreme southern part of the Monitor Range (vicinity of the Ellendale mining district), Pancake Range, and Quinn Canyon Range are partly covered by sand. We were unable to determine whether range exhumation or burial prevailed in this area but judged that the processes were alternating from time to time and place to place. Climbing dunes and blow sand on the slopes of bedrock hills near Ellendale suggest that the hills are perhaps being buried by fine sand winnowed out of Ralston Valley. Many of the dunes in Railroad and Big Smoky Valleys are supplied with sand from the old beach and near-shore bottom deposits of now desiccated Pleistocene lakes (fig. A8). The dunes are concentrated close to the source of sand. Isolated small areas elsewhere in the bolsons of the mapped region similarly receive their sand supply from nearby Pleistocene lacustrine deposits. The blown sand high on the slopes of the Pancake Range west of Duckwater is more difficult to relate to Pleistocene lake deposits, but such a source, perhaps in Railroad Valley, appears most logical.

The age of the sand deposits is uncertain. If they are aggrading, they could be Holocene; if they are eroding, they could be pre-Holocene. The deposits west of Duckwater and the even thicker accumulations to the north in

the vicinity of Brown Summit probably are related to the pre-Holocene Quaternary pluvial environment in Railroad Valley.

A group of unique aeolian features can be seen on black and white aerial photographs of Railroad Valley (fig. A9). They consist of north-trending and north-apexing swaths impressed on a nearly flat part of the valley. David H. Scott (oral commun., June 26, 1973), who made a brief field examination, reported that they are composed of fine-grained sand. About five swaths can be seen on the aerial photographs; three are about ½ mile (.8 km) long, and the others are far larger. The largest swath (no. 1, fig. A9) is 8 miles (13 km) long and a little over 1 mile (1.6 km) wide at its maximum; the next largest (no. 2, fig. A9) is 4 x ½ miles (6 x .8 km). Since swaths crosscut most other geomorphic features, such as modern drainages and a Pleistocene(?) beach, they must be related to quite recent wind action.

The geometry of the swaths is intriguing; the two largest ones narrow markedly over about one-third of their length. The largest swath is also slightly arcuate in plan, but the others are straight and more nearly bilaterally symmetrical. Each of the larger swaths appears to be circumscribed by a narrow belt of deeper fine-grained

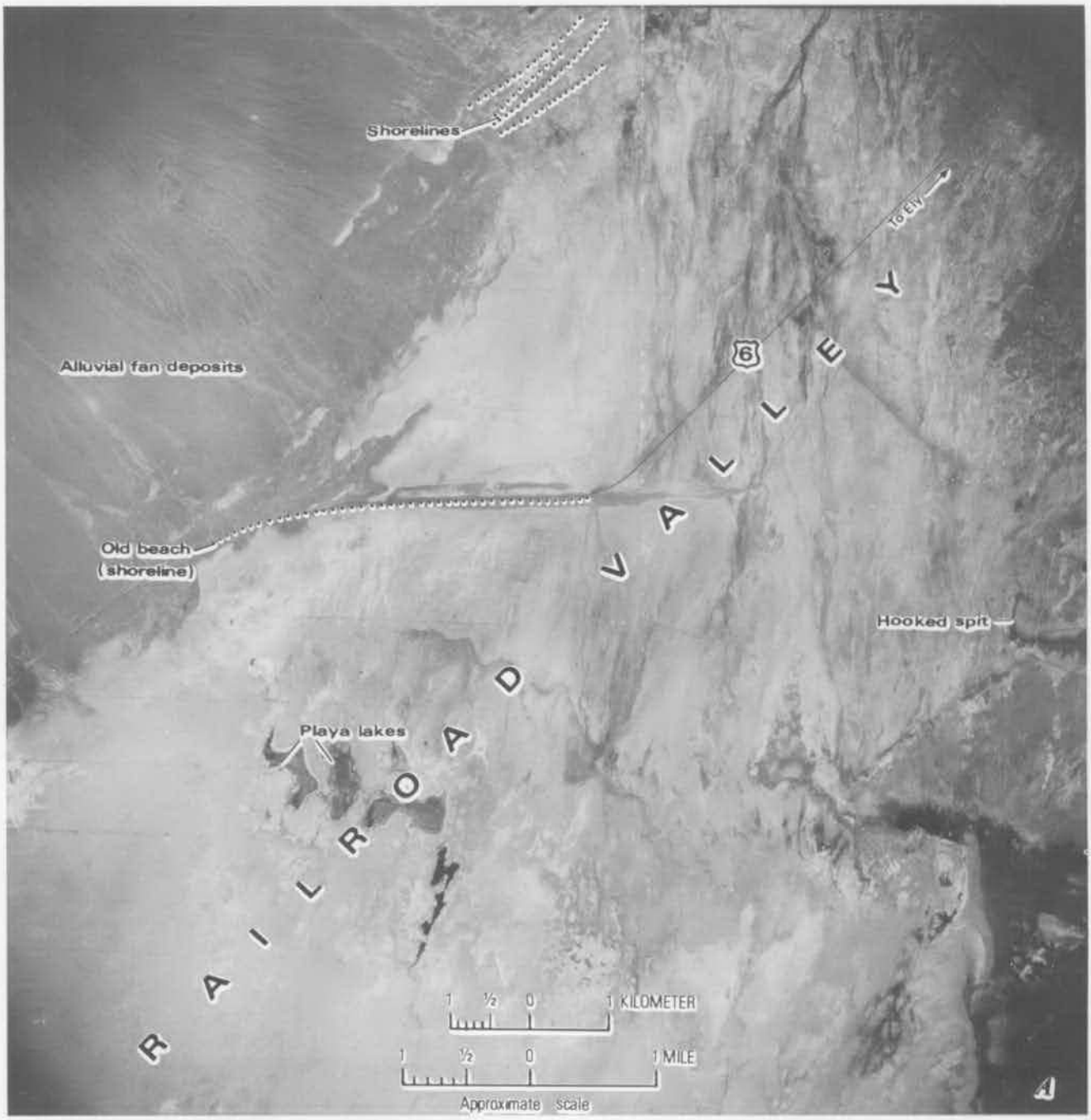


FIGURE A7. Landforms that resulted from pluvial lakes in Railroad Valley. A, light area covering most of photo is silt of lacustrine origin, modified by wind. B, beaches (old shorelines) that resulted from pluvial lakes in Big Smoky Valley. *A*, U.S. Geological Survey photograph no. 15835, Western U.S. Project 109, strip 83, roll 125. *B*, U.S. Geological Survey photograph no. 15496, Western U.S. Project 109, strip 77, roll 123.

sand bent through a sharp apex on the north. A contrasting gray tone between the interior and exterior of the swaths defines the belts on the photographs. The belts and the swaths gradually become too diffuse to recognize southward, but the belts appear not to have had closure.

David H. Scott (oral commun., June 26, 1973) visited the area of the swaths, confirmed their depositional nature, and suggested a genetic relation to a postulated wind channel that would have carried sand down from the north. This weakly supported hypothesis would allow the swaths to be classified as a type of barchan dune; in this event, wind would have had to sweep from the north. It is true that Railroad Valley narrows at this point, but constant southward- or northward-sweeping winds were not noted; if such a wind pattern exists, it has left no other obvious traces.

Kleinhampl suggests the possibility of a cataclysmic origin, perhaps related to tornadic winds that moved northward and left the surface at a point coincident with the apices of the swaths. The relatively even width of the swaths along much of their length could reflect the steady momentary path of a tornado prior to a subsequent quick rise of the air column from the ground. This hypothesis is perhaps no better supported by evidence than the previous one, but it might explain the general absence of relief on the features and the observation that the prevailing wind pattern is from the west, as in other intermontane valleys, and should form dunes

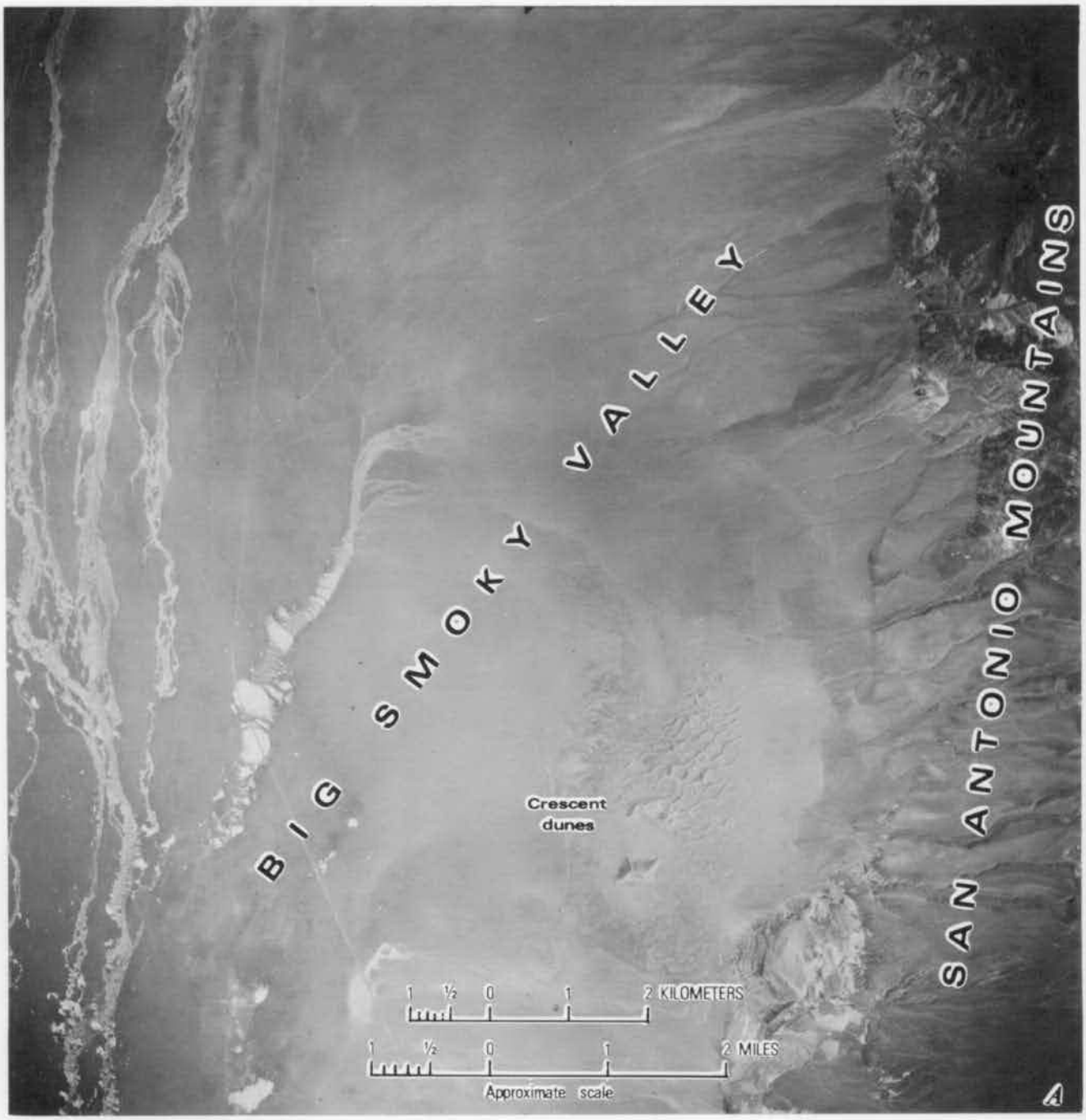
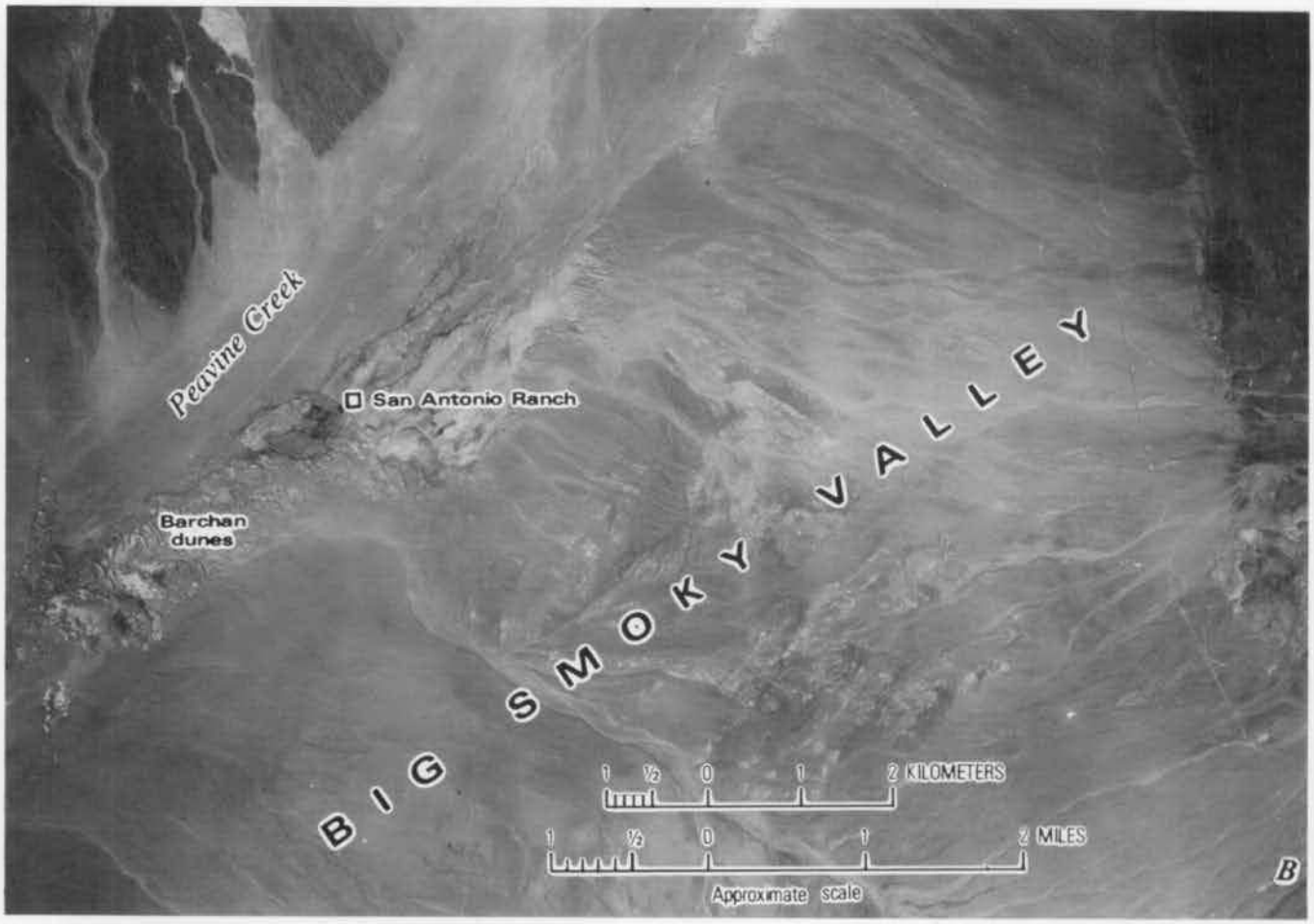


FIGURE A8. Crescent dunes, barchan dunes, and their sand sources. A, crescent dunes in Big Smoky Valley, along west flank of San Antonio Mountains. Note large stationary dune, 250 feet high, at south end of dune field; other dunes are predominantly transverse dunes. B, barchan dunes, partly stabilized, San Antonio ranch in Big Smoky Valley, just south of the Toiyabe Range. Note arrangement of dunes transverse to trend (NE.) of valley and, presumably, transverse to prevailing winds. C, dunes and their sand sources—old beaches of pluvial lakes, Railroad Valley. Note proximity of dunes to old beach levels that are composed of abundant unconsolidated sand-size material. *A*, U.S. Geological Survey photograph no. 15150, Western U.S. Project 109, strip 87, roll 120. *B*, U.S. Geological Survey photograph no. 16158, Western U.S. Project 109, strip 85, roll 128. *C*, U.S. Geological Survey photograph nos. 12082, 12810, Western U.S. Project 109, strips 87, 86, rolls 96, 103, respectively.

oriented east-west. An argument against this hypothesis is suggested by the general absence of evidence for other such tornadic disturbances in historic time in the region.

Sources for the sand are available in all directions, so neither interpretation of origin is favored by a preferred source area. The fact that these features are known to occur only in this area argues against their origin as typical dunes. Similar features may exist elsewhere and simply may not have been reported, or, as suggested by their weak development in Railroad Valley, they may be obliterated within a short span of years.

Transversely patterned alluviated ground (figs. A10 and A11), a feature of enigmatic origin, is locally common in some of the lowest parts of the drier inter-



montane valleys, including Coal, Gabbs, Hot Creek, Railroad, Ralston, and Stone Cabin Valleys. Aerial photographs show that the transversely patterned areas consist of alternating light and dark ribs transverse to the main drainages. Where two such areas were examined in Ralston Valley (fig. A12), the dark ribs consisted of desert pavement and the light ribs of fine silt. Both kinds of ribs appeared flat and were moderately sinuous laterally. Some ribs anastomose laterally, but most end laterally against very shallow furrows filled with fine silt. The furrows are drainage channels into playas. The distribution of shrubs and clumps of grass partly controlled the size and shape of the ribs (fig. A12), but vegetation is believed to be a secondary factor in the origin of the ribs. The pattern may originate from wind scouring across drainage passageways. In some localities, however, it is evident that some drainage from bordering alluvial fans follows the transverse pattern, and water as the main agent in development of the pattern has not been ruled out.

Springs and Fault Scarps
(includes thermal waters)

A large number of small springs and seeps are scattered throughout the mapped region. Some are marked by calcareous sinter and tufa terraces, mounds, and cones deposited by cold and warm springs, some of which may have been sublacustrine (fig. A13). These springs are most extensively distributed and best developed in Railroad Valley. Many here still issue warm water; one (no. 14, fig. A13) yielded a water temperature of about 120°F just above the muddy ooze in the orifice. Coyote Hole Spring (no. 12, fig. A13) had a temperature of about 105°F at the issuing end of a pipe tap. The temperatures were daytime readings made in October 1960 and are believed to represent the average temperatures for this time of year. Big Warm Spring at Duckwater (no. 17, fig. A13), a warm spring essentially neutral to the touch, is one of the largest in the region and discharges an average of about 14 second-feet (Maxey and Eakin, 1951, p. 134, tables 4A and 4B). Together with several smaller springs, Big Warm Spring supplies more than enough water to irrigate the several square miles of pasture and cultivated land on and adjacent to the Duckwater Indian Reservation. A 2.4 square mile (6.2 km^2) tufa terrace, from which the main springs issue, lies just east of the cultivated area and attests to the importance of these springs in the recent past.

The most picturesque of all the calcareous tufa deposits is that at Dianas Punch Bowl in Monitor Valley, near Potts Ranch. Its nearly symmetrical cone rises approximately 60 feet (18 m) above the valley and has a

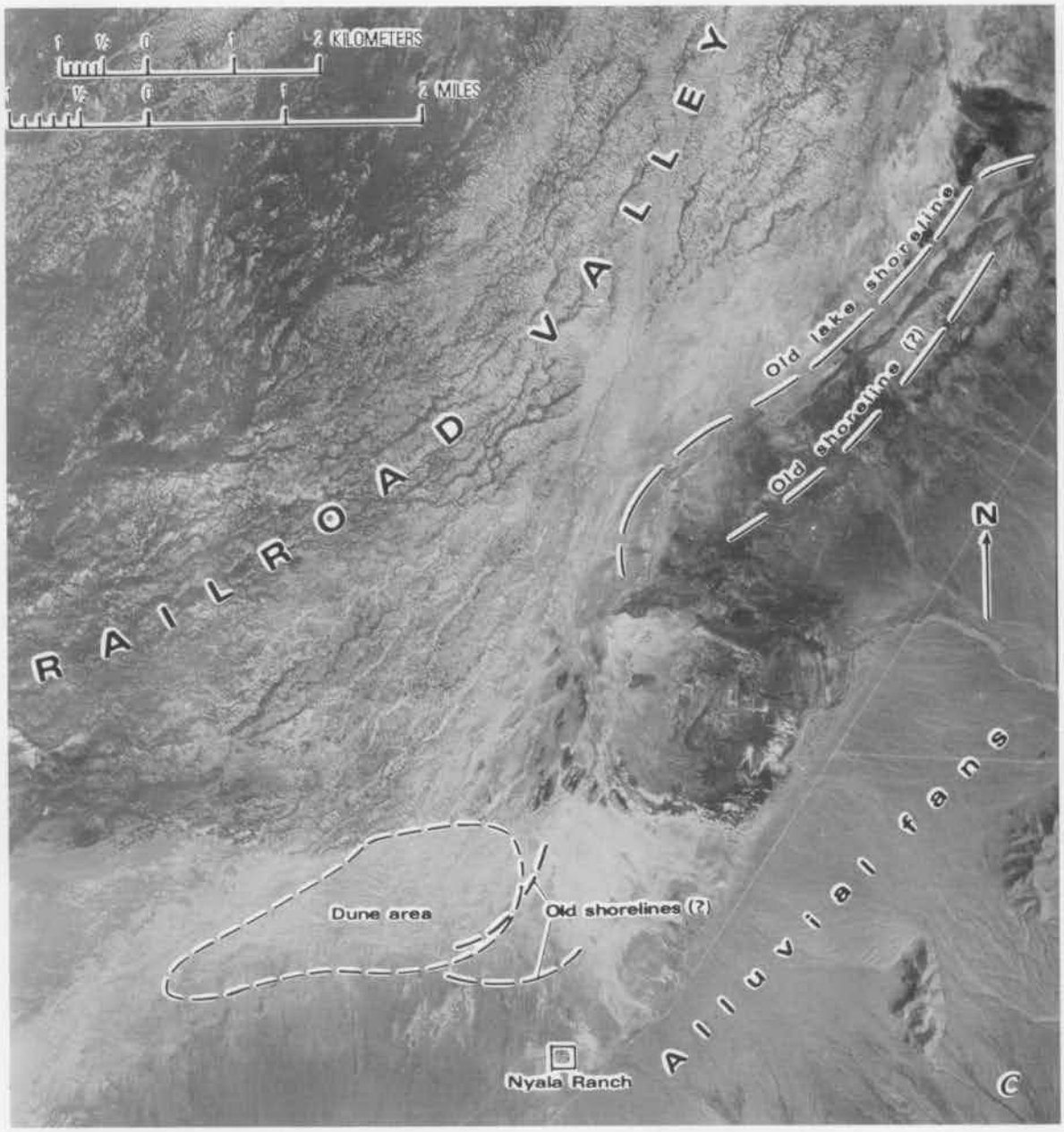


FIGURE A8 (continued)

main circular orifice about 40 feet (12 m) in diameter. Crystal-clear artesian water, at a temperature of about 130°F, stands about 35 feet (11 m) below the top of the tufa cone.

Almost all of the springs in the region lie mainly in or adjacent to mountainous and hilly terrain; they are variously related to faults and to contacts between permeable and impermeable rocks. Many of the springs in the intermontane valleys are believed to lie along major basin-and-range-type normal faults, some of which are presently concealed by basin-fill deposits (pl. A1 and figs. A14 and A15). Such springs include those on the west side of Big Smoky Valley (Meinzer, 1917, p. 44); most of the springs, including Big and Coyote, along the west and east sides of Railroad Valley (figs. A13, A14 and pl. A1); and those along the east side of White River Valley. The major springs that furnish numerous ranches with water for pasture along the east side of Railroad and White River Valleys have a conspicuous northeast-trending alignment (fig. A14 and pl. A1). This arrangement clearly mirrors the northeasterly trending steep west fronts of the Grant and Egan Ranges. Maxey and Eakin (1949, p. 33–34; 1951, p. 149) class the springs on the east side of Railroad and White River Valleys as probable gravity springs directly related to permeability contrasts along contacts between lacustrine deposits in the valleys and the fan deposits that issue from canyons along the range fronts (fig. A15). It is not unreasonable, however, to infer fault control for the line of springs, even though that control

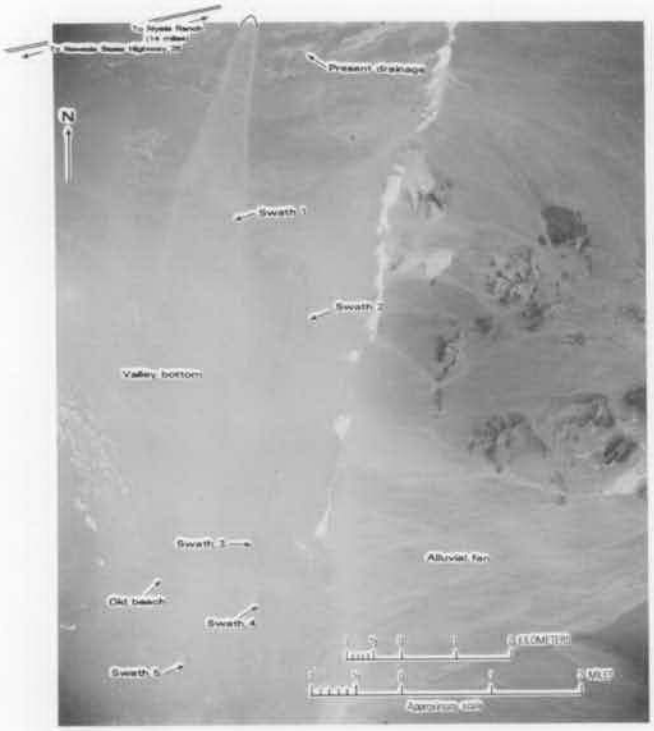


FIGURE A9. Wind erosional features in Railroad Valley. U.S. Geological Survey photograph no. 15135, Western U.S. Project 109, strip 89, roll 120.

may be indirect (fig. A15, cross section B) rather than direct (fig. A15, cross section A). Recently published data indicate that, of the two cross sections, figure A15A (with modifications) most nearly represents the conditions in Railroad Valley. There, petroleum exploration led to techniques that aid recognition and evaluation of the complicated fault zones peripheral to intermontane basins (Foster, 1979). The excellent diagrams and information in Foster's report are highly recommended.

Several features in Monitor Valley, primarily fault scarps, may reflect the rejuvenation of or an initial stage in the evolution of a basin-range-type mountain. A 5-mile (8-km)-long fault scarp, extending southwest from Potts Ranch (pl. A1) across an unconsolidated alluvial fan, exhibits apparent upthrow of several feet on the east (valley) side. A postulated concealed fault nearby extends from Dianas Punch Bowl southward along the west edge of a group of low volcanic hills. The faults disrupt the broad, gently east-sloping bajada extending out from the Toquima Range. Thus, it appears that a largely concealed and perhaps newly emerging structural block underlies the central part of Monitor Valley. The hot spring at Dianas Punch Bowl and springs near Potts are probably controlled by the fault just described.

Other changes in base level during the Pleistocene and Holocene are reflected in remnants of valley-train alluvial terraces in the Grant and White Pine Ranges. At least two alluvial terraces, in various stages of dissection, are visible in Little Fish Lake Valley; nearly as many occur to the east in the adjacent Hot Creek Valley. Pleistocene and (or) Holocene base-level changes have occurred in others parts of northern Nye County, such as in Big Smoky Valley, and in all these areas the effects of change are locally well developed and readily visible.

In a few places the fault scarps formed in recent fan and alluvial deposits along the edges of valleys extend as lineaments across drainage channels (fig. A16). The scarps are typical of basin-and-range fault traces; some are arcuate and others are straight. One special feature of some of the scarps is their arrangement, locally fanlike, into a series of subparallel en echelon breaks. These breaks are readily visible on aerial photographs (fig. A17). Such arrangements are best developed near Potts Ranch, Monitor Valley, but they also appear in Ione, Little Fish Lake, Hot Creek, Little Smoky, and Railroad Valleys. These en echelon faults give the appearance of having developed during settling of basin-fill sediments, perhaps by compaction, during movement on concealed master faults in underlying bedrock. Major basin-and-range-type faulting in underlying consolidated rocks apparently triggered such a response in overlying unconsolidated material along the east side of Fairview Peak (Churchill County) after the 1950 Fallon earthquake.

GLACIAL GEOLOGY

Direct evidence of alpine glaciation is confined largely to the high Toiyabe and Toquima (Mount Jefferson area) Ranges. Well-developed biscuit-board topography characterizes the eastern and northern heights of the Mount Jefferson massif in the Toquima Range (fig. A18). Glaciated U-shaped valleys there start at 9200 feet (2800 m) in elevation and culminate at about 11,000 feet (3300 m) in well-formed cirques. Tarns, lateral and ground moraines, and a rock glacier(?) lie within the glaciated valleys. Terminal moraines of the valley glaciers lie between 9000 and 9600 feet (2700 and 2900 m) in elevation (fig. A18). Kame topography in the form of a small outwash plain, or possibly an older terminal moraine, extends downward from below a well-developed terminal moraine to about 8800 feet (2700 m) in elevation in one of the valleys. Erosion may have removed other such features because relief is extreme in the area.

Although glacial features are much less well preserved in the Toiyabe Range than in the Toquimas, ground and terminal moraines were noted by Ferguson and Cathcart (1954), and aerial photographs show several cirques and more moraines in the vicinity of Toiyabe Dome and Toiyabe Dome East Summit (pl. A1). The cirques lie at 10,400–11,200 feet (3200–3400 m), an elevation similar to that for cirques in the Toquima Range. What appear to be ill-preserved moraines are situated as low as about 8900 feet (2700 m) in elevation, with most above 9000 feet (2700 m). Outwash plain features extend to about 8400 feet (2500 m) in elevation. From Nevada Highway 8A, even more subtly preserved inferred glacial features are discernible high along the range's eastern flank from approximately North Twin River southward to Jett Canyon. From this vantage point, U-shaped hanging valleys and upland bedrock terraces are visible, and the

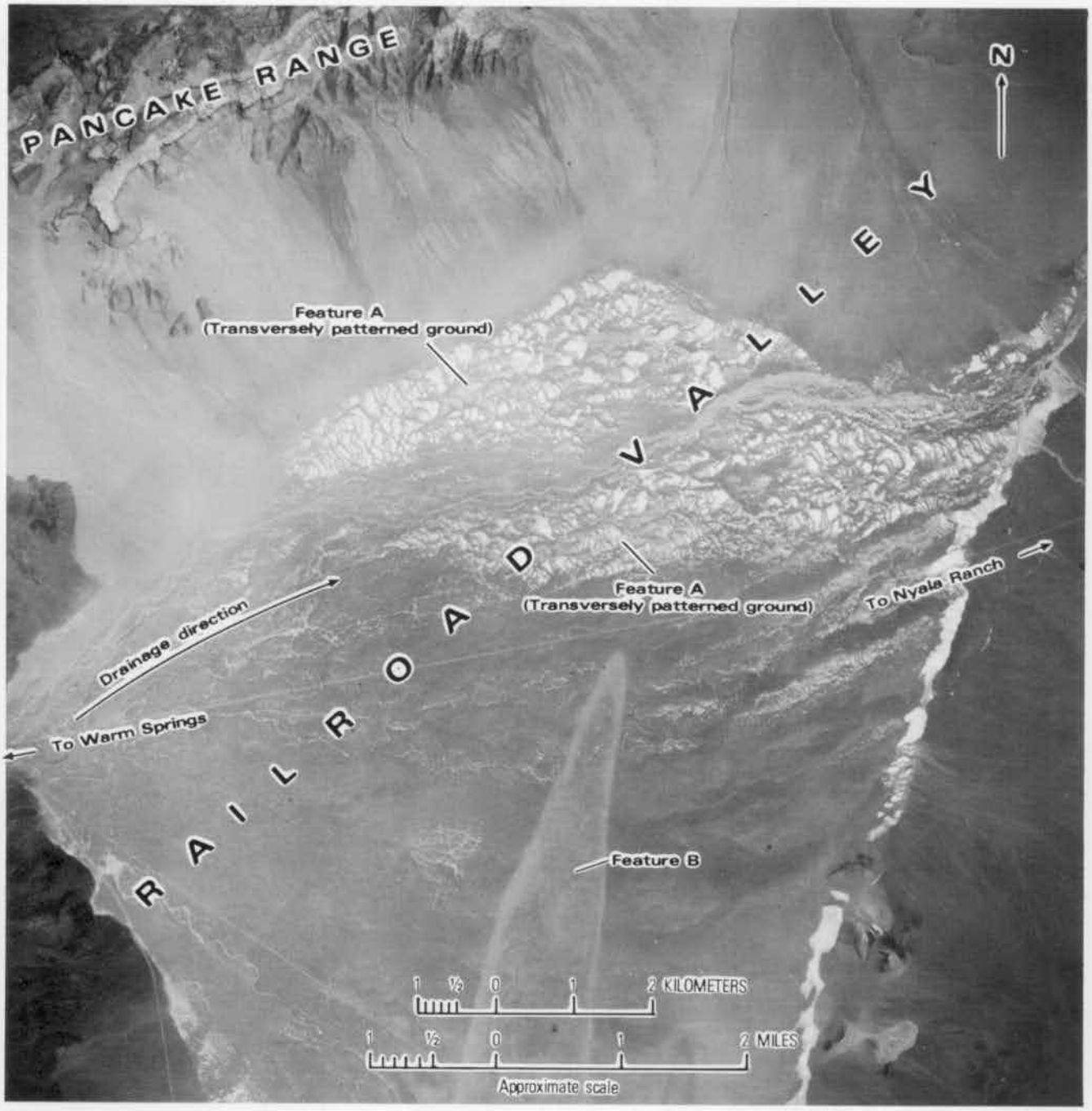


FIGURE A10. Erosional effects in Railroad Valley. U.S. Geological Survey photograph no. 15100, Western U.S. Project 109, strip 88, roll 120.

relations between many of the glacial features can be observed. Pleistocene glaciation also appears to have affected that part of the high Toiyabes from the county boundary northward into Lander County.

Holocene erosion obliterated all but the grossest aspects of glacial topography in the range. Preservation is poor because the extreme relief of the range and the considerable precipitation have combined to cause extensive erosion. Relief ranges from about 700 to nearly 2500 feet (200–760 m) per mile in the vicinity of the described glacial features.

The major glaciation of the Toquima and Toiyabe Ranges may correlate with the Tioga Glaciation of the Sierra Nevada, described by Blackwelder (1931) and others (Matthes, 1930, p. 50–83; 1939; Birman, 1964, p. 41–45). This tentative correlation is based primarily on the form and elevations of the main moraines. Glaciation in both the Toiyabe and Toquima Ranges developed largely above 9000 feet (2700 m) and similarly affected the higher parts of both ranges. Some of the relict glacial features of the Toiyabe Range, particularly the terraces and hanging valleys, may represent a

Pleistocene glacial epoch (Tahoe?) older than the inferred Tioga.

Whether or not the Little Ice Age (Neoglacial period) of Matthes (1939, p. 520; 1942, p. 190–215) of post-Thermal Maximum time (Birman, 1964, p. 71–75) gave rise to renewed glaciation in the region is not known. We have not studied this aspect of glaciation, but several factors affect the problem: unstable slopes and at least one rock glacier appear in the Mount Jefferson area, but glacial polish and striae were not noticeably abundant along the single traverse made. We favor the view that the earlier glaciated Mount Jefferson and the high Toiyabe areas have undergone renewed glaciation since the Thermal Maximum of about 4000 years ago, and that effects of the youngest glaciation will be amply demonstrated by careful work.

Broad U-shaped forms characterize parts of some of the largest canyons in the Grant Range (Little Meadows Creek Canyon) and the Quinn Canyon Range (especially Dry, Hooper, and Water Canyons) (fig. A19). Spurr (1905a, p. 72) attributed this shape to development beginning above the surface of a Pliocene lake; as the lake

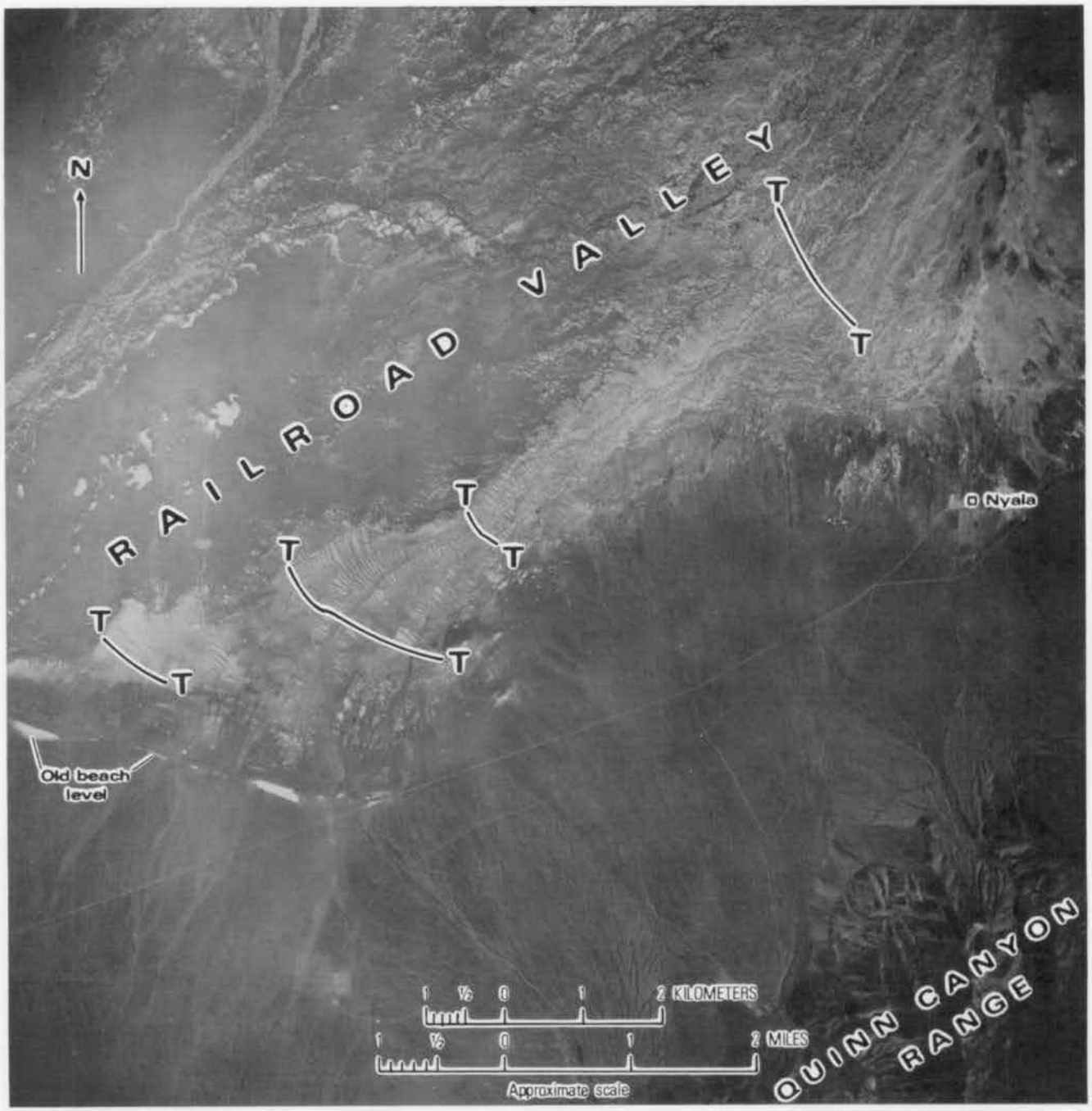


FIGURE A11. Transversely patterned alluviated ground in Railroad Valley. Note change in trend of transverse lineations, denoted by lines marked T-T. U.S. Geological Survey photograph no. 12081, Western U.S. Project 109, strip 87, roll 96.

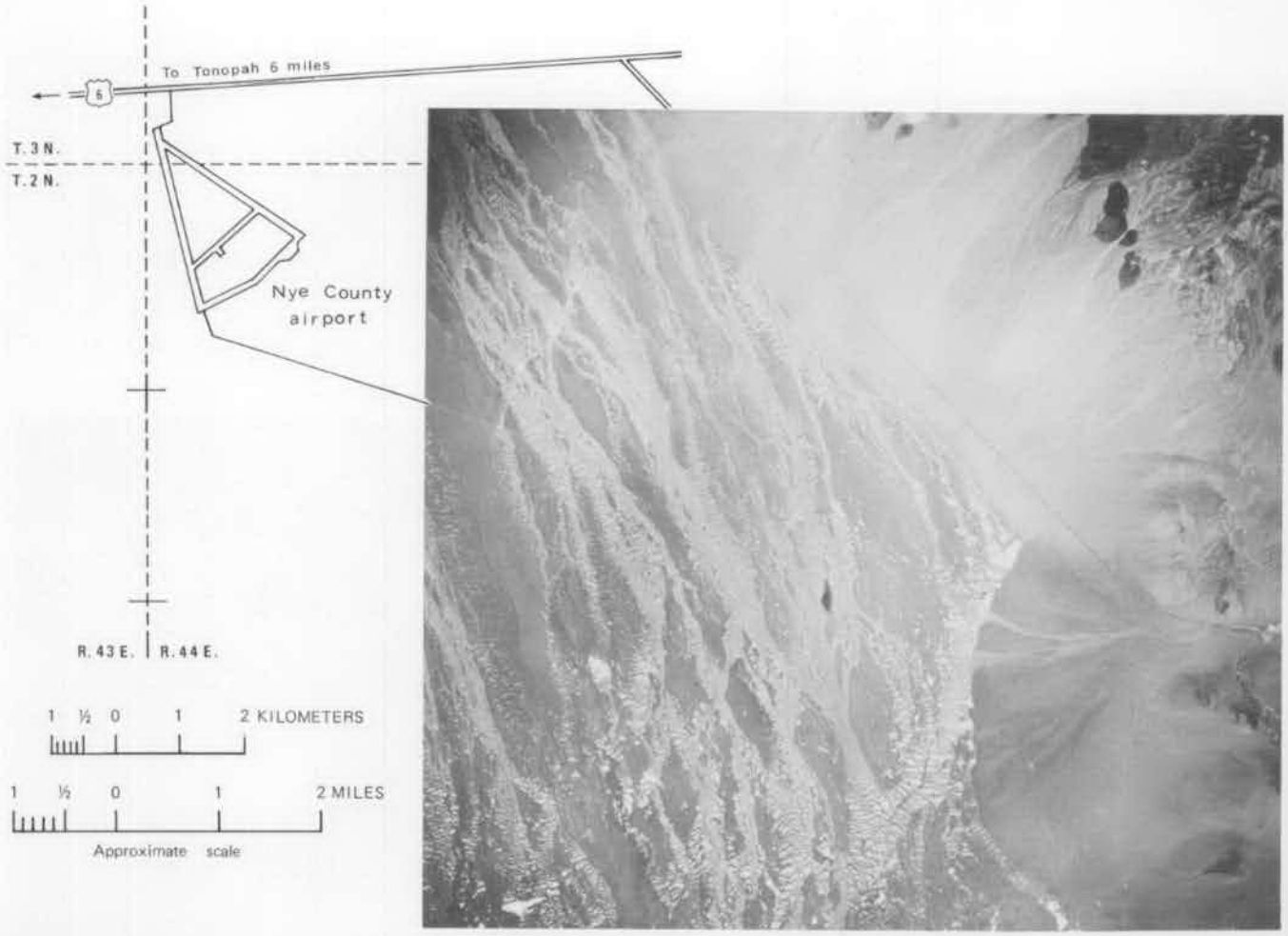


FIGURE A12. Transversely patterned alluviated ground in Ralston Valley. U.S. Geological Survey photograph no. 913, Western U.S. Project 109, strip 90, roll 10.

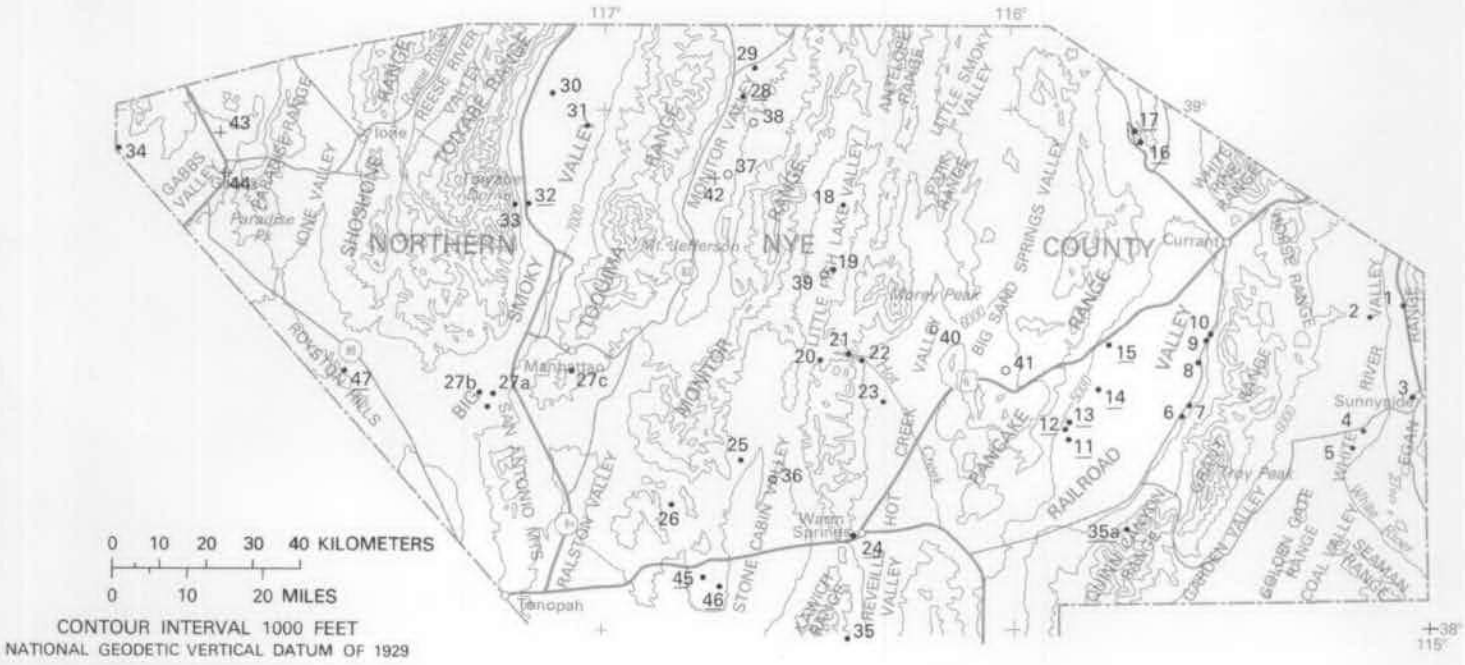


FIGURE A13. Thermal springs tufa aprons and domes, and drilled wells and deep drill holes with warm water.

EXPLANATION FOR FIGURE A13

3. •16

Thermal springs

Number refers to accompanying list. Parenthetical numbers in list are springs not visited by us and partly listed by Horton (1964). Underlined numbers on map are sites with calcareous tufa aprons and domes; which in some cases are associated with live springs.

Outline of large calcareous tufa apron

o40

Deep drill hole
Number refers to list below

+44

Drilled wells having warm to hot water
Number refers to list below

List of springs: *Water temperatures, where known, in °F.*

Map No.	Name and comments
(1)	Emigrant (Riordan Ranch?) Springs
(2)	Moorman (Morman) Springs (100°)
(3)	Unnamed; location uncertain; no. 121 in Horton (1964)
(4)	Hot Creek Spring ([1]180°, 88°)
(5)	Moon River Spring ([2]92°)
(6)	Willow Springs ([3, 3a]60°)
(7)	Bullwacker Springs ([3, 3a]59°)
(8)	Butterfield Springs ([3, 3a]64°)
(9)	Kate Spring ([3]73°)
(10)	Blue Eagle Springs (multiple) ([3]83°)
11	Abel Spring ([3]115°)
12	Coyote Hole Spring ([3]113°, see text)
13	Storm Spring ([3]98°)
14	Chimney Hat Spring ([3]140, [4, 5]150°)
(15)	Lockes Springs (includes Big ([4]95°, [3]100°), North ([3]95°), and Reynolds ([3]97°))
16	Little Warm Spring ([3]56°, 60°)
17	Big Warm Spring ([3]90°)
(18)	Fish Springs
(19)	Warm and Upper Warm Springs
20	Upper Warm
21	Upper Hot Creek Ranch Spring ([4]92°)
(22)	Hot (Hot Creek) Spring ([4]180° hottest spring)
(23)	Blue Jay
24	Warm Springs ([4]141°)
25	Unnamed
(26)	Unnamed; no. 127 in Horton (1964)
(27a)	Indian Springs of Horton (1964); location uncertain (see 27b and 27c)
(27b)	Indian Springs of Horton (1964) most likely here (see 27a)
(27c)	Indian Springs; possibly that referred to by Horton (1964) (see 27a and 27b)
28	Dianas Punch Bowl ([6]~130°, see text and ~140°)
(29)	Unnamed; at Potts Ranch ([6]~140°)
(30)	Unnamed; near McLeod Ranch
(31)	Charnock Springs; location uncertain; many springs here
32	Darrough (Darroughs) Hot Springs[7]
(33)	Unnamed; no. 115 in Horton (1964)
(34)	Unnamed, possibly Rawhide Hot Spring
(35)	Unnamed[8]
35a	Unnamed; in Willow Canyon and probably part of Willow Springs. Tufa terrace present and many springs and orifices in vicinity. Two cold springs, flowing in October 1963, issue from thin-bedded limestone.

List, incomplete, of deep drill holes, several of which tap warm water

Maximum temperatures, where given, in °F; total depth, in feet, given in parentheses; analyses of lithium (Li) and fluorine (F) in parts per million. Excludes the numerous holes drilled for oil and gas, all of which are in and east of Railroad Valley. Data are from Hoover and others (1969) and Dinwiddie and Schroder (1971).

Map No.	Designation and comments
36	UCe-2 (1,659)
37	UCe-16 (4,353) 128°
38	UCe-3 (2,000)
39	UCe-10 (2,963) ~114°-118°; artesian water (see text)
40	UCe-18 (6,514) ~130°; Li, 14-62; F, 0.12-0.40
41	HTH-23 (7,500?)

List, incomplete, of drilled wells having warm to hot water

Map No.	Name and comments
32	Darrough Hot Springs; tested by drilling (see text)
42	Unnamed; see U.S. Geological Survey Mosquito Creek 7½-minute quadrangle
43	Unnamed; water hot[9]
44	Numerous drilled wells at Gabbs (see text)[9]

List of sites of known prehistoric springs:

Map No.	Designation and comments
45	Unnamed; no water issues; tufa in ledge, forming 1-foot-thick apron that overlies bedrock of andesite and rhyolite
46	Unnamed; prehistoric; travertine along fault in rhyolite—no water issues
47	RP-3 on pl. B1; travertine deposit that has been quarried. Steeply dipping, along dike; no water issues

[1]Eakin, 1966
[2]Maxey and Eakin, 1949
[3]Van Denburgh and Rush, 1974
[3a]Not thermal today; prehistoric status unknown; tufa deposits may be present
[4]Rush and Everett, 1966
[5]In October 1960, we measured 120°F in the hottest part of the spring and noted that after a snowfall and a mild period of some snowmelt that the same spring was cold to the touch. Several calcareous tufa domes and mounds, partly coalescing, are present at this locality. Water does not issue from all orifices; some former sites of issue are sealed by tufa.
[6]Rush and Everett, 1964
[7]See section on geothermal resources, this report
[8]Water is apparently piped from here eastward to the Reveille mill site. There, water in a pond is warm to the touch, indicating that warm water issues from the source spring.
[9]Well no. 13/36-28B1 in Eakin (1962b)

FIGURE A14. Alignment of springs along part of east edge of Railroad Valley. Dark areas are wet marshes or pastures associated in many places with springs. Springs may be related to basin-range-type fault (see fig. A15). U.S. Geological Survey photograph no. 15200, Western U.S. Project 109, strip 85, roll 121.

lowered, erosion continued but had less time to act on the newly emerged rocks, making the lower courses more youthful. That this observation may be correct is suggested by figure A19, which shows that in one area the enlarged U-shaped parts of many of the major drainages essentially terminate at nearly the same level; i.e., about 5300 feet (1600 m), along the east side of Railroad Valley. The inference of large amounts of water in the lakes and even the shapes of the canyons could be used to construe a glacial climate. However, contrary evidence given below leads to the conclusion that there is little or no reason to believe that Pleistocene glaciation or any glaciation occurred in the eastern part of the region. Most likely, the lakes only reflect one or more periods of climatic wetness. Indurated pebbles and cobbles form valley-train terraces and vast gravel aprons on pediments at the west base of the White Pine Mountains (Broom Canyon and vicinity). Lumsden (1964, p. 127–128) inferred that the fanglomerates formed prior to the present relief of the range and prior to the

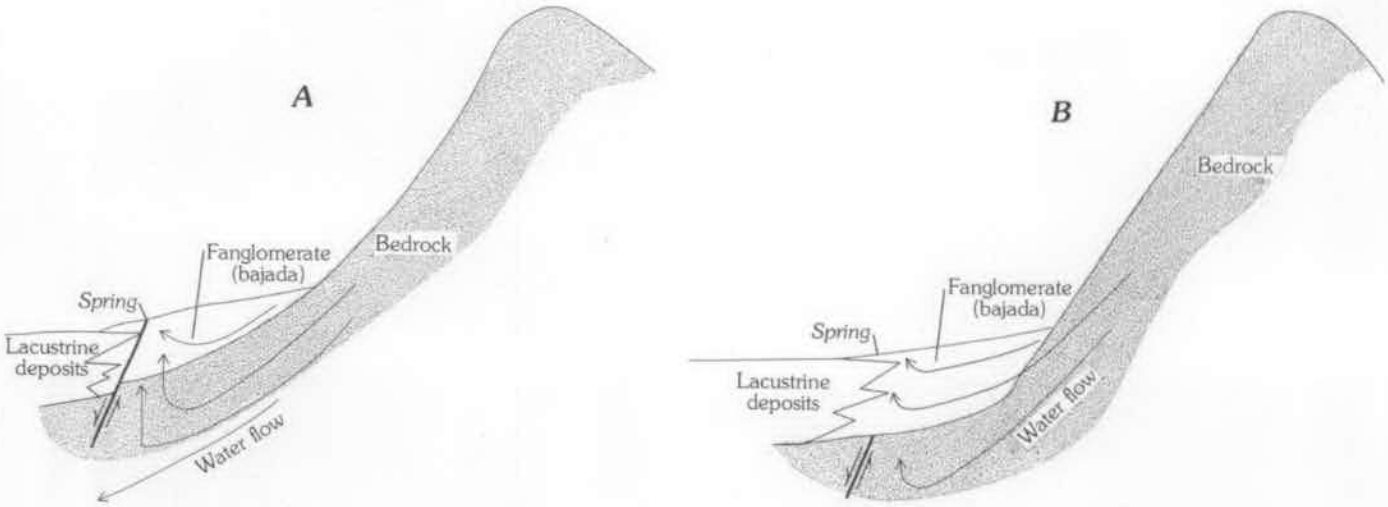


FIGURE A15. Idealized cross sections showing possible relation of springs to postulated range-front faults along west edges of Grant and Egan Ranges. *A*, direct fault control of spring. *B*, indirect fault control of spring.

Pleistocene because only lower Paleozoic, well-rounded clasts were found in them. Thick indurated gravels also crop out in and near Scofield Canyon, Grant Range.

Modification of numerous other major canyons in the Toquima and Toiyabe Ranges took place during the Pleistocene, but these canyons probably developed in the Pliocene. The evidence of Tioga(?) Glaciation in the Toquima and Toiyabe Ranges indicates that meltwater most likely flowed through at least Meadow, Moore, and Pine Creeks, ancestral Manhattan Gulch in the Toquima Range, and possibly through other canyons as well. The broad ancestral form of Manhattan Gulch extends well out from the Toquima Range beneath a cover of Quaternary fanglomerate (Ferguson and Cathcart, 1954). Pliocene-formed canyons in the Toiyabe Range that carried out Pleistocene glacial meltwaters most certainly include Peavine, Reese River, and South Twin River Canyons, and probably the other main canyons along the east front of the range between Peavine and South Twin River as well. Several other major drainages, such as the canyons of San Juan and Washington Creeks in the Toiyabe Range; Northumberland and Stoneberger Creeks in the Toquima Range; Barley, Clear, Copenhagen, Danville, Horse Heaven, Hunts, Long, McCann, and Savory Creeks in the Monitor Range; and Hot Creek in the Hot Creek Range, may never have carried glacial meltwater. But prior to glaciation these creeks most likely existed in ancestral forms not unlike their present ones. Clearly, a great volume of water once flowed through the canyons. The last period of great flow apparently fed the late Pleistocene Lakes Tonopah and Toiyabe that filled Big Smoky Valley between the post-Sangamon Interglaciation of Pleistocene age and the Holocene (75,000–4000 years b.p.), coincident with the time of Lakes Bonneville and Lahontan (Ferguson and Cathcart, 1954; Meinzer, 1917, p. 29–41; Morrison and Frye, 1965, figs. 2, 6, p. 35). Lakes Tonopah and Toiyabe were apparently fed by interior drainage and therefore were saline (Meinzer, 1917, p. 30), whereas the lake in Railroad Valley, during at least part of its lifespan, may have drained southward through the Colorado River system.

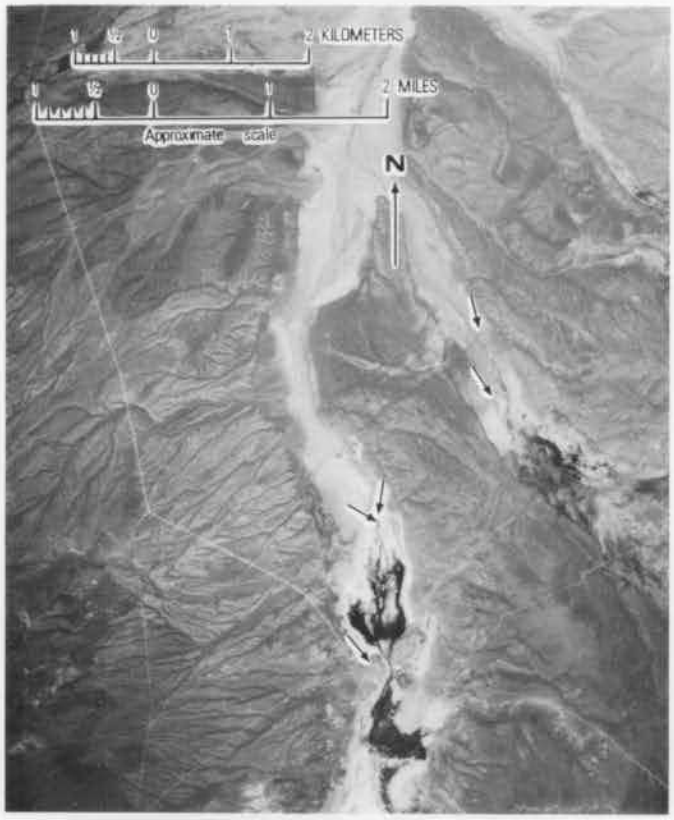


FIGURE A16. Fault traces cutting most recent alluvium near Potts, Monitor Valley, Nye County. U.S. Geological Survey photograph no. 15502, Western U.S. Project 109, strip 77, roll 123.

STRATIGRAPHY

Cambrian System

INTRODUCTION

Cambrian strata are exposed at localities throughout most of northern Nye County; a nearly complete sequence crops out extensively only in the mountain arc bordering the east side of Railroad Valley, including the Grant, Quinn Canyon, and White Pine Ranges. The next most complete section is near Tybo in the Hot Creek Range, where the siliceous clastic strata of the Lower Cambrian are missing. Farther west in the Toiyabe Range, this siliceous clastic section is about all that is preserved. Incomplete but important sections also crop out in the southern Monitor Range (near Belmont and Ellendale) and in the Toquima Range (near Manhattan and Round Mountain). Minor exposures in the Shoshone Mountains (near Ione) and in the Paradise Range were mapped as Cambrian by Kleinhampl and Ziony (1967), but are herein provisionally assigned to the Jurassic Dunlap Formation. Cambrian strata are undoubtedly present beneath much

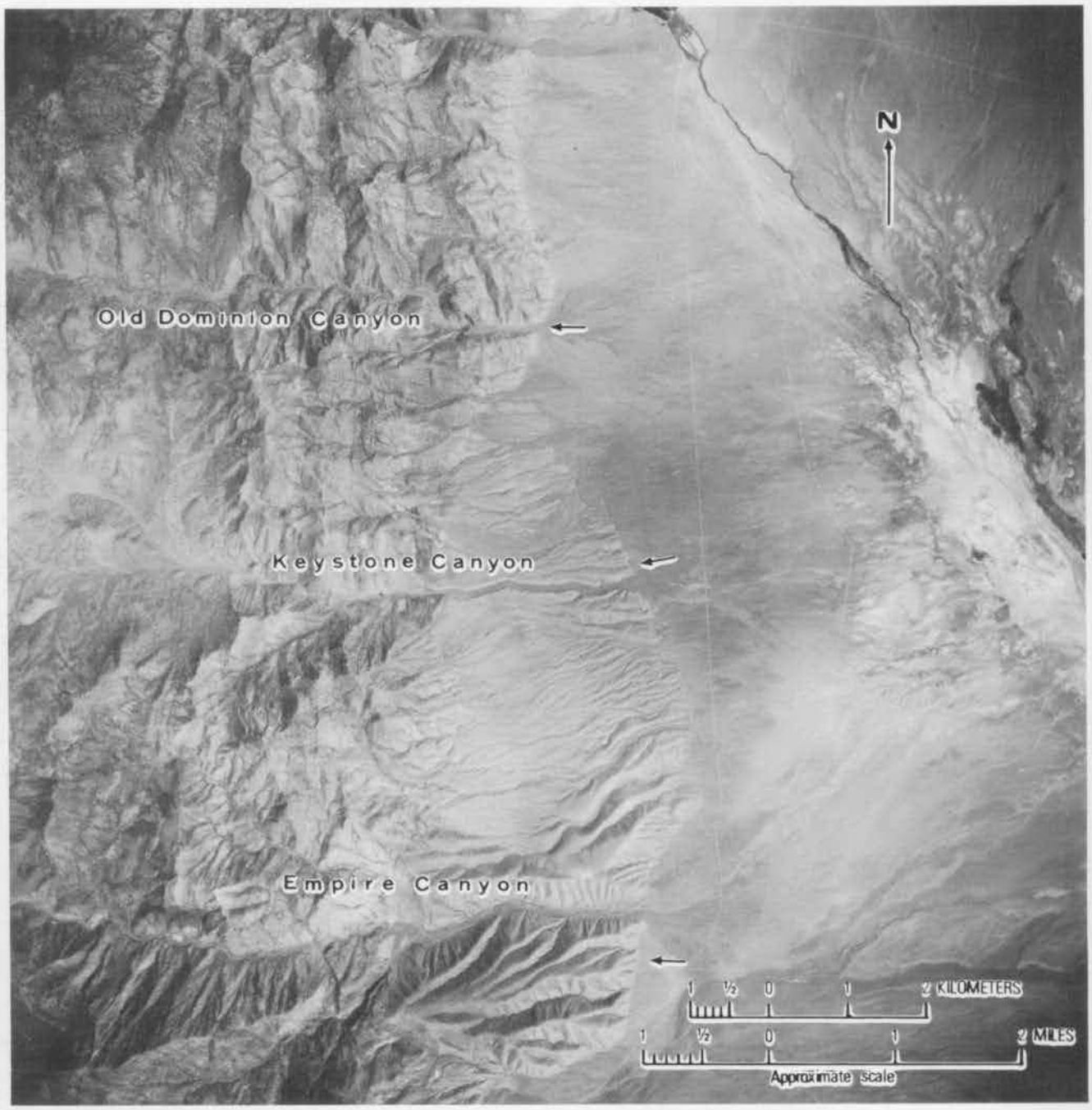


FIGURE A17. Segmented and arcuate fault scarps along east front of Hot Creek Range, vicinity Empire to Old Dominion Canyon, Nye County. U.S. Geological Survey photograph no. 15189, Western U.S. Project 109, strip 85, roll 121.

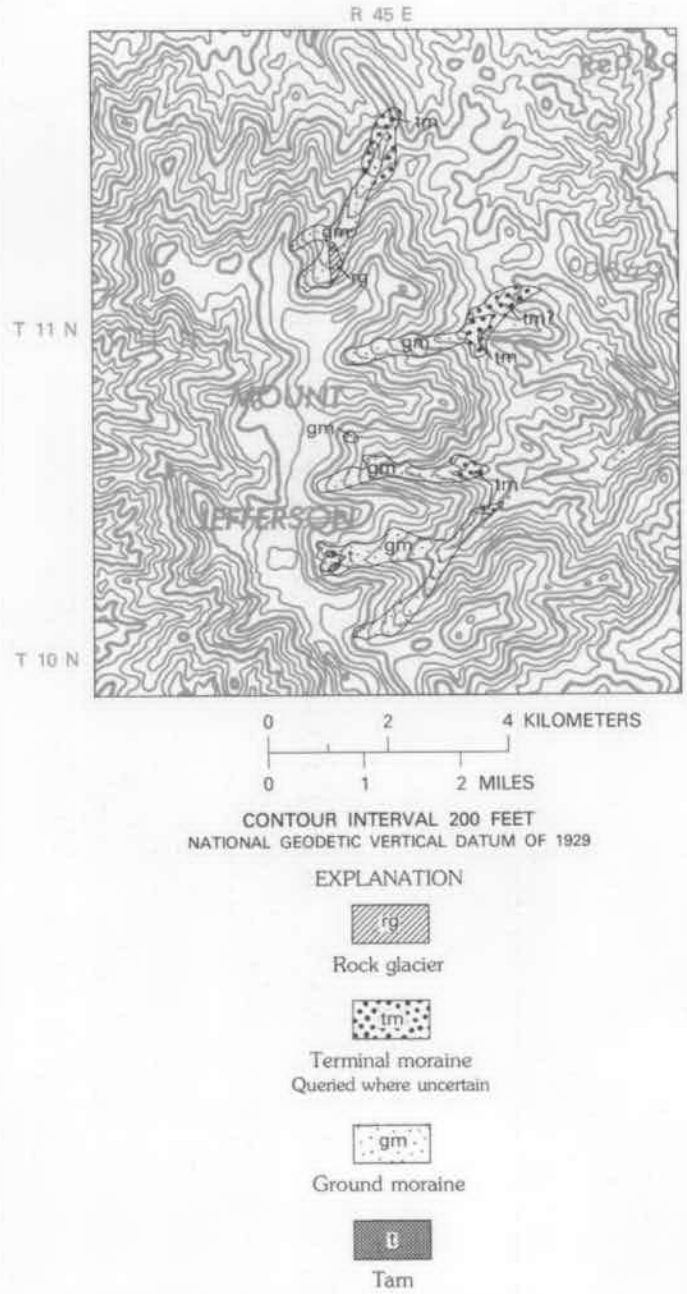


FIGURE A18. Moraines on glaciated Mount Jefferson, Nye County. Base from U.S. Geological Survey, Tonopah 1x2° quadrangle, scale 1:250,000,1971.

of the younger covering rocks from the eastern border of the mapped region to at least as far west as the Toiyabe Range and probably even farther west.

Six formations totaling about 7000 feet (2133 m) in thickness were recognized in the White Pine Mountains by Lumsden (1964, p. 14). From bottom to top, these are the Prospect Mountain Quartzite, Pioche Shale, Pole Canyon Limestone, Lincoln Peak Formation, Dunderberg Shale, and Windfall Formation. This nomenclature seems eminently suited to the region and has been used in this bulletin (pl. A1) wherever possible. A considerable lateral variation in the facies and, therefore, in the formations from north to south (Palmer, 1960, p. 53–58), caused by irregularities in the margins of the normal east-west transgressive and regressive seas, led Cebull (1967, p. 25–35) to introduce some new unpublished formation names: Sidehill Spring and Little Meadow Formations, or formations A and B, respectively (*in* Cebull, 1967, fig. 3). Cebull's names are locally more applicable in the southern Grant Range; we have generally included his formations in an undifferentiated unit (shale and limestone, undivided, pl. A1).

In the Hot Creek Range, 40 miles (64 km) west, only three formations constituting Middle and Upper Cambrian strata crop out. These total about 4975 feet (1500 m) in thickness and include the Swarbrick Formation (Bonanza King Formation), Dunderberg Shale (Tybo Shale), and Windfall Formation (Hales Limestone). Farther west, near the boundary with Lander County and northward, the Cambrian section may be complete but very disrupted, based on evidence supplied by Means (1962), Washburn (1970), Stewart and McKee (1968a, fig. 3), and Stewart and others (1977). But farther south in Nye County the section consists almost exclusively of siliceous clastic strata, including the Cambrian Gold Hill Formation in the Toiyabe Range, and the Gold Hill and the successively overlying Wood Canyon, Zabriskie, and Carrara Formations in the Toquima Range.

SILICEOUS CLASTIC STRATA OF PRECAMBRIAN Z AND EARLY CAMBRIAN AGE

The oldest exposed rocks in northern Nye County are largely Early Cambrian and consist of mildly metamorphosed equivalents of sandstone, siltstone, and shale—quartzite, phyllitic schist, and slate and phyllite. Calcareous strata are relatively minor and of greater abundance upward. The rocks are variously assigned to the Prospect Mountain, Zabriskie, Wood Canyon, and Gold Hill Formations. Figure A20 shows the nomenclature used in various parts of the mapped area. The Prospect Mountain Quartzite crops out in the Grant and Quinn Canyon Ranges, and its partial correlatives, the Wood Canyon Formation and the Zabriskie Quartzite, were mapped farther west near Ellendale in the southern Monitor Range and near Belmont in the Toquima Range. The Gold Hill Formation, another partial correlative, was also mapped in the Monitor Range (Big Ten Peak) and Toquima Range (near Jefferson Creek and from near Manhattan southward) and is most widespread even farther west in the Toiyabe Range.

The Prospect Mountain Quartzite (pl. A1) (Hague, 1883, p. 254) is best displayed in an estimated 4500-foot (1372-m) section in the Grant Canyon–Irwin Peak area of the Grant Range, where the base is covered (Hyde and Huttrer, 1970, p. 506), and in a more than 3000-foot (914-m) section in the Grant Range near Troy (Cebull, 1967, p. 14), where the base is also covered. In both cases, the unit is overlain conformably by the Lower and Middle Cambrian Pioche Shale. Some subunits of Pioche-like lithology appear in the upper part of the formation. The Prospect Mountain is typically thin- to thick-bedded, locally cross-stratified (especially near the top) quartzite that forms pale-yellowish-gray

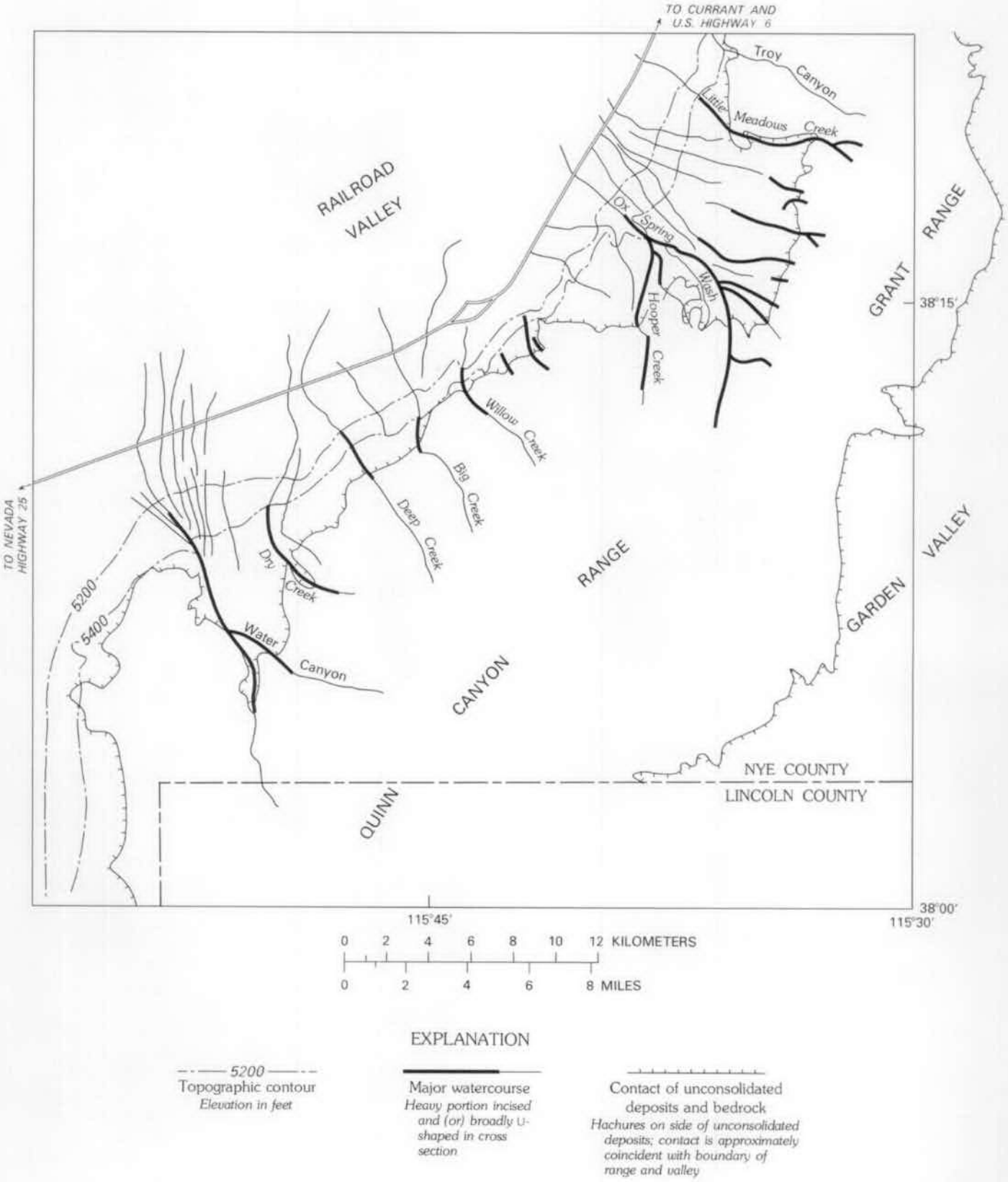
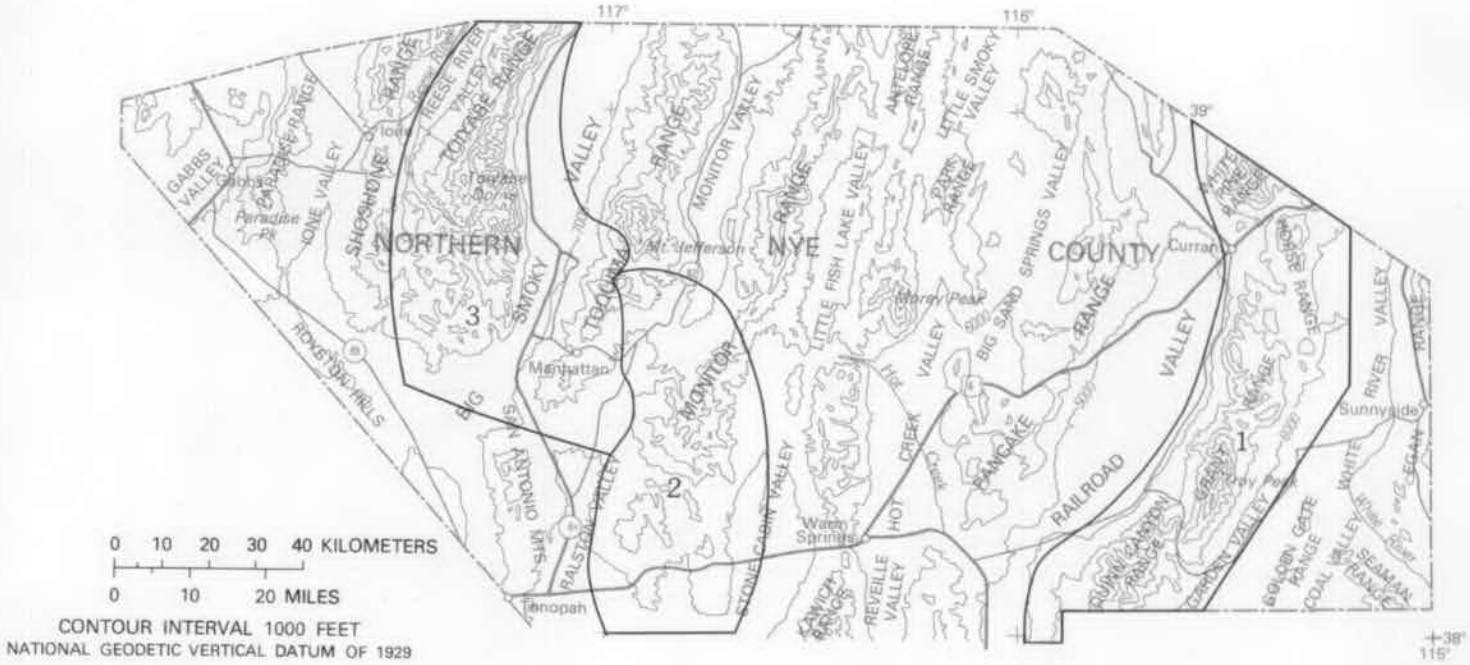


FIGURE A19. Major drainages and the relation of their broad, U-shaped parts to elevation in a part of northern Nye County.



AREA 3

Gold Hill Formation and Gold Hill(?) Formation (Queried in southern Toiyabe Range in vicinity of Boyd and Antelope Canyons, where possibly allochthonous and more properly mapped with the Harkless Formation.)

AREA 2

Shale and limestone (May include equivalents of the Gold Hill to Carrara Formations and possibly the Bonanza King Formation.)

Zabriskie Quartzite and underlying Wood Canyon Formation, undifferentiated

Gold Hill Formation (Mapped only near Big Ten Peak, Monitor Range.)

AREA 1

Shale and limestone (Includes Pole Canyon Limestone and younger units.)

Pole Canyon Limestone

Pioche Shale

Prospect Mountain Quartzite

FIGURE A20. Map units used in various parts of northern Nye County, for upper Precambrian and for Lower and lower Middle Cambrian strata on the geologic map (pl. A1).

cliffs and steep, broken slopes covered with reddish-brown talus. The formation is chiefly a somewhat poorly sorted medium-grained quartzite that very rarely contains pebbles. Cebull (1967, p. 16) gives a composition of quartz (70%–100%), feldspar (trace–20%), most of which is plagioclase, and muscovite (0–15%). Twenty feet (6 m) of a gritty quartzite crops out in the White Pine Mountains and has been mapped as part of the Prospect Mountain Quartzite by Lumsden (1964, p. 17), and a faulted segment of the formation consisting chiefly of pale-reddish-brown to pink quartzite also crops out east of Nyala in the Quinn Canyon Range.

On the basis of regional correlations, Stewart modified the generally inferred Early Cambrian age of the Prospect Mountain to Precambrian Z and Early Cambrian (1974, p. 617). This formation is conformably and gradationally below the *Olenellus*-bearing Pioche Shale.

The partially correlative Gold Hill Formation at its type locality in the Toquima Range (Manhattan district) was described as consisting of "not over 5000 feet [1500 m]" of exposed beds bounded at the bottom and top by faults and consisting of quartzite, sandstone, schist, slaty rocks, and minor limestone (Ferguson, 1924, p. 18–20). A well-displayed section in the Toiyabe Range near Summit Canyon measured approximately 5200 feet (1585 m) (J. H. Stewart, oral commun., 1969; Stewart and others, 1977). The base of the Gold Hill is covered here, and the unit apparently grades upward into the Broad Canyon(?) Formation (a correlative of part of the Ordovician Palmetto Formation). Thoroughly shattered quartzite of the Gold Hill Formation, recemented by silica, crops out in the low hills of the Lead Mine Canyon area (Longstreet mining district), Monitor Range, about 22 miles (35 km) north-northwest of Ellendale. The quartzite forms pale-pinkish-brown to very light gray resistant nubbins, caps, and interbeds on subdued brownish hills of contorted schistose and phyllitic shale and siltstone. The extremely shattered and contorted character of these rocks, coupled with their relations to the surrounding Tertiary volcanic rocks, indicate that the Paleozoic strata are in part megabreccia masses (landslides?) within the Tertiary section. A possible source for the breccias is in the high mountain closed by the 8800-foot (2682 m) con-

tour, 3 miles (4.8 km) east of Lead Mine Canyon, where a prominent cliff of quartzitic strata as much as 1000 feet (305 m) thick crops out high on the west and south slopes. Dating of the pre-Tertiary rocks near Lead Mine Canyon is imprecise, but worm trails exist and scrappy trilobite material in the shaly strata suggest Early Cambrian olenellid forms. Other outcrops of the Gold Hill in the Toquima Range (Jefferson Canyon and Manhattan mining districts) also contain abundant quartzite and lesser amounts of schistose and phyllitic shales.

Outcrops of Wood Canyon Formation and Zabriskie Quartzite in northern Nye County are the northernmost recognized exposures of these formations, which are extensive in southern Nevada and adjacent parts of California (Hazzard, 1937, p. 309; Wheeler, 1948, p. 26; and Nolan, 1929, p. 463–464). The units are combined on the present map (pl. A1) and described below, but please note that some geologists would apply a different nomenclature to the strata. J. H. Stewart (oral commun., 1984) recently examined the Cambrian section in the Toquima Range, concluded that a tongue of the Zabriskie is indeed present, but believes that the formation name Harkless should be used there for this tongue and for the shaly silty strata beneath mapped as Wood Canyon Formation by Ervine. Stewart would also apply the Harkless terminology to a similar section in the Ellendale mining district, southern Minotor Range. The Wood Canyon was studied north of Belmont by Ervine (1972, p. 15–23), where the lower part of the formation is missing and supplanted by plutonic rocks: about 1350 feet (412 m) of micaceous quartzite and siliceous schist and, in the upper part, minor limestone constitute the preserved middle (> 560 ft or > 171 m) and upper (700–800 ft or 214–244 m) members of the formation. Quartzites are predominant in the middle member. Colors of the lower strata tend to reddish and purplish grays and browns that are set off from the olive-tinted, lighter grays of the upper member by a medial light-gray to brown, yellowish-weathering quartzite 120 feet (36 m) thick. A tentatively identified *Protopharetra raymondi* (an Early Cambrian archeocyathid), echinoderm fragments, and casts of worm burrows from a 1-foot zone about 75–125 feet (23–38 m) beneath the top of the Wood Canyon represent the lowest fossil horizon from which Ervine collected specimens (1972, p. 21). The lithology, stratigraphic position, and fossils permit correlation with the Wood Canyon Formation. The Campito and Poleta Formations are partial correlatives farther southwest in Esmeralda County (Stewart, 1966, p. C68–C71).

The previously mentioned Zabriskie Quartzite, as defined by Hazzard (1937, p. 309–310), consists of about 160 feet (49 m) of quartzite and is considered to have formation rank by most workers in the Great Basin (Wheeler, 1948, p. 26; Barnes and others, 1965; and Stewart, 1966, p. C72), who have assigned 6 to 1150 feet (2 to 350 m) of strata to it, including correlatives such as the Corkscrew Quartzite of former usage (Cornwall and Kleinhampl, 1964, p. J3–J4). As mapped and defined by Ervine (1972, p. 23–28), the Zabriskie near Belmont includes 260 feet (79 m) of relatively clean, very fine to medium-grained quartzite and intercalated siliceous schist in a 2:1 ratio, with muscovite scattered in about half of the quartzite. The somewhat reddish-, orangish-, and yellowish-brown cliffy-weathering unit here and near Ellendale (southern Monitor Range), where there is an estimated similar thickness, is fairly characteristic of the Zabriskie. The abundant and conspicuous *Scolithus* (filled worm burrows oriented perpendicular to bedding) in some zones at the Belmont locality are also characteristic. *Scolithus* occur in north-striking, vertical beds that form bold outcrops in Antone Canyon just above its junction with Meadow Creek, about 5 miles (8 km) northwest of Belmont. Mica in the abundance noted by Ervine is not typical of the formation elsewhere (Stewart, 1970, p. 47). At the Ellendale locality, a moderately well sorted, commonly fine grained, and thin- to thick-bedded blocky-splitting quartzite predominates, and there are local intercalations of shale (some with worm tracks) and phyllite (yellowish gray, pale browns, and pale red), argillite (yellowish gray), and shaly siltstone and quartzitic siltstone (pale reds to browns and olive gray). This association is common in the transitional zone between the Wood Canyon Formation and the Zabriskie Quartzite of southern Nevada and in the Harkless Formation, another partial correlative, in Esmeralda County. The term "Harkless" is preferred by J. H. Stewart (written commun., 1975) for sections containing abundant siltstone.

The Zabriskie is conformable with and gradational downward through several feet into the underlying Wood Canyon Formation and is overlain conformably by the Carrara Formation. Stratigraphic position of the Zabriskie between these two formations establishes its age as Early Cambrian. Fragmented casts and molds of olenellid trilobites in the quartzite at Ellendale verify this age assignment (A. R. Palmer, written commun., Sept. 1963). These trilobites are the only known diagnostic fossils reported from the formation, and Palmer's conclusion is quoted here:

> Field no. 917-1 (USGS Colln. 4233-CO—S½ of SW¼ sec. 10, T. 2 N., R. 47 E., Ellendale mining district, Monitor Hills, S. of U.S. Highway 6, Monitor Range, Nye Co., Nevada.
>
> The olenellid fragments in this collection include reticulate pieces probably of a species of *Wanneria*, and many cephala of a small olenellid that seems to be undescribed. Its form, however, is similar to an undescribed species of the Carrara and they may represent the same genus. *Wanneria* is known at present only from the Saline Valley (= Zabriskie plus lower Carrara) Formation, or beds that Stewart mapped as Harkless. The sandy Saline Valley with *Wanneria* may actually be a temporal correlative of part of the Zabriskie, so the chances are reasonably good that the quartzite at 917-1 is related to the Zabriskie.

CARRARA FORMATION

The Carrara Formation (pl. A1) in the mapped region crops out only near Belmont (also see fig. A20). This is the northernmost-known exposure of the formation, which is named for strata lithologically transitional between the underlying Zabriskie Quartzite and the relatively pure carbonates of the overlying Bonanza King Formation in southern Nevada (Cornwall and Kleinhampl, 1961). A section about 1300 feet (396 m) thick,

consisting of four members, informally designated "*a*" through "*d*," was described by Ervine (1972, p. 28–34). Strata consist of interbedded limestone, shale, and phyllite and lie conformably above the Zabriskie. The upper contact is mapped as a fault by Ervine (pl. A1), who noted considerable deformation in the upper Carrara and overlying schists (mapped in the present report with shale and limestone [pl. A1] and tentatively correlated with the Mayflower Schist at Manhattan). Ervine (1972, p. 30–32) has stated that his lowest member is the most economically important stratum in the Barcelona mining district and is also probably an important ore-bearing unit at Manhattan. The 150 foot (46 m) thick member is composed of phyllitic rocks separated by a limestone bed that is generally about 30 feet (9 m) thick. The limestone is close to the stratigraphic horizon of the ore-bearing Combined Metals Member of the Pioche Shale at Pioche. It is in part a crepe-weathering limestone that locally contains vague forms suggestive of *Girvanella*. Thin zones of fossil hash containing olenellid trilobite fragments occur in the upper part of the member in brown shaly limestone and calcareous siltstone (A. R. Palmer, written commun., 1963). The stratigraphic position and lithology of the formation establish its correlation with the type Carrara, and olenellid trilobite scraps confirm an Early Cambrian age for at least part of the formation near Belmont.

PIOCHE SHALE

The Pioche Shale, first defined by Walcott (1908, p. 11–12) near Pioche, Nevada, was redefined by Westgate (1932, p. 8–10), subsequently split by Deiss (1938, p. 1152–1160), and then restored to the redefinition of Westgate (Wheeler and Lemmon, 1939, p. 34–35). This formation was mapped in the Grant Range, where exposures are thickest, and in the White Pine Range, where the section is complete but only 300 feet (91.5 m) thick (see fig. A20). Near Troy, in the Grant Range, the formation may be as much as 700 feet (213 m) thick (Cebull, 1967, p. 18–20). Hyde and Huttrer (1970, p. 506) measured approximately 400 feet (122 m) of a partial section in Grant Canyon, where Huttrer (1963) suggests that 100 feet (30 m) of blue-gray limestone corresponds to the Combined Metals Member of the Pioche.

Lumsden (1964, p. 18–20), using Kellogg's description (1963, p. 688), described the Pioche in the White Pine Mountains as a:

> ...Heterogeneous sequence of argillite (65 percent), quartz sandstone (20 percent) and limestone (15 percent)....

and continues with:

> ...Argillites...varicolored khaki, greens, browns, and reds...thin ledges of sooty black limestone...toward the top of the Pioche...ledges become thicker and more common with...*Girvanella*....Thin beds of micaceous and quartose sandstone are scattered throughout....

This description aptly fits the Pioche in the Grant and Quinn Canyon Ranges. The age of the Pioche is Early and early Middle Cambrian, on the basis of faunal data from the type locality near Pioche (Westgate, 1932); diagnostic fossils have not been found in northern Nye County. Farther west in the Toquima and Toiyabe Ranges, the Pioche probably can be correlated with part of the Gold Hill Formation.

POLE CANYON LIMESTONE

The Pole Canyon Limestone was first defined in the Snake Range, east-central Nevada, by Drewes and Palmer (1957, p. 110). They divided the formation into five members, A through E. Kellogg (1960, 1963), and Lumsden (1964) subsequently recognized this formation in the Egan and White Pine Ranges, respectively. Pole Canyon Limestone is the term used here for the thick-bedded limestone lying conformably above siliceous clastic strata in the Grant and Quinn Canyon Ranges (fig. A20). This designation is preferable to Eldorado Limestone as applied by Cebull (1967, p. 21–25), because the Pole Canyon is a well-defined unit a short distance to the east in the Egan Range, where Kellogg (1960, 1963) measured nearly 2000 feet (610 m) of it. In contrast, the Eldorado, in its type locality at Eureka, Nevada, is of equivocal thickness, is commonly altered, has been redefined numerous times (Nolan and others, 1956, p. 9–11), and is perhaps best left restricted to the Eureka mining district. The Pole Canyon Limestone is commonly combined on the map with quartz silty and shaly carbonate beds and shale of the overlying Lincoln Peak Formation and Dunderberg Shale in northern Nye County (shale and limestone, undivided, pl. A1 and fig. A20). Cebull's (1967, p. 21–23) Eldorado Limestone of the Grant Range (Pole Canyon Limestone of this bulletin) is a 1000-foot (305-m)-thick, commonly deformed and attenuated, light- to dark-gray calcareous marble with thinner bedded silty zones in the lower and upper parts. The Pole Canyon Limestone is 675 feet (206 m) thick nearby in the White Pine Mountains, where Lumsden (1964, p. 20) identified all five of its members of the Snake Range section, but mapped only three: a lower shaly limestone with some shale, 125 feet (38 m) thick; a middle thin-bedded limestone member, 210 feet (64 m) thick; and an upper, 340 foot (104-m)-thick member of massive, coarse-grained, partly oolitic limestone.

Cebull (1967, p. 23) found only the algae *Girvanella* in strata that we assign to the formation, but one of our collections (USGS colln. 4236–CO) yielded a Middle Cambrian form of the trilobite *Ogygopsis* from pyritized, dark-gray, very fine grained, recrystallized limestone: "The slightly pyritized and distorted pygidia of *Ogygopsis* [sp.] with 7 pleural furrows show that this is a Middle rather than Lower Cambrian member of the genus. It could be from anywhere within the lower half of the Middle Cambrian" (A. R. Palmer, written commun., Sept. 1963). Thus, at least part of the Pole Canyon in the Grant Range lies within the lower half of the Middle Cambrian, an age designation that conforms with that clearly established by Lumsden (1964, p. 25–29) in the White Pine Range, where the formation is early and middle Middle Cambrian in age. Lumsden's collections are especially noteworthy because they are comprehensive. The lower member of the Pole Canyon Limestone contains the *Albertella* zone (earliest Middle Cambrian) of Rasetti; the middle member contains the

Glossopleura zone; and the upper member, though not fossiliferous, lies below the *Elrathina-Bathyuriscus* zone (medial Middle Cambrian).

ROCKS STRADDLING THE MIDDLE AND LATE CAMBRIAN BOUNDARY

The map units described here are of late Middle and early Late Cambrian ages. Nomenclature applied to these strata in various parts of the county is shown in figure A21. East of Railroad Valley, the units exhibit complex stratigraphic relations that mirror the complexities found in units of the same interval elsewhere in east-central Nevada but are considerably different from the sections in southern Nevada (summarized by Longwell and others, 1965, p. 18–20) and south-central Nevada (summarized by Cornwall, 1972, p. 7–9). Because of the complexities, workers established somewhat different sections at Eureka (Nolan and others, 1956, p. 12–19), the Egan Range (Kellogg, 1963, p. 689–692), and the Snake Range (Drewes and Palmer, 1957, p. 113–116). The strata of this interval in northern Nye County include the Lincoln Peak Formation and shale and limestone, undivided. The Lincoln Peak is extensive in the Egan, Grant, Horse, Quinn Canyon, and the White Pine Ranges, but is differentiated on the map (pl. A1) from shale and limestone, undivided only in the Egan Range and in the Currant Creek drainage between the Horse and the White Pine Ranges.

Other outcrops that may in part be of comparable age and lithology elsewhere in northern Nye County lie in the Hot Creek Range (Swarbrick Formation), in the Ellendale mining district south of U.S. Highway 6 (Monitor Range), and in the Toiyabe Range near the border of Nye and Lander Counties. The rocks in the latter two places were left undifferentiated (shale and limestone, pl. A1) and are described elsewhere.

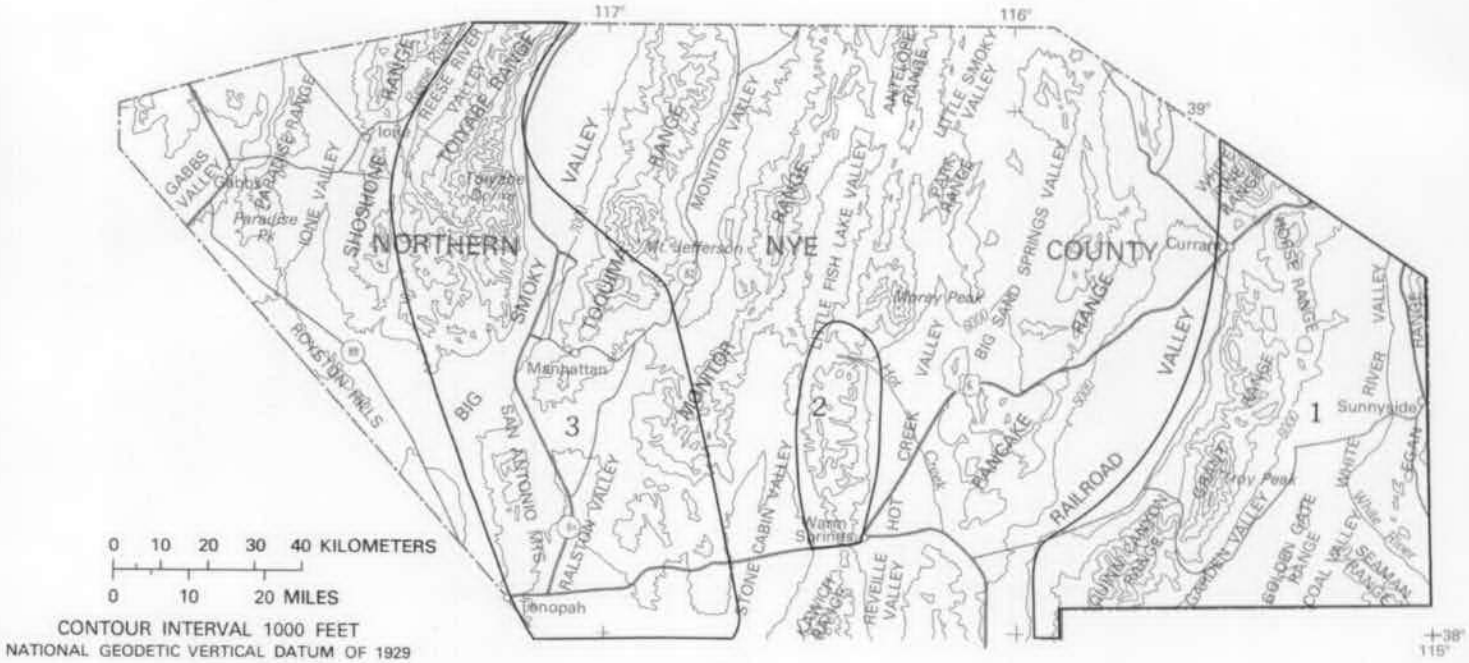
Lincoln Peak Formation

The Lincoln Peak Formation (pl. A1) consists of very thin bedded limestone, shaly limestone, shale, and calcareous shale, which at its type locality in the Snake Range is more than 1000 feet (305 m) thick (Drewes and Palmer, 1957, p. 113) but is incomplete there. Where complete elsewhere in the Snake Range, the formation is most likely about 4000–4500 feet (1219–1372 m) thick (D. H. Whitebread, oral commun., 1969). More than 3000 feet (914 m) of yellow- to orange-weathering shale and thin-bedded limestone composes the formation in the White Pine Range, according to Lumsden (1964, p. 30). He recognized two members, a lower member of limestone alternating with siltstone and an overlying member of limestone alternating with shale—units originally considered formations by Wire (1961). In the White Pine Range the Lincoln Peak lies conformably above the Pole Canyon Limestone and underlies the Dunderberg Shale; in the type locality it underlies the Johns Wash Limestone (Drewes and Palmer, 1957, p. 113). At and near its type locality, the Lincoln Peak Formation has been dated as late Middle and early Late Cambrian from the presence of the *Bolaspidella, Cedaria, Crepicephalus,* and *Aphelaspis* trilobite zones (Drewes and Palmer, 1957, p. 114; D. H. Whitebread, oral commun., 1969). A sparse trilobite fauna found near Currant places the basal part of the Lincoln Peak in the *Bathyuriscus-Elrathina* zone of medial Middle Cambrian age. Most of the formation is somewhat younger here and has been tentatively assigned to the upper Middle to lower Upper Cambrian on the basis of scarce trilobites and its stratigraphic position beneath the Dunderberg Shale (Lumsden, 1964, p. 32–36). The Patterson Pass Shale and Emigrant Springs Limestone of Kellogg (1963) in the Egan Range correlate with parts of the Lincoln Peak Formation (Kellogg, 1963, p. 689–690; Langenheim and Larson, 1973, chart 2) and are mapped as Lincoln Peak (pl. A1). The upper part of the Emigrant Springs is somewhat younger (Kellogg, 1963, p. 690) than the Lincoln Peak as used by Lumsden (1964, p. 32–38). Formation A of Cebull (1970) in the central and southern Grant Range is generally correlative with the Lincoln Peak, and the strata there and locally elsewhere are mapped (pl. A1) as shale and limestone, undivided, and described in a separate section below. Strata mapped as Swarbrick Formation in the Hot Creek Range probably correspond temporally to the Lincoln Peak but are lithologically distinctive. At Eureka, to the northwest, the sequence of Secret Canyon Shale and Hamburg Dolomite is the time equivalent of the Lincoln Peak, but only the Secret Canyon Shale exhibits lithologic similarity (Nolan and others, 1956, p. 11–18).

The depositional environment responsible for the thinly layered clastic rocks of the Lincoln Peak and its lithic equivalents migrated laterally with time. This is indicated by changes in faunal assemblages and the appearance of limestone tongues, large enough to map as discrete units, above Lincoln Peak and its correlatives in parts of eastern Nye, northern Lincoln, and White Pine Counties. Palmer (1960, p. 53, figs. 3, 4) discussed such changes in the eastern part of this region and partly defined two detrital belts—an inner one on the east and an outer one on the west separated by a middle carbonate belt.

Shale and Limestone, Undivided

Shale and limestone, undivided, a very extensive map unit (pl. A1), includes shaly limestone, limestone, shale, and calcareous shale and lies stratigraphically chiefly between the Pole Canyon Limestone and the higher Windfall Formation of Late Cambrian age. Rocks of the interval consist of undifferentiated Lincoln Peak Formation and Cebull's (1967, p. 25–27, 31–35; 1970) correlative of the Lincoln Peak interval in the Grant Range—formation A, possibly Cebull's overlying formation B, and the Dunderberg Shale. The Lincoln Peak Formation has been described and the Dunderberg is described in a separate section below. Cebull's (1970) formation A consists of between 4000 and 7000 feet (1219 and 2134 m) of very thin bedded, silty limestone with subordinate intercalated limestone and calcareous siltstone. Nodular and bedded shale appears near the top of the formation. Limestone and shale tend to be gray, and the silty rocks are reddish brown, yellow, and orange. The overlying formation B consists of thick-bedded and massive limestone approximately 500 feet



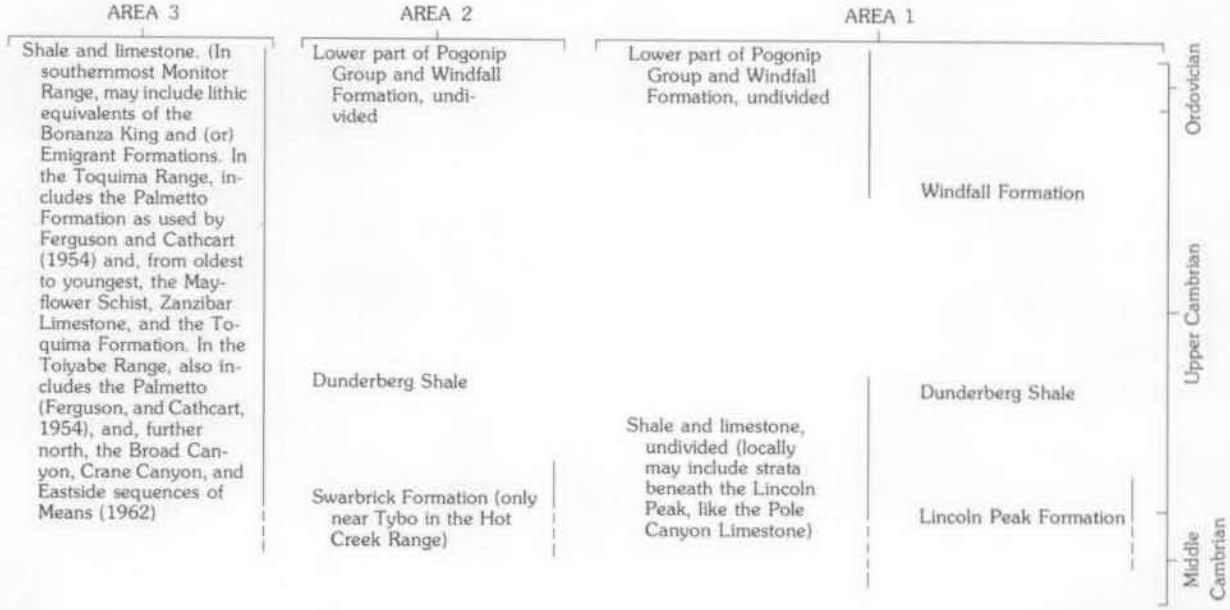


FIGURE A21. Map units used in various parts of northern Nye County for all Middle and Upper Cambrian strata on the geologic map (pl. A1). Vertical line represents approximate age range of the units.

(152 m) thick at its type locality south of the Troy mining district. A white upper member, as opposed to the dark-gray lower member, commonly forms a conspicuous light band on the cliffs and serves as a marker horizon in the area (fig. A22).

The upper part of Cebull's formation A yields a fauna of the *Dunderbergia* zone (Lochman-Balk and Wilson, 1958), thus indicating a late Dresbachian (early Late Cambrian) age. Formation B of Cebull yielded faunas of the *Dunderbergia* zone and the younger *Elvinia* zone and is thus Late Cambrian in age (Cebull, 1967, p. 34–35).

Swarbrick Formation

The Swarbrick Formation (pl. A1) (Ferguson, 1933, p. 13–14) is the unit at the base of the exposed Paleozoic section in the Hot Creek Range. The name is retained here because it has precedence over possible correlatives defined elsewhere in Nevada. At Tybo in the Hot Creek Range, about 1700 feet (518 m) of strongly deformed Swarbrick is exposed (Quinlivan and Rogers, 1974); here it conformably underlies the Upper Cambrian Dunderberg Shale. Ferguson (1933) had estimated a considerably greater exposed thickness. The pale-reddish-

brown-weathering Swarbrick is very thin to thin-bedded, flaggy to slabby, medium-gray limestone alternating with grayish-black chert that increases in abundance upward. Microcrystalline quartz composes 80%–90% of the chert layers; dolomite rhombs and sponge spicules are also present (Cook, H. E., 1966, p. 10). The thinness and regularity of the beds in the Swarbrick have a counterpart in the middle one-third of the Bonanza King Formation, even though the lithologies differ, with the latter consisting of relatively purer dolomite and containing only minor cherty and quartz silty zones (Hazzard, 1937; Cornwall and Kleinhampl, 1961; 1964, fig. 1).

An early Late Cambrian fauna of the *Aphelaspis* zone occurs in the uppermost 10 feet (3 m) of the Swarbrick, but diagnostic fossils have not been found elsewhere in the formation, which may be Middle Cambrian in part (Quinlivan and Rogers, 1974). The overlying Dunderberg Shale has yielded trilobites of the *Prehousia* zone and older faunas, indicating that the Swarbrick is pre-latest Dresbachian (pre-latest early Late Cambrian).

DUNDERBERG SHALE

Introduction

The Dunderberg Shale (Walcott, 1908) has its type area in the Eureka mining district (Nolan and others, 1956, p. 18–19). Outcrops of shale in the Hot Creek Range, previously assigned the name "Tybo Shale" (Ferguson, 1933, p. 14–16), were recently reassigned to the Dunderberg Shale (Quinlivan and Rogers, 1974). Thus, the name "Tybo Shale" is now abandoned.

Distribution, Thickness, and Lithology

The Dunderberg Shale was mapped (pl. A1) locally in the Hot Creek Range from Tybo north to Hot Creek Canyon and near Currant in the Horse and southern White Pine Ranges. Lithologically similar outcrops in the Grant Range are not differentiated on the geologic map and are locally included with other strata, such as shale and limestone, undivided (pl. A1), in Scofield Canyon, where the Johns Wash Limestone and Corset Spring Shale may be the more proper names for the Dunderberg-like beds there. Table A7 cites thicknesses of the Dunderberg Shale, as reported by others.

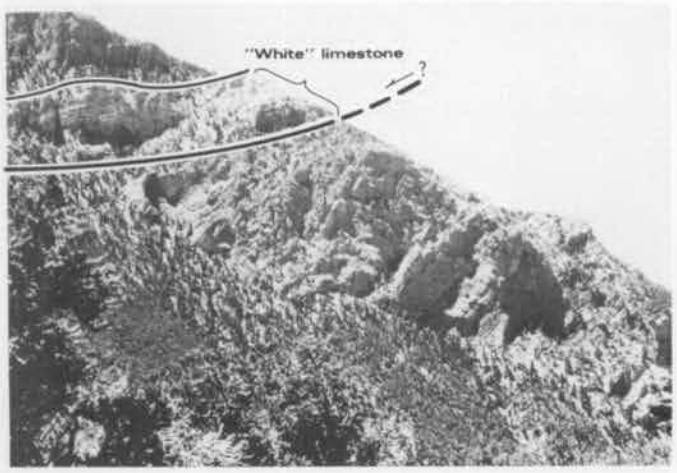


FIGURE A22. View to south of ridge on south of Little Meadow Canyon, Grant Range; shows "white" limestone marker bed of formation B of Cebull (1970), here assigned to "shale and limestone, undivided," in the Upper Cambrian of the Grant Range. *Photo courtesy of S. E. Cebull.*

In the Hot Creek Range, the formation is typically an olive- to dark-gray fissile shale with minor intercalated calcareous shale and limestone in beds and lenses 3–6 inches (7.5–15 cm) thick. Where exposed east of Railroad Valley, limestone interbeds are more common, as are brown-weathering colors; interbedded chert is present in the more doubtfully assigned Horse Range section (Lumsden, 1964, p. 38; also see Wilhoites Formation of Wire, 1961). Metamorphism to phyllite has affected the interval in many of the outcrops east of Railroad Valley (Hyde and Huttrer, 1970, p. 507; Lumsden, 1964, p. 39).

Age and Correlation

In the mountains just east of Railroad Valley, the Dunderberg Shale generally cannot be differentiated from the underlying and, in part, laterally gradational Lincoln Peak Formation. The Dunderberg, therefore, is considered to be part of an intertonguing and gradational series of shale and shaly and silty limestone. Its contact with the underlying Swarbrick Formation in the Hot Creek Range is tectonically disturbed but appears to be gradational (Quinlivan and Rogers, 1974). The upper contact of the Dunderberg is also gradational, but the gradation occurs across a relatively thin sequence of beds.

An abundant early Late Cambrian fauna of the pterocephaliid biomere (Palmer, 1965), including the *Dunderbergia* faunizone of Lochman-Balk and Wilson (1958, p. 333), among others, characterizes the Dunderberg Shale at most places; it is not uncommon for the fossils to be deformed at Tybo. Temporally equivalent strata include the Johns Wash Formation and Corset Spring Shale of the Snake Range (Drewes and Palmer, 1957), the lower approximately several hundred feet of the Wilhoites Limestone of Wire (1961) in the Horse Range, the upper part of Formation A of Cebull (1970, fig. 3) in the Grant Range (see A. R. Palmer, *in* Cebull, 1967, p. 28), and part of Cambrian A and B units of Hyde and Huttrer (1970, p. 507) in the Grant Range.

WINDFALL FORMATION

Distribution, Thickness, and Lithology

The Windfall Formation of the Eureka mining district (Nolan and others, 1956, p. 19–23) was recognized and mapped at several places in the eastern part of the mapped region, including locally in the Horse, White Pine, and Grant Ranges.

The cliff-forming Windfall consists predominantly of limestone that is thick bedded and locally silty in the lower part, similar to the type Catlin Member at Eureka, and thin bedded with localized chert intercalations in the upper part. Resistance of the unit, coupled

TABLE A7. Thickness of Dunderberg Shale, northern Nye County, Nevada.

Hot Creek Range Tybo Canyon	Hot Creek Range Hot Creek Canyon	White Pine Range	Horse Range	Grant and Quinn Canyon Ranges
[1] ~ 500–800 ft (153– ~ 244 m) [2] ~ 1600 ft (488 m)	[3] 1500–2000 ft (457–610 m)	[4] 900 ft (274 m)	[5] 430 ft (131 m)	[6] Several hundred feet (~ 100 m)

[1] Quinlivan and Rogers (1974).
[2] Ferguson (1933).
[3] Cook, H. E. (1966).
[4] Lumsden (1964).
[5] Lumsden (1964); also, see Wire (1961).
[6] Not mapped as Dunderberg, but this part of a very thick unit (∈sl, pl. A1) lithologically and probably temporally resembles the Dunderberg. See Cebull (1967).

with the relative weakness of the adjoining formations, emphasizes the cliff-forming characteristics of the Windfall locally, as in the Horse and White Pine Ranges.

The lower contact of the Windfall Formation is sharp but conformable, passing from the less resistant fissile Dunderberg Shale and equivalent beds upward into thicker bedded limestone. The upper contact of the Windfall with the Pogonip Group is conformable but more gradational than the lower contact. Cebull's (1967, p. 37) upper contact, which we accepted for the map in the Grant Range, was placed at the last occurrence of silt characteristic of the Windfall.

Different thicknesses of the Windfall in northern Nye County have been reported: 640 feet (195 m) in the Grant Range (Cebull, 1967, fig. 3) and as much as 2900 feet (884 m) in a composite section in the northern Horse and southern White Pine Ranges (Lumsden, 1964, pl. III). The strata are thinner in the White Pine Range than in the Horse Range. As shown on the geologic map (pl. A1), the Windfall in the Grant Range is about 1140 feet (347 m) thick and includes what Cebull terms the "Windfall Formation" and "formation B" (Cebull, 1970).

Elsewhere in the Quinn Canyon Range, in the Pancake Range about 16 miles (26 km) northwest of Duckwater, and in extensive exposures in the Hot Creek Range, the Windfall Formation is recognizable and probably mappable, at least in part. But at these outcrops it is not differentiated from the Ordovician Pogonip Group (see Lower part of Pogonip Group and Windfall Formation, undivided, pl. A1). The lithic equivalent of the Windfall in the Hot Creek Range, the Hales Limestone of some reports, has been assigned thicknesses ranging from a minimum of 700 feet (213 m) to more than 3000 feet (915 m), although a thickness of about 1675 feet (511 m) (Quinlivan and Rogers, 1974) may be the most realistic average (see Lower part of Pogonip Group and Windfall Formation, undivided, pl. A1).

Age and Correlation

Scattered trilobites of several zones ranging up from the *Elvinia* zone date the Windfall generally as Late Cambrian (Franconian and Trempeleauan). Locally strata of Windfall affinity extend into the Lower Ordovician, such as the outcrops in the northern Antelope Range (Eureka County) and in the thick section in the Hot Creek Range, most of which is Ordovician (see Lower part of Pogonip Group and Windfall Formation, undivided, pl. A1).

The approximate stratigraphic equivalents of the Windfall in eastern Nevada are the Notch Peak Formation, the Mendha Formation (Pioche district), and the Whipple Cave Formation (Egan Range) (Hose and Blake, 1976; Kellogg, 1963; Tschanz and Pampeyan, 1970); in southern Nevada and California the Nopah Formation is correlative. The Windfall is generally more thin bedded and thinner splitting than most of these units, but all form conspicuous cliffy exposures. Farther west in northern Nye County, part of the Hales Limestone (Ferguson, 1933; Quinlivan and Rogers, 1974) in the Hot Creek Range (which we did not differentiate on the map [see Shale and limestone, pl. A1]) is a stratigraphic equivalent of the Windfall and bears a close lithic affinity. However, the Hales is generally younger (Early Ordovician, Quinlivan and Rogers, 1974) than the typical Windfall, except possibly in the northern Antelope Range (Merriam, 1963, p. 14–16, fig. 6).

Cambrian and Ordovician Systems

Rocks astraddle the Cambrian and Ordovician boundary, and locally extending into the Ordovician, are described under the next two subheadings.

LOWER PART OF POGONIP GROUP AND WINDFALL FORMATION, UNDIVIDED

The cliff-forming limestone section whose age straddles the Cambrian-Ordovician boundary is difficult to subdivide in the field, and on plate A1 it is left undifferentiated at many places in the Quinn Canyon Range, the Pancake Range northwest of Duckwater, and in the Hot Creek Range where the Hales Limestone (Ferguson, 1933) is the primary constituent.

In the Pancake Range, about 21 miles (33.6 km) northwest of Duckwater, most of these strata consist of platy, very thin to thin-bedded, fine- to medium-grained

shaly limestone. The medium-light-gray to medium-gray limestone has abundant yellowish-orange to pale-yellowish-weathering argillaceous to silty layers and local zones of dull deep reddish and brownish colors. The whole section weathers to uniformly chip-strewn yellow-brown to grayish slopes. Zones of limestone-pebble conglomerate are present locally, and the shaly limestone is overlain by massive, very thin bedded cherty limestone, with pale-yellowish-brown chert in nodules and broad lenses.

Fossil collections made from the Goodwin Formation part of this undifferentiated sequence were examined and described by R. J. Ross, Jr., and L. A. Wilson (written commun., 1962):

USGS Coll. D966 CO. 15512-F2a. Located 35,400 ft. S41 ½° W of Spring at Pogues station, T. 14 N., R. 54 E., Nye Co., Nev.
Symphysurina spicata
Kainella sp.
Apheoorthis sp.
Age: very low Pogonip (Goodwin)—Early Ordovician, zone D or lower of Ross (1952).

USGS Coll. D967 CO. 15512-F3. Same location as F2a.
Symphysurina sp.
Kainella? sp.
Age: Probably same as F2a or very nearly so.

USGS Coll. D995 CO. (15512-F4) Basal Pogonip Group. Located 38,800 feet S44°45′ W of spring at Pogues Station in T. 14 N., R. 53 E., Nye County, Nevada.
Symphysurina cf. *S. brevispicata* Hintze
These specimens are intermediate between Hintze's species and *S. cleora* Walcott.

USGS Coll. D996 CO. (15512-F5) Located 37,600 feet S63° W of spring at Pogues Station, T. 15 N., R. 53 E., White Pine County, Nevada.
Asaphellus? sp. (three pygidia)
The abundant trilobite fragments in this bioclastic limestone have not produced any identifiable heads.
My guess is that this collection is younger than your F2a, F3, or F4. Asaphids like *Asaphellus* appear in the Utah sections above *Symphysurina*. Still Goodwin.
A single specimen of the conodont *Drepanodus* was obtained from this collection.

The Hales Limestone near Tybo is a platy to slabby, laminated to thin-bedded, aphanitic to medium-grained limestone that commonly forms cliffy medium-gray outcrops; locally the formation is thicker bedded and darker gray. Intraformational conglomerate is common, as are zones of clay- to sand-size clastic material and gray to black chert lenses; quartzite to 40 feet (12 m) thick locally caps the formation (Quinlivan and Rogers, 1974).

A "probable thickness of about 3000 feet" (Ferguson, 1933, p. 16) for the Hales Limestone at Tybo has been reduced to about 1675 feet (511 m) by Quinlivan and Rogers (1974), who note that the Cambrian-Ordovician boundary lies somewhere between 175 and 415 feet (53–415 m) above the base of the formation. They state that below this horizon, the Hales is Late Cambrian and carries an *Elvinia* zone fauna, whereas above "...the Hales is Early Ordovician (Tremadocian) in age and equivalent to lower Goodwin Limestone in the Antelope Valley area."

CAMBRIAN AND ORDOVICIAN SHALE AND LIMESTONE

Introduction

Strata assigned to the Cambrian and Ordovician shale and limestone unit (fig. A21 and pl. A1) form extensive outcrops in the Toquima and Toiyabe Ranges and locally in the southern Monitor Range and the San Antonio Mountains. The outcrops in the Toquima Range lie chiefly south of Mount Jefferson. Many of these and other exposures, except for those in the Monitor Range, were mapped as undifferentiated slate, limestone, and chert by Ferguson and Muller (1949, pl. 1); they were later largely assigned to the Ordovician Palmetto Formation by Ferguson and Cathcart (1954). Ferguson (1924) had earlier divided these strata at Manhattan into three successively younger formations: the Mayflower Schist, Zanzibar Limestone, and the Toquima Formation. Several broad outcrops in the Toiyabe Range near the joint boundary of Lander and Nye Counties were studied by Means (1962, p. 76–80, map 1), who applied the names "Broad Canyon," "Crane Canyon," and "Eastside sequences." The Eastside sequence was shown by Stewart and McKee (1968a, fig. 3) to consist of the Pogonip Group in Nye County and to include Silurian and Devonian rocks as well in Lander County. Kleinhampl and Ziony (1967) included all the above-mentioned rocks with undifferentiated Cambrian and Ordovician shale and limestone, and the present bulletin retains this convention (pl. A1). The unit may be thickest in the Toquima Range.

The strata in many places are believed to be partly or entirely allochthonous, as in the southern Monitor Range and in the Toiyabe Range near the county line, and perhaps near Tonopah and at Manhattan. In the Monitor Range, the lithology is exotic with respect to presumed coeval units nearby, and the same may be true of the sections near Tonopah and at Manhattan.

Thickness and Lithology

Generally, the strata are composed of mildly to moderately metamorphosed equivalents of shale, mudstone, limestone, chert, and locally, greenstone. Phyllite, schist, argillite, and slate form the largest part of the map unit; however, any one rock type may predominate locally, or two or more may be nearly equal in abundance. Limestone, commonly recrystallized, is abundant locally. Where in close contact with plutonic bodies, it may be altered to a semifriable material and (or) to a bleached and finely or coarsely recrystallized marble or other contact-zone mineral assemblages, including tactite containing molybdenite and chalcopyrite.

The thickest known exposed section is near Manhattan, where a minimum of 5600 feet (1700 m) of strata was originally separated by Ferguson (1924, p. 21–25) into three successively younger formations: the Mayflower Schist (about 800 feet or 244 m thick), Zanzibar Limestone (about 800 feet or 244 m thick), and the Toquima Formation (probably exceeds 4000 feet or 1220 m in thickness). Later, Ferguson and Cathcart

(1954) estimated that the section here exceeded 5000 feet (1525 m) but indicated that the thickness was uncertain, because the top and bottom are not exposed and unrecognized isoclinal folds may be present. Knotty schists farther north in the Barcelona district near Belmont are similar to the Mayflower and could be about 1500 feet (457 m) thick according to Ervine (1972, p. 35), who also described (p. 39) more than 800 feet (244 m) of Zanzibar Limestone.

Lithologic aspects of the Manhattan section of Ferguson (1924, p. 20–25), which is described below along with parts of one near Belmont, are in part common to many of the rocks mapped as Cambrian and Ordovician shale and limestone (pl. A1). At the base at Manhattan a knotted schist that grades laterally to fine-grained chloritic schist was mapped separately as the Mayflower Schist by Ferguson (1924, pl. 1, p. 20–21) and was described as possibly interbedded with the overlying Zanzibar Limestone.

Ervine (1972, p. 34–38, 74–90) studied, described, and pictured similar schists and other rocks of the Barcelona district. The following summarizes his findings: the rocks are andalusite-cordierite-quartz-mica schists that weather to greenish, reddish, or brownish-gray colors and are characterized, as at Manhattan, by a wavy micaceous foliation and knots of cordierite with or without andalusite. Minor, unsystematically spaced thin interbeds of gray to blackish limestone, hornfels, phyllite, slate, and rarer pebble lenses are included with the schist. Cordierite knots increase in number and size nearer the plutons of the district (as they do at Manhattan [Ferguson, 1924, p. 20–21]). The schists become phyllitic more than about 5000 feet (1525 m) from the plutons but retain enough biotite and muscovite to indicate that, even this far away, the hornblende-hornfels metamorphic facies has been attained locally. The pelitic rocks of the Barcelona district display the full range of the hornblende-hornfels facies of thermal metamorphism; within about 100 feet (31 m) of the plutonic bodies, the metamorphic grade is about at the upper limit of the facies and locally attains the pyroxene-hornfels facies. Beyond about 5000 feet (1525 m) from the plutons, the metamorphic grade approaches the less severe albite-epidote-hornfels facies, and chloritic rocks locally represent a retrogressive alteration. Similar conditions may be observed locally near Round Mountain, where, because of structural dislocations, rocks of the hornblende-hornfels facies have been emplaced onto rocks of the greenschist facies (Foster, 1971, p. 965).

The Zanzibar Limestone is a distinctive blue-gray limestone intercalated with and locally laterally intertonguing with very dark gray to brownish-black-weathering siliceous slaty and cherty beds (jaspilite and slate of Ferguson). The unit weathers to cliffs and broken slopes and characteristically displays a very thin- to thin-bedded, platy to flaggy, and locally massive splitting quality. Just west of Manhattan, the lower part forms a low cliff that yields upward to a steep slope broken by steplike ledges, whereas a high cliff looms prominently on the south side of Wall Canyon in the Toiyabe Range.

The Toquima Formation is composed chiefly of dark slate and chloritic schist. Scattered structureless white to grayish quartzite beds and lenses as much as 50 feet (16 m) thick at or near the base commonly cause graptolites to be preserved in the superjacent slates. Other minor lithologies include limestone and chert similar to those in the Zanzibar and as much as 200 feet (61 m) thick and, higher in the section, massive brown to gray limestone.

A much deformed section is probably at least 1000 feet (305 m) thick in the sparsely fossiliferous fault-bounded blocks about 5 miles (8–9 km) south of the mouth of West Northumberland Canyon, Toquima Range. Limestone and shale (some papery and phyllitic) are relatively abundant here, along with dark-gray slaty and cherty rocks; the section is of special interest because some of the strata contain Cambrian as well as Ordovician fossils. The Toquima is generally best considered in its original context as a formation but is not separately mapped (pl. A1).

At the Ellendale mining district in the southern Monitor Range, the Cambrian and Ordovician shale and limestone map unit consists of several distinct facies. Thin-bedded, cliffy, medium- to dark-gray dolomite and limestone and shaly limestone intercalated with similarly colored chert, the whole as much as 800 feet (244 m) thick (crude map measurement), form the extreme western end of an isolated mountain (summit elevation 7281 feet) (pl. A1). Similar but much less extensive limestone less than 100 feet (30 m) thick crops out low on the east flank of this mountain. On the west flank of the mountain, the dark-hued cliffy carbonate section (which is commonly sheared and mildly deformed, particularly so downward) grades downward through a transitional zone of interbedded shaly limestone, shale, and a little siltstone into a dominantly light-gray phyllitic shale. A low-angle fault with minor apparent displacement cuts the transitional zone. The thick carbonate strata resemble the Bonanza King Formation, but the interbedded gray shales enhance a resemblance to the informally adopted (Albers and Stewart, 1972, p. 20) middle (shale) and upper (limestone and chert) members of the Emigrant Formation of Esmeralda County. Cornwall (1972, pl. 1) included similar carbonate strata in the Emigrant(?) just south of the Ellendale district in the Monitor Hills. The Emigrant is a partial correlative of the Bonanza King Formation and includes all strata between the underlying Lower Cambrian Mule Springs Limestone and the overlying Lower Ordovician Palmetto Formation. The Bonanza King is mid- to late-Middle and early Late Cambrian in age (Cornwall, 1972) and has a somewhat smaller age span than the Emigrant. A poorly preserved acrotretid brachiopod and trilobite fauna (field colln. 11556–3 and USGS colln. 4234–CO) in the dark carbonate and chert beds at Ellendale suggests a late Middle to Late Cambrian age, according to A. R. Palmer (written commun., 1963).

Another facies consisting of chiefly interbedded brown to medium-gray slaty siliceous strata and dark-gray quartzite(?) along with locally contact-metamorphosed rocks, including marble and tactite, is located

1-3 miles (1.6-4.8 km) southeast of mountain 7281. The section is locally highly deformed and for this reason was not measured, but it is estimated to be not less than about 1000 feet (305 m) thick. This facies could prove to be Early Cambrian or even Devonian in age.

The strata in the San Antonio Mountains tend to be very dark gray, brownish black, and reddish brown on both fresh and weathered surfaces. The strata consist of interlayered units of chert, argillite, limestone, greenstone, and quartzite. Chert and argillite units predominate, but all the lithologies are fairly common except for limestone. No measurement is available for the incomplete section in the San Antonio Mountains, where perhaps as much as several thousand feet is exposed.

In the boundary area of Lander and Nye Counties, Means (1962, p. 76-78) obtained thicknesses of about 1000 feet (305 m) for his Broad Canyon sequence and at least several thousand feet for his Crane Canyon sequence. Here, deformed and faulted strata made section measuring difficult, and he gave no thickness for beds termed the "Eastside sequence." Means considered this sequence to be similar to the Crane Canyon sequence but allochthonous, and it has since been shown to consist of strata that correlate with several units of diverse ages belonging to the carbonate assemblage (Stewart and McKee, 1968a, fig. 3). The Broad Canyon sequence consists predominantly of slates and phyllites with several hundred feet of argillite and marble in the lower part and a black siliceous argillite at the base (Means, 1962, p. 77). The Crane Canyon sequence includes in its lower part as much as several hundred feet of slate or argillite overlain by evenly bedded laminated marble and a much thicker upper part consisting mostly of intercalated, gray to pale-yellow-brown impure limestone and shale (Means, 1962, p. 77-78). The Crane Canyon sequence is the only Cambrian unit mapped by Means that contains a fauna younger than the Middle Cambrian (Stewart and McKee, 1968a, p. 11).

In general, the Broad Canyon is more siliceous and concomitantly less rich in carbonates than the Crane Canyon (Means, 1962, p. 76-77; Stewart and McKee, 1968a, p. 11). Means (1962, p. 75 [fig. 3], p. 78) considers his Broad Canyon and Crane Canyon sequences to represent somewhat different facies. Basically, they are partly correlative in age and lithology. Stewart and McKee (1968a, p. 3, fig. 3) consider them not only as different facies but also as different structural levels. Stewart and McKee (1968a, p. 11) considered the Broad Canyon sequence to include both Cambrian and (Lower) Ordovician beds. Means (1962, p. 79) more cautiously correlated the Broad Canyon with slate of the Palmetto and suggested at least a partial Ordovician age.

An estimated 850 feet (259 m) of beds overlying the Gold Hill Formation were assigned to the Broad Canyon(?) by J. H. Stewart (oral commun., 1969), who measured the section in Summit Canyon, Toiyabe Range (Stewart and others, 1977), about 12 miles (19 km) south of the boundary between Lander and Nye Counties. The basal 200-300 feet (61-91 m) of this interval are phyllite and quartzitic siltstone that seemingly grade downward into the Gold Hill; phyllite and limestone form the remainder. Unlike Stewart, we show these rocks as part of the Cambrian and Ordovician shale and limestone unit (pl. A1) and prefer to consider them as the Palmetto Formation, following the usage of Ferguson and Cathcart (1954) while recognizing that the Palmetto here may include rocks that straddle the Cambrian-Ordovician boundary. The entire shale and limestone section farther south in the Toiyabe Range is a minimum of 2500 feet (762 m) thick, where an upper cherty part comparable to that at Manhattan is presumed missing because of pre-Permian erosion (Ferguson and Muller, 1949, p. 52; Ferguson and Cathcart, 1954).

Contacts and Age

The undifferentiated Cambrian and Ordovician shale and limestone unit in the region is generally in fault contact with adjacent units. The contact is least likely to be faulted, and mapped as unfaulted, in the Toiyabe Range locally between Pablo and Jett Canyons, farther north between North Twin River and Park Canyons, and in Washington Creek Canyon. Where examined in the former two areas, the contact appears to be gradational downward into generally noncalcareous phyllitic and schistose strata that lack limestone interbeds but are intercalated with quartz silty and sandy beds, all of which are somewhat metamorphosed. The underlying Cambrian rocks tend to weather brownish compared to the pale-greenish-gray tints of the overlying strata. The formation is commonly in fault contact with overlying older or younger Paleozoic rocks. The fault may be low or high angle. In other places, the contact is an unconformity with overlying rocks consisting of Tertiary volcanic strata and, locally, undated pre-Tertiary strata, some formerly regarded as Permian or Permian(?) in age and mapped as Diablo(?) or Pablo(?) Formations on the present map. Plutonic bodies have invaded the unit in other places and obliterated depositional contacts, such as in the southern Toquima Range.

As mentioned above, Cambrian and Ordovician shale and limestone (pl. A1) have been regarded in the past chiefly as Ordovician and Ordovician(?) and assigned variously to the Palmetto Formation (central and southern Toquima and Toiyabe Ranges) and to the Broad Canyon, Crane Canyon, and Eastside sequences of Means (1962, p. 76-79) (northern Toiyabe Range). The ages were established from a combination of fossil (graptolite) evidence, stratigraphic position, and similarity of lithology to other units of known age. However, many rocks within this map unit have never been directly dated, and because some, such as the Mayflower Schist and Zanzibar Limestone, may include Cambrian beds, they are assigned a Cambrian and Ordovician age in this report. The presence of some Cambrian strata and the presumed Ordovician age of other strata has been verified by recent discoveries of fossils that are described in more detail below.

Three graptolite zones have been described from shale of the shale and limestone unit at Manhattan, and additional zones at Wall Canyon in the Toiyabe Range are being studied by F. G. Poole (oral commun., 1975).

Ross and Berry (1963, p. 24–27, table 1) have restudied graptolites previously identified by Kirk from collections of Ferguson (1924, p. 22–23) at Manhattan; their studies show that the graptolites range from the *Climacograptus bicornis* through the *Orthograptus truncatus* var. *intermedius* into the *Orthograptus quadrimucronatus* zones (nos. 12, 13, and 14, respectively) of the Marathon area (Texas) of Berry (1960, p. 7–8, fig. 3) (corresponds with zones 10, 11, and 12 of Elles and Wood [1914]). Thus, at least upper Middle and Upper Ordovician strata are represented at Manhattan.

Other previously studied graptolite collections listed, and in part revised by Ross and Berry (1963, p. 26–28, table 1), include one in the Toiyabe Range between Wall and Pablo Canyons referred to Berry's zone 14 (Upper Ordovician, Eden and Maysville) and others near Belmont referred to Berry's zone 10 and, questionably, to zone 11 (Middle Ordovician, approximately Porterfield to possibly Trenton). Ferguson (1921, p. 386) also reported Ordovician graptolites near Mariposa Creek several miles south of Round Mountain. More recently, we submitted new graptolite collections for study. R. J. Ross, Jr., reported (written commun., Oct. 11, 1966) on two of these; one, from the Toiyabe Range (small gulch on north side of Wall Canyon (NW/4 NW/4 S35,T10N,R42E [unsurveyed]), yielded several graptolite genera that place the host dark-gray platy shale in the Caradoc or Ashgill (mid-Middle to Upper Ordovician):

USGS Collection D1729 CO (field no. 15324-1):

Climacograptus sp.	No proximal end of any of the
Orthograptus sp.	specimens is preserved. As a
Glyptograptus sp.	result, positive identification is
Dicellograptus? sp.	almost impossible.

The other collection from the San Antonio Mountains (near the Midway mine and Maggy Blues site, NW/4 NE/4 S31,T5N,R44E) contained graptolites of the highest Caradoc (upper part of *Orthograptus quadrimucronatus* zone of Berry), and the beds here should be the time equivalent of the lowest part of the Hanson Creek Formation at Martins Ridge (Monitor Range):

USGS Collection D1733 CO (field no. 15146-5):

Climacograptus cf. *C. tubuliferus* Lapworth
Climacograptus cf. *C. putillus* (Hall)
Climacograptus sp.

A less homogeneous section containing some similar lithologic elements, lying about 9 miles (14 km) to the southwest near Rays (site), was described by Bonham and Garside (1974, p. 43), who reported as yet unconvincing evidence of fossil wood(?) found in quartzite by F. G. Poole. They conclude that the age and designation of the outcrops are ambiguous and that the rocks could correlate with the Valmy Formation as suggested by J. H. Stewart (but not with the Palmetto Formation) or could even be late Paleozoic on the basis of the supposed wood.

Two localities near Northumberland Canyon (about 7–8 miles [11–13 km] west-southwest of the Northumberland Mine) yielded a somewhat different fauna. Field collection 13368-8 from limestone in the NW/4 SE/4 S6,T12N,R45E (unsurveyed) was studied by J. W. Huddle (written commun., Aug. 25, 1964), who identified the following conodonts: compound forms of species of *Cordylodus* and a *Euprioniodina?* sp. and simple forms *Oneotodus* sp. and *Drepanodus* sp. He stated that all the genera reported have been found in Lower Ordovician rocks but that this faunule is mainly of compound forms—unlike most Lower Ordovician assemblages, which are composed mainly of simple forms. Thus, he gave their age as Ordovician and probably Middle or Late Ordovician. Nearby, USGS Collection 5475-CO (field no. 13368-12a) from limestone in the SW/4 S1,T12N,R44E reported by A. R. Palmer (written commun. Nov. 30, 1965) contained hexactinellid sponge spicules and fragments of a tiny phosphatic brachiopod like *Ophisthotreta,* of which he stated:

> At present, brachiopods of this general appearance seem to be characteristic of beds of early Upper Cambrian (pre-Dunderberg) age. . . .The brachiopods are fairly distinctive and I cannot recall seeing specimens with the characters that your specimens show in residues of any younger Cambrian or post-Cambrian beds.

Stratigraphic problems concerning the Cambrian and Ordovician map unit (shale and limestone, pl. A1) at and near Manhattan deserve attention and more study. Ferguson (1924, p. 20–25, 37) noted some of the difficulties here when he first defined and elaborated upon units such as the Mayflower Schist and successively overlying Zanzibar Limestone and Toquima Formation. The succession of lithologies is unlike the well known Ordovician carbonate-assemblage rocks farther east and the correlation, made by various workers, with the Palmetto Formation farther southwest was asserted on the basis of similarity of lithology and age (Edwin Kirk, *in* Ferguson, 1924, p. 25; Ferguson and Cathcart, 1954). The lithologic similarity is ambiguous at best, and the Ordovician age has not been verified, because none of the strata between the underlying Cambrian Gold Hill Formation and the Toquima Formation has yielded recognizable fossils. In fact, some of the rocks of this interval, such as the Mayflower and possibly part of the Zanzibar, could be Cambrian. That part of the Toquima Formation with quartzitic beds might be correlative with the Ordovician Valmy Formation or Vinini Formation as mapped by McKee (1972) at Petes Summit, Toquima Range. In a general aspect, however, the Vinini may be somewhat more shaly than the Toquima. The Zanzibar, which grades laterally and upward into black slaty strata (Ferguson, 1924, p. 21), resembles the Crane Canyon sequence of Means (1962, p. 77–78), and the Crane Canyon has been shown by Stewart and others (1977) to contain Late Cambrian fossils. Ervine (1972, p. 13, fig. 5) seems to have accepted a Cambrian age for the Mayflower-Zanzibar interval in the Barcelona district and places it above the Carrara. Evidence supporting to varying degrees an Ordovician age for the Mayflower-Zanzibar interval includes Ferguson's (1924, p. 21) observation that the upper part of the Zanzibar grades into slate with micaceous markings suggestive of metamorphosed graptolites. Ferguson (1924, p. 20) also mentioned that the brown-oxidized and brown-weathered gray siliceous schists of the Cambrian Gold Hill Formation differ from the overlying, dark-greenish,

aluminous Mayflower Schist. The strong chemical difference may reflect a change in conditions between depositional realms induced by events that are separated by a major time difference; that is, Cambrian versus Ordovician. The Zanzibar Limestone also bears a resemblance to part of the Eastside sequence of Means, which locally carries an Ordovician graptolite fauna that to Means (1962, p. 79) suggested a correlation with the Copenhagen Formation. More recently, the Eastside sequence was shown to include the Ordovician Pogonip Group in Nye County, the Silurian and Devonian Roberts Mountains Formation, and the Pogonip just to the north in Lander County (Stewart and McKee, 1968a, fig. 3).

Ordovician System

Ordovician strata are extremely widespread in northern Nye County, and nearly complete sections as much as a few thousand feet (1000 m) thick crop out in almost every mountain range from the Toiyabe Range and San Antonio Mountains eastward. Farther west, Mesozoic and younger rocks conceal the older strata, which are believed to extend continuously across the mapped region. Nomenclature used in various parts of northern Nye County for the Ordovician strata is summarized in figure A23. A predominantly carbonate facies prevails through the breadth of the ranges from the Hot Creek Range eastward. This facies is supplanted farther west by darker-colored, more shaly and silty rocks that are commonly considered to have been deposited in deeper quieter water of the Cordilleran geosyncline (or geocline). Lateral gradation as well as intertonguing probably account for the change in the Ordovician strata, but intertonguing relations have not been seen. The facies change apparently takes place through a transition zone at least several miles wide, details of which are obscured by structural discontinuities in which thin plates of the more westerly facies have been displaced eastward against and onto the carbonate facies. It is believed that in a general way composition becomes gradationally more siliceous and finer grained westward, along with a parallel decrease from an abundant shelly fauna on the east to an impoverished fauna on the west, where conodonts and pelagic forms like graptolites are more abundant.

Persistence of lithology and uniform thickness characterize the Ordovician rocks of the carbonate assemblage in much of the eastern part of northern Nye County. Individual units in the Pogonip Group are recognizable over a large part of the mapped region, as are the Eureka Quartzite and the Late Ordovician Ely Springs Dolomite and its correlative, the Hanson Creek Formation.

POGONIP GROUP

The term "Pogonip" has undergone a long evolution, beginning with King (1878, p. 188), who first applied the name to Cambrian and Ordovician rocks between prominent quartzites at Pogonip Ridge in the Hamilton mining district of White Pine County, less than 20 miles (32 km) northeast of Nye County. Nolan and others (1956, p. 23-24) and Merriam (1963, p. 17-19) summarized the history of the nomenclature; they gave group status to the Pogonip and applied the name at Eureka, Nevada, to Ordovician strata between the Cambrian Windfall Formation and the Ordovician Eureka Quartzite, a classification followed in this bulletin. Their subdivision of the group into three formations—the Goodwin Limestone, Ninemile Formation, and Antelope Valley Limestone at Eureka and vicinity, Nye and Eureka Counties—is also accepted, even though the small scale of our map precluded showing these units separately. Other workers (Hintze, 1951, p. 11-12; 1952, p. 48-56; Webb, 1956, p. 46-52, and Kellogg, 1963, p. 692-694) have recognized different subunits in the Pogonip (see Lumsden, 1964, p. 53-56). Several other units included with the Pogonip Group on the county map are the Dominion Formation of H. E. Cook (1966, p. 14-15), the Copenhagen Canyon Formation (Merriam, 1963, p. 25-27) and the Stoneberger Shale and Perkins Canyon Formation of Kay and Crawford (1964, p. 431-433). Except for the Dominion, these formations are briefly described in the text.

Distribution, Lithology, and Thickness

The Pogonip Group is well developed as far west as the Hot Creek Range in Nye County, beyond which the Goodwin Limestone at the base of the group was not recognized. The Goodwin was named for dominantly well-bedded, relatively massive, gray, fine-grained cherty limestone in the Eureka district (Nolan and others, 1956, p. 25). The formation is generally similar lithologically in Nye County, where the lower and upper boundaries of the Goodwin probably cannot be placed everywhere at the same horizon because of their transitional character. The basal beds grade downward into similar beds of the Upper Cambrian Windfall Formation, making selection of a contact difficult. The upper contact is more easily chosen, except near Tybo, and is placed at the base of a relatively thick sequence of shaly and silty strata of the overlying Ninemile Formation. The thickest section of Goodwin, 1800 feet (549 m) in the Grant Range, consists of thick-bedded massive limestone with abundant white to black chert and was assigned to the lower Pogonip by Cebull (1970, p. 1831). Merriam (1963, p. 20) reported a thickness of 1800 feet (549 m) in the Antelope Range at a locality near the Nye County boundary, and H. E. Cook (1966, p. 15) reported 1700 feet (518 m) near Tybo in the Hot Creek Range. This figure is at variance with the 740 feet (226 m) of Goodwin measured by Quinlivan and Rogers (1974) near Tybo, where the unit is thinner bedded and a siltier limestone than in the Grant Range. Closer to Eureka in the northern Pancake Range, an unmeasured section at least several hundred feet thick of incompletely exposed thick-bedded cherty limestone typical of the Goodwin crops out but is left undifferentiated on the map (lower part of Pogonip Group and Windfall Formation, undivided, pl. A1).

The middle formation of the Pogonip, the Ninemile Formation (like the uppermost formation, the Antelope Valley Limestone), was named for outcrops just north of Nye County along the west flank of the Antelope

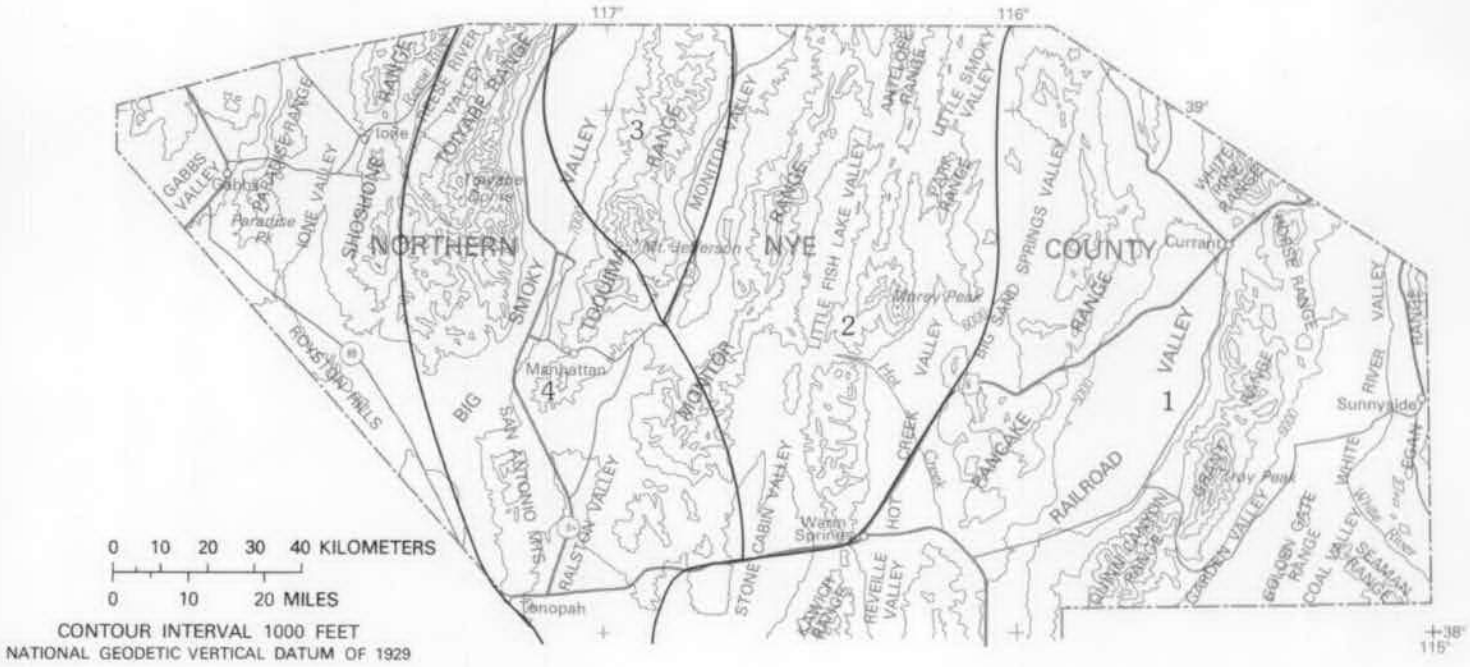


FIGURE A23. Map units used in various parts of northern Nye County for all Ordovician strata on the geologic map (pl. A1).

Range (Nolan and others, 1956, p. 27; Merriam, 1963, p. 22–24). Argillaceous shale, calcareous shale and siltstone, and shaly and silty limestone compose the Ninemile Formation, which commonly weathers to yellowish and brownish slopes broken locally by low ledges and cliffs of the more calcareous material.

Lower and upper contacts of the Ninemile Formation are gradational at the type locality (Nolan and others, 1956, p. 27; Merriam, 1963, p. 22–24), and similar contact relations were observed at several localities in Nye County, including the Grant Range (Cebull, 1967) and the Hot Creek Range. Thickness of the Ninemile ranges from as little as 195 feet (59 m) (Hot Creek Range) to 550 feet (168 m) (Antelope Range) in complete sections west of Railroad Valley to as much as 1644 feet (501 m) (Horse Range) and commonly about 1400 feet (427 m)

(Grant Range) east of Railroad Valley, where boundaries of the unit are more controversial and subjective (table A8). Here the lithologic contrasts and weathering characteristics that commonly distinguish the formation from the overlying and underlying grayer, cliffy formations of the Pogonip are less clear, and the previously mentioned alternate subdivisions of the Pogonip evolved (Hintze, 1952, p. 60–74).

The Antelope Valley Limestone, the uppermost formation of the Pogonip Group, consists of medium- to thick-bedded, slabby to massive limestone that weathers to form gray and yellowish-gray cliffy outcrops. Thin-bedded and platy limestone, locally parted and mottled with tan and brownish argillaceous material, forms scattered beds and zones. Quartz silty and sandy zones are most common in the basal and upper parts of the formation.

The lower contact of the Antelope Valley Limestone appears to be gradational in northern Nye County and is designated as the base of the relatively thick cliffy limestone above intercalated calcareous siltstone, shale, and limestone of the Ninemile Formation. Merriam (1963, p. 23) described the lower contact as apparently gradational downward into the faunally distinctive Ninemile in the Monitor Range near the type locality. The contact of the Antelope Valley with the overlying Eureka Quartzite is sharp in the southern part of the mapped region, particularly in the Reveille Range, as it is in Lincoln County (Tschanz and Pampeyan, 1970, p. 24). Elsewhere, at many places, a sequence of shale, limestone, and, locally, even quartzite intervenes between the cliffy limestone of the Antelope Valley and the Eureka Quartzite. Although mapped with the Pogonip Group, this sequence best corresponds to units mapped as separate formations elsewhere, such as the Copenhagen Formation of the Antelope Valley area (Merriam, 1963, p. 25–27), which was extended into Hot Creek Canyon, Hot Creek Range, by Lowell (1965, p. 263). Hintze (1951, p. 11–12) recognized other units unrelated to the Antelope Valley high in the Pogonip Group in eastern Nevada and western Utah.

The Antelope Valley Formation or its equivalents are distributed from the eastern limit of the county at the Egan Range west to the Toquima Range. Complete sections are exposed in the Egan, Grant, Quinn Canyon, White Pine, Hot Creek, Antelope, Monitor, and Toquima Ranges. Most of the formation is concealed by younger rocks and alluvium in the central Pancake and Reveille Ranges, where the exposed thicknesses are given as greater than 80 feet (24 m) and greater than 600 feet (183 m), respectively (Quinlivan and others, 1974; Ekren and others, 1973, respectively). The Kawich, Golden Gate, and Seaman Ranges are the only ranges of consequence where the Antelope Valley is not exposed, although the unit originally was deposited across the entire region and is only locally concealed beneath younger rocks. This view is corroborated by extensive outcrops of the Pogonip Group farther south in Lincoln County, such as in the Worthington Mountains just south of the Nye County line (Tschanz and Pampeyan,

TABLE A8. Thicknesses of Pogonip Group and its formations, northern Nye County, Nevada.
[Thickness given in feet; equivalents in meters in parentheses]

Unit	Area									
	Toquima Range	Monitor Range	Antelope Range	Hot Creek Range	Pancake Range	Reveille Range	Grant Range	White Pine Range	Horse Range	Egan Range
Pogonip Group	[1] ~ 2000 (610) Includes Stoneberger Shale	[2]1870 (570)	[3] ~ 3450 (~ 1052) north of county line	[4] ~ 3100 (945)			[3]3970 (1211) [8]3800-4200 (1159-1281)	[7]3250 (991) or 2000 (610) maximum [8]2990 (911) nearby in Blackrock Canyon	[9]4660 (1421)	[10]3351-3555 (1021-1083) complete section only outside the county
Antelope Valley Limestone	[1] ~ 1000 (~ 305)	[11]1373 (418) maximum at Martins Ridge, Eureka County [2]540 (165) Clear Creek	[3] ~ 1200+ (~ 366) only 1000 ft or 305 m measured; base covered	[2]700-1425 (213-434) [13]519 minimum	[14] > 80 (> 24) exposed	[15]600+ (> 183) exposed	[5]770 (235) 900-1100 (275-335)		[16]1610 (491)	
Ninemile Formation		[17]130 (40) Top only, base concealed [11]343 (105) composite section, Whiterock Canyon, Eureka County	[5]550 (168)	[12]195 (59)			[5]1400 (427) [18]900 (275) possible equivalent		[16]1644 (501)	
Goodwin Formation		At least [2]1330 (405) zones A and B of Greene [19]620 (189) max. exposed Applebush Hill	[5]1800 (549)	[12,19]740-1700 (226-518) [21]1020± (311) Hot Creek Canyon			[5]1800 (549)		[16]1557 (475)	

[1]Kay and Crawford (1964)
[2]Greene (1953)
[3]Merriam (1963)
[4]Ferguson (1933)
[5]Cebull (1970)
[6]Hyde and Huttrer, 1970
[7]Lumsden (1964)
[8]Hintze (1952)
[9]Ptacek (1962)
[10]Kellogg (1963)
[11]Bortz (1959)
[12]Quinlivan and Rogers (1974)
[13]Lowell (1957)
[14]Quinlivan and others (1974)
[15]Ekren, Rogers, and Dixon (1973)
[16]Wire (1961)
[17]Behnke (1961)
[18]Hyde (1963)
[19]H. E. Cook (1966)
[20]Scales (1961)
[21]Lowell (1965)

1970, pl. 2). Thickness exceeds 1200 feet (366 m) at the type locality and nearby area adjacent to Antelope Valley, such as Martin Ridge (Merriam, 1963, p. 24); elsewhere, variable but similar thicknesses are reported, with the greatest in the east: 800–1000 feet (244–305 m) in the Toquima Range (Kay and Crawford, 1964, p. 432); and 700–1425 feet (213–434 m) near Tybo in the Hot Creek Range (Quinlivan and Rogers, 1974). Thicknesses of the Antelope Valley Formation may not be very meaningful east of Railroad Valley, where many workers have used an alternate nomenclature and have not recognized the Antelope Valley. Cebull (1970, fig. 3) and Hyde (1963, p. 16), however, measured 770–1100 feet (235–335 m) of strata that may be equivalent to a large part of the Antelope Valley.

Age

The Goodwin Limestone is generally considered to be Early Ordovician (early Canadian) on the basis of fossil collections from the Great Basin, including Nye County. At Tybo, the basal 115 feet (35 m) yielded late Tremadocian fossils (Quinlivan and Rogers, 1974). Ross (1964, p. C67, C69) has reported on several collections made within the upper 175 feet (53 m) of the formation at the south end of Rawhide Mountain (Hot Creek Range), stating that, "Some elements of this fauna are found in the uppermost Goodwin in Ninemile Canyon, Antelope Range, Nev." For a description of fauna from the Goodwin beds about 21 miles (34 km) northwest of Duckwater in the Pancake Range, see the section of this bulletin on the Lower Part of Pogonip Group and Windfall Formation, Undivided (also pl. A1).

An Early Ordovician age (approximately upper Canadian) for the Ninemile Formation is based on numerous paleontological studies best summarized by Merriam (1963, p. 23), who stated that the shell-bearing strata of the Ninemile may approximately correlate with the graptolite-bearing lower part of the Vinini Formation. But, he noted, there was no physical evidence for intertonguing or gradation westward into the Vinini. The shelly and graptolite faunas are intermixed, however, on the south slope of Rawhide Mountain, Hot Creek Range. A very abundant, diverse, and well-preserved trilobite and brachiopod fauna composes the bulk of the fauna from the Ninemile (Ross, 1964, p. C65, C67–C69). The Stoneberger Shale of Kay and Crawford (1964) in the Toquima Range, a partial correlative of the Ninemile, has yielded a sparse brachiopod and trilobite fauna, the most significant forms of which are "...found in zones H and J in the Pogonip section in western Utah, in the uppermost Fillmore and lower Wah Wah limestones" (Kay and Crawford, 1964, p. 431).

Trilobites, gastropods, and a large brachiopod fauna from several zones (*Orthidiella, Palliseria,* and *Anomalorthis,* from lowest to highest) within the Antelope Valley Limestone date the strata here as Middle Ordovician and at least as young as the Whiterockian (Llanvirnian) (Merriam, 1963, p. 25). Ross (1970, p. 17–28; Ross and Shaw, 1972, p. 7, 9) has tabulated numerous fossil data from the Antelope Valley Formation at Hot Creek Canyon (Hot Creek Range), Ikes Canyon (Toquima Range), and Clear Creek Canyon (Monitor Range). The Hot Creek collections are all from the *Anomalorthis* zone and suggest a Marmor, Porterfield, or younger age; conodonts from Clear Creek are apparently early Middle Ordovician; and the Ikes Canyon collections suggest a Marmor (Chazy) to Porterfield (Black River) age.

COPENHAGEN FORMATION

Introduction

The Copenhagen Formation is part of a stratigraphic interval several hundred feet thick in the Great Basin that has attracted considerable attention and study because of complex facies relationships and, in the case of the Copenhagen, because it contains a new fauna (Merriam, 1963, p. 26–27). Cooper (1956, p. 127–128) included the interval in what he termed the "Eureka Group": the Eureka Quartzite and carbonate, brown sandstone, and calcitic sandy, silty, and argillaceous beds between the Eureka and the underlying Pogonip Group. The facies relations of the Copenhagen have been described by Hintze (1951, p. 5–7, 11–12, 18–22), Webb (1956, p. 11–28; 1958, p. 2339–2340, 2363–2367, fig. 6), Christensen (1957), Lowell (1957), and Merriam (1963, p. 25–27).

The Copenhagen is too thin to show separately on the geologic map (pl. A1); although it is included with the Pogonip Group, it is reasonably distinctive and therefore is briefly described below. The Copenhagen was formally defined on the basis of outcrops on the east side of Copenhagen Canyon, Monitor Range, just north of Nye County (Merriam, 1963, p. 25–27); the strata have also been described by Kirk (1933, p. 28–29, 32–33), Greene (1953), and Christensen (1957, p. 63–70).

Lithology

Fossiliferous, yellowish-brown-weathering silty and arenaceous limestone with argillaceous partings and, in the upper part, considerable shale characterize the Copenhagen. The fossils in limestone are largely brachiopods and trilobites that commonly form prominent hash beds, and a basal quartzitic sandstone contains an *Endoceras*-type cephalopod (Greene, 1953, p. 14–15; Merriam, 1963, p. 26–27). The assemblage, distribution, and abundance of fossils in the formation, along with the above-stated features, distinguish the unit from underlying and overlying units such as the Antelope Valley Limestone of the Pogonip Group and the Eureka Quartzite, respectively. At the type section, the formation was divided by Merriam (1963, p. 26) into a very thin lower quartzitic sandstone (member A), a much thicker buff to yellowish-brown-weathering, well-bedded silt- and shale-parted limestone (member B), and an upper dark-gray silty limestone to calcareous sandstone with carbonaceous shale interbeds (member C). No effort was made to differentiate these members in Nye County, but all are represented (Christensen, 1957, p. 64–68; Lowell, 1965, p. 263).

Outcrops of the Copenhagen in northern Nye County are largely characterized by some argillite and laminated to thin-bedded, shaly to flaggy, very dark-gray, aphanitic to fine-grained limestone with many beds containing quartz silt, or even sand in low to moderate amounts. Argillaceous partings are not uncommon in the limestone. An abundant shelly fauna imparts a coarse coquinoid aspect to some of the more calcareous beds, particularly in Hot Creek Canyon, Hot Creek Range. Both fresh and weathered rocks of the formation in Nye County tend to be darker hued than in the type area, and the unit weathers to dark-yellowish-brown, brownish-gray, and dark-gray slopes. Where very thin, the unit may be covered by talus from the overlying Eureka Quartzite and younger rocks. The basal quartzitic sandstone (member A of Merriam) is chiefly an impure ferruginous unit that locally is very well cemented by silica and iron oxides.

Contacts

The basal contact of the Copenhagen Formation is placed at different horizons by different workers. At Martin Ridge, the type section, Merriam (1963, p. 26) considered a 25-foot-thick (7.5-m-thick) *Endoceras*-bearing sandstone resting conformably on the Antelope Valley Limestone to be its basal member. This sandstone extends farther south in the Monitor Range and east into the Antelope Range (Kirk, 1933, p. 32–33). Some workers in Nye County place the sandstone, whose basal contact, however sharp, is unconformable at Clear Creek (Monitor Range), with the Antelope Valley Limestone and consider the sandstone's upper sharp but conformable contact with silty carbonate beds as the base of the Copenhagen (Greene, 1953, p. 14–16; Christensen, 1957, p. 107; Lowell, 1957, p. 37). Lowell (1965, table 1) later included the sandstone with the Copenhagen.

The upper contact of the Copenhagen is commonly covered and not generally observable. However, its position is unanimously chosen at the base of the readily mappable, overlying massive cliffy Eureka Quartzite. Merriam (1963, p. 27) discussed the gradational nature of the contact, whereas Greene (1953, p. 15) speculated that it was an unconformity. Erratic thicknesses of the Copenhagen and its local absence in the Hot Creek Range led H. E. Cook (1966, p. 19–20) to consider the contact as an erosional surface, at least in part.

Distribution and Thickness

Scattered outcrops of the Copenhagen extend from the type area in Copenhagen Canyon, where the unit is about 350 feet (107 m) thick, southward in the Monitor Range to Clear Creek Canyon, and as far east as the Hot Creek Range. Temporally equivalent beds are thought by Means (1962, p. 79) to be present perhaps as far west as the Toiyabe Range. At Clear Creek Canyon, Greene (1953, p. 13–19) measured as much as 35 feet (11 m) of strata, his zone D, and as much as 105 feet (32 m) of strata, his zone E, which combined are assignable to the Copenhagen. He noted that there is considerable variation in the thickness of zone E, presumably caused by erosion that preceded the deposition of the overlying Eureka Quartzite. The thickest section of Copenhagen in Nye County is the 470 feet (143 m) measured "on the west face of the Antelope Range...about 7/8 mile south of the Eureka County line" by Webb (1958, p. 2340), who stated that the top was not exposed but suggested that a composite section would possibly total about 600 feet (183 m). Christensen (1957, p. 63–64, 97–98) measured only 395 feet (120 m) here, which can be raised to 431 feet (131 m) by adding to the base 36 feet (11 m) of sandstone that he excluded from the formation. This section's lithology would then approximately correspond to the 350 foot (107 m) type section in the Monitor Range, Eureka County (Merriam, 1963, p. 26). About 20–40 feet (6–12 m) of beds compose the formation in Hot Creek Canyon, Hot Creek Range, and some workers attribute as much as 50 feet (15 m) of strata to the formation near Music Canyon at the south end of the range (Lowell, 1957, p. 14; 1965, table 1; Christensen, 1957, p. 65). It has not been conclusively demonstrated, however, that the strata at the latter locality correlate with the Copenhagen, and they are described in the present report with the Antelope Valley Formation of the Pogonip Group.

Age and Correlation

The studies of Merriam and associated workers, including G. A. Cooper of the Smithsonian Institution, have established clearly that the Copenhagen is younger than the *Anomalorthis* zone of the uppermost part of the underlying Antelope Valley Limestone (Pogonip Group) and contains faunas most like those found elsewhere in the Caradocian (Porterfield to Barneveld intervals) (Ross and Shaw, 1972). Langenheim and Larson (1973, cols. 28, 45, 46) include these stages in the Upper Ordovician, but most workers place the stages in the upper Middle Ordovician.

Merriam (1963, p. 27) regards the Copenhagen as being equivalent to the lower brown part of the two-part Eureka Quartzite of Kirk (1933, p. 28). This concept has been accepted by numerous other workers (Langenheim and Larson, 1973, cols. 28, 45, 46), but not Webb (see section of this bulletin on the Eureka Quartzite—Age) or Christensen. Christensen (1957, p. 75–81, especially p. 80) described a Swan Peak–Copenhagen facies as the lateral equivalent of the Crystal Peak Dolomite and extended the facies into central Nevada from the type locality in Utah (Webb, 1956, p. 12), where it underlies the Eureka Quartzite. A northward coarsening of the Copenhagen was interpreted by Christensen (1957, p. 85) to indicate that the source of the sediments lay in that direction. Webb (1958, p. 2364), however, believed that the source lay eastward (cratonward). He also specifically rejected facies equivalency of the Copenhagen and the lower Eureka of the standard (Lone Mountain) section, contrary to Merriam (1963, p. 27). Webb came closer to accepting Christiansen's interpretation by correlating the Copenhagen with a lower shaly quartzite member of the Eureka farther east.

To the west, several formations at different structural levels in the Toquima Range are considered to be temporal equivalents of the Copenhagen. One of these, named the Caesar Canyon Limestone by Kay and Crawford (1964), is a close lithic equivalent that may have been deposited coextensively with the Copenhagen in the same depositional basin (Kay and Crawford, 1964, p. 432, 449). The other correlatives of the Copenhagen here include the upper part of the Petes Summit and the lower part of the Sams Spring Formations of Kay and Crawford (1964, p. 434–435, figs. 4, 5), which represent part of more siliceous assemblages of allochthonous rocks. The lithologically partly similar Eastside sequence of Means (1962, p. 78–79) in the Toiyabe Range contains the graptolite *Diplograptus decoratus*, which led Means to suggest a correlation of this sequence with the Copenhagen Formation. However, Stewart and McKee (1968a, fig 3; Stewart and others, 1977, pl. 1) consider the Eastside to be a composite of several other units, including the Pogonip Group adjacent to the Nye-Lander County line and Silurian and Devonian strata farther north.

EUREKA QUARTZITE

Introduction

The Eureka Quartzite was named for its occurrence in the Eureka mining district (Hague, 1883, p. 253, 262; 1892, p. 54), and a standard section was later described by Kirk (1933, p. 30 and 34) at Lone Mountain, west of Eureka, Nevada. Nolan and others (1956, p. 29) formally recognized this generally accepted redesignation of the type locality.

The Eureka has been well studied and described by numerous workers, who include, besides those previously cited, Hintze (1951, p. 22–23), Merriam (1963, p. 27–31), and especially Webb (1956, p. 13–14; 1958, p. 2335–2377), whose 1958 paper is still the definitive work on the stratigraphy of the formation.

Lithology

The light color and quartzite lithology of the cliff-forming Eureka Quartzite readily distinguish it from darker hued grays of the underlying and overlying carbonate strata. The formation in northern Nye County consists almost exclusively of well-sorted, fine- to medium-grained, dense, white to pale-yellowish-brown and pinkish quartzite that is massive splitting, partly laminated, and cross-laminated; layering is commonly obscured. Where several colors are present, the white is commonly confined to the upper part of the formation, a feature first noted by Kirk (1933, p. 28). Purity of the quartzite is exceptional; however, a dolomitic cement is common in the basal and top several feet or so of the formation, where the lesser resistance to weathering leads to a softer, partly friable, less cliffy zone. This softer zone is particularly well displayed locally in the Hot Creek Range. Here also are one or two zones of very light to dark-gray limestone and dolomite commonly 20 feet (6 m) and as much as 35 feet (11 m) thick intercalated near the middle of the formation (Cook, H. E., 1966, fig. 15; Webb, 1958, p. 2346). Webb defined a dark dolomite member of the Eureka, which corresponds to one of these zones and noted its occurrence in the Hot Creek Range and at Clear Creek Canyon (site of Crocker Ranch), Monitor Range.

Contacts

Nolan and others (1956, p. 30–31) have concluded that the lower and upper contacts of the Eureka are unconformities; Merriam (1963, p. 29), however, concluded that the Hanson Creek Formation conformably overlies the Eureka at Lone Mountain. The correlation chart of Langenheim and Larson (1973) shows the upper contact generally as conformable and the lower as locally unconformable or questionably conformable in most places. The lower contact everywhere in northern Nye County is moderately sharp with local evidence of some gradation and with beds concordant across the contact. This contact is defined at the readily mappable change from gray and brown calcareous strata of the underlying formations to the pale-yellowish, slightly friable quartzitic siltstone or vitreous quartzite. The subjacent unit is the Antelope Valley Limestone except west of the Hot Creek Range, where it is locally the Copenhagen Formation. According to Webb (1958, p. 2370–2372, fig. 13), the type Eureka Quartzite, at Lone Mountain, bevels regionally across the Copenhagen Formation.

The upper contact of the Eureka is everywhere relatively sharp, and quartzite of the Eureka contrasts with overlying dark-gray cherty dolomite of the Late Ordovician Ely Springs Dolomite and its correlatives. Several inches to a few feet of quartz-sandy dolomite commonly occurs in the lower part of the overlying Late Ordovician dolomites and imparts an aspect of upward gradation but may represent reworked Eureka. There is a general concordance of bedding between the Eureka and its overlying units. A reported local disconformity or unconformity at the top of the Eureka in the Hot Creek Range (Ferguson, 1933, p. 20; H. E. Cook, 1966, p. 21–22) is not sustained by other mapping (this bulletin and Quinlivan and Rogers, 1970). The unconformity was based on the discontinuity of the Eureka at Tybo and on an interpretation at nearby Keystone Canyon of a sedimentary contact exhibiting relief between the Roberts Mountains Formation and the underlying Eureka, with the normally intervening Ely Springs Dolomite absent. Later mapping showed that the discontinuity of the Eureka was the result of faults and that the Ely Springs is present in unfaulted sections.

Distribution and Thickness

The Eureka Quartzite is present throughout the eastern half of northern Nye County to as far west as the Monitor Range. In the mapped region the maximum thickness of the Eureka is 621 feet (189 m), and it is commonly more than about 350 feet (107 m) thick where fully exposed, with a generally westward thinning to 183 feet (56 m) at Clear Creek Canyon, Monitor

Range, and even local absence in the Hot Creek and Monitor Ranges. The formation is thickest in the Egan Range, commonly exceeding 500 feet (153 m), with one of the thickest (621 ft or 189 m) sections anywhere of Eureka near the Whipple Ranch (Kellogg, 1963, table 4). A thickness of 400 feet (122 m) is generally exceeded in the Grant, Horse, and White Pine Ranges as well. These and other thicknesses reported by various workers are given in table A9. The different thicknesses variously attributed to the Eureka Quartzite at its standard section at Lone Mountain (table A9) represent an unresolved problem. Merriam (1963, p. 27–30) considered the change from his measured 350 feet (107 m) at the standard section to about 150 feet (46 m) near Antelope Valley as coincident with a facies change: the lower darker part of the Eureka is replaced southward by the shaly and silty limestone of the Copenhagen Formation. About 30 feet (9 m) of beds assigned to the Copenhagen by Lowell (1965, p. 265) at Hot Creek Canyon, Hot Creek Range, may similarly account for some of the thinness of the Eureka (280–365 feet or 85–111 m) there. Webb (1958, p. 2343, 2370–2376, figs. 6, 13), however, did not utilize any such explanation for changes in thickness of the type Eureka. He, too, ignored cited differences in the measured thickness of the type Eureka and described the Copenhagen as a unit bevelled prior to deposition of the type Eureka. He attributed the increased thickness of the Eureka southeastward from Lone Mountain and Antelope Valley to the incorporation of higher units of quartzite in the formation. A considerable part of the great variability in thickness of the Eureka in the Hot Creek Range (locally absent but generally 280–365 feet [85–111 m]) has been attributed to the previously referenced and discredited erosional surface at the top of the formation (see the section of this bulletin on Eureka Quartzite—Contacts). Supposedly, post-Eureka and pre-Silurian erosion had removed all but the channel fillings of Eureka, which in Tybo Canyon appeared to form discontinuous lenses as much as 100 feet (31 m) thick (Ferguson, 1933, p. 20; H. E. Cook, 1966, p. 22).

Age

Merriam (1963, p. 30) considered the Eureka, based chiefly on stratigraphic position, to be late (latest) Middle to early Late(?) Ordovician. Fossils are noticeably absent from the formation in northern Nye County and almost everywhere else nearby, except for corals found at Cortez in Lander County (Duncan, 1956, p. 217). The formation in northern Nye County stratigraphically overlies the Antelope Valley Limestone of the Pogonip Group or, locally, in the westernmost exposures, the upper Middle Ordovician Copenhagen Formation. The upper part of the Antelope Valley is, in general, possibly as young as Marmorian (medial Middle Ordovician) (Ross, 1964, p. C69, C76–C77). In the southern Great Basin, the base of the Eureka climbs stratigraphically from east to west and ranges from Whiterockian in the east to at least Porterfieldian and most likely Marmorian in the west (Ross, 1964, p. C86). Webb (1958, p. 2363–2364, 2367, fig. 13) considered the Eureka of the standard section at Lone Mountain to be younger than the medial Trentonian Series (Wilderness ian?) and to bevel the Copenhagen Formation, which he correlated with an older member of the Eureka (shaly quartzite member) farther east. He specifically excluded equivalency of the Eureka of central Nevada (standard section) with the Copenhagen, whereas Merriam (1963, p. 26–27) favored a correlation of the lower part of this Eureka with the Copenhagen. Langenheim and Larson (1973) assigned the Eureka largely to the

TABLE A9. Thickness of Eureka Quartzite, northern Nye County and vicinity, Nevada.
[Thicknesses given in feet; equivalents in meters in parentheses. Localities arranged in relative geographic position]

Lone Mountain (standard section)
[1]225 (69)
[2]350 (107)
[3]181 (55), revision of, p. 2341

Monitor Range—Antelope Range
Dobbin Summit vicinity:
[3]220 (67), p. 2345
Clear Creek Canyon:
[3]183 (56), p. 2345
[4]264 (80)

Hot Creek Range
Hot Creek Canyon:
[4]280–365 (85–111)
Near Hot Creek Canyon:
[5]345 (105)
Tybo quadrangle:
[10]235± (72±)
(Formation locally absent in range)

Reveille Range
[11]310± (95±)

Pancake Range
Portuguese Mountain quadrangle:
235+ (72+), base [7]covered

White Pine Mountains
Blackrock Canyon:
[3]449 (137)
[3]450 (137)

Horse Range
[8]390 (119) minimum

Grant Range
North:
[3]405 (123)
[12]400 (122)
[4]442 (135)
Central:
[13]250–325 (76–99)
South:
[14]400 (122)

Quinn Canyon Range
Not measured

Egan Range
[3]509–520 (155–159)
Lund:
[6]509 (155)
Shingle Pass:
[6]513 (156)
Whipple Ranch:
[6]621 (189)

Golden Gate and Seaman Ranges
No outcrops in northern Nye County

[1]Kirk (1933, p. 30).
[2]Merriam (1940, p. 21; 1963, p. 29).
[3]Webb (1958, mainly figure 5 and as indicated).
[4]Lowell (1965, table 1).
[5]Lumsden (1964, p. 59).
[6]Kellogg (1963, pl. 1 and table 4).
[7]Quinlivan and others (1974).
[8]Christensen (1957, p. 88).
[9]Ptacek (1962, p. 27).
[10]Quinlivan and Rogers (1970).
[11]Ekren, Rogers, and Dixon (1973).
[12]Kirkpatrick (1960, p. 16).
[13]Hyde and Huttrer (1970, p. 507 and 510).
[14]Cebull (1967, p. 61).

Trentonian Series and the Porterfieldian to "Trentonian" Stages (early Late Ordovician) of North America and the lower Caradocian of Europe. The Eureka lies beneath the Late Ordovician (Richmondian) Ely Springs Dolomite and its correlative, the Hanson Creek Formation.

ELY SPRINGS DOLOMITE AND HANSON CREEK FORMATION

Introduction

The unit that most commonly overlies the Eureka Quartzite in northern Nye County is chiefly dark to light gray, sparingly cherty dolomite of the Ely Springs Dolomite (pl. A1), whose type locality is in the Pioche mining district, Lincoln County (Westgate, 1932, p. 15–16). The formation is laterally almost as extensive as the underlying Eureka and, although commonly mapped with lithologically similar overlying formations of Silurian and, locally, Devonian age (pl. A1), was recognized as far west as the Pancake Range. It is also present in the Egan, Grant, Horse, Quinn Canyon, Reveille, and White Pine Ranges (pl. A1). A minor outcrop of Ely Springs(?), near hill 7281 in the Ellendale mining district, southern Monitor Range (not shown on pl. A1), is believed to be imbricated in a thrust plate of the Roberts Mountains Formation (pl. A1). A unit consisting of limestone and dolomite elsewhere in the Monitor Range and dolomite in the Hot Creek Range occupies the same stratigraphic position as the Ely Springs and where differentiated from lower and higher strata is assigned to the Hanson Creek Formation (pl. A1), whose type locality is in the Roberts Mountains (Merriam, 1940, p. 10–11).

Concerning the application of the names Hanson Creek Formation and Ely Springs Dolomite, Langenheim and Larson (1973) extended the former into the Hot Creek Range, following Lowell (1957, p. 17–18; 1965, fig. 3). This usage is accepted in this bulletin by the present authors; however, other workers have assigned these rocks to the Ely Springs or Ely Springs(?) Dolomite (Ross, 1964, p. C64–C66; Quinlivan and Rogers, 1970, p. 8). The presence of the Copenhagen Formation, Eureka Quartzite, and Roberts Mountains Formation in the Hot Creek Canyon (Lowell, 1965, p. 263) and at Rawhide Mountain is perhaps most suggestive of an affinity to the Ordovician section at Antelope Valley, where the Hanson Creek Formation is recognized.

The term Fish Haven Dolomite (Richardson, 1913, p. 409–410) was used by some workers (Moores and others, 1968, p. 1708; Kellogg, 1963, p. 695) for strata of the Ely Springs interval in the White Pine, Grant, and Egan Ranges, even though these areas are a large distance (300 mi or 483 km) from the type locality of the Fish Haven. The term Fish Haven is not used in this bulletin.

Lithology

The lower part of the Ely Springs Dolomite consists of medium-dark- to dark-gray and brownish-black dolomite with local zones of intraformational conglomerate (Big Creek area, Quinn Canyon Range) and of interbedded chert in nodules and thin anastomosing lenses that may be best developed at Reveille and near Ellendale in the southern Monitor Range. These lenses and nodules are sparse in many of the other sections. The upper part is a somewhat less cliffy, lighter gray dolomite that locally weathers pinkish gray to tan and contains argillaceous material and sparse silt-size quartz. A minor amount of calcareous cement in the upper part of the formation becomes increasingly abundant upward, and in places the uppermost beds are more properly classified as dolomitic limestone. In fact, dolomite is not even exposed in the partial section of Ely Springs in T9N,R60E of the Grant Range, but the occurrence of such a high percentage of limestone is probably uncommon. The lower dark- and upper light-colored divisions of the formation are well displayed north of Big Creek in the Quinn Canyon Range; in the White Pine Mountains, where they are 120 and 300 feet (37 and 90 m) thick, respectively (Lumsden, 1964, p. 59–60); and in the Egan Range, where the upper division is thin and largely encompassed by the 30-foot (9-m) argillaceous zone mentioned by Kellogg (1963, pl. 1) 20 ft (6 m) below the top of the formation. The Ely Springs Dolomite is chiefly slabby to massive splitting; bedding is commonly faintly laminated. Zones in the lower part are especially rich in comminuted pelmatozoan fragments. Whole fossils are not abundant, but silicified brachiopods and corals (present locally in one to several zones) (Lumsden, 1964, p. 60) commonly weather brown on outcrops, resist erosion, and protrude from the dolomite matrix. They are most readily found in place and in any event are relatively easy to collect.

The Ely Springs Dolomite in the large, east-tilted, north-trending fault block in the Pancake Range northwest of Lockes Station contains several key fossil zones. Together with R. J. Ross and Leonard Wilson, we collected fossils (later examined by Ross) and crudely measured a well-exposed section about 410 feet (125 m) thick of dolomite divisible into four main units (fig. A24). The upper three units probably equate with the 105-foot- (32-m)-thick upper part of the twofold Ely Springs described by Quinlivan and others (1974) as being about 310 feet (95 m) thick in the area. As can be seen in figure A24, dark-gray dolomite, similar to the type Ely Springs but with little of the typical chert, composes the lower half of the formation and is chiefly overlain by typically lighter hued dolomites that are silty locally and have an atypical lithographic texture. The top of the formation was drawn between the readily picked lighter lithographic dolomite and the overlying, massive, dark-gray, sugary-textured dolomite containing chert modules and pentamerid(?) brachiopods near its base. There is a notable absence of the abundant chert that characterizes the Ely Springs farther east and south in Nevada (Westgate, 1932, p. 15; Cornwall and Kleinhampl, 1961). A 15-foot (4.6-m)-thick unit of cherty dolomite (unit 3, fig. A24) about 85 feet (26 m) beneath the top of the formation is the only really cherty unit and could be mistaken for the basal unit of the Roberts Mountains Formation, which, however, is not present in the Pancake Range.

Height above base of Ely Springs, in feet	Unit	Lithology	Fossils
	Laketown Dolomite	Dark-gray dolomite, sugary textured and cherty; cross-stratified laminae in detail but thin to thick bedded in gross aspect and massive	
413			Pentamerid(?) brachiopods
400			
		Light-gray lithographic dolomite	Fossil collection 61–RJ–63, with corals, brachiopods
326	Ely Springs Dolomite	Medium-dark-gray dolomite intercalated with chert stringers	Large crinoid stems
311			
300			
		Lithographic dolomite, silty, light gray with pinkish areas causing overall tan appearance	Fossil collection 61–RJ–64 (approximate location)
			Fossil collection 61–RJ–65 (approximate location)
235			
200			Fossil collection 61–RJ–66 (*Girvanella*-like fossils)
			Fossil collection 61–RJ–67 (approximate location) with corals
100		Dark-gray to black dolomite with very little chert; intraformational conglomerate (may be turbidite) is common and contains brown-weathering dolomite clasts and pebbly to sandy pockets; some graded beds	
0			
	Eureka Quartzite	Quartzite	

FIGURE A24. Generalized stratigraphic section, Ely Springs Dolomite, vicinity of field station 15838–9, about 6 miles (10 km) northwest of Lockes Station, Pancake Range, Nye County.

The Hanson Creek Formation in northern Nye County consists of dolomite and limestone, with the lower part generally more dolomitic, massive, and darker hued than the upper part. Greene (1953, p. 22–24) described the formation at Clear Creek, Monitor Range, as consisting of dolomite, commonly quartz silty, of varying but generally dark-gray hues in the lower part and thinner bedded, tan to brown and pinkish silty argillite in the upper part. The "argillites" are in most cases argillitic to silty calcareous strata. The formation consists chiefly of massive gray dolomitic beds in the Hot Creek Range (Quinlivan and Rogers, 1970, p. 8; Lowell, 1957, p. 17–18).

The most obvious similarity between the Ely Springs Dolomite and the Hanson Creek Formation in northern Nye County, besides their approximately identical stratigraphic position, is their carbonate lithology; where dolomite is abundant in the latter unit, it is difficult to distinguish between the two. Some of the basal beds of both formations are also very silicified or sandy, and other clayey and quartz silty and sandy zones are scattered predominantly in the upper parts of the formations. Such zones are not prominent compared to their carbonate components, but they are generally recognizable by their lighter hued colors. However, well-developed limestone and graptolitic facies compose significant parts of some of the sections of the Hanson Creek Formation but not of the Ely Springs. The Ely Springs is also generally somewhat less flaggy and platy in its upper part than are many of the sections of Hanson Creek in the Monitor Range.

Contacts

The contact of the Ely Springs Dolomite and Hanson Creek Formations with the underlying Eureka Quartzite is readily mappable by the sharp change from dolomite, above, to vitreous quartzite, below, even though the lowest dolomite locally contains considerable quartz sand. Details were given in the description of the Eureka Quartzite.

East of Garden Valley and in the Pancake Range, the top of the Ely Springs was mapped at the top of a light-gray, locally silty, pale-brownish-weathering dolomite that separates darker gray dolomites below and above. The light-gray dolomite composes one-third to one-half of the Ely Springs section in the Pancake Range but elsewhere is generally less thick. It is well displayed in the Egan Range and at least as far west as in the small hill just west of the Adams-McGill Reservoir in Garden Valley, and is considered a correlative of the 30- to 50-foot (9- to 15-m)-thick unit placed in the basal Laketown Dolomite in northern Lincoln County by Tschanz and Pampeyan (1970, p. 28). Kirkpatrick (1960a, pl. 1, p. 18) has assigned 225 feet (69 m) of what may be the same zone to the upper part of an approximately 550-foot (168 m)-thick Ely Springs section near Blue Eagle Mountain in the northern Grant Range. The same distinctive mappable horizon was not assuredly recognizable everywhere in the Reveille, Grant, and Quinn Canyon Ranges, and there the Ely Springs Dolomite was mapped together with the Laketown Dolomite and locally with Devonian strata as well (dolomite; dolomite, undivided; and dolomite and limestone, pl. A1). At these places, similar ledgy and cliffy dolomites commonly extend throughout the interval of presumed Late Ordovician and Silurian age. The Ely Springs has a light-gray upper part and is readily differentiated from adjacent formations in Big Creek, Quinn Canyon Range, but is left undifferentiated (dolomite, undivided, pl. A1) because the formation is broken by faults into segments too small to show separately. See Sainsbury and Kleinhampl (1969, pl. 1) for more detail.

In and west of the Hot Creek Range, the upper part of the Hanson Creek Formation is similarly light colored. It commonly consists of platy to flaggy, tan- to pinkish-and light-gray-weathering argillitic and calcitic dolomite and dolomitic limestone and appears to pass without a significant lithologic break into the overlying Roberts Mountains Formation, notwithstanding the regional unconformity shown by Langenheim and Larson (1973). These formations exhibit a concordance of bedding, thinness, and partial lithologic similarity that led us to map them as undifferentiated rocks at most places (dolomite, pl. A1). Locally, as on the east face of Clear Creek Mountain, Monitor Range, we placed the contact between the formations some distance below a discontinuous massive light-gray dolomite(?) cliff (fig. A25). The cliff possibly corresponds with the 320-foot (98-m)-thick upper part of Greene's zone I (Roberts Mountains Formation) (1953, p. 27) or may even be a tongue of the Lone Mountain Dolomite (not differentiated on the map). Elsewhere, similar to other workers in the region, we generally place the upper contact of the Hanson Creek at the base of a reasonably persistent ledge-forming chert zone (Merriam, 1963, p. 31–32, 38). Lowell (1957, p. 36) noted the presence of this zone in Hot Creek Canyon but included it with the Hanson Creek; it is locally present near Dobbin Summit but not at Clear Creek in the Monitor Range (see locality of USGS fossil colln. D1087–CO in the section of this bulletin on Ely Springs Dolomite and Hanson Creek Formation—Age).

Near Clear Creek Canyon, where Greene (1953, p. 24, 27) placed the contact in a covered zone above slope-forming, thin-bedded (platy to flaggy) "argillite" (actually, an argillitic to silty carbonate), and below more noticeably ledgy dolomite, we concluded that the platy light-hued strata extend well up into Greene's next overlying unit (zone I, Roberts Mountains Formation) and that the most distinctive mappable upper contact for the Hanson Creek would be that beneath all the platy beds and just above the ledge of relatively homogeneous medium-gray dolomite and limestone that caps the Eureka Quartzite. This contact, which is probably lower than and not correspondent with the top of the Richmond interval, would leave about 100–155 feet (30–47 m) of section in the Hanson Creek Formation at two places—Clear Creek Mountain and near Dobbin Summit at the Miniature Grand Canyon, where the main road crosses the Eureka Quartzite east of the divide. Webb (1958, p. 2345) described the Hanson Creek Formation and overlying strata at the latter locality:

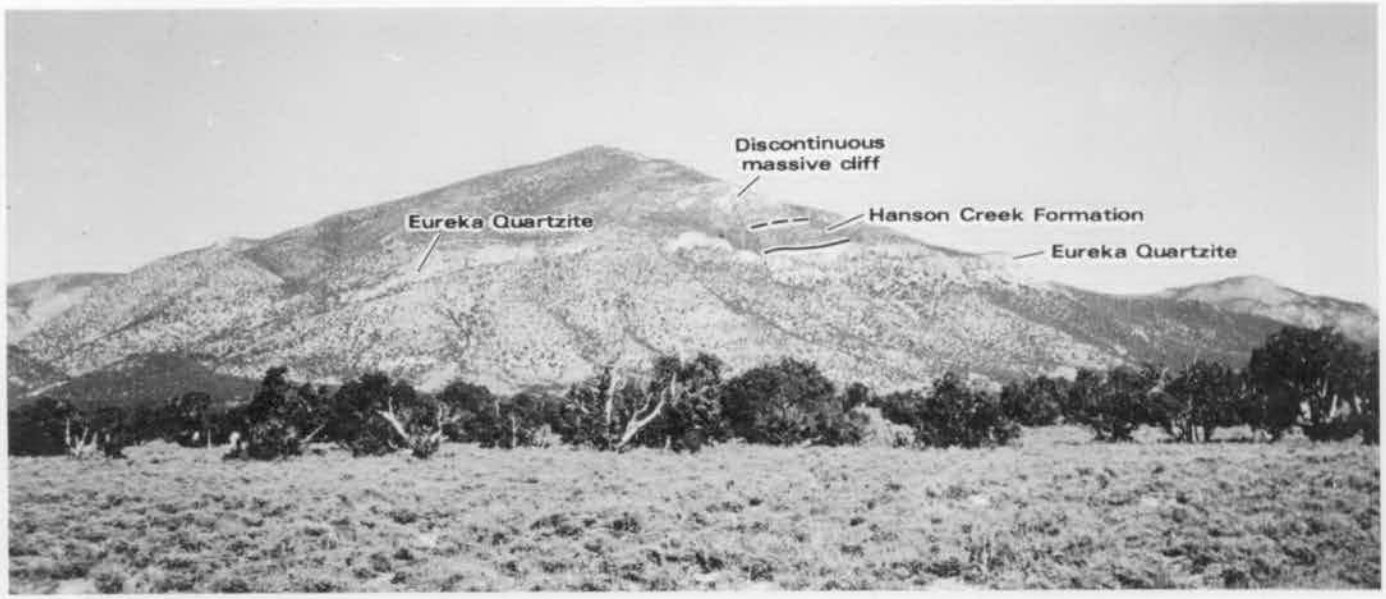


FIGURE A25. Discontinuous massive cliff (white in photo), below which lies the Hanson Creek Formation; east face of Clear Creek Mountain, Monitor Range. Eureka Quartzite forms lower more nearly continuous white ledge in photograph.

> One hundred feet of light-gray-weathering finely grained dolomites are overlain by 45 feet of dark gray to black medium-grained dolomite with abundant calcite veinlets; these are overlain by at least 140 feet of yellow and reddish brown quartz siltstones and limestone conglomerates apparently correlative with the similar Silurian beds of Ike's Canyon.

Webb's 100-foot and 45-foot (30-m and 14-m) dolomite units are possibly correlative with the above-described Hanson Creek beds that typically underlie platy strata, the lower 50–100 feet (15–30 m) of which may correlate with the previously described platy upper part of the Hanson Creek Formation at Clear Creek. These platy strata along the Dobbin Summit Road are separated from similar strata above by a 5-foot (1.5-m)-thick ledge of brownish-weathering, dirty-looking, medium- to coarse-grained clastic limestone. The higher platy strata are intercalated with fairly numerous bioclastic coquinoid dolomite ledges and altogether resemble the Silurian Masket Shale of Kay and Crawford (1964, p. 439–440) (Roberts Mountains Formation) in the Toquima Range and, to some extent, the Lower Devonian (Helderbergian) Rabbit Hill Formation. The highest 140-foot (43-m)-thick silty and conglomeratic unit mentioned by Webb (see quotation above) sounds most like the Rabbit Hill.

The Monitor Range marks the western limit of exposures of the Late Ordovician carbonate-assemblage rocks, including the Ely Springs Dolomite in the southern part of the Monitor Range (Ellendale mining district) and the Hanson Creek Formation farther north in the range at Clear Creek Canyon, near Dobbin Summit, and in the mountainous terrain flanking Antelope Valley. Farther west, near Mill Canyon and north in the Toquima Range, the Sams Spring, Joes Canyon, and Perkins Canyon Formations of Kay and Crawford (1964, p. 433 and 435–436), as used by Langenheim and Larson (1973), or Vinini Formation (McKee, 1972), are more siliceous time-equivalent units representative of the siliceous and volcanic assemblage, which was deposited under different conditions from the carbonate assemblage. Elsewhere in the Toquima Range, in the Toiyabe Range, and in the San Antonio Mountains, rocks of equivalent age are believed to compose an undetermined thickness of strata near the top of the several-thousand-foot (760- to 1525-m)-thick section of siliceous and volcanic assemblage rocks assigned by Ferguson and Cathcart (1954) to the Ordovician Palmetto Formation (described in a separate section below).

Thickness

Considering their persistence over so much of the eastern Great Basin, the Hanson Creek and Ely Springs or Fish Haven Dolomite are relatively thin, but not so thin as the underlying Eureka Quartzite. Thicknesses of the Ely Springs Dolomite in northern Nye County range from about 400 to 750 feet (122 to 229 m) (table A10). The thickest exposures of the Hanson Creek Formation west of the Pancake Range are in Clear Creek Canyon, Monitor Range, where a complete section is 270 feet (82 m) thick (Greene, 1953, p. 23–25). Nearer the Nye-Eureka County line north of the Indian Spring Ranch, Antelope Range, the upper part of the formation is lapped by Tertiary volcanic rocks, and the section is incomplete. Nearby in Eureka County, complete sections are about 300 feet (92 m) and greater than 350 feet (107 m) thick at Lone Mountain and Whiterock Canyon, respectively (Nolan and others, 1956, p. 33; Merriam, 1963, p. 31). Only 75 feet (23 m) was measured at Rawhide Mountain in the Hot Creek Range, and about 105 feet (32 m) farther north in Hot Creek Canyon, where we exclude the uppermost several feet of chert from a section of Hanson Creek originally measured and mapped by Lowell (1957, p. 17, 36).

TABLE A10. Thicknesses of Ely Springs Dolomite (Oes), Fish Haven Dolomite (Ofh), and Hanson Creek Formation (Ohc) reported in northern Nye County and vicinity, Nevada.

[Thickness given in feet; equivalents in meters in parentheses. Localities arranged in relative geographic position]

Eureka Mining District				
[1]Ohc 300-350+ (92-107)				
Monitor Range	Hot Creek Range	Pancake Range	White Pine Mountains	Egan Range
Dobbin Summit	Tybo-Hot Creek	Lockes Station	Hamilton mining district	[2]Ofh 495-527 (151-161)
[3]Ohc 145-200? (44-61)	[4]Oes 105-145 (32-44)	(northwest of)	[5]Ohc 600-850 (183-259)	
Clear Creek	Rawhide Mountain	Oes 310 ± -413	Blackrock Canyon	
[6]Ohc 270 (82)	[7]Ohc 75 (23)	[8](94 ± -126)	[9]Oes 780 (238)	
			Southern part	
			[10]Ofh 420 (128)	
	Reveille Range		Horse Range	
	[11]Oes 90 ± (28 ±)		Central part	
			[12]Oes 770 (235)	
			(incomplete)	
			Grant and Horse Ranges	
			Northern parts	
			[13]Ofh 510 (155)	
			(base faulted)	
			Central and southern parts	
			[14]Oes 700? (213)	

[1]Merriam (1963, p. 31).
[2]Kellogg (1963, p. 695).
[3]Modified from Webb (1958, p. 2345).
[4]Lowell (1957, p. 17, 36; Quinlivan and Rogers, 1970, p. 8).
[5]Humphrey (1960, p. 25).
[6]Greene (1953, p. 23-24).
[7]Ross, Jr. (1964, p. C64-C65).
[8]Smaller thickness from Quinlivan and others, 1974; greater thickness from unpublished data of R. J. Ross, Jr., and F. J. Kleinhampl.
[9]Rich (1956, p. 34).
[10]Moores and others (1968, p. 1708).
[11]Ekren, Rogers, and Dixon (1973).
[12]Ptacek (1962, p. 28).
[13]Wire (1961, p. 136-137).
[14]Modified from Cebull (1967, p. 62-63).

Age

Langenheim and Larson (1973) generally show the basal part of the Ely Springs Dolomite and Hanson Creek Formation in the Trentonian Stage of the Ordovician and only the uppermost parts of these formations within the Richmondian. Tschanz and Pampeyan (1970, p. 29) also indicated their acceptance of a Middle and Late Ordovician age for the Ely Springs and its correlatives. However, Nolan and others (1956, p. 33-34), in summarizing reports of other workers, reported that regionally the two formations contained fossils only diagnostic of the Late Ordovician (Richmondian), including mainly brachiopods and corals and, in the Hanson Creek Formation of the Monitor Range, graptolites. Merriam (1963, p. 32) concurred with this age for strata in the Antelope Valley area and noted the presence of a major biologic discontinuity at the boundary of the Eureka Quartzite and the Hanson Creek Formation, with abundant rugose corals and new groups of brachiopods and trilobites in the Hanson Creek. He cited studies of graptolites by Rudolf Ruedemann and R. J. Ross, Jr., that support this age assignment, but he also mentioned a very early collection containing a trilobite assigned to the somewhat older Trentonian. The fauna in the type Ely Springs Dolomite also was said by Edwin Kirk to be characteristic of the approximately Richmondian part of the Late Ordovician (Cincinnatian) (Westgate, 1932, p. 16). Collections by the present authors and coworkers in northern Nye County and studies by other geologists farther east (Kellogg, 1963, p. 695; Hose and Blake, 1976) tend to confirm the Richmondian age of these rocks. Our fossil collections are described below.

Collection 61-RJ-63 (fig. A24), from strata assigned to the Ely Springs Dolomite in the Pancake Range (west base of the linear mountain block culminating in peak 8023, in NW/4 S25,T9N,R54E, unsurveyed), yielded *Palaeophyllum* sp. and streptelasmatid and favositoid corals, one of the latter of which is possibly a *Nyctopora*. The collection is almost certainly Ordovician (W. A. Oliver, Jr., written commun., 1961). Lower collections in the same section yielded no diagnostic fossils (fig. A24), and another nearby collection, 15838-3 in SW/4 S36,T9N,R54E (unsurveyed), yielded only two poorly preserved silicified plectambonitacean brachiopods not useful for dating (J. M. Berdan, oral commun., Feb. 27, 1975).

Collections from the Hanson Creek Formation near Dobbin Summit in the Monitor Range contain a fauna dated as young as Caradoc to Ashgill (Late Ordovician); two collections are close together in the NE/4 S18,T13N,R49E in flaggy, very thin-bedded, very dark gray to black, aphanitic to very fine-grained shaly limestone below a 10-20-foot (3-6-m)-thick cherty zone considered to be the basal member of the Roberts

Mountains Formation. The highest (USGS colln. D1087-CO) yielded conodonts, ostracodes (*Leperditia*(?)), and graptolites (*Climacograptus supernus* Elles and Wood, *C.* sp. (possibly *C. tubuliferus*), *Lasiograptus* sp., and *Orthograptus truncatus* cf. var. *pauperatus* Elles and Wood) of about zone 14 or possibly 15 of Elles and Wood (reported on by R. J. Ross, Jr., and W. B. N. Berry, written commun., 1963 and 1964). The lowest collection here (USGS D1084-CO) contains *Climacograptus hastatus* var. *martini* Ross and Berry, a graptolite very common farther north in the same formation (R. J. Ross, Jr., written commun., 1963).

Other fossils, including graptolites, brachiopods, and corals, were also seen in the lower massive part of the Hanson Creek Formation in the Monitor Range at Clear Creek, where Greene (1953, p. 23) noted one form, *Conchidium*(?), of Silurian affinity. Fossils in an approximately corresponding lithologic zone overlying the Eureka Quartzite near where Dobbin Summit Creek crosses the Eureka (close to the center of the N/2 S5,T12N,R49E) suggest a Silurian age to A. J. Boucot (written commun., Nov. 7, 1967). Boucot's faunule (colln. USNM loc. 13656) came from a light-colored unit beneath the typical Roberts Mountains Formation. He gave the age as Ludlow and stated that an age affinity with the Lone Mountain Dolomite is indicated on the basis of *Pentamerifera* sp. The collection included, additionally, *Gracianella* sp., an indeterminate dalmanellid, and an indeterminate smooth spiriferid.

Mullens and Poole (1972) have found Early Silurian conodonts in Eureka County in the upper part of the Hanson Creek Formation above a quartz-sand-bearing zone that at Copenhagen Canyon, Monitor Range, is 18 feet (5.5 m) beneath the top of the formation. Merriam (1963, p. 32, 36) summarized the paleontologic questions concerning the system assignment of the Richmond interval, and this confusion accounts for most of the difficulty of age assignment. In northern Nye County, it is quite possible that the conformable-appearing contacts of the Ely Springs Dolomite and the Hanson Creek Formations with overlying units may not coincide everywhere with the Ordovician-Silurian boundary. This time horizon is difficult to identify in the region and surrounding areas, such as Lincoln County to the east (Tschanz and Pampeyan, 1970, p. 28) and Antelope Valley near the Eureka-Nye County border (Merriam, 1963, p. 32). The paucity and poor preservation of fossils in dolomite of the Ely Springs and Hanson Creek have exacerbated the problem (Merriam, 1973a, p. 4).

ORDOVICIAN SILICEOUS AND VOLCANIC ASSEMBLAGE

Allochthonous siliceous strata, in some places associated with volcanic rocks of Ordovician and Ordovician(?) age, form numerous small to large outcrop areas from the Toquima Range west in northern Nye County (Clipper Canyon Group and shale and limestone, pl. A1; also see fig. A23).

In the southern Monitor Range, 1.5 miles (2.5 km) northeast of McKinney tanks (pl. A1), an outcrop of dark gray to black, highly siliceous rock has been included with Cambrian and Ordovician shale and limestone. The rock, however, is allochthonous, and the outcrop might more properly be labeled either Vinini Formation or Palmetto Formation.

The allochthonous Ordovician siliceous and volcanic assemblage in the northern Toquima Range is assigned to an undifferentiated unit that includes the Vinini Formation as mapped by McKee (1972; 1976) near Petes Summit and its presumed equivalents and near-equivalents farther south: the Clipper Canyon Group and the Pinecone and Willow Canyon Formations of Kay and Crawford (1964). The strata near Petes Summit consist predominantly of dark-gray to black and brownish-black, well-layered, generally thin-bedded chert and siliceous shale and argillite, and a little limestone and massive structureless fine-grained gray quartzite (McKee, 1972). The quartzite forms an excellent marker bed and appears in numerous fault blocks as a resistant ledge in what are otherwise monotonous dark slopes. Farther south, the units mapped by Kay and Crawford (1964) extend to about Red Rock Canyon (east side of the range), and the Pinecone and Willow Canyon Formations are each said to attain a thickness of at least 1000 feet (305 m). The rocks of all the cited units of Kay and Crawford (1964) are crudely similar, as one might suspect from the assignment of units to proximal stratigraphic assemblages. They consist mostly of deformed dark gray to black (fresh and weathered), shaly to thin-bedded and, locally, structureless chert and siliceous argillite, mudstone, and siltstone. Greenish chert predominates in the Willow Canyon Formation (Kay and Crawford, 1964, p. 436). These units form ledge-broken slopes and, locally, sheer cliffs. Weathered rubble includes irregular pebble- to cobble-size fragments; locally, surfaces are strewn with chips or blocks. The dark color of the rocks is one of the major distinguishing features, along with the resistant ledgy and cliffy aspect of their deformed beds. Kay and Crawford (1964, pl. 4, fig. 2, p. 436–437) described numerous intercalated dark-weathering lavas, including pillow lavas, in their Willow Canyon Formation. In general, though, the lavas are relatively small in volume and in total outcrop area.

Some strata near East Northumberland Canyon mapped with the Pinecone and Willow Canyon Formations, undifferentiated, by Kay and Crawford (1964) have been reassigned to the Devonian (chert, pl. A1) and probably correlate with the Slaven Chert (F. G. Poole, written commun., 1974). The remaining bulk of the rocks, especially the Pinecone Formation, is partly dated by Ordovician graptolites, whereas the Willow Canyon Formation is as yet undated because the only known fossils are radiolaria. The stratigraphic position of the Willow Canyon, therefore, is based on the general lithic similarity of the beds to the faunally dated allochthonous rocks, for example, the Clipper Canyon Group and the Pinecone. Graptolites in the Pinecone "...range from upper Arenigian or Llanvirnian to Caradocian, about equivalent to the Chazyan, Bolarian and Trentonian series" (high Lower Ordovician into Middle Ordovician), according to Kay and Crawford (1964, p. 436).

Ordovician and Silurian Systems

LOCAL ORDOVICIAN AND SILURIAN FORMATIONS OF KAY AND CRAWFORD (1964)

(Parautochthonous and Autochthonous, including Stoneberger Shale, Caesar Canyon Limestone, Diana Limestone, Gatecliff Formation, Masket Shale, and Perkins Canyon Formation)

Introduction

Kay and Crawford (1964, p. 431–433, 437–440) defined six new formations in the northern Toquima Range in parautochthonous and autochthonous sequences. These include, without implying a precise stratigraphic order, the Ordovician Caesar Canyon Limestone, Diana Limestone, Perkins Canyon Formation and Stoneberger Shale, and the Silurian Gatecliff Formation and Masket Shale. They are chiefly restricted to the Toquima Range; the Gatecliff and Masket have also been recognized by Kay and Crawford (1964, p. 438–44) in the southern Toiyabe Range between Pablo and Wall Canyons. The Perkins Canyon Formation and the Stoneberger Shale are mapped with the Pogonip Group (pl. A1) in this report. The Masket Shale is locally reassigned to and mapped with the Roberts Mountains Formation (pl. A1) except where it is grouped with the Caesar Canyon Limestone, Diana Limestone, and Gatecliff Formation, undifferentiated (pl. A1). Brief descriptions of the six formations follow.

Stoneberger Shale

The Stoneberger Shale is herein considered equivalent to part of the Pogonip Group, in particular to the Ninemile Formation, and is so mapped (pl. A1). Dark-brown-weathering black argillite and intercalated, very thin bedded, platy quartzose siltstone characterize the Stoneberger according to Kay and Crawford (1964, p. 431), who noted that the greater than 1000-foot (305-m)-thick formation somewhat resembles the Ninemile but contains more argillitic and siliceous material. They did not differentiate the Stoneberger from the Pogonip on their map, however, and neither do we. McKee (1972, 1976) also used the name "Ninemile" instead of "Stoneberger" and indicated that the formation is 500–700 feet (170–215 m) thick in the Toquima Range.

Perkins Canyon Formation

The Perkins Canyon Formation crops out extensively along and near East Northumberland Canyon as brownish-black slopes and rounded hills consisting of more than 1000 feet (305 m) of laminated aphanitic argillitic limestone and intercalated black shaly argillite. The Perkins Canyon and overlying strata are less calcareous and more siliceous than correlative units in the same area, and Kay and Crawford considered the formation to be part of what they term the "Striped Hill parautochthonous sequence." On our map, for purposes of legibility and because the formation has vague lithologic affinities to the Ninemile Formation, the Perkins Canyon was not differentiated from the Pogonip Group (pl. A1). Kay and Crawford (1964, p. 433) stated that the Perkins Canyon Formation contains abundant graptolites, the oldest reported being Arenigian (zone 4 or 5 of Elles and Wood [1914]) and the youngest being Ashgillian (zones 14 and 15), or, in North American terms, Canadian (Lower Ordovician) and highest Cincinnatian (highest Upper Ordovician), respectively. They further reported that the Perkins Canyon Formation underlies the Gatecliff Formation with possible disconformity and regional unconformity.

Caesar Canyon Limestone

The Caesar Canyon Limestone crops out only in the limited exposures of the August Canyon autochthon north of the mouth of Mill Canyon and near the head of West Northumberland Canyon. It consists of a maximum of about 150 feet (46 m) (Kay and Crawford, 1964, p. 432) of medium- to dark-gray, aphanitic to very fine-grained argillaceous shaly limestone and quartzose silty and sandy limestone that is locally siliceous and ferruginous. Basal strata consist of heterogeneous lithologies arranged in thin zones; they include platy shaly limestone, purplish-weathering, black to brown silty shale, and laminated to very thin bedded ferruginous and calcareous-cemented phosphatic sandstone and silty to sandy limestone, similar to the outcrop about 1.5 miles (2.4 km) up from the mouth of Mill Canyon just west of the large tributary of North Mill Canyon. Here, the entire complement of lithologies forms a zone only 5–8 feet (1.5–2.5 m) thick, and the ferruginous silty beds carry beautifully preserved graptolites identified as *Orthograptus* sp. and the trilobite *Cryptolithus* sp. (R. J. Ross, Jr., oral commun., June 1965). Fossil evidence indicates that the lower and upper contacts of the formation are probably unconformities (McKee, 1976, p. 14). The formation has been dated from abundant and diverse fossils—brachiopods, graptolites, and trilobites—as Bolarian (Mohawkian) and Trentonian (Cardocian of Europe) or Middle Ordovician (Kay and Crawford, 1964, p. 433). McKee and Ross (1969, fig. 5) showed the Caesar Canyon Formation as the upper part of a time-transgressive unit that includes a slightly older Copenhagen Formation on the east. They also show the Caesar Canyon as a partial correlative of the Hanson Creek Formation in Antelope Valley and the Monitor Range and of the Hanson Creek(?) Formation in the northern Toquima Range at Petes Canyon window, Lander County. McKee (1976, p. 14) noted more specifically that graptolite studies indicate a correlation with the lower part of the Hanson Creek. Ross and Shaw (1972, p. 9, 11) suggested that trilobite-bearing shale and siltstone in the middle of the Caesar Canyon Limestone correlate with the uppermost beds of member C of the Copenhagen Formation. They also mentioned graptolite studies of W. B. N. Berry, which place the Caesar Canyon in the late Middle Ordovician, about Trenton-Eden stages and the graptolite zone 13 of Berry (1960).

Gatecliff Formation

This formation in the type locality in Mill Canyon consists of about 200 feet (61 m) of three subequally thick units of dolomite, quartz sandy dolomite (locally a dolomitic quartzite), and black chert that irregularly replaces dolomite. The three parts, however, are not everywhere equal in thickness, nor are they everywhere present. Contact relations of the formation differ somewhat in each of the tectonic slices hosting the formation (Kay and Crawford, 1964, p. 438). The Gatecliff lies conformably on the Caesar Canyon Limestone in the August Canyon autochthon, lies with disconformity on the Antelope Valley Formation of the Pogonip Group in the Prospect parautochthonous sequence, and lies with possible disconformity on the Perkins Canyon Formation in the Striped Hill parautochthon. The quartzitic unit superficially resembles the Eureka Quartzite, but close inspection reveals that the quartz grains are more angular, more poorly sorted, and generally coarser than typical Eureka and contains more dolomitic matrix than the Eureka. Very poorly preserved corals, brachiopods, and crinoid columnals were collected from a thin medium-light-gray-weathering dolomite between the chert unit and the dolomitic quartzitic sandstone-sandy dolomite. The latter unit also contains very sparse traces of brachiopods and abundant pelmatozoan debris. The pelmatozoan debris is commonly in irregular pockets as much as a few feet (1 m) across. McKee (1976, p. 17) reported that the lower dolomite at Mill Canyon yielded Silurian corals. The upper cherty member of the Gatecliff is elsewhere reported to contain Early Silurian graptolites, and Ashgillian (uppermost Ordovician) graptolites occur in the directly underlying Perkins Canyon Formation of the Striped Peak parautochthon (Kay and Crawford, 1964, p. 433; McKee, 1976, p. 17) (see the section of this bulletin on Silurian and Devonian Systems—Roberts Mountains Formation). The main lithologies within the Gatecliff have some affinity to lithologies found in the dolomitic sections generally assigned to the Hanson Creek Formation in the Antelope Valley region, but the Gatecliff contains more cherty and quartz sandy zones. The Hanson Creek may be partly correlative with the Gatecliff. This is indicated by the work of Mullens and Poole (1972), who have determined, from conodonts studied by J. W. Huddle and stratigraphic work, that the upper part of the Hanson Creek in nearby parts of Eureka County is Early Silurian. McKee (1976, p. 17) indicated that the upper chert unit of the Gatecliff correlates with the basal chert of the Roberts Mountains Formation.

Diana Limestone

The Diana Limestone crops out discontinuously from about Mill Canyon to Ikes Canyon near the front of the Toquima Range and attains a thickness of at least 77 feet (23 m) (Ross, 1970, p. 21). In the Toquima Range Kay and Crawford (1964, pl. 1, p. 439) described a 38-foot (12 m)-thick section of Diana consisting of relatively unfossiliferous gray to dark-gray limestone, some of which is clearly calcarenitic. McKee (1976, p. 15) explained the dating of the Diana as Ordovician or Silurian and concluded that late Middle or Late Ordovician trilobites, graptolites, and conodonts better represent the age of the unit than do Silurian corals and brachiopods. Fossils collected by R. J. Ross, Jr., especially trilobites, and including conodonts studied by J. W. Huddle, indicated a late Middle or Late Ordovician age for the formation and enabled Ross to propose the equivalency of the Diana to the uppermost Copenhagen Formation or the lower Hanson Creek Formation (Ross, 1970, p. 21–23). Kay and Crawford (1964) depicted the Diana as a correlative of the Gatecliff Formation and a substitute for the Gatecliff in their Mill Canyon autochthonous sequence, which is one of the oldest and lowest structural levels observable there.

Masket Shale of Kay and Crawford (1964)

The name Masket Shale was used by Kay and Crawford (1964) for several hundred feet of chiefly platy, buff-weathering argillaceous limestone above the Antelope Valley Limestone and below the McMonnigal Limestone in their Mill Canyon sequence between Ikes and Mill Canyons, northern Toquima Range. They designated a type section there and recognized the Masket in their nearby autochthonous August Canyon sequence, where the formation includes some thick-bedded coarser limestone in the basal 200 feet (61 m). They named these basal strata the Bastille Limestone Member. McKee (1976, p. 19) described this member as about 125 feet (38 m) of mainly dolomite with interbeds of fossil-bearing limestone. They also applied the term Masket to similar but less calcareous and more siliceous strata in their parautochthonous Prospect and Striped Hill sequences, near Northumberland Canyon farther south in the Toquima Range, and in Pablo Canyon, Toiyabe Range.

We reassign the Masket of the August and Mill Canyon sequences to the Roberts Mountains Formation, following McKee (1976, p. 17–19) except for his retention of the term Masket in the August Canyon sequence. In the other areas where the Masket was recognized by Kay and Crawford (1964), we have combined the Masket with the Caesar Canyon Limestone, Diana Limestone, and Gatecliff Formation, undifferentiated (pl. A1).

The Masket-like part of this undifferentiated unit in the Toquima Range (Prospect and Striped Hill sequences) varies from argillitic limestone to siliceous argillite, depending to a considerable degree on the local facies in any one thrust slice; the more siliceous beds are associated with the more westerly facies. In the Pablo Canyon area, Toiyabe Range, equivalent strata include more than 500 feet (154 m) of buff-weathering platy argillaceous siltstone and some siliceous shale and dolomite interbeds in the lower part (Kay and Crawford, 1964). We noted platy silty dolomite, quartzitic sandstone alternating with siliceous shale, and minor platy calcareous siltstone and shaly to silty limestone there as well. Additional data comparing the Masket to its partial correlative, the Roberts Mountains Formation, appears with the description of that unit.

Silurian and Devonian Systems

Nomenclature used in various parts of northern Nye County for Silurian strata (fig. A26) does not vary much across the region. The rocks are shaly to massive carbonate strata nearly everywhere, except locally for somewhat more siliceous facies in the Toquima and Toiyabe Ranges. Locally the Silurian rocks are included with older and younger beds.

ROBERTS MOUNTAINS FORMATION

Introduction

The name Roberts Mountains Formation was first applied to limestones in the Roberts Mountains in Eureka County and then to a more accessible dolomitic section at Lone Mountain near Eureka (Merriam, 1940, p. 11–12, 19–21). The section at Lone Mountain was commonly used as a reference section in the 1960's, even though it differed considerably from the type section. Winterer and Murphy (1960) restudied the type area wherein important facies relations between limestone and dolomite were described, and, thereafter, Merriam (1973b, p. 13) reassigned rocks that had been termed the Roberts Mountains Formation at Lone Mountain to unit 1 of the type Lone Mountain Dolomite. Strata in the Toquima Range between Ikes and Mill Canyons to which Kay and Crawford (1964, p. 439) gave the local name Masket Shale is herein reassigned to the Roberts Mountains Formation, following McKee (1976, p. 17–19) except for his retention of the term Masket in the autochthon of the August Canyon sequence of Kay and Crawford (1964). T. E. Mullens (unpub. data) most recently prepared a definitive stratigraphic study of the Roberts Mountains Formation.

Lithology

The lower half of the type section of the Roberts Mountains Formation consists of laminated to slabby argillitic fine-grained limestone alternating with less abundant, coarser grained limestones; the upper half grades from similar rocks up into less well bedded more dolomitic material and, near the top, dolomite. Outcrops weather to pastel grays and tans and form chip- and plate-covered steep slopes that alternate with ledges and cliffs. The thinner bedded, finer grained strata contain graptolites (monograptids), whereas the coarser limestones are characterized by an abundant, more varied fauna including bryozans, corals, crinoids, and brachiopods (shelly facies) (Merriam, 1973a, p. 5–8).

Roberts Mountains Formation of fairly typical lithology was recognized from the Monitor Range west into the Toiyabe Range but was differentiated on the map (pl. A1) only in part of the Monitor Range (Ellendale area) and the Toquima Range between Ikes and Mill Canyon. The following description applies, except where noted, to the Roberts Mountains and generally to its partial correlative, the Masket Shale, which is grouped with older strata on the map (pl. A1) and is briefly described in the section of this bulletin on Ordovician and Silurian Systems—Masket Shale of Kay and Crawford (1964).

Pale gray to yellowish-orange, shaly and platy argillitic limestone and siliceous argillite weathering to conspicuous yellowish-orange talus slopes and softly shaped hills predominate nearly everywhere in the Toquima Range. The coloration is more distinctive and tanner than that of the Roberts Mountains Formation at its type locality. The strata resemble much of the undifferentiated Roberts Mountains Formation near Dobbin Summit in the northern Monitor Range and are exposed in a series of thrust plates and autochthon.

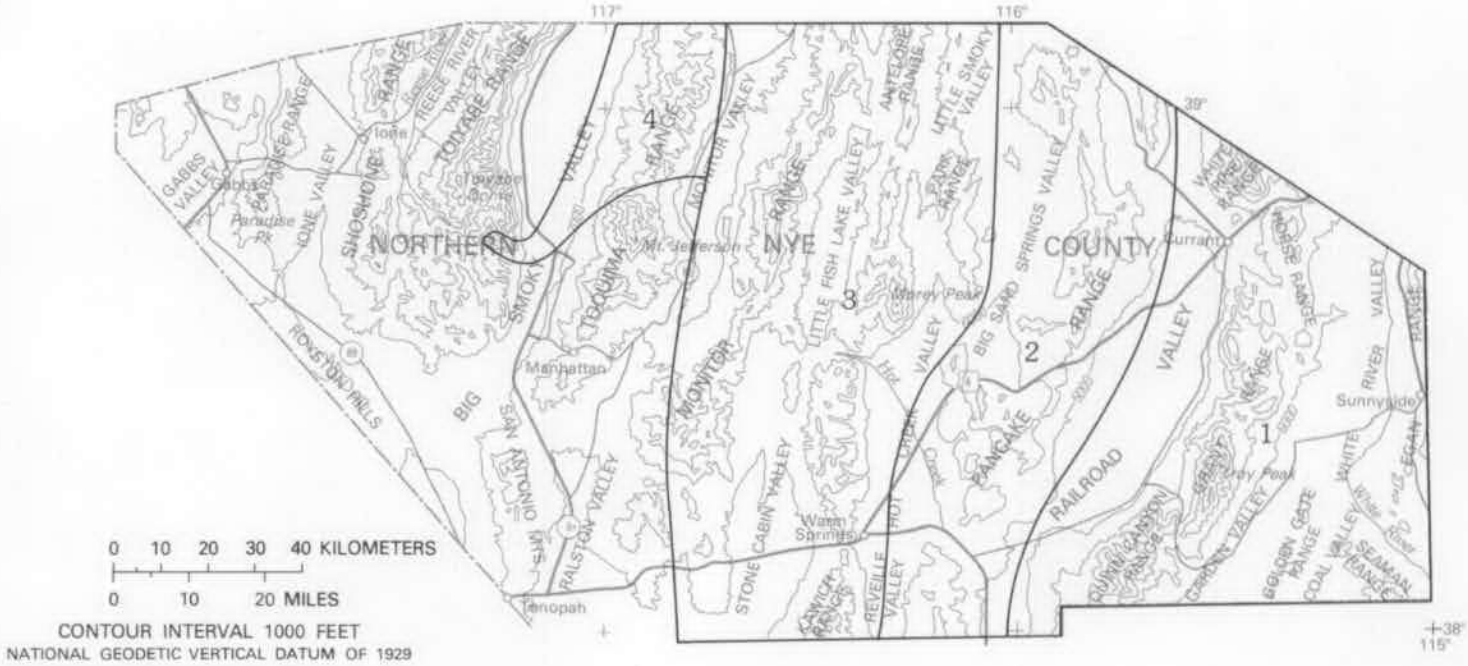
Several local thicker bedded bioclastic coquinoid beds contrast with the platy strata and are well exposed in Ikes Canyon. Superficially similar (in thickness and detrital character) bioclastic strata crop out in the undifferentiated Roberts Mountains Formation in the Monitor and Hot Creek Ranges. Also similar, but much thicker than any of these, is the partly bioclastic Bastille Limestone Member of the Masket Shale.

Contacts

The contact in northern Nye County between the Roberts Mountains Formation and the underlying Hanson Creek Formation, described more completely with the latter unit, is one of bedding concordance. However, several writers have indicated that, on a more regional basis, the formation must unconformably overlie older strata because those strata are not the same unit everywhere, particularly in Lander County to the north (Stewart and McKee, 1977; T. E. Mullens, written commun., Sept. 17, 1968). A marker bed of ledge-forming dark-gray chert, with chert decreasing gradationally upward through interlayered chert and carbonate beds, is the basal member of the formation in the type locality, and similar chert is remarkably persistent geographically (Nolan and others, 1956, p. 37; Merriam, 1963, p. 38). The chert zone is absent locally, as at Clear Creek Canyon, Monitor Range, but it is present in other areas, as the Hot Creek Range, where opinion differs as to whether the strata should be assigned to the Roberts Mountains Formation.

Distribution, Thickness, and Locality Descriptions

In the central Monitor Range, outcrops of Roberts Mountains Formation proved too narrow to depict separately and, where not included with undifferentiated Ordovician and Silurian strata (dolomite, pl. A1), were grouped with Ordovician, Silurian, and Devonian beds (dolomite and limestone, undivided, pl. A1) because of inadequate mapping. The formation is apparently absent from the Clear Creek area but crops out near Dobbin Summit and may also be present in T9N,R48E, northwest of the Daugherty Ranch. The formation was mapped with Middle and Upper Ordovician strata in the Hot Creek Range (see dolomite, pl. A1), although extensive outcrops there were assigned to the Roberts Mountains Formation by Lowell (1957, p. 18–19). Some outcrops were too small or narrow to



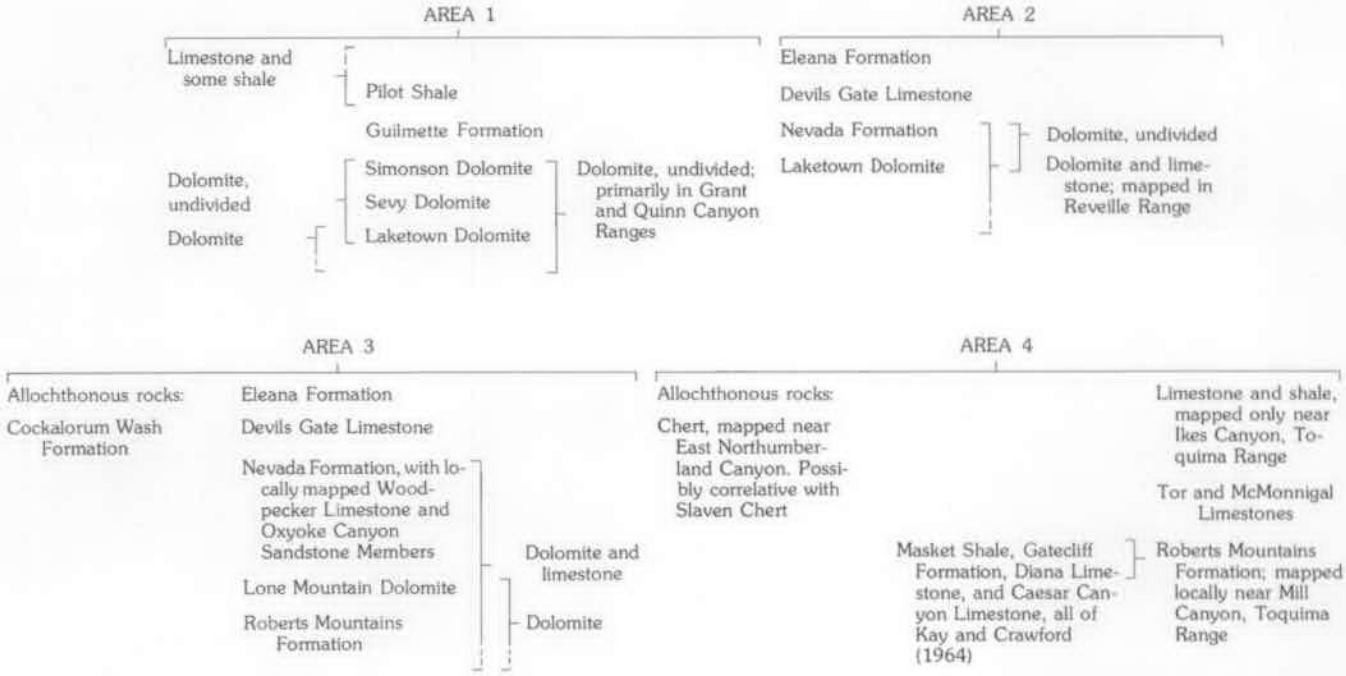


FIGURE A26. Map units used in various parts of northern Nye County for all Silurian and Devonian strata on the geologic map (pl. A1).

show separately on the map, and in some of these areas existence of the formation was uncertain.

In the Monitor Range, dolomitic strata 610 feet (186 m) thick at Clear Creek Mountain were assigned to the Roberts Mountains Formation by Greene (1963, p. 27), who stated that the section was incomplete, with upper beds faulted out. These dolomitic rocks were excluded from the Roberts Mountains by T. E. Mullens (oral commun., Feb. 13, 1975), presumably because of their cliffy, massive, poorly bedded dolomitic character, which more nearly resembles the Lone Mountain Dolomite. However, some of the strata are platy to flaggy, similar to the type Roberts Mountains, which also contains some massive dolomitic beds. At Dobbin Summit, about 400 feet (122 m) of Roberts Mountains Formation was measured in a section containing several fossil horizons (T. E. Mullens, oral commun., Feb. 13, 1975). The strata are poorly graptolitic, platy to flaggy limestones that form pastel reddish- to yellowish-brown and gray broken slopes. The rocks are grouped with the Hanson Creek Formation on the map (see dolomite, pl. A1), and the platy limestones of the Roberts Mountains

persist upward through interbedded, more massive, coarser grained limestones into Devonian strata. The latter are referred to the Helderbergian Rabbit Hill Limestone whose lower contact here is placed at the base of a bioclastic limestone ledge. At Ellendale in the southernmost part of the Monitor Range, at least several hundred feet (100 m) of the Roberts Mountains Formation is present in a thrust plate, but the base and top of the formation are probably missing.

Here, the platy to laminated sequence of limestone with minor calcitic dolomite beds is distinctive in that some zones contain disseminated silt- and sand-sized quartz grains. Graptolites are also relatively common compared to other localities and are readily seen because their impressions contrast in color with the host strata. The fresh rocks are light to medium gray and weather to pastel yellowish brown, grayish orange, olive gray, and even pinkish gray. These colors contrast with minor erratically distributed, regularly layered, medium-gray-weathering chert lamellae and cherty lenses and beds as much as several inches thick; the colors also contrast with siliceous (argillaceous?) lamellae that appear in longitudinal section as rusty-colored discontinuous streaks a few tenths of an inch to a few inches long.

About 700 feet (210 m) of Roberts Mountains is attained in the Toquima Range by including the Masket Shale and upper cherty part of the underlying Gatecliff Formation, both named by Kay and Crawford (1964, p. 437–439) (Merriam, 1973a, p. 10). McKee (1976, p. 17) gives a total thickness of about 350 feet (110 m) for the Roberts Mountains at Mill Canyon and a thickness more than twice as great just across the Nye County boundary to the north. An incomplete section farther west, in a thrust plate between Wall and Pablo Canyons, Toiyabe Range, consists of partly equivalent strata, including the Gatecliff Formation and Masket Shale. This section is somewhat more than 500 feet (150 m) thick (Kay and Crawford, 1964, p. 438–439). Farther north in the range, near the Lander-Nye County line, about 1000 feet (315 m) of the Roberts Mountains Formation is exposed (Stewart and McKee, 1977).

Extensive dolomitic strata in the Hot Creek Range that are possibly assignable to the Roberts Mountains Formation, but not differentiated by us (pl. A1), measure 486 feet (150 m) at Hot Creek Canyon (Lowell, 1957) and range in thickness from 300 to 540 feet (90 to 165 m) southward in the Tybo quadrangle (Quinlivan and Rogers, 1970, p. 8). Seven feet of chert in what we consider to be the basal part of the formation was originally placed in the uppermost part of the underlying Hanson Creek Formation by Lowell (1957, p. 17 and 36). Rocks in the range that could be assigned to the Roberts Mountains Formation consist of beds similar in stratification and splitting qualities to the type Roberts Mountains. However, these rocks are chiefly dolomite rather than limestone, weather only to darker gray hues than to the more typical lighter pastels, and are much less fossiliferous. A low cliff of white to medium-light-gray chert, 7 feet (2 m) thick at Hot Creek Canyon and 8–10 feet (2.5–3 m) thick on the southern spur of Little Rawhide Mountain, lies at the base of the sequence. This unit is overlain by several hundred feet (about 100 m) of medium and medium-dark-gray 7–30 foot (2–9-m)-thick, platy to massive, laminated, very fine grained dolomite alternating with (cyclic) 0.5–5-foot (0.15–1.5-m)-thick, somewhat coarser grained, ledge-forming, bioclastic limestone and dolomite. Near Little Rawhide Mountain, the bioclastic beds contain fragments of numerous kinds of fossils: corals, brachiopods, bryozoans, crinoids, and, locally, silicified bioherms to 3 feet (1 m) long and 1 foot (.3 m) thick in the outcrop. Dark-gray chert composes about 5–15% of the alternating section near Little Rawhide Mountain, where it forms mostly 0.5–1.0-inch (13–25-mm)-thick interbeds in scattered zones in the platy dolomite. Where examined at Hot Creek Canyon, the alternating sequence is overlain by less clearly layered but thin-bedded, monotonously cliffy, medium-gray, fine-grained dolomite 153 feet (47 m) thick (unit 27 of the Roberts Mountains Formation as used by Lowell, 1957, p. 34). This unit lacks the bioclastic beds of the alternating sequence.

The Roberts Mountains Formation was not recognized east of the Hot Creek Range or in the Reveille Range, where its undifferentiated equivalents appear to be represented by dolomite of the Laketown Dolomite (pl. A1) and other undifferentiated Ordovician, Silurian, and Devonian map units (pl. A1). In the Reveille Range, chert makes up as much as 100 feet (30 m) of what may be part of this stratigraphic interval, but the predominant lithology, dolomite, does not resemble the Roberts Mountains and was not mapped as such by us or by Ekren, Rogers, and Dixon (1972b).

Age and Correlations

The thin- and regular-bedded, finer grained dolomite of the Roberts Mountains Formation equivalent in the Hot Creek Range may correlate with a dolomitic zone at Lone Mountain west of Eureka. Merriam (1940, p. 13, 21) originally designated this zone of dolomite as Roberts Mountains Formation and later (1973c, p. 13) termed it Lone Mountain Dolomite unit 1. Here in Hot Creek Canyon, the thin-bedded unit passes gradationally upward into cliff-forming, massive, obscurely bedded, light-gray dolomite of presumed Silurian age that is locally mapped as Lone Mountain Dolomite or is included with undifferentiated Ordovician and Silurian dolomite (pl. A1). T. E. Mullens (oral commun., Feb. 13, 1975) reported that farther west, near Dobbin Summit in the Monitor Range, the Roberts Mountains Formation passes upward into lowest Devonian (Helderbergian) limestone through a conformable series of interstratified platy argillaceous calcitic beds and coarser grained limestone ledges. He drew the top of the Roberts Mountains at the base of a bioclastic limestone ledge, a contact comparable to that on our map (pl. A1) (see also the section of this bulletin on Limestone, undifferentiated (includes Rabbit Hill Limestone). Neither the undisturbed base nor the top of the Roberts Mountains Formation was seen in the southern Monitor Range, where the lower contact is a low-angle fault and

the upper part of the formation has been removed by erosion. Farther west, in a thrust sequence in the Toquima Range, Devonian strata (McMonnigal Limestone of Kay and Crawford, 1964, p. 440–441) lie conformably and gradationally above the Roberts Mountains, and in another thrust sequence, the Devonian Tor Limestone lies above in sedimentary contact, where the Tor occupies the stratigraphic position of the McMonnigal (McKee and others, 1972, p. 1564, 1567; McKee, 1976, p. 20).

The Roberts Mountains Formation has been well studied to the north in Eureka County where the unit contains fairly abundant graptolites and conodonts and, locally, an abundant shelly fauna with brachiopods, bryozoans, and corals. There the fauna from the middle and upper Roberts Mountains Formation is considered by Clark and Ethington (1964, p. 679) to be at least as young as latest Ludlovian (latest Silurian, or possibly Early Devonian if graptolite data of A. J. Boucot are substantiated) (see Clark and Ethington, 1964, p. 680–681). Within the type section in the Roberts Mountains, Johnson and others (1967, p. 681–682) placed the Silurian-Devonian boundary 706 feet (215 m) up in the formation, above which horizon are a few feet of strata with faunules transitional upwards into about 600 feet (185 m) of beds with Gedinnian zone fossils. Other workers who have considered the formation Silurian in age have done so on the basis of faunal studies that emphasize coral zonation (Nolan and others, 1956, p. 37; Merriam, 1963, p. 38–39; 1973a, p. 15, 26; 1973b, p. 2–4, fig. 4). McKee (1976, p. 17), however, notes that Silurian coral zone E of Merriam (1973c, p. 14–16) is Lower Devonian when the Silurian-Devonian boundary is defined according to McLaren (1970), who subscribed to views of the Committee on the Silurian-Devonian boundary whereby the lowest Devonian should include the *Monograptus uniformis* zone. Modern published studies of conodonts, graptolites, and shelly fauna from the Roberts Mountains Formation in the northern Toquima Range indicate a Llandovery (upper Lower Silurian) to Early Devonian age (McKee, 1976, p. 18). A section in Ikes Canyon, Toquima Range, was recently established as one of several reference sections for the Silurian and found to contain representatives of Silurian coral zones A and D in the Roberts Mountains Formation (Merriam, 1973a, p. 10, 15, 20, 21). Two fossil collections in northern Nye County ascribed to the formation, but not reported previously, are described below (information supplied by A. J. Boucot and J. G. Johnson, written commun., Oct. 12, 1967). Collection USNM loc. 13655 is especially important because it comes from a site where the Roberts Mountains Formation and overlying Rabbit Hill Limestone form a continuous section.

Collection USNM loc. 13655, collected in 1967 by A. J. Boucot from basal beds of Roberts Mountains Formation, southwest side of Dobbin Summit Road, Monitor Range, about .25 mile (.46 km) south and 1.25 mile (2.3 km) east of NW corner of T12N,R49E; elevation about 8200 feet (2500 m): *Dicaelosia* sp. (short lobed), *Dalejina* sp., *Salopina* sp., *Schizophoria* sp., *Anastrophia* aff. *magnifica, Gypidula* sp. (smooth), *Sphaerirhynchia* cf. *gibbosa, Atrypa* sp. (biconvex), *Atrypina* sp., indet. smooth atrypid, *Cryptatrypa* sp., *Rhynchospirina* cf. *siemiradzkii, Nucleospira* sp., *Howellella?* sp., *"Reticularia"* cf. *laeviplicata, Megakozlowskiella* sp., and *Cyrtina* sp. *Schizophoria, Megakozlowskiella,* and *Cyrtina* in this collection are a sound basis for a Gedinnian (Devonian) age assignment. The fauna indicate a clear correlation between the beds at Dobbin Summit and the upper 600 feet (183 m) of beds of the Roberts Mountains Formation in the Roberts Mountains, where many Gedinnian collections have been made.

Collection USNM loc. 11081, collected in 1964 by A. J. Boucot a short distance north of the Cunningham prospect (pl. B1), Tybo district, Hot Creek Range: *Dolerorthis* sp., *Dicaelosia* sp., *Isorthis* sp., smooth pentamerid sp., *Conchidium*(?) sp., *Cymbidium* sp., *Gypidula* sp., *Coolinia*(?) sp., *Plectodonta* sp., lamelose rhynchonellid sp., *Atrypa* "reticularis", *Spirigerina* sp., *Lissatrypa* sp., *Nucleospira*(?) sp., and *Spirinella* aff. *S. pauciplicata* (Waite). The collection is probably Ludlow age (Upper Silurian) because of the presence of *Cymbidium*. Monograptids were noted but not collected near Dobbin Summit and are most common in the platy limestones of the NE/4 NE/4 S18,T13N,R49E (unsurveyed). Graptolites at other localities are sparse to rare in similar appearing strata. Fairly abundant graptolites characterize the somewhat anomalous-appearing Roberts Mountains Formation at Ellendale, where the section gives evidence of having been thermally metamorphosed.

A major step in clarifying the genetic and stratigraphic relations between the predominantly thin-bedded calcareous Roberts Mountains Formation and the more massive, poorly or obscurely bedded Lone Mountain Dolomite was made by Winterer and Murphy (1960, p. 117–139), who proposed that the Roberts Mountains was a facies marginal to a north-trending reef complex on the east represented by the Lone Mountain Dolomite. However, restraint in acceptance of this hypothesis is suggested by Merriam (1973a, p. 28–29), who briefly compared the Great Basin rocks with those of the Niagara and Gotland patch reefs and concluded that the similarity is poor. Regardless of Merriam's conclusions, facies changes and probable local intertonguing between the Roberts Mountains Formation and the Lone Mountain Dolomite are documented (Winterer and Murphy, 1960; Merriam, 1973b, p. 16), and additional work should lead to resolution of the problem concerning the depositional environment of the beds. Merriam (1973a, p. 5, 28) classed the Roberts Mountains Formation as part of the intermediate limestone belt of the Silurian Cordillera. He further stated that the coral-rich bioclastic beds do not represent reef structures but instead consist mostly of banklike accumulations (interreef? facies) of little-worn corals transported from nearby sources. This observation would seem to apply to the bioclastic beds that we have seen intercalated in the Roberts Mountains Formation of northern Nye County, including those in the Hot Creek Range.

LONE MOUNTAIN AND LAKETOWN DOLOMITES

Introduction

Massive, poorly or obscurely bedded dolomites are assigned to the Laketown Dolomite in and east of the Pancake Range and to the partly correlative and lithologically similar Lone Mountain Dolomite in and west of the Hot Creek Range. We restrict the Lone Mountain Dolomite to the region where the calcareous Roberts Mountains Formation, a formation that intertongues with the Lone Mountain Dolomite, was recognized. One of the earliest references to the Lone Mountain Dolomite in northern Nye County was that of Ferguson (1933, p. 20), who at Tybo correlated "...several hundred feet of massive dolomite with some limestone near the base..." with the Silurian part of the original unrestricted Lone Mountain Limestone of Hague (1883, p. 262; 1892, p. 57) near Eureka. Later, a formalized redefinition of the Lone Mountain Formation in its restricted sense was given by Merriam (1940, p. 13-14); Nolan and others (1956), following Merriam, used the name Lone Mountain Dolomite (restricted) near Eureka. Merriam (1973c, p. 12) thereafter revised the Lone Mountain Dolomite at the reference section at Lone Mountain to include 2500 feet (762 m) of strata "...from the bottom of the Silurian basal chert directly overlying the Hanson Creek Formation to the base of the Nevada Formation." With this revision Merriam's (1940) Roberts Mountains Formation and Lone Mountain Formation at Lone Mountain became Lone Mountain Dolomite units 1 and 2, respectively. The name Laketown Dolomite, originally proposed in northern Utah (Richardson, 1913, p. 410), has become widely used in eastern and southeastern Nevada (Young, 1960, p. 162; Kellogg, 1960, p. 191; Rigby, 1960, p. 174; Tschanz, 1960, p. 201; Tschanz and Pampeyan, 1970, p. 29).

Distribution, Thickness, and Lithology

Laketown Dolomite extends from the Egan Range on the east to the Pancake Range on the west. It is generally about 1000–1430 feet (305–436 m) thick. The best and least disturbed sections are exposed along the west front of the Egan Range, in the Horse Range, and in the Pancake Range west of Lockes Station. Equivalent strata in the Reveille Range (dolomite and limestone, undivided, pl. A1) are about 1500 feet (457 m) thick and well exposed. The Laketown consists of fine- to medium-grained, relatively massive, poorly or obscurely bedded, inhomogeneous dolomite that is generally dark brownish gray in its lower part and passes upward through a thin transition zone of light-yellowish-gray dolomite into an upper brownish-gray part. In some places the upper brownish-gray part is poorly developed or missing and cannot be used as a guide to the top of the formation. Chert, chiefly dark gray and nodular to bedded, is scattered mostly in the lower and upper parts, but it is absent or not prominent in some sections. Sedimentary breccias, some of which may be solution breccias, are present locally. Compared to other Paleozoic formations, fossils are sparse and poorly preserved, although many could have been destroyed by recrystallization. Fragments resembling crinoid columnals are an exception; these are as much as ½ inch (1 cm) or so across and were seen in most areas. In places, they are very abundant. Solitary and colonial corals and pentamerid brachiopods are less abundant but locally numerous.

The brachiopods commonly occur in scattered zones throughout as much as 65 feet (20 m) of strata near the base of the formation, and in the Pancake Range west of Lockes Station are clustered in zones throughout the basal 280 feet (85 m) of section (Quinlivan and others, 1974). Locally in the Pancake Range and elsewhere, fossils such as the brachiopods are so silicified and resistant to weathering that they form prominent brownish casts that are commonly interlaced with a reticulated network of similarly colored silica veinlets. At other places, especially higher in the section, scattered zones of sparse large bivalves are commonly coarsely recrystallized to dolomite that appears white in contrast to somewhat finer grained and darker hued hosting dolomite. Silicified remnants of chain corals were noted in some places, and Kellogg (1963, p. 695) has reported bioherms formed from broken favositid corals.

In the Grant Range, the Laketown Dolomite is best and most completely exposed just north of Blue Eagle Mountain. Here the formation is less recrystallized, altered, or structurally contorted than elsewhere in the range. Other good sections of the Laketown Dolomite and adjacent formations occur in various fault blocks in Big Creek Canyon, Quinn Canyon Range. At both places, there are well-layered, thin- to thick-bedded zones in the formation in addition to the more regionally characteristic poorly or obscurely bedded strata. Fossils are present at both localities.

The lowest of Kirkpatrick's (1960a) three units in the Laketown of the Grant Range is a well-bedded, very fine grained dolomite that weathers blackish and, in the upper part, dark brown. Massive, fine- to medium-grained, light-gray dolomite characterizes the middle unit, and silicified corals and bryozoans are common, especially near its top. The upper unit consists of well to poorly bedded, dark-gray to brown, cherty, fine- to medium-grained dolomite that weathers medium- and dark-brown. Poorly preserved fossils are common, and *Halysites* was considered by Kirkpatrick to be diagnostic of the formation here. Merriam (1973a, p. 4), however, noted that halysitids are also abundant in Late Ordovician beds and therefore cannot be used definitively without identification of the genera and species. Chert is present in all three units but is especially common in the upper one.

The lithology of the Lone Mountain Dolomite, given below, is summarized from short descriptions by Lowell (1957, p. 34), H. E. Cook (1966, p. 25), and Quinlivan and Rogers (1970). A monotonously massive, obscurely bedded, very light- to light-gray, fine- to medium- grained dolomite characterizes the formation. Cook said that the dolomite weathers to a characteristic yellowish-orange. A saccharoidal texture is common and seemingly

related to pervasive wisps of medium- to coarse-grained secondary dolomite. Departures from the normal lithology include local coarse-grained dolomitic limestone near the lower contact, some scattered quartz sand near the top, and very minor medium-and dark-gray dolomite that is present locally, especially in the upper and lower parts of the formation.

The Lone Mountain Dolomite west of the Pancake Range was mapped only in the Hot Creek Range. It may locally extend into the Monitor Range farther west (northwest of the Daugherty Ranch and near Danville and Green Monster Canyons) where the strata were left undifferentiated (dolomite and dolomite and limestone, undivided, pl. A1). Lowell (1957, p. 34) measured 473 feet (144 m) at Hot Creek Canyon and noted that the upper part had been eroded away. A similar thickness of presumed equivalent strata (500 feet or 152 m) was left undifferentiated by Quinlivan and Rogers (1970) in the Tybo quadrangle to the south, where, from their description, it may be construed that the section is disconformably overlain by Middle Devonian beds. H. E. Cook (1966, p. 25) measured a thickness of at least 1000 feet (305 m) but may have included part of the Nevada Formation in his total.

The Lone Mountain Dolomite is about half as thick as the Laketown Dolomite. Its relative thinness can be explained almost entirely by the exclusion of the Roberts Mountains equivalent (300–540 feet [91–165 m] thick) from the Lone Mountain in the Hot Creek Range and the inclusion of the probable Roberts Mountains equivalent in the Laketown Dolomite. It is not clear to what extent an unconformity at the tops of the Laketown and Lone Mountain Dolomites might have affected the thicknesses of these formations.

Contacts and Age

The lower and upper contacts of the Laketown Dolomite generally appear to be gradational, with concordant beds adjacent to the contacts. However, subtle features associated with the upper contact indicate the possible existence of an unconformity; these features are described later on. The conformable lower contact of the Laketown Dolomite is placed just above a medium-light-gray, relatively well bedded blocky dolomite that is locally calcitic and forms a conspicuous light-colored band (fig. A24). Basal beds of the overlying Laketown consist of relatively massive, poorly bedded dolomite that forms a thicker dark-gray layer strongly contrasting with the lighter one beneath. In the Reveille and Pancake Ranges, the basal contact of the Laketown equivalents may be unconformable (Ekren, Rogers, and Dixon, 1972b; Quinlivan and others, 1974).

The upper contact is generally placed within a sequence of light-gray dolomite, at a position where the more obscurely bedded strata of the Laketown pass into the better layered aphanitic dolomite of the overlying Devonian Sevy Dolomite. In some places, such as the Egan and Grant Ranges, the upper Laketown Dolomite has some darker gray and brownish-gray layers that contrast with the overlying Sevy Dolomite, which is more consistently lighter gray. The contact is gradational locally in the Grant and Quinn Canyon Ranges.

An unconformity may mark the upper contact of the Laketown Dolomite; in the White Pine Mountains, Lumsden (1964, p. 64) described a possible disconformity with an overlying discontinuous 6 foot (2 m) thick purple sandstone representing a probable channel-fill unit. In the Egan Range, an unconformity is indicated by the upper surface of the formation, which exhibits several feet of relief (Kellogg, 1963, p. 695). In the Pancake and Reveille Ranges, several workers have noted quartzose sandy dolomite at the top of the dolomites believed to be equivalent to the Laketown Dolomite and have indicated an unconformity there (Ekren, Rogers, and Dixon, 1972b, Quinlivan and others, 1974). Not enough work was done in the Grant and Quinn Canyon Ranges to establish irrefutably the nature of the basal and upper contacts. Indications are, however, that beds adjacent to the contacts appear to be concordant where not faulted, such as near Big Creek and Sawmill Canyons, Quinn Canyon Range. Hyde and Huttrer (1970, p. 512) stated that the contact with the overlying Sevy Dolomite is gradational where observed in the central Grant Range south of Blue Eagle Mountain. Kirkpatrick (1960, p. 20–25) also preferred to consider the lower and upper contacts as conformable and seemingly gradational north of Blue Eagle Mountain. However, the presence of a widespread unconformity at the top of the formation, as described by Osmond (1954, p. 1916), readily explains the great discrepancies in the thickness of the Laketown Dolomite at different localities in the Grant and Quinn Canyon Ranges, such as at Heath Canyon and in the hills north of Sherwood Wash (Grant Range), where the strata are anomalously thin. But until we exclude the possibility that the contacts at the latter localities are not faulted, any interpretation remains open to challenge.

The Silurian of the Reveille section merits special mention because it appears to be more like the Silurian of the Pancake and the more easterly ranges. Assignment to the Laketown Dolomite of the predominantly dolomitic sequence would seem logical. Probable time correlatives of the 1500-foot (457-m)-thick undifferentiated dolomites (pl. A1) of the Reveille section include the Roberts Mountains Formation for the lower one-third (550+ ft or 168+ m) and the Lone Mountain Dolomite for the upper two-thirds (950 ft or 290 m) (Ekren, Rogers, and Dixon, 1972b).

The Lone Mountain Dolomite at Tybo Canyon in the Hot Creek Range was originally described as lying unconformably on discontinuous lenses of the Eureka Quartzite and, where the Eureka was absent, on the Pogonip Group (Ferguson, 1933, p. 20). H. E. Cook (1966, p. 21–22) later presented supportive evidence for this erosional interval (see the section of this bulletin on Ordovician System—Eureka Quartzite). Our work and that of others (Quinlivan and Rogers, 1970), however, indicates that, except where faulted, a normal succession of Hanson Creek Formation, Roberts Mountains Formation equivalent, and Lone Mountain Dolomite occurs above the Eureka. This normal succession appears

to continue farther north as well, and the lower contact of the Lone Mountain Dolomite or equivalent strata is conformable, if not gradational, with the older carbonate units and cannot mark a major unconformity such as that proposed by Ferguson and Cook. The confusion of earlier workers concerning the nature of the lower contact of the Lone Mountain in the Hot Creek Range was probably caused by the local similarity of the Lone Mountain Dolomite, Roberts Mountains Formation, and Hanson Creek Formation, as well as by a possible unconformity at the top of the Hanson Creek and by numerous faults. Scattered quartz sand near the top of the Lone Mountain in the Hot Creek Range (Quinlivan and Rogers, 1970, p. 8) seems to have its counterpart at similar horizons in the Lone Mountain Dolomite at Lone Mountain west of Eureka. The widespread sand distribution may have considerable significance and may be comparable to previously described quartz sandstone just above the Laketown Dolomite farther east. There the sandstone is considered to mark an unconformity at the top of the Laketown, whose upper part has been shown to be laterally equivalent to the upper Lone Mountain (see below).

On the basis of the occurrences in both formations of *Howellella*-like brachiopods, Merriam (1963, p. 41) proposed that the upper part of the Lone Mountain Dolomite at Antelope Valley was, in part, laterally equivalent to the upper part of the Laketown Dolomite. Later, Merriam (1973a, fig. 7, p. 16) strengthened this correlation by describing a biofacies in the upper Lone Mountain and Laketown characterized by the rugose coral *Entelophyllum* and the brachiopod *Howellella pauciplicata*. Merriam (1973a, p. 16) also stated that complete time-stratigraphic equivalence of the formations has not yet been established by paleontological evidence. Faunal control is incomplete for rigorously dating the Laketown and Lone Mountain Dolomites, because fossils are sparse and poorly preserved. The Laketown, however, is now considered to include beds at least as old as Early Silurian and certainly as young as Late Silurian and probably as young as earliest Devonian. Fossils are not abundant, especially in the upper part of the formation, but numerous corals have been reported locally, particularly in the Egan Range (Kellogg, 1963, p. 695) and in the White Pine Mountains (Lumsden, 1964, p. 64). At the latter place, the most fossiliferous part was the lower of three members, which contained *Halysites* sp., orthid brachiopods (*Resserella*?), pentamerid brachiopods (*Gypidula*?), *Virgiana* sp., zaphrentid corals, and *Synaptophyllum*(?) sp. The upper member contains *Favosites* sp., orthid brachiopods, and crinoid columnals, the latter being abundant in scattered zones throughout much of the formation everywhere in northern Nye County. A collection made by A. J. Boucot and A. D. Ptacek from the Laketown of the Horse Range contained *Virgiana* sp. and an indeterminate rhynchonellid(?) and was assigned to the *Virgiana* zone of middle Llandoverian (Early Silurian) age, which is about at the Albionian and Niagaran Series boundary (A. J. Boucot, oral commun., Oct. 12, 1967). A major study of the rugose corals by Merriam (1973a, p. 20) gave some precise ages for some of the Laketown sections outside Nye County: corals representative of Silurian coral zone A (late Llandoverian or late Early Silurian) were found in an isolated fault block of the Laketown in the Confusion Range. Also, the brachiopod *Howellella pauciplicata* from the upper part of the formation in the Confusion Range is tied into the Ludlovian high Silurian coral zones D and E of Merriam (1973a, p. 16, 21, and 25), and possibly supportive evidence is provided by the dasycladacean alga *Verticillopora*, which occurs within a few hundred feet stratigraphically below (Merriam, 1973a, p. 21, 25). Silurian coral zone E of Merriam, mentioned above, should be considered Early Devonian, according to studies in the Toquima Range (McKee, 1976, p. 17). McKee cites McLaren's (1970) comments on the Committee on the Silurian-Devonian Boundary and their choice of the Silurian-Devonian boundary at the base of the *Monograptus uniformis* zone. The upper, generally finer grained and locally better layered part of the massive, poorly bedded dolomites that we consider part of the Laketown Dolomite in the Pancake and Reveille Ranges are viewed by some as Devonian (Ekren, Rogers, and Dixon, 1972b; Quinlivan and others, 1974).

The Lone Mountain Dolomite is now generally considered to be largely the lateral equivalent of the Roberts Mountains Formation (Merriam, 1973b, p. 16), but the age of the strata is a matter of controversy. Merriam (1973a, p. 13–16; 1973b, p. 15–17) assigned a Silurian age to the formation on the basis of a coralline fauna and regional stratigraphic relations, whereas other geologists have indicated that a considerable part of the formation is Devonian. The latter assignment was discussed by Johnson and others (1967, p. 685, fig. 3), who indicated that not only is the Lone Mountain Dolomite in the northern Roberts Mountains partly equivalent to and partly overlying the Roberts Mountains Formation (which they date as Silurian and Devonian) but it is also partly equivalent to the Windmill and Rabbit Hill Limestones. They assign these limestones to the Siegenian (Lower, but not lowest Devonian) on the basis of graptolite and brachiopod studies. Poole and others (1967, columns 3 through 6 of fig. 2a, and fig. 2b) also presented data indicating a time equivalence of part of the Lone Mountain and Sevy Dolomites.

Devonian System

Two different formal nomenclatural schemes are used for Devonian strata in northern Nye County (fig. A26); one, derived from the Gold Hill mining district of western Utah, is largely restricted to the eastern part of the mapped region in the Egan, Golden Gate, Grant, Horse, Seaman, Quinn Canyon, and the White Pine Ranges (outcrop area 1 in fig. A26). Another formal nomenclature, that derived from the Eureka area, Nevada, is generally used in and west of Railroad Valley in northern Nye County (outcrop areas 2 and 3 in fig. A26) including the Fish Creek, Hot Creek, Monitor, Pancake, Park, and Reveille Ranges. The name Cockalorum Wash Formation is applied locally within

the Fish Creek and Hot Creek Ranges, and several informal names are used in the Toquima Range farther west (see the section of this bulletin on Devonian System—McMonnigal and Tor Limestones). Elsewhere and locally within the mapped region, the Devonian strata are not formally defined (see limestone, limestone and shale, and chert, pl. A1) or are left undifferentiated and are variously combined with Ordovician and (or) Silurian rocks. Units of Devonian and Mississippian age, such as the Eleana Formation and the Pilot Shale, are described in the section of this bulletin on Devonian and Mississippian Systems. The Gold Hill terminology (established by Nolan [1935a]), which includes the Sevy Dolomite, Simonson Dolomite, and the Guilmette Limestone, in ascending order, is described first below. Some workers (Osmond, 1962, p. 2034) would extend portions of this terminology westward into the Eureka area, but we feel that such a practice would lead to confusion because the Eureka nomenclature is already well established. The Eureka terminology, established first in a restricted form by Merriam (1940, p. 14) and later elaborated upon by Nolan and others (1956, p. 40–52), includes the Nevada Formation and the overlying Devils Gate Limestone and is described later on.

Three gross facies of Devonian rocks are recognized in northern Nye County. One of the facies is confined to widely distributed shelf and nearshore deposits in the eastern half of the region and is commonly referred to as the eastern carbonate assemblage. This facies consists mostly of thick units of limestone and dolomite containing an abundant shelly fauna, and the Gold Hill or Eureka terminology is applied to these rocks. In the second facies, a transitional one found locally in and west of the Hot Creek Range, shelly faunas are not as widespread and carbonate units are generally more evenly and thinly layered throughout. Some units even consist of dark siliceous argillite (chert) interbedded with limestone, such as near Warm Springs. Strata of this facies are variously mapped (pl. A1) chiefly as either Cockalorum Wash Formation or undifferentiated Ordovician, Silurian, and Devonian rocks (dolomite and limestone, undivided). A third facies containing abundant chert is recognized farther west and is clearly related to the siliceous and volcanic assemblage rocks of what is commonly regarded as the eugeosynclinal environment. F. G. Poole (oral commun., 1974) has noted such chert in the Toquima Range. The eugeosynclinal rocks (chert, pl. A1) and probably even some of the transitional rocks (Cockalorum Wash Formation, pl. A1) are allochthonous; that is, beds transported to their present position from a more westerly depositional site.

SEVY DOLOMITE

Introduction

The Sevy Dolomite has been described in detail by Osmond (1954, p. 1914–1931; 1962) and Nolan (1935a, p. 18–19). Nolan named the formation for outcrops in the Gold Hill mining district, west-central Utah.

Lithology

The Sevy consists of unfossiliferous, olive-gray, dense aphanitic dolomite that typically weathers to yellowish gray and very light gray. Fresh gray rock may exhibit a faint pinkish cast. The rock is laminated to very thin bedded, but stratification is not readily visible except locally on weathered surfaces. The unit forms steep ledgy slopes caused by a slabby to locally blocky splitting quality. Sedimentary structures such as cross stratification and breccias are common locally, but outcrops of the main part of the formation impart a sense of overall sameness to the beds. In the Quinn Canyon Range the monotonous homogeneity of the main part of the formation is broken near the base by locally interbedded darker and (or) coarser grained beds. A pale-brown-weathering quartz sandstone is widespread in the uppermost part of the formation, as defined by most workers, and it is locally underlain by a locally calcitic and cherty argillaceous dolomite member. The capping sandstone, informally known throughout the region as the Sevy sand, was redesignated by Osmond (1954, p. 1918–1926; 1962, p. 2038–2048) as the sandy member of the Sevy. Despite its thinness, it is amazingly persistent; it extends throughout much of the Egan and Golden Gate Ranges but is discontinuous in the Grant Range. The member has been mapped locally in the Quinn Canyon Range by Sainsbury and Kleinhampl (1969, pl. 1). An equivalent sandstone unit, mapped with the Nevada Formation, crops out in the Pancake Range several miles west of Lockes Station. The member and its equivalents range in thickness from a wedge edge to about 175 feet (53 m). A thickness of 65 feet (20 m) at Blue Eagle Mountain may be a maximum for the Grant and Quinn Canyon Ranges, and commonly the member attains a thickness of only a few tens of feet in the mapped region (Osmond, 1962, fig. 9, table 1). The great thickness (175 ft or 54 m) of the sandy member equivalent in the Pancake Range measured by Quinlivan and others (1974) consists of interbedded sandstone (quartzite) and dolomite with quartzite predominant in the basal 20–60 feet (6–18 m); Osmond's (1962, fig. 9, table 1) greater than 90-foot (27-m) thickness probably represents only the more quartzitic part of the 175-foot (54-m) thickness.

The argillitic, locally calcareous and cherty dolomite unit lying just beneath the capping sandy member of the Sevy is termed the "cherty argillaceous dolomite member" by Osmond (1954, p. 1918; 1962, p. 2036–2038, table 1), who first described it. The member is of more local extent than the sandy member and does not form especially distinctive outcrops but generally weathers to orangish or a somewhat more yellowish gray than the main dolomitic part of the Sevy Dolomite and equivalent rocks. We accept the view expressed by Osmond (1962, p. 2038) that his cherty argillaceous dolomite member represents an incursion of the sea eastward onto the dolomite of the Sevy that was being deposited in a mudflat (sabkha) environment. We recognized the member near the fluorspar prospects of the Sawmill Canyon area, Quinn Canyon Range, where it is about 10–20 feet (3–6 m) thick. Chert that occurs in the member in some areas in Lincoln County (Osmond, 1954, p. 1918)

appears to be absent near Sawmill Canyon. In the Pancake Range, however, chert is conspicuous and forms a reddish-weathering unit comparable to one in the Worthington Range of Lincoln County. The member was not recognized by Osmond (1962, table 1) 5 miles (8 km) north of Sawmill Canyon near the Bordoli Ranch at Blue Mountain, however, where he measured a thickness of 38 feet (12 m) for the sandy member. In the Pancake Range several miles west of Lockes Station in a major north-elongate fault block, rocks equivalent to the cherty argillaceous member are about 130 feet (40 m) thick and are underlain by a 25-foot (8-m)-thick unit of quartz silty and sandy carbonate strata. Basal beds of the 130-foot (40-m)-thick unit in the Pancake Range contain spirifers and coral fragments; these spirifers are the only fossils, other than corals, collected from the Sevy in northern Nye County. Quinlivan and others (1974) assigned the 130-foot (40-m)-thick unit to the Nevada Formation and the 25-foot (8-m)-thick unit to an underlying unnamed Silurian and Devonian unit, whereas we mapped both units with the Nevada Formation (pl. A1), or, in some cases, with undifferentiated Silurian and Devonian dolomites (dolomite and limestone, undivided, pl. A1).

It is plain that Osmond's (1962, table 1) definition of the cherty argillaceous dolomite member is different locally from our usage because he tentatively assigned to it only part of a 90-foot (27-m) unit in the Pancake Range. He stated that the same member is 800 feet (244 m) thick at Hot Creek Canyon in the Hot Creek Range, but an assignment of such a great thickness must be doubted, especially as the carbonates at Hot Creek Canyon are generally coarser grained and more dolomitic and cliffy than the typical cherty argillaceous member of the Sevy. In addition, Osmond stated that the unit is 220 feet (67 m) thick in the Reveille Range, but we do not recognize the member there. Ekren, Rogers, and Dixon (1972b), in a detailed study at Reveille, used an informal terminology and tentatively correlated their units with the Devonian section at Eureka. They described 2–3 feet (1 m) of quartzose dolomite capping about 265 feet (81 m) of dolomite just beneath the Nevada Formation that could represent the sandy and cherty argillaceous members, respectively, of the Sevy.

Distribution and Thickness

The Sevy is well developed and widely distributed in the eastern part of the county westward to the Pancake Range. In and west of the Pancakes, the Eureka terminology is used for Devonian strata, and beds equivalent to the Sevy are included in the Nevada Formation. The Sevy is generally about 500–1000 feet thick (152–305 m) thick. Ptacek (1962, p. 31) reported 885 feet (261 m) in the Horse Range. Other thicknesses include 700–1000 feet (213–305 m) and 500 feet (152 m) in the northern and southern Grant Ranges, respectively (Moores and others, 1968, p. 1708; Cebull, 1970, fig. 3), and about 1100 feet (335 m) in the southern White Pine Mountains and northern Horse Range area (Lumsden, 1964, p. 66–67). Osmond (1954, fig. 1; 1962, fig. 19, table 1) obtained somewhat different thicknesses in these areas, apparently because he placed contacts (especially the basal one) at different positions than other authors.

Contacts and Age

Considerable evidence for a regional unconformity at the base of the Sevy Dolomite in eastern Nevada and western Utah has been presented by numerous workers and summarized by Osmond (1962, p. 2034). The basal contact in northern Nye County was chosen at the generally abrupt change from medium- to coarse-grained blotchy and vaguely banded dolomite below to aphanitic, more homogeneous, light-gray-weathering dolomite above. This contact was described in more detail with the section of this bulletin on Silurian and Devonian Systems—Lone Mountain and Laketown Dolomites. The upper contact of the Sevy in the mapped region was placed at the top of the thin brown sandy dolomite member of the Sevy of Osmond, and where that member is absent, at the generally abrupt change from aphanitic light-gray-weathering dolomite up into noticeably coarser grained tan or darker gray dolomite of the Simonson Dolomite (Osmond, 1962, p. 2048). Sevy-like beds may alternate with the coarser grained dolomites in the lower part of the Simonson.

The Sevy Dolomite lies above Middle and Upper Silurian strata and below the Middle Devonian Simonson Dolomite. Fossils are rare in the formation and are found in northern Nye County only in the equivalent to the basal beds of the cherty argillaceous dolomite member of Osmond. Those fossils from strata correlative to this member near Lockes Station in the Pancake Range are considered to represent the Emsian Stage (high Lower Devonian).

Osmond (1962, p. 2048–2049) summarized regional faunal evidence for the age of the Sevy and concluded that most of the formation is Early Devonian, with the upper part (sandy member of Osmond) possibly Middle Devonian. Another interpretation by Poole and others (1967, figs. 2a, 2b) suggested that the formation includes Ludlovian (Upper Silurian) and Emsian (Lower Devonian) in some areas and thus is largely coeval with the Lone Mountain Dolomite. The Sevy, as used in this bulletin and probably as used by Osmond and other workers in eastern Nevada (Tschanz and Pampeyan, 1970, p. 32–34; Hose and Blake, 1976), is the time equivalent of the Beacon Peak Dolomite Member (Lower Devonian) and Oxyoke Canyon Sandstone Member (Lower and Middle Devonian) of the Nevada Formation.

SIMONSON DOLOMITE

Introduction

Osmond (1954, p. 1931–1954) made a careful regional study of the Simonson Dolomite and extended the formation from its type locality in the Gold Hill mining district, western Utah, to the Grant Range (Nolan,

1935, p. 19–20). Other Nevada workers who have studied the formation include Kellogg (1963, p. 696, 698) in the Egan Range, Lumsden (1964, p. 70–73) in the White Pine Mountains, Tschanz and Pampeyan (1970, p. 34–36) in Lincoln County, and Hose and Blake (1976) in White Pine County.

Lithology

Abundant, evenly and well-bedded dolomite composes the bulk of the Simonson Dolomite. Much of the formation weathers to characteristically prominent, light- and dark-gray to brown and dark-brown, broadly striped dolomite that forms broken cliffs and steep stepped slopes. Close inspection reveals that some of the darker beds have mottled rather than banded colors. The lighter hued interbeds in many cases resemble the dolomite of the Sevy. Chocolate-brown beds are common above the basal part of the formation, which is commonly gray to tan. Many of the darker hued beds carry abundant disseminated masses of white-weathering fossil corals whose forms resemble spaghetti and are widely known as spaghetti beds. They are very distinctive in the Simonson but not restricted to the formation, being also present in the overlying Guilmette Formation. The dolomites of the formation are aphanitic or very fine to coarse grained, the coarser grained material being prevalent in the lower part of the formation and in the beds of darker hue in the overlying section. Strata are laminated to thick bedded, and the rocks exhibit a slabby to blocky splitting quality. The different colored bands and their repetition reflect variations in texture, mineral composition, chemical state, and cyclic changes in the depositional environment. The brown coloration, for example, is caused by bitumen that amounts to 3%–5% by volume of the brown beds (Osmond, 1954, p. 1954).

Calcareous strata are rare in most of the formation and are somewhat more abundant in the upper part. In the southern Egan and Pahranagat Ranges, Tschanz and Pampeyan (1970, p. 34–35) assigned 50 feet (15 m) of limestone to the uppermost part of the Simonson, presumably because the limestone contains the key brachiopod *Stringocephalus*. Osmond (1954, p. 1946) stated that generally limestone in the formation increases in quantity northwestward and appears lower in the section. In northern Nye County, beds equivalent to the Simonson contain large amounts of limestone west of Railroad Valley, where the name "Nevada" is used instead of "Simonson."

Generally poorly developed quartz sandy zones occur locally in the Simonson; such a zone occurs in the southern Egan Range, where quartz sandy dolomite lies in the basal part of the formation (Kellogg, 1963, pl. 1). Other rock types noted locally include a biostromal member and minor intraformational conglomerate. Penecontemporaneously deformed layers are common in the Simonson and are best seen in contrastingly colored layers (Osmond, 1956, p. 36–39). Fossils are much more abundant than in the underlying Sevy Dolomite. The formation was not subdivided for the present map, but four members were described in eastern Nevada by Osmond (1954, p. 1931). These include, from lowest to highest, (1) a coarse member (tan coarse-crystalline dolomite), (2) a lower alternating member (alternating brown and gray dolomite with an overall striped appearance), (3) a brown cliff member (dolomite biostrome—see also Reso, 1963, p. 909), and (4) an upper alternating member (similar to the lower alternating member but thicker bedded). In some sections, the members are subequal in thickness and in others the alternating units (2) and (4) predominate. Kellogg (1963, p. 696) readily recognized all four members in the southern Egan Range, and they may well extend into the Golden Gate and Seaman Ranges. However, in the White Pine Mountains, the brown cliff member is absent (Lumsden, 1964, p. 70), and the distinction between members was not everywhere obvious in the southern Grant Range, where the Simonson commonly forms massive cliffs of recrystallized, locally shattered and recemented dolomite. Beds equivalent to the Simonson in the Pancake and Reveille Ranges are mapped with the Nevada Formation or are not differentiated from other lower Paleozoic strata.

The lower and upper contacts of the Simonson Dolomite are conformable. The lower contact is sharp, with the aphanitic light-gray-weathering dolomite of the Sevy below and coarser grained, generally darker tan or gray dolomite above. We accept the upper contact defined by Tschanz and Pampeyan (1970, p. 35). This contact is at the base of the yellow bed—a fairly prominent yellowish-gray, nonresistant, argillaceous to silty, thin-bedded to platy dolomite that overlies the more typically resistant striped gray dolomites of the Simonson. This zone contains abundant limestone locally, especially in western exposures, but the contact proved to be easily mappable as far west as the Grant Range, where the yellow zone becomes discontinuous and diffuse and is difficult to trace along outcrops. Where these difficulties appeared, the contact was placed at the change from blocky gray and brown dolomites below to gray limestones above that commonly are very thinly bedded and form cliffs.

Distribution and Thickness

The Simonson Dolomite is recognized in all the ranges east of Railroad Valley, and equivalent strata are recognized as far west as the Pancake Range. In the latter area, the strata equivalent to the Simonson are included in the Nevada Formation. The Simonson is approximately coextensive with the underlying Sevy Dolomite and overlying Guilmette Formation. The formation is thickest, and anomalously so, in the southern Grant Range, where Cebull (1967, p. 68; 1970, p. 1831) estimated a minimum thickness of 2000 feet (610 m), a thickness that could be caused by repetition of beds by faulting. The Simonson thins northward to about 700 feet (213 m) in the central Grant Range, 800–1000 feet (244–305 m) in the northern Grant Range and vicinity, and 659 feet (201 m) just north of the county at Blackrock Canyon, White Pine Mountains (Hyde and Huttrer, 1970, fig. 2; Moores and others, 1968, p. 1708; and Lumsden, 1964, p. 234–235, respectively). Ptacek (1962, p. 33) measured 1260 feet (384 m) in the Horse

Range. An unmeasured section of Simonson in the Seaman Range may be similar in thickness to the section in the south Egan Range—1061-1168 feet (323-356 m) as measured in seven sections by Kellogg and Osmond (Kellogg, 1963, p. 696). In the Pancake Range, the Simonson equivalent west of Lockes Station and near Portuguese Mountain is 1145 feet (349 m) thick (Quinlivan and others, 1974), and southward in the Reveille Range is greater than 650 feet (198 m) thick in an incomplete section, according to Ekren, Rogers, and Dixon (1973).

Age

Diagnostic Middle Devonian fossils occur in the Simonson Dolomite in a few areas (Osmond, 1954, p. 1950-1951; Poole and others, 1967, fig. 2; Tschanz and Pampeyan, 1970, p. 35-36; Langenheim and Larson, 1973; Kellogg, 1963, p. 696, 698). The formation contains a fauna of the *Stringocephalus* zone (Merriam, 1940, p. 9, 58-59) that marks the top of the Middle Devonian (Givetian) (Merriam, 1963, p. 47, 49; Poole and others, 1967, p. 901-902. This zone was used by some workers to demarcate the uppermost part of the formation in eastern Nevada (Nolan, 1935a, p. 20; Reso, 1963, p. 909; Tschanz and Pampeyan, 1970, p. 34-35). Others (Osmond, 1954, p. 1951; Lumsden, 1964, p. 72-74; C. W. Merriam, *in* Tschanz and Pampeyan, 1970, p. 36) indicate that *Stringocephalus* either extends into the basal overlying Guilmette Formation or is restricted to the Guilmette. The depauperate fauna of the zone is characterized by *Stringocephalus* sp., a brachiopod that is abundant in the Simonson in areas in and east of the Egan Range. It was also reported at Blue Eagle Mountain in the Grant Range (Osmond, 1954, p. 1950-1951) but not elsewhere in the range. Other fossils in the *Stringocephalus* zone are the small rod-shaped coral *Cladopora* and stromatoporoids in cabbage-size heads. In general, the Simonson fauna is poorly preserved and recrystallized (dolomitized). The fauna of the older Middle Devonian (Eifelian) *Pinyonensis* zone was not recognized in the Simonson of northern Nye County, but strata of this age occur in the middle or lower part of the formation.

The Middle Devonian age of the Simonson, its lithology, and its stratigraphic position above the Lower Devonian Sevy Dolomite and below the Upper Devonian Guilmette Formation provide the basis for correlating the formation with the interval of the Nevada Formation encompassed by the Sentinel Mountain Dolomite and Bay State Dolomite Members. The limestone facies of the Nevada represented by the Woodpecker Limestone Member is absent from that part of northern Nye County underlain by the Simonson Dolomite.

GUILMETTE FORMATION

Introduction

The earliest published maps showing the Guilmette Formation in northern Nye County include Kellogg's (1960, pl. 1) map of the southern Egan Range and McJannett's (1960) map of east-central Nevada. Nolan (1935a, p. 20-21) defined the Guilmette in western Utah, and other workers noted this distinctive dolomite and limestone unit in eastern Nevada as far west as the longitude of the Grant Range (Langenheim and others, 1960, p. 65 and fig. 3; Kirkpatrick, 1960b; Moores and others, 1968, p. 1708; Kellogg, 1963, p. 698-700; Lumsden, 1964, p. 73-78. Tschanz and Pampeyan (1970, p. 36-42) and Hose and Blake (1976) give the most recent summaries of the pertinent stratigraphy of the formation in eastern Nevada. Several other reports giving useful descriptions of the Guilmette in part of the Grant Range and the Horse Range include the works of Kirkpatrick (1960a, p. 31-34), Wire (1961, p. 57-67), Ptacek (1962, p. 35-37), Huttrer (1963, p. 26-28), and Hyde (1963, p. 25-29). All of these reports on the geology of Nye County have been used to some degree in the following summarized description of the Guilmette.

Lithology

Limestone and dolomitic limestone containing thin layers of argillaceous and fine silty material compose much of the Guilmette Formation in northern Nye County. These rocks constitute a northern extension of the limestone facies of the Guilmette that was described by Tschanz and Pampeyan (1970, p. 37) in Lincoln County. The formation in northern Nye County, particularly in its western exposures, thus differs considerably from the predominantly dolomitic Guilmette in its type area. Dolomite interbeds are, however, common locally in Nye County, particularly in the lower and upper parts of the formation in the White Pine Range (Lumsden, 1964, p. 74-75) and central Grant Range (Hyde, 1963, p. 25, 28). Quartz sandy zones and sandstone beds with rounded fine grains are also present locally, such as in the top 500 feet (152 m) of the formation in the southern White Pine Range (Lumsden, 1964, p. 75) and in the upper part of the formation in the Seaman Range (Tschanz and Pampeyan, 1970, p. 37). In the Egan Range, limestone of the Guilmette grades southward into dolomite, and near Sunnyside and Gap Mountain, an upper member defined by Kellogg (1963, p. 698, table 5) is more than 50% dolomite. Limestone is more prevalent farther west, especially in the Golden Gate, Grant, and Horse Ranges, and dolomite in the latter two ranges is generally confined to the basal and upper parts of the formation and is interbedded with limestone. The lower dolomites lithologically resemble those of the Simonson Dolomite, unlike the upper dolomites, which tend to weather brown and are associated with silty and sandy beds as well as subordinate limestone. The Guilmette typically weathers to light-grayish cliffs and steep slopes, with the cliffy exposures predominant and especially notable in the upper part of the formation. A yellowish-weathering, locally tan, nonresistant, thin-bedded, argillaceous to silty limestone and dolomite unit, commonly about 60-80 feet (18-24 m) thick, marks the lowest part of the formation throughout much of the mapped region (see the section of this bulletin on Devonian System—Simonson Dolomite contact relations). It is locally absent from the

westernmost exposures of the formation or so diffuse as not to be useful for mapping purposes. The zone is also widely distributed in Lincoln County, where it is dominantly dolomitic and was first mapped and noted by Kellogg (1963, p. 192) and Tschanz (1960, p. 202), who termed it the "yellow bed."

The basal contact of the Guilmette is conformable, generally relatively sharp to abruptly gradational, and, except near Currant, readily mapped. It is best defined in northern Nye County and seemingly also in Lincoln County at the horizon where the gray-striped dolomites of the underlying Simonson Dolomite give way to limestones or the yellow-bed zone of the Guilmette. Where the latter zone was not recognized, the contact was placed in most areas below the lowest gray limestone, which commonly forms very thin bedded low cliffy ledges and on fresh surfaces is generally darker gray than most of the higher limestones in the formation. Choosing the lower contact of the Guilmette presents special problems in the southern White Pine Mountains and Currant area. In the White Pine Mountains, the lower 200 feet (61 m) of the Guilmette as mapped by Lumsden (1964, p. 71–74, 235–236) consists of alternating zones of thinly bedded partly silty limestone and dolomite with a 50-foot (15-m) tan calcareous siltstone at the base. These strata could not readily be correlated with the previously described yellow-bed zone.

Weathered surfaces of the more massive beds in the Guilmette are generally pock-marked and pitted and weather to mottled yellowish, tan, and gray. Where dolomitic in the upper part of the formation or very silty and sandy, the strata weather brown, such as locally in the upper several hundred feet (more than 100 m) of section in the Grant, Horse, and White Pine Ranges (Ptacek, 1962, p. 37; Hyde, 1963, p. 28; and Lumsden, 1964, p. 75). Parallel regular layering of slabby to massive character is typical, and platy to flaggy zones are less common than in the lower part of the formation. Stratification thickness generally corresponds to the splitting quality. Minor wavy and graded bedding is also found in the formation. Nodular and crinkly weathering limestones are present locally, as is sparse brown chert in irregular lenses and nodules. Compared to the weathered rock, the fresh rock is the same color or darker gray, and the more thinly split and bedded strata tend to be somewhat darker gray than the other beds. The limestone and dolomite tend to be very fine to medium grained, and many beds consist of subangular to rounded carbonate grains. Very broad lenticular zones of well-cemented intraformational limestone breccia, as much as 300 feet (91 m) thick and commonly about 20–50 feet (6–15 m) thick, are scattered prominently throughout the formation. They are distinctive even from a distance because their white calcite matrix starkly contrasts with the enclosed fragments and limestones of the adjacent beds. The breccias commonly have been prospected, but in spite of their prominent coloration and apparent mineralization, exploration of the breccias is apparently no more warranted than is exploration of other parts of the formation, except possibly where cross faults are suspected. Many of these are probably solution breccias.

The upper contact of the Guilmette was taken at the sharp change from relatively massive cliffy limestone below to thinly bedded limestone and black shales in the Pilot Shale above. Where the Pilot is absent from parts of the Grant, Horse, Quinn Canyon, and the southern White Pine Ranges, the upper contact of the Guilmette is placed above either massive cliffy limestone or less cliffy, thin-bedded limestone and below the massive Mississippian Joana Limestone that commonly contains abundant white nodular and lenticular chert. Where the Pilot is present, its talus commonly obscures the contact with the Guilmette. In these places, the contact is approximated by the top of the highest massive cliffy limestone, above which the Pilot forms a steep slope.

Tschanz and Pampeyan (1970, p. 37) and earlier workers, particularly Kellogg (1963, pl. 2), recognize that pre-Mississippian erosion caused the westward thinning and wedging out of young Devonian rocks (including rocks containing the *Cyrtospirifer* zone fauna) across northern Lincoln County. This unconformity is probably the same as that shown by Kellogg (1963, pl. 2) in Nye County within the Pilot Shale at Gap Mountain and between the Guilmette and Joana Limestone at Currant Creek. Other workers relate the absence of the entire Pilot Shale over most of the Grant, Horse, and White Pine Ranges (Wire, 1961, p. 61; Hyde, 1963, p. 30; Hyde and Huttrer, 1970, p. 513) to erosion along this unconformity. We believe, following Lumsden (1964, p. 79), that the absence of the Pilot in these ranges is due to faulting. The contact of the Guilmette with the overlying Joana Limestone is interpreted to be a bedding-plane fault along which the less competent Pilot Shale was largely eliminated. Lumsden (1964, p. 75) noted thick zones of extensively silicified and brecciated Guilmette near outcrops of the Joana Limestone, and Ptacek (1962, p. 39) confirmed a fault between the two formations in the Horse Range.

Distribution and Thickness

The Guilmette Formation crops out extensively in the mountains east of Railroad Valley. Equivalent rocks extend farther west to the Hot Creek Range and possibly into the Monitor Range as well. The Guilmette is one of the thickest and most extensive formations in the eastern part of the mapped region. Kellogg (1963, pl. 1) measured 1818–2568 feet (554–783 m) in the southern Egan Range; Ptacek (1962, p. 36) measured 1900 feet (579 m) in the Horse Range, and Moores and others (1968, p. 1708) measured 2000 feet (610 m) in the northern Grant Range. Adjacent to Nye County at Blackrock Canyon in the southern White Pine Range, Lumsden (1964, p. 79, 239) measured 2410 feet (735 m) in an incomplete section. Unmeasured sections in the Quinn Canyon, Golden Gate, and Seaman Ranges probably have thicknesses comparable to those just cited.

Age

The Guilmette Formation is assigned to the early Late Devonian (Frasnian of Europe or Senecan of North America) on regional correlation charts (Langenheim

and Larson, 1973), whereas in Lincoln County, Tschanz and Pampeyan (1973, p. 40, fig. 13) considered the age of the formation to be Middle as well as Late Devonian. The latter authors credited Kellogg (1960, 1963) and Reso (1963) with a sustaining view; however, this view is in part contradicted by Reso (1963, p. 910), who stated that a large fauna from the formation is entirely early Late Devonian.

The Guilmette contains a widespread Late Devonian (Frasnian) fauna, and most geologists report a *Stringocephalus* fauna of Middle Devonian (Givetian) age in the lowermost part of the formation in northern Nye County (Wire, 1961, p. 62; Huttrer, 1963, p. 27; Hyde, 1963, p. 29; Lumsden, 1964, p. 73–74). Osmond (1954, p. 1950–1951), however, reports *Stringocephalus* in the directly underlying Simonson Formation at Blue Eagle Mountain, Grant Range.

The fauna of the *Stringocephalus* zone is characterized by the medium to large brachiopod *Stringocephalus*, which is commonly so poorly preserved as to be identifiable mainly from cross sections in the outcrop where the shell is replaced by secondary carbonates. The zone appears to be very thin—less than 20 feet (6 m) at the Blue Eagle Mountain locality (Osmond, 1954, p. 1950). Huttrer found *Stringocephalus* in the central Grant Range about 100 feet (30 m) above the base of the Guilmette. Lumsden (1964, p. 73–74) described an 8-foot (2-m)-thick *Stringocephalus* zone 200 feet (61 m) above the base of the Guilmette in the southern White Pine Range, and from his description the zone appears to lie somewhat above the top of the previously described yellow-bed interval but no more than about 150 feet (46 m) above. The 200-foot (61-m)-thick unit assigned to the basal Guilmette by Lumsden (1964, p. 73–74, 76–78) contains an even older faunal zone, the *"Martinia" (Warrenella) kirki* zone of Merriam (1940, p. 56–57, table 2; 1963, p. 46–49). The *Warrenella* zone, in association with strata mapped as Guilmette, seems to extend at least as far south as Blue Eagle Mountain, Grant Range (Kirkpatrick, 1960a, p. 32–33; Wire, 1961, p. 62–64). We believe that Lumsden may have misassigned the *Warrenella*-bearing unit to the Guilmette, and that the correlation indicated for the 200 feet (60 m) of strata is with the Woodpecker Limestone Member of the Nevada Formation at Eureka. This alternative assignment of the strata to the Nevada Formation would be consistent with Humphrey's (1960, p. 28–31) usage of the Eureka terminology for the Devonian rocks in the Hamilton mining district farther north (White Pine County), where the *Warrenella* zone also occurs. Although we have used the map data of Lumsden, Kirkpatrick, and Wire (pl. A1), exclusion of the 200-foot (60-m)-thick unit with its *Warrenella* fauna would not significantly affect the map position of the lower contact of the Guilmette because of the steep terrain and the small map scale (1:250,000).

In general, the Guilmette, as used in this bulletin, is the time-rock equivalent of most of the Devils Gate Limestone, including the lower or Meister Member and the major part of the upper or Hayes Canyon Member, near Eureka, Nevada. In the western part of the mapped region, the formation probably also includes beds that are the time correlative of the Bay State Dolomite Member, the member below the Meister, in the upper part of the Nevada Formation. The local inclusion on the map of an equivalent to the Woodpecker Limestone Member, an even older member of the Nevada Formation, was previously described for the Guilmette of the Grant and White Pine Ranges.

The highest faunal zone identified in the Guilmette of northern Nye County is the *Spirifer argentarius* zone of Merriam (1940, p. 59, table 2; 1963, p. 54) and thus serves to date the formation as no younger than Senecan (Frasnian of the early Late Devonian). This faunal zone was identified in the southern Egan Range, where *S. engalmanni*, some *S. argentarius*, and mainly *Tenticospirifer utahensis* are present in it (Kellogg, 1963, p. 700). The *S. argentarius* zone was initially considered to be Middle Devonian; later, it seemingly was considered to mark the base of the Upper Devonian strata (Nolan and others, 1956, p. 51). Merriam (1963, p. 54) still later described the *S. argentarius* zone in the light of its assignment to the Frasnian (Late Devonian) by authorities in the field.

NEVADA FORMATION

Introduction

The Nevada Formation is used in the modern restricted sense of Merriam (1940, p. 14–15) and is applied to the strata above the Silurian Lone Mountain Dolomite and below the Late Devonian Devils Gate Limestone. The evolution of the nomenclature and good descriptions of the formation at major reference sections near Eureka, Nevada (Hague, 1883, p. 264–266; 1892, p. 63–68; Merriam, 1940, p. 14–16, 22–25) are further elaborated upon by Nolan and others (1956, p. 40–48) and by Merriam (1963, p. 44–49). No one has yet described the formation well in northern Nye County. A briefly described undifferentiated partial section in the Hot Creek Range (Lowell, 1957, p. 20–21) is not readily accessible in the literature, nor is the better account of the Nevada Formation by H. E. Cook (1966, p. 27–29, fig. 19). Therefore, the reader is directed to useful but concise published descriptions in U.S. Geological Survey publications (Quinlivan and others, 1974; Ekren, Hinrichs, Quinlivan, and Hoover, 1973).

We confine the terminology for the Devonian rocks developed at Eureka, Nevada, specifically the Nevada Formation and overlying Devils Gate Limestone, to a somewhat arbitrary geographic area embracing the Duckwater Hills and the Fish Creek, Hot Creek, Monitor, Pancake, and Reveille Ranges (fig. A26). Equivalent rocks farther east are referred to the Sevy, Simonson, and Guilmette Formations.

Lithology

The Nevada Formation in northern Nye County is typified by both limestone and dolomite. The carbonate strata are medium light to medium dark gray and shades of brownish-gray, with the colors commonly arranged

in alternating bands as much as several tens of feet thick and as little as several inches thick. Bedding is typically parallel and thin to thick, with very thin bedded shaly limestone and very thick bedded dolomite and some wavy beds present locally. The formation weathers mostly to slabby and massive-splitting steep ledgy slopes and cliffs, colored in alternating or continuous hues of brownish gray and light to dark shades of gray. In general the dolomites lithically resemble the Sevy and Simonson Dolomites mapped farther east. Chert is rare in the Nevada Formation and occurs in the form of dark-gray to black lenses and stringers in undivided rocks of the formation in the Pancake Range about 12 miles (19 km) southwest of Lockes Station (Ekren, Hinrichs, and Dixon, 1972) and in the Woodpecker Limestone Member in Hot Creek Canyon, Hot Creek Range (H. E. Cook, 1966, p. 28).

Lithic equivalents of the five members of the Nevada Formation originally defined near Eureka, Nevada (Nolan and others, 1956, p. 41–46) are all represented in northern Nye County, but not all were recognized at any one place, and none is differentiated on the map (pl. A1). The five members are, from oldest to youngest: (1) Beacon Peak Dolomite, a uniformly bedded light-gray-weathering dense dolomite; (2) Oxyoke Canyon Sandstone, a brown-weathering, commonly carbonate-cemented, fine- to medium-grained sandstone; (3) Sentinel Mountain Dolomite, a sequence of alternating light- and dark-gray and chocolate-brown, commonly medium- to coarse-grained dolomite; (4) Woodpecker Limestone, a thin- to medium-bedded, commonly argillaceous limestone and shaly limestone; and (5) Bay State Dolomite, a thick-bedded, generally dark-gray dolomite with zones of interbedded light-gray dolomite. Two new members, the Grays Canyon Limestone and South Hill Sandstone Members (Nolan and others, 1974), locally overlie the Beacon Peak and Sentinel Mountain Dolomite Members, respectively, near the Eureka County line.

The members of the Nevada Formation, except for the South Hill Sandstone Member, are well exposed at and near Portuguese Mountain and west of Lockes Station in the central Pancake Range. In addition, the Woodpecker Limestone Member or its equivalent is well exposed near the New Reveille mine (T2N,R51½E), Reveille Range, and about 4.5 miles (7 km) northwest of Tybo at the Outlook(?) prospect, and locally northwest of Morey Peak, in the Hot Creek Range. A faulted sliver of the member was also noted about 1500 feet (457 m) southwest of the northern summit of Rawhide Mountain in the Hot Creek Range. The Woodpecker tends to be less cliffy than other members and may locally weather to yellowish gray in contrast to more common gray hues. A tendency to weather as alternating slopes and ledges with a cyclicity of 10–50 feet (3–15 m) was noted by H. E. Cook (1966, p. 28) in Hot Creek Canyon, Hot Creek Range, and may be characteristic elsewhere. The member is easily recognized in the field by its lithologic characteristics and by fairly ubiquitous pteropods that appear on weathered rock surfaces as several-millimeter-long, slender, wedge-shaped forms (conical in three dimensions) that are darker gray and contrast with the enclosing limestone.

Quartz sandy parts of the Nevada Formation are minor volumetrically, but generally are prominent because they form cliffs weathering to light brownish and grayish colors or, where quartzitic, even white, such as in the hills in and surrounding Little Smoky Valley. At least two sandstone members, the Oxyoke Canyon Sandstone Member and the newly defined South Hill Sandstone Member, separated from the Oxyoke by the intervening Sentinel Mountain Dolomite Member, are recognized just north of Nye County in the Pinto Summit quadrangle (Eureka County) and extend into Nye County. Individual outcrops of these sandstones, especially where quartzitic, are difficult to differentiate from each other and from the Eureka Quartzite; and they may have inadvertently been mismapped because all crop out in the same area near the Eureka and Nye County border. Obscure to prominent, thin quartz silty and sandy zones are not uncommon elsewhere in the Nevada Formation. The thickest of such zones may be the one exposed in the northward-elongate block of Paleozoic rocks west of Lockes Station, where Quinlivan and others (1974) measured 175 feet (53 m), of which the basal 20–60 feet (6–18 m) is chiefly quartzite and probably correlates with Osmond's (1954, p. 1918, 1920) sandy member of the Sevy Dolomite. Calcareous fine sandstone and siltstone were also reported in the range south of Lockes Station (Ekren, Hinrichs, and Dixon, 1972). Other quartz sandy and quartzitic zones were noted in the Hot Creek Range. One such persistent zone in which quartz grains float in carbonate matrix presents a stratigraphic problem. This zone in Hot Creek Canyon composes about 15 feet (5 m) of strata in a section of massive dolomite and calcitic dolomite about 250–375 feet (76–114 m) thick. The section was assigned to the Beacon Peak Dolomite Member of the Nevada Formation by H. E. Cook (1966, p. 27–28), but that part below and including the sandy zone was correlated by W. J. Carr and H. W. Dodge, Jr. (written commun., 1974) with the Lone Mountain Dolomite and with another zone farther south at Rawhide Mountain, where Quinlivan and Rogers (1970) made the same correlation. The latter interpretation may be correct, because otherwise the Lone Mountain Dolomite would be anomalously thin in the Hot Creek Range. The evidence supporting the assignment of this sandy zone to the Nevada Formation is its stratigraphic proximity to a limestone facies of the Nevada correlating with the Woodpecker Limestone Member. The limestone lies only a few hundred feet stratigraphically above the sandy zone in Hot Creek Canyon. At Rawhide Mountain, where examined in the saddle between the twin summits of the mountain, the sandy zone is also near the Woodpecker equivalent in badly faulted ground. Here the zone is brecciated, silicified, and mineralized with partly oxidized copper, lead, and silver sulfide minerals. The same and other sandy zones crop out in faulted segments elsewhere in the range, such as on the main ridge east of North Sixmile Canyon west of the Morey mining district.

Outcrops of the Nevada Formation along the east front of the Pancake Range south of Lockes Station consist of laminated to very thick bedded, fine- to

medium-grained dolomite locally alternating with limestone in light- to dark-gray bands and, in some zones, anastomosing stringers of dark-gray to black chert that locally weathers brownish. Spaghetti beds are common here, and aside from the unusual presence of chert, the outcrops justify attention because of their brecciated and altered (silicified, iron-oxidized, and pyritized) appearance.

Contacts

The lower contact of the Nevada Formation is probably not shown everywhere at precisely the same horizon because of the difficulty of correlating beds within a sequence of somewhat similar rocks. Generally, however, the underlying cliffy, massive, fine- to medium-grained Lone Mountain Dolomite appears to pass gradationally up into somewhat darker gray, better layered, aphanitic to fine-grained dolomite that stratigraphically displays several hundred feet of a decided banded or striped appearance. A disconformable contact with the underlying Lone Mountain Dolomite is indicated, because intervening earliest Devonian (Helderbergian) beds (Rabbit Hill Limestone) are absent, except in the Monitor Range. An unconformity shown at the base of the Nevada Formation by Quinlivan and others (1974) is not the same, however, because it is within the lower Nevada as we use the name and is probably near the top of the Beacon Peak Dolomite Member equivalent.

Where overlying rocks have not been stripped away by erosion, the Nevada Formation is most commonly either faulted against younger Paleozoic or Tertiary rocks or is overlain directly by Tertiary rocks or Quaternary alluvium. In the normal succession, the Nevada is overlain by the Upper Devonian Devils Gate Limestone, and such a relation is observable at Portuguese Mountain, Pancake Range, where the contact appears to be conformable with no visible or appreciable break. In northern Nye County both the Nevada and the overlying Devils Gate Limestone contain similar units of limestone and dolomite. Therefore, in faulted incomplete sections, care must be taken not to confuse the change from a dolomite to a limestone facies of the Nevada with the dolomite to limestone transition described between the Nevada and the overlying Devils Gate Limestone in the eastern part of the Eureka mining district (Nolan and others, 1956, p. 46). Any thick section of at least several hundred feet of relatively massive, thick-bedded cliffy limestone is more likely to be Devils Gate rather than the Nevada Formation. Another source of confusion is that calcareous and dolomitic spaghetti beds commonly everywhere associated with the Nevada Formation are also locally very abundant in the Devils Gate, as at Portuguese Mountain, and may be mistaken for the Nevada Formation. The *Stringocephalus* zone, characteristic of the Simonson Dolomite and Guilmette Formation, also occurs within the Nevada Formation, and the prominence of some zones of this medium-large brachiopod serve as a guide to the upper Nevada. Quinlivan and others (1974) locally included about 100 feet (30 m) of limestone of Devils Gate lithology in the upper part of the Nevada in the Portuguese Mountain quadrangle and placed the upper contact of the Nevada at the base of a yellowish-gray silty limestone and dolomite zone in the Devils Gate. This zone, however, can easily be confused with a similar but stratigraphically higher one.

Distribution and Thickness

Excellent exposures of the Nevada Formation occur in all the ranges west of the Duckwater Hills, except for the Monitor and Park Ranges. The most complete sections are at and near Portuguese Mountain in the Pancake Range, where about 1450 feet (442 m) of Nevada Formation was described (Quinlivan and others, 1974). The Nevada is incompletely represented farther west in the Hot Creek Range, where Quinlivan and Rogers (1970) measured more than 650 feet (198 m) in the Tybo quadrangle and H. E. Cook (1966, p. 27–28) measured 975 feet (297 m) in Hot Creek Canyon. A greater thickness may be represented in the northern part of the range (northwest of Morey Peak), but the section is highly faulted there. Farther south, in the Reveille Range, a greater than 650-foot (198-m)-thick section is covered at the top (Ekren, Rogers, and Dixon, 1973). The Nevada Formation probably is concealed in the Duckwater Hills. Merriam (1963, p. 42) commented on the apparent absence from the Monitor Range of the calcareous Nevada and younger Devonian strata that he associates with the normal western Devonian sequence typified by the Lone Mountain section near Eureka. He indicated that no one has satisfactorily accounted for their apparent absence, which may have resulted from erosion, deformation, or nondeposition. As much as several hundred feet of unstudied strata near Danville Canyon and Daugherty Ranch might be assignable to the Nevada but is included with dolomite and limestone, undivided (pl. A1). Adjacent to the mapped region on the north, especially in the Antelope Range in Eureka County, the Nevada Formation is about 2400 feet (731 m) thick. Farther northeast in the Pinto Summit quadrangle, the reconstructed formation is greatly thickened to 2545–3615 feet (776–1102 m) (Nolan and others, 1974).

Age

Excellent faunal control for the age of the Nevada Formation was documented in studies at Lone Mountain and elsewhere near Eureka by Merriam (1940, p. 22–25, 52–59; 1963, p. 45–49; Nolan and others, 1956, p. 46–48). From this work, the age was established as late Early Devonian through Middle Devonian (Coblenzian through Givetian). Supporting faunal evidence has also been described in northern Nye County. In the Reveille Range, Ekren, Rogers, and Dixon (1973) mention two-hole crinoid ossicles and a conodont fauna suggestive of the Emsian (upper Coblenzian) and successively overlying faunas of the *Leptathyris circula* zone and of "...a faunal zone intermediate between the *Stringocephalus* and *Warrenella kirki* zones". In the central Pancake Range, a fauna probably representative

of the *Spirifer pinyonensis* zone (Eifelian) was reported in strata whose description (Quinlivan and others, 1974) seems to fit that of Osmond's (1954, p. 1918; 1962, p. 2036–2038) cherty argillaceous dolomite member of the Sevy Dolomite. Quinlivan and others also report finding in the upper half of the Nevada "algal heads, stromatoporoids, gastropods, and brachiopods" such as *Stringocephalus*, the latter of which marks the top of the Middle Devonian and locally can be a guide to the upper Nevada. Fossils in the Nevada Formation of the Tybo quadrangle were reported on by Quinlivan and Rogers (1970, p. 7):

> Fossils from uppermost 100 feet of formation are late Middle Devonian in age (upper *Warrenella kirki* zone to lower *Stringocephalus* zone). Fossils from 50–75 feet above base are medial Middle Devonian in age and suggest a hiatus at or near base of formation.

The Nevada Formation as mapped in the present report is considered to be the approximate time-rock correlative of the Sevy and Simonson Dolomites mapped farther east, the major difference being that the Nevada contains, besides dolomite, abundant limestone. A limestone unit as much as several hundred feet (100 m) thick in the Nevada of the Hot Creek and Reveille Ranges correlates lithologically and faunally with the Woodpecker Limestone Member of the Nevada in the section at Eureka, but this unit is not differentiated everywhere on the map (pl. A1). The pteropod *Styliolina* was identified by C. W. Merriam from collections northwest of Tybo at the Outlook(?) prospect and in Hot Creek Canyon. In addition, eurypterids occur at the latter locality.

In the central Pancake Range, Quinlivan and others (1974) divided an approximately 730-foot (222-m)-thick upper unit of Silurian and Devonian dolomite into lower and upper sequences and considered their unit to be stratigraphically just below the Nevada Formation. In the present report, their approximately 340-foot (104-m)-thick lower sequence is correlated with the Lone Mountain Dolomite and so mapped, whereas their approximately 390-foot (119-m)-thick upper sequence is correlated with the bulk of the Sevy Dolomite and the Beacon Peak Dolomite Member of the Nevada Formation and is at places mapped with the latter formation.

DEVILS GATE LIMESTONE

The term Devils Gate Limestone is used in the same sense as originally defined by Merriam (1940, p. 16–17) at Devils Gate west of Eureka and elaborated upon by Nolan and others (1956, p. 48–52) and Merriam (1963, p. 49–56).

Lithology

Limestone and limey dolomite compose the bulk of the Devils Gate and are lithically and faunally similar to the previously described correlative strata of the Guilmette Formation. Dolomite is common especially in and near the Portuguese Mountain quadrangle, where it is interbedded with limestone and is also present as irregularly dolomitized parts of the formation (Quinlivan and others, 1974). Weathered outcrops of the Devils Gate in general have considerably more homogeneity of color than those of the underlying Nevada Formation, although locally, as at Portuguese Mountain, the unit may display some of the same alternating color bands as the Nevada. Overall coloration ranges from medium light to medium dark gray, especially where dolomite prevails. The Devils Gate contains spectacularly resistant units that in the Paleozoic section, along with the overlying Joana Limestone, appear generally as massive medium-gray sheer limestone cliffs, some of which, toward the upper part of the Devils Gate, are composed of a series of very thick, massive ledges scarcely separated from each other. Lower in the formation, more thinly bedded and split units form a series of alternating less sheer cliffs, benches, and stepped steep slopes. Quartz sandy and quartzitic zones locally impart a brownish cast to the grays but do not appreciably alter the topographic expression of the units.

The basal unit of the Devils Gate is a yellowish-gray-weathering, argillaceous, platy to slabby, laminated to thin-bedded limestone and (or) dolomite and calcareous dolomite. At and near Portuguese Mountain, this zone, here termed the "yellow bed" for its probable correlative at the base of the Guilmette Formation, is less resistant than adjacent strata and forms a slope. Where examined just south of the summit at Portuguese Mountain, the yellow bed is argillaceous to quartz silty dolomite. About 3000 feet (915 m) northeast of the summit, it is similar and also includes calcareous dolomite, all of which somewhat resembles dolomite in the Sevy Dolomite but lacks the Sevy's darker appearance on fresh surfaces. Here the yellow bed zone is overlain by about 15 feet (5 m) of noticeably very thinly bedded, platy to blocky, very dark gray, medium-grained limestone that in turn is overlain by massive, more thickly bedded limestone bearing well-preserved stromatoporoids, calcitized gastropods, and locally abundant "spaghetti" (*Amphipora* sp.). About 6¾ miles (11 km) northeast of the summit, in T11N,R55E, the yellow bed zone is directly overlain by possibly as much as 60–80 feet (18–24 m) of flaggy, thin-bedded gray limestone that locally is intercalated with or grades laterally into minor calcareous dolomite and dolomite with lithologic affinities to dolomitic strata of the Nevada Formation. However, the bulk of the overlying Devils Gate here consists of thicker bedded and split (flaggy to massive, thin- to thick-bedded) aphanitic to medium-grained strata as typified about 12 miles (19 km) west of Currant. Here, also, abundant spaghetti beds and common zones bearing stromatoporoids to 1½ feet (46 cm) in diameter are prominently displayed. Slump structures and coquinoid beds with brachiopods and corals are less common but still notable. Colors typifying the formation here are chiefly medium light gray to medium gray and olive gray on fresh surfaces and the same or slightly lighter shades and, locally, light yellowish gray to light gray on weathered surfaces.

Fossils in the Devils Gate of the mapped region are less common than in the formation near the type locality and in the correlative Guilmette Formation. They are, nevertheless, common enough in scattered zones

throughout the formation to characterize it and distinguish it from the underlying Nevada Formation. However, cladoporoid-bearing spaghetti beds cannot be so used because they are ubiquitous in both formations. Fossils, which are easily seen in outcrops, commonly are crowded or dispersed in layers. Limonitic brown silicified fossils characterize some layers, and these fossils locally tend to weather free. In other zones, fossils are commonly replaced by coarse white or gray calcite and may be poorly preserved or only removable from the enclosing rock with difficulty. Brachiopods are abundant locally and, with the present stage of paleontological knowledge, could prove useful in detailed stratigraphic studies. Crinoid columnals are locally common in the upper part of the formation, as in the Duckwater Hills. Algal heads, stromatoporoids, and corals, especially *Cladopora?*, are especially prominent and ubiquitous in much of the Devils Gate.

Contacts

The lower contact of the Devils Gate Limestone is conformable and abruptly gradational upward from dolomite of the Nevada Formation into limestone and dolomite. The contact was generally drawn just beneath a rather prominent, yellowish-gray-weathering nonresistant zone, described in the section on Lithology, that is probably correlative with the yellow bed in the basal Guilmette Formation. Gray limestone of the Devils Gate type, however, can be found locally beneath this contact, as in the uppermost 100 feet (30 m) of the underlying Nevada at Portuguese Mountain and about 6¾ miles (11 km) northeast of this peak in the Pancake Range.

The upper contact of the Devils Gate was generally placed at the change from massive limestone to shaly limestone and shale marking the Pilot Shale in the Duckwater Hills and was more difficult to recognize consistently farther west because of the absence of characteristic Pilot. In the Pancake Range along the east flank of Portuguese Mountain, the contact marks a disconformity and was placed locally at the base of an irregularly lenticular, dark-brown, silicified fanglomerate assigned to the Early Mississippian Joana Limestone. Locally, flaggy or massive limestone of the Joana lies on the Devils Gate. Off the northwest flank of the mountain, about 10 feet (3 m) of very thin bedded, platy to flaggy limestone, intervening between the Devils Gate and the Joana, may represent the West Range equivalent of the Pilot Shale but was included in the uppermost Devils Gate on the map. This places the Devils Gate-Joana contact just beneath massive but thin-bedded cliffy Joana that, except for scattered white chert, resembles cliffy limestone of the Devils Gate. The upper disconformable contact cannot be traced westward into the Hot Creek Range because, even though the formations in question are present, they are in separate fault blocks.

Distribution and Thickness

The original extent of the Devils Gate Limestone may have equalled that of the underlying Nevada Formation, but the distribution is presently limited to the Duckwater Hills, the northern part of the Hot Creek Range, and the Pancake Range; the most complete sections and best exposures are near Portuguese Mountain in the Pancake Range. Quinlivan and others (1974) measured and described more than 3000 feet (914 m) of strata in the formation near Portuguese Mountain. At other outcrops about 5 miles (8 km) west-southwest of Lockes Station and near Morey Peak in the Hot Creek Range, the formation is generally incomplete because of deformation and faults. A section with the base missing occurs in the Duckwater Hills, Nye County, a short distance south of a similarly incomplete section 1547 feet (472 m) thick in White Pine County measured by Holland (1956, p. 14, table 1).

Age

The Devils Gate is closely dated by locally abundant fauna near Eureka. The age assignments of the faunal zones and, consequently, the formation itself have been modified by various paleontologists since first reported by Merriam (1940, p. 16–17, 27, table 2) and Nolan and others (1956, p. 50–51). Merriam (1963, p. 54–55) evaluated these changes and appeared finally to regard the Devils Gate as chiefly early Late Devonian (Frasnian), with the lowest part probably latest Middle Devonian (highest Givetian) and the uppermost part extending above the Frasnian into the Famennian Devonian. Poole and others (1967, column 5 of fig. 2a), in their symposium paper on the Devonian of the southwestern United States, accepted this age assignment for the formation.

The age of the formation in northern Nye County is approximately defined only by faunas in overlying and underlying formations. *Stringocephalus* in the upper part of the underlying Nevada Formation, and marking the top of the Middle Devonian, defines the lower limit of the age for the Devils Gate. Early Mississippian (Kinderhookian) conodonts occur in the overlying Joana Limestone in the Portuguese Mountain quadrangle (Pancake Range) (Quinlivan and others, 1974).

The lower part of the Devils Gate about 50 feet (15 m) stratigraphically above the yellow bed yielded bryozoans, corals(?), one poorly preserved brachiopod, stromatoporoids, *Amphipora* sp., and a new genus of gastropod related to *Omphalotrochus*—identified by E. L. Yochelson (written commun., Sept. 1962) (fossil colln. 15378-4, shipment SW-62-10, collected about 3000 feet (915 m) northeast of the summit of Portuguese Mountain from a medium-light-gray to pale-yellowish-brown and olive-gray (5Y 4/1) calcarenite and calcilutite).

OTHER DEVONIAN ROCKS

Introduction

Scattered patches of Devonian and presumed Devonian strata in the western two-thirds of northern Nye County that could not be correlated with more widely distributed formations are described below. The most

easterly of these map units, the Cockalorum Wash Formation (pl. A1), is described first. Devonian strata have not been recognized west of the Toquima Range. Their absence is largely attributed to removal by erosion prior to the Mississippian, with any Devonian that survived erosion most likely having been eroded away either prior to the Permian or possibly during uplift and tectonism associated with the Early Triassic Sonoman orogeny. Faulting in which strata were sliced out along major low-angle faults could account for the local absence of Devonian but is not the preferred explanation. Some unrecognized Devonian strata may underlie or crop out in the Toiyabe Range, where all rocks with affinities to the siliceous detrital and volcanic assemblage were assigned to the lower and upper Paleozoic.

Cockalorum Wash Formation

Introduction

A sequence of fine to very coarse grained siliceous clastic rocks and limestone in southernmost Eureka County (Merriam, 1967; 1971) was named the Cockalorum Wash Formation by Merriam (1973a, p. 14–15). The name is derived from outcrops in the center of the Cockalorum Wash quadrangle, in the southernmost Fish Creek Range. The same rocks extend southward into northern Nye County and have been assigned to the formation in the present report; however, the correlations are equivocal (see the section on Age and Correlation). Merriam's description of the type section is summarized below.

Lithology

The formation consists of shaly siltstone, sandstone, and limestone. According to Merriam (1973a, p. 14), the lower 600 feet (183 m) of the type section consists of tan-weathering shale, platy siltstone, and sandstone with arenaceous to conglomeratic limestone in lenses and interbeds, above which some of the limestone is thicker bedded and finer grained but still interbedded with the siliceous clastic strata. The upper 500 feet (152 m) of the section is predominantly light-gray limestone in units as much as 175 feet (53 m) thick. Some of the limestones contain fragments of brachiopods, gastropods, and tentaculites. Algal(?) debris, radiolarians(?), and corals are also present and locally abundant; for example, the coral *Hexagonaria* occurs in cobble-sized heads in a limestone at the top of the type section. Eurypterid claws, seen mostly as carbonized films, are fairly common in the tan- and light-gray-weathering shaly siltstone and are best found on weathered surfaces. Both eurypterids and coral heads of *Hexagonaria* are useful guides to the Cockalorum Wash Formation in the type area and also farther south in the Hot Creek Range. North-northwest of Morey Peak in the Hot Creek Range, black carbonaceous and siliceous shale, siltstone, and minor laminated chert are also included by us with the Cockalorum Wash. These strata form dark-brown- to black-weathering slopes and are moderately to highly deformed in many exposures. Scattered vanadiferous and uraniferous(?) mineral deposits have been prospected in these beds.

Contact relations of the Cockalorum Wash Formation with other rocks are generally either faulted or obscured by alluvium. In the Hot Creek Range, one contact mapped as a fault could represent an unconformity along which there has been only slight movement. The contact is in the approximate center of S20,T10N,R51E, about 4¾ miles (8 km) west-northwest of Moores Station. Here, a nonresistant pale-red to reddish-brown and a pale-greenish-gray to pale-yellowish-brown (stained) siliceous argillite and siltstone lacking eurypterids is provisionally assigned to the Cockalorum Wash Formation. Deformed, steeply north-dipping, overlying Joana Limestone consists, from bottom to top, of several feet of brown-weathering chert grit that locally encloses boulder-sized clasts of limestone, a limestone-pebble conglomerate with clasts containing Devonian corals (C. W. Merriam, oral commun., Jan. 1965), and medium-gray limestone that is commonly quartz silty and sandy and weathers brownish. This limestone contains *Kinderhookian* conodonts (colln. 15310–F58 studied by J. W. Huddle, written commun., Nov. 8, 1965) and locally has lenticles and layers of chert-pebble conglomerate and intercalated white to light-brown argillite and siltstone.

Distribution and Thickness

Poorly exposed outcrops of the formation are scattered in the southern Fish Creek Range and isolated hills southward into the Hot Creek Range. A single complete section is nowhere exposed, and Merriam (1973a, p. 14–15) described a composite section about 1200 feet (366 m) thick in the type area. There and elsewhere, the formation is commonly strongly deformed and faulted and its thickness in northern Nye County was not determined. The sections near Morey Peak and near Warm Springs, Hot Creek Range, are probably similar in thickness to or thinner than that in the type area.

Age and Correlation

The age and correlation of the Cockalorum Wash Formation is controversial. Some workers have not used the term in the Hot Creek Range as we have and, instead, have used Pilot Shale and (or) Joana Limestone (W. J. Carr and H. W. Dodge, Jr., written commun., 1974). Merriam (1973a, p. 11–15) described the type section as containing the Middle Devonian coral zone F and corresponding in age to unit 4 of the Nevada Formation at Lone Mountain west of Eureka and to the Woodpecker Limestone Member of the Nevada Formation in the Diamond Mountains east of Eureka (Merriam, 1973a, figs. 2 and 7, p. 9–10). R. K. Hose (written commun., Nov. 1, 1979) indicated that the Cockalorum Wash Formation of Merriam (1973a) included not only a Middle Devonian partially coralline limestone, but also elements of the Pilot Shale and Woodruff Formation, as well as sandstone of Mississippian age (probably younger than Osage). The formational elements are not

in normal superposition but are juxtaposed along low- and high-angle faults in the vicinity of the type area.

The diagnostic fossils of the Cockalorum, moreover, have all come from the calcareous strata rather than from the siliceous argillite, shale, and siltstone that in many cases are not in direct contact with the fossiliferous limestone (R. K. Hose, oral commun., Apr. 1975). We included tan-weathering, gray, platy siliceous siltstone, locally slightly calcareous, as a major constituent of the Cockalorum Wash Formation, especially near Morey Peak (Hot Creek Range) and north into the Fish Creek Range. The siltstone is notable for eurypterid claws scattered at several horizons. The Woodruff Formation in the Pinon Range near Carlin, Nevada, contains very similar eurypterid-bearing strata, is allochthonous there, and was assigned to the siliceous assemblage (Smith and Ketner, 1968). Eurypterid claws have been reported in somewhat similar host rocks in the upper part of the Pilot Shale in the northern Pancake Range (Holland, 1956, p. 20–21), where they have engendered little excitement but are a marker for the upper Pilot. They also occur in the Pilot or Chainman Shale of the Hamilton mining district in black siliceous shale.

Calcareous beds in the higher part of the Cockalorum Wash Formation bear a resemblance to some of the limestone east of Eureka in the Woodpecker Limestone Member of the Nevada Formation and to parts of the lower 425 feet (129 m) of unit 4 of the Nevada Formation at Lone Mountain (Merriam, 1973a, p. 10). A fairly common limestone in all of these units is a light-gray-to tan-weathering platy limestone with discontinuous pinkish argillaceous(?) partings; scattered zones of tentaculites occur in the limestone in all the areas except apparently at the Warm Springs locality in the southernmost Hot Creek Range.

The eurypterid-bearing unit in northern Nye County and other strata similar to that which we mapped as Cockalorum Wash Formation in the Hot Creek Range have been included with the Woodruff Formation and unnamed allochthonous Mississippian siliceous strata in the nearby Fish Creek Range, Eureka County, by Desborough and others (1979). The validity of the name Cockalorum Wash Formation is clearly questionable. Thus, until the fragmented Cockalorum Wash Formation in its type area and as mapped in northern Nye County is better understood, no nomenclature or correlations can be construed as correct or final.

McMonnigal and Tor Limestones

Introduction

A map unit combining the McMonnigal and Tor Limestones (Kay and Crawford, 1964, p. 440–441) in the Toquima Range (pl. A1) is separated from other Silurian and Devonian units because of partly different lithologies and temporal equivalency, although elements of the Rabbit Hill Limestone are recognizable in the McMonnigal. The McMonnigal and the Tor are part of thrust sequences (Mill Canyon and June Canyon sequences) differentiated by Kay and Crawford within the autochthonous rocks, and they indicated that the Tor was displaced about twice as far (25–30 mi or 40–48 km) southeastward from its original depositional site as the McMonnigal.

Lithology

Both the McMonnigal and Tor are limestone but differ in that the Tor is a very light gray to white, massive to structureless, thick-bedded cliff-forming unit, whereas the McMonnigal is a gray, thin- to thick-bedded limestone containing in its lower part subordinate tan-weathering, platy, very thin-bedded limestone that is similar to much of the limestone in the underlying Roberts Mountains Formation. The Tor is commonly coarsely recrystallized, and parts of it retain traces of an original coquinoid (bioclastic) character. Some of the thicker gray limestone beds within the McMonnigal also exhibit a coarsely bioclastic texture, with crinoidal and shelly debris predominating; intervening platy limestone contains sparse graptolites.

McKee and others (1972, p. 1564) have described the basal contact of the McMonnigal Limestone as gradational downward for about 50 feet (15 m) into the more thinly bedded Roberts Mountains Formation (Masket Shale of Kay and Crawford). The upper part of the McMonnigal is absent by faulting and removal by present-day erosion. McKee and others (1972, p. 1567) described the Tor Limestone as generally being in fault contact with the underlying Ordovician Antelope Valley Limestone (the so-called disconformable contact of Kay and Crawford, 1964, p. 440). At only one place did they note a sedimentary contact, with the Tor resting on several feet of the intervening Roberts Mountains Formation (see also McKee, 1976, p. 20).

Distribution and Thickness

The McMonnigal and Tor Limestones are recognized only in the northern part of the Toquima Range, where outcrops cluster within a few miles north and south of Ikes Canyon. Kay and Crawford (1964, p. 440–441) estimated that only about 100 feet (30 m) of the McMonnigal was preserved and that the Tor attained a thickness of about 500 feet (152 m). However, McKee and others (1972, p. 1564, 1566) stated that a composite section of the McMonnigal may be as much as 400 feet (122 m) thick. They also stated that although the Tor's total thickness is unknown, the earlier 500-foot (152-m) estimate is reasonable, and they measured one section of about 200 feet (60 m).

Age

A fauna first described from the McMonnigal by Kay and Crawford (1964, p. 440) as having Early Devonian Helderbergian (Rabbit Hill) and Oriskanian affinities was also described by McKee and others (1972, p. 1567) and Merriam (1973b, p. 7), who noted not only the presence of Merriam's (1974, p. 19–20) Devonian coral zone A, but also beds with corals of Merriam's (1973c, p. 14–16, 21) Silurian coral zone E (comparable to the Cayugan Series of the Eastern United States or Ludlovian Stage of Europe, but see the sections of this

bulletin on Ordovician and Silurian Systems—Masket Shale of Kay and Crawford (1964) and Silurian and Devonian Systems—Roberts Mountains Formation, under which are described the earliest Devonian strata of the Toquima Range). The age of these strata are defined on the basis of the *Monograptus uniformis* zone, which includes Silurian coral zone E of Merriam. The lower McMonnigal correlates with the lower Tor and the upper part of the Roberts Mountains Formation, and it has been suggested that the higher parts of the McMonnigal and Tor may also be correlative (McKee and others, 1972, p. 1567). McKee (1976, p. 21) later stated that higher parts of the McMonnigal correlate with the Rabbit Hill Limestone.

Limestone, Undifferentiated
(*includes Rabbit Hill Limestone*)

Introduction

The designation "Limestone, undifferentiated" on plate A1 includes various thin-to thick-bedded limestone, cherty limestone, and minor calcarenite and limestone-pebble conglomerate. Most of the map unit, however, consists of the Rabbit Hill Limestone, which crops out near Dobbin Summit, Monitor Range. The Rabbit Hill Limestone was named by Merriam (1963, p. 42–44) for rocks exposed on Rabbit Hill in the Monitor Range, southern Eureka County. He later (1973b) described the formation in detail and elaborated upon the Dobbin Summit section, in the Monitor Range, Nye County, 19 miles (31 km) south-southwest of Rabbit Hill. The Dobbin Summit locality marks the southernmost known limit of the formation (Merriam, 1973b, fig. 1), and the unconformity above the Rabbit Hill at this locality aids in the interpretation of the structural history of the region. Strata partly equivalent in age to and partly similar lithologically to the type Rabbit Hill crop out farther west near Ikes Canyon, Toquima Range, and on the present map are grouped as the McMonnigal and Tor Limestones (pl. A1) and described in the section on other Devonian rocks. Merriam (1973b, p. 4–5) considered the Rabbit Hill to be a Devonian counterpart of the Silurian Roberts Mountains Formation, which in the Cordilleran geosyncline lies within a north- to northeast-trending intermediate limestone belt about 100 miles (161 km) wide between a dolomite belt on the east and a siliceous belt on the west.

Lithology

The typical dark-gray, nearly black, fine-grained, platy and flaggy limestone, calcareous shale, and argillaceous limestone with scattered coarse-grained bioclastic limestone of the Rabbit Hill Limestone (Merriam, 1963, p. 42–43) is further characterized locally by yellowish-, orange-, and brown-weathered ledgy slopes, and, at Dobbin Summit, by two distinguishing features that greatly aid in the recognition of the formation: (1) extremely fossiliferous gray limestone (bioclastic, with micro- and mega-fossils) and (2) small to large concentrations of coarse silt and gritty quartz sand in wispy zones and broad swaths in the limestone that impart a reddish- to orangish-brown- and brown-weathered appearance to many of the outcrops. Quartz grains that commonly float in the limestone and elsewhere are so concentrated as to form moderately cemented gritty sandstone with a calcareous matrix. In general, the formation forms slopes broken locally by low cliffs and ledges, and the slopes are partly covered by talus and lag of irregularly shaped chips, plates, and flags. The extremely abundant fauna consists chiefly of corals, brachiopods, and trilobites. Many fossils are as much as 1/2 inch (1 cm) or so across, and some are even larger. They are commonly and selectively silicified (Merriam, 1973b, p. 4), tend to weather to shades of brown, and fall free of the enclosing rock to form a rubbly debris. The contrast in color and resistance of fossils compared to the enclosing rock coupled with their abundance permit them to be readily seen from several feet away.

The Rabbit Hill Limestone conformably overlies the Silurian and Devonian Roberts Mountains Formation, to which the reader is also referred for details. Merriam (1973b, p. 7–8, 12) first described the contact and noted that it could be seen at Coal Canyon, Simpson Park Range, and in Nye County at Dobbin Summit, Monitor Range. The contact is well exposed at the latter place, where the present authors and later T. E. Mullens (oral commun., Feb. 13, 1975) placed the contact at the base of a bioclastic limestone ledge. T. E. Mullens (unpub. data) indicates that the contact is conformable and that conditions of sedimentation were similar from Silurian into Early Devonian (Helderbergian) time. There is little or no lithologic contrast across the contact, aside from the intercalated bioclastic limestone ledge used to mark the base of the Rabbit Hill.

The upper contact of the Rabbit Hill Limestone at Dobbin Summit is also difficult to characterize; however, the contact must represent either an unconformity or a fault because the overlying limestone is most likely Mississippian in age. Missing strata, besides a presumed thin part of the upper Rabbit Hill, include the rest of the Lower, Middle, and Upper Devonian beds, which crop out in relatively complete sections in much of the adjacent region. The contact is generally covered by talus on a moderate slope and was placed where the obvious Helderbergian fossils disappear from the float. Gross lithologic characteristics, particularly that of very thin-bedded limestone, seem to extend upward unchanged. Locally, a prominent but discontinuous, resistant, dark-gray silicified (jasper) ledge about 0.5–2 feet thick marks the approximate horizon and may represent a breccia along a low-angle fault. It might be more logical to place the top of the formation above all the continuous limestone and at the base of brown-weathered siliceous shales of the Chainman Shale, except that some intervening limestone contains a post-Helderbergian conodont fauna with Mississippian affinities.

Thickness and Distribution

Outcrops of the Rabbit Hill Limestone and equivalent rocks in Nye County are confined to a relatively limited area in the Monitor and Toquima Ranges near the

Eureka and Nye County boundary. The formation next crops out, according to Merriam, in the Simpson Park Range well north of Nye County. The best exposures in Nye County are on the east side of the Monitor Range near Dobbin Summit, where about 400 feet (122 m) of the formation is exposed in a section in fault or unconformable contact with overlying Mississippian rocks. About 250 feet (76 m) of Rabbit Hill is exposed at the type locality and 1100 feet (335 m) at Coal Canyon, Simpson Park Range (Merriam, 1973b, p. 6, 8). Both sections are incomplete.

Age

Merriam (1973b) collected and comprehensively described the Rabbit Hill fauna from scattered localities in Nevada and collated data of other workers. An extensive Helderbergian (Gedinnian) fauna characterizing the Rabbit Hill Formation at the type locality allowed Merriam (1963, p. 43–44, 1973b, p. 10) to date the unit as early Early Devonian. Only the lower Rabbit Hill fauna is present there, whereas at Dobbin Summit a higher Rabbit Hill fauna augments the lower and includes the large spirifers *Costispirifer arenosus* subsp. *dobbinensis* and *Acrospirifer kleinhampli*, which "...are precursors of the later Early Devonian fauna [*Spirifer kobehana* of Oriskany age (or Siegenian stage of Europe)] of Nevada unit 1 and Great Basin Devonian coral zone B" (Merriam, 1973b, p. 7, 12). Fossil evidence comes mainly from brachiopods and trilobites and, to a lesser degree, from corals and conodonts. Ostracodes have been less useful for dating but nonetheless helpful (Merriam, 1973b, p. 11).

Temporal equivalents of the Rabbit Hill Limestone include the Beacon Peak Dolomite Member of the Nevada Formation, which contains the Rabbit Hill fauna but is lithologically distinct, and the lower part of the Wenban Limestone of the Cortez area, Lander County (Merriam, 1973b, p. 11–12).

Limestone and Shale, Undifferentiated

A very small isolated outcrop (limestone and shale, pl. A1) near the mouth of Ikes Canyon, Toquima Range, was briefly described by McKee and others (1972, p. 1564):

> An indeterminate thickness of thin-bedded, cherty, petroliferous-smelling limy shale...in a fault block...may represent rocks that could have been stratigraphically above the McMonnigal Limestone in the Mill Canyon sequence [of Kay and Crawford, 1964].

Chert

Several square miles of deformed, thin-bedded, dark-gray to black chert and minor amounts of siliceous argillite and siltstone cropping out from near the mouth of East Northumberland Canyon northward to about Mill Canyon in the Toquima Range are herein assigned to an undifferentiated chert unit (chert, pl. A1). The chert is possibly correlative with the Slaven Chert on the basis of data supplied by F. G. Poole (oral commun., 1974). The thickness was not measured but is estimated at several hundred to 1000 feet (100 to 300 m). The beds were originally mapped as the Pinecone Formation and undifferentiated Willow Canyon and Pinecone Formations and assigned to Ordovician allochthonous rocks (Kay and Crawford, 1964, pl. 6). Shawe and others (1969) mapped the locality while studying barite deposits associated with the beds and retained this assignment. During that study, however, F. G. Poole (oral commun., 1974) collected conodonts that have been studied by J. W. Huddle and support reassignment to the Devonian and correlation with the Slaven or equivalent beds. In the type area in the northern Shoshone Range, the Slaven was considered to be Middle Devonian and probably Late Devonian (Gilluly and Gates, 1965, p. 41) but is now known to be Early to Late Devonian (Berdan, 1977). As such, the formation is approximately contemporaneous in deposition with the Nevada Formation and the lower part of the Devils Gate Limestone. The "Slaven" is allochthonous in its present position in the Toquima Range.

Devonian and Mississippian Systems

Predominantly clastic Upper Devonian and Mississippian strata are widely distributed through northeastern Nye County; Mississippian beds crop out locally even as far west as the San Antonio Mountains (fig. A27). These rocks correspond to the lower part of the overlap assemblage of Roberts and others (1958) and presumably were derived from the Antler orogenic belt which was intermittently emergent in central Nevada from Late Devonian through Permian time. The predominantly clastic Cockalorum Wash Formation, which is probably an allochthonous part of the overlap assemblage, was described with Devonian rocks because the unit had been dated as Devonian by Merriam (1973a). Mississippian strata may be included in the Cockalorum, however, which would indicate equivalency with the Pilot Shale, described later.

WEST RANGE LIMESTONE

The West Range Limestone (Westgate and Knopf, 1932, p. 16–19) is not differentiated on the present map (pl. A1), although it was shown capping Gap Mountain in the southern Egan Range by Kellogg (1960, pl. 1, p. 192; 1963, p. 700–702, fig. 2), who divided it into three members not everywhere present in the southern Egan Range: a lower limestone member, a middle shale member, and an upper limestone and shale member. He essentially followed the original usage, placing the formation above the Guilmette Limestone and below limestone of Mississippian age, and identified the fauna of the West Range Limestone as encompassing and extending above the *Cyrtospirifer* zone of Merriam (1940, p. 61–67, table 2) into a *Leioproductus* fauna of probable Kinderhookian age (Kellogg, 1963, p. 701–702). We have followed the usage of Tschanz and Pampeyan (1970, p. 36) and included Kellogg's lower limestone member and upper shale and limestone member of

the West Range Limestone, together totalling 125 feet (38 m) with the Pilot Shale at Gap Mountain in the southernmost Egan Range. The same units of the West Range Limestone are also included with the Pilot in the Seaman and Golden Gate Ranges. As noted by Kellogg (1963, p. 701) and documented by Lumsden (1964, p. 75–77, 238–239), the West Range Limestone is absent from the ranges west of White River Valley. We noted a possible West Range equivalent at Portuguese Mountain, Pancake Range, and mapped it with the Devils Gate Limestone.

PILOT SHALE

Spencer (1917, p. 26) defined the Pilot Shale: "soft, highly carbonaceous shale rest[ing] on the Nevada Limestone" in the Ely district, approximately 35 miles (56 km) northeast of the boundary between Nye and White Pine Counties. Nolan and others (1956), Tschanz and Pampeyan (1970), and others have applied the term through much of eastern Nevada to include all the slope-forming rocks between the cliff-forming limestones of the Devils Gate or Guilmette Formations below and the Joana Limestone above; we follow their usage.

The Pilot Shale occurs only in the eastern part of northern Nye County and is best developed in the South Egan, Seaman, and Golden Gate Ranges. The formation is either greatly thinned or is absent in a broad sector, which includes the White Pine and Horse Ranges and parts of the Egan, Grant, and Pancake Ranges. Some rocks included in the Cockalorum Wash Formation in the Hot Creek Range near Morey Peak may also be equivalent to the Pilot Shale (W. D. Carr and H. W. Dodge, Jr., written commun., 1974).

The Pilot in northern Nye County is composed mainly of medium-gray, platy, thin-bedded, argillaceous limestone that weathers yellowish gray or yellowish brown and commonly forms a conspicuous nonresistant zone beneath cliffy Joana Limestone. Less commonly, the unit may be a platy calcareous siltstone. Clay shale is only locally developed.

A sequence that Kellogg (1963) termed the "West Range Formation", which we consider to be the Pilot Shale, is located in the South Egan Range about 10 miles (16 km) south of the Sunnyside Whipple Ranch. He recognized two members there: a lower unit (55 ft or 17 m thick) of thin-bedded argillaceous limestone with subordinate intercalated shale; and an upper unit (75 ft or 23 m thick) containing a thin quartzose sandstone succeeded by interbedded platy limestone and calcareous mudstone. The Pilot Shale of the Seaman Range in Lincoln County just south of the Nye County line is represented by yellowish calcareous siltstone and silty limestone (Tschanz and Pampeyan, 1970).

The contact of the Pilot Shale with the underlying Devils Gate Limestone or Guilmette Formation is sharp but is presumably conformable. Within his West Range Formation, Kellogg (1963, pl. 2) indicated an unconformity that separates Upper Devonian and Lower Mississippian faunas. We believe that physical evidence of such a break is lacking.

The thickness of the formation varies considerably through eastern Nevada, probably owing to pre-Joana warping and erosion (Langenheim and others, 1960, p. 71; Langenheim, 1960, p. 72). The thickest sections exposed in northern Nye County are adjacent to White River Valley. Kellogg measured 125 feet (38 m) of West Range Formation (our Pilot Shale) about 10 miles (16 km) south of the Sunnyside Whipple Ranch and 210 feet (64 m) near Whipple Peak, a few miles east of the Nye County line. Tschanz and Pampeyan (1970) report between 90 and 140 feet (28 and 43 m) of Pilot Shale in the Seaman and Golden Gate Ranges in Lincoln County. The Pilot thins abruptly north and west of southern White River Valley. Throughout the northern Grant Range, the White Pine Range, and parts of the Horse and Pancake Ranges, the unit is absent or less than 10 feet (3 m) thick. About 30 feet (9 m) crops out in the Horse Range 4 miles (6 m) southeast of Wells Station Summit. However, just east of Moody Peak in the Pancake Range, an estimated 100–125 feet (31–38 m) of yellowish-weathering silty limestone and siltstone of the Pilot Shale is exposed in a klippen of a low-angle thrust fault; this sequence may have been tectonically transported from a deeper Pilot basin, which originally lay in the Eureka area to the northwest.

We obtained no diagnostic fossils from the Pilot Shale. Faunas collected by Kellogg (1963, p. 701–702), however, clearly indicate that the unit includes both Upper Devonian and Lower Mississippian strata. The Pilot Shale corresponds to the West Range Formation of Kellogg and is the temporal equivalent of the Narrow Canyon Limestone of southern Nevada. It may also be correlative with the lowest part of the Eleana Formation of the Nevada Test Site.

JOANA LIMESTONE

The Joana Limestone, first described by Spencer (1917, p. 26) from the Ely mining district, is a relatively thin unit that occurs widely across eastern Nevada and parts of western Utah. In northern Nye County, the Joana can be confidently mapped as far west as the Hot Creek Range and possibly to the Monitor Range, where, however, different map units are used (limestone and shale, undifferentiated, at Clear Creek and limestone of Dobbin Summit).

The Joana Limestone rests disconformably on the Guilmette Limestone in parts of the Grant, Horse, and White Pine Ranges, and on the Devils Gate Limestone in part of the Pancake Range. Its contact with the Pilot Shale, where the Pilot is present, is sharp and is probably also a disconformity. These relations contrast with those in the Eureka district where Nolan and others (1956, p. 55) interpreted the Pilot-Joana contact as gradational.

Two lithologic units, whose relative thickness varies from place to place, make up the formation in most of the study area. The lower is a thick-bedded to massive, coarse-grained, gray crinoidal limestone that commonly forms a prominent ledge or cliff. Locally, it contains abundant nodular white chert. South of Portuguese Mountain in the Pancake Range, this unit consists of

thinner bedded crinoidal limestone with intercalated dark-gray shale. The upper unit comprises fine- to medium-grained, thin-bedded, platy to flaggy, dark-gray limestone and silty limestone. These rocks generally are less resistant than the lower unit and weather to a ledge-and-slope topography. The strata are abundantly fossiliferous at most localities and yield a varied coral and brachiopod fauna; equivalent rocks in the Pancake Range, however, are nonfossiliferous.

An unusual facies of the Joana crops out in thrust plates west of Big Louie Spring in the northern Pancake Range. The lower 75 feet (23 m) of the formation there consists of platy fossiliferous limestone, in part sandy, which is overlain by a massive to thick-bedded conglomerate of pebbles, cobbles, and boulders of limestone set in a limestone matrix. The conglomerate facies east of Portuguese Mountain (Pancake Range) is commonly jasperized.

The conglomeratic aspect of the Joana carries westward to northwest of Morey Peak in the Hot Creek Range, where, however, chert and quartz-bearing grit and chert and quartz sand and silt in a calcareous matrix predominate over the coarser clastic constituents.

The Joana displays a gradual increase in thickness eastward from the Pancake Range. We observed an estimated 75 feet (23 m) of Joana just north of Portuguese Mountain and about 180 feet (55 m) a few miles south. Lumsden (1964, p. 81) reported about 200 feet (61 m) in the southern White Pine Range. In the Horse Range, between 410 and 445 feet (125 and 136 m) crops out (Wire, 1961; Ptacek, 1962). Approximately 520 feet (159 m) is exposed near Heath Canyon in the central Grant Range (Huttrer, 1963). In the Egan Range a few miles east of Sunnyside Whipple Ranch, Kellogg (1963, p. 703) measured 705 feet (215 m) of strata assigned to the Joana.

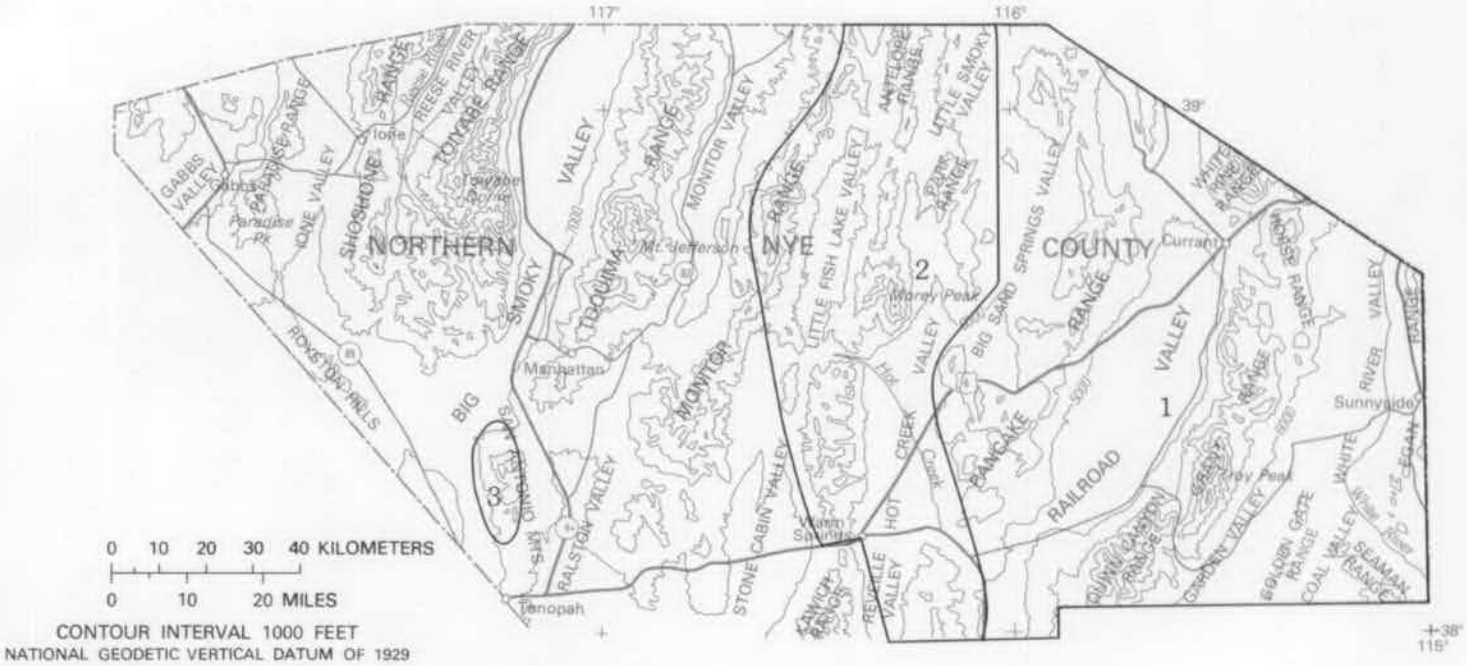
Faunal studies of the Joana of the surrounding region have established its age as Kinderhook and Osage (Early Mississippian) (Nolan and others, 1956, p. 55–56; Langenheim, 1960, p. 79), and collections from the formation in northern Nye County confirm this assignment. The Joana correlates temporally and reasonably well lithologically with massive limestone, limestone conglomerate, and chert and quartz silty, sandy, and gritty limestone at Clear and Tulle Creeks and Dobbin Summit, Monitor Range, where different unit designations were applied (limestone and shale, undifferentiated and limestone of Dobbin Summit, respectively, pl. A1). The Joana is the temporal equivalent of the Lodgepole and Madison Limestones of the northern Rocky Mountain region. It also correlates with the Mercury and Monte Cristo Limestones of southern Nevada and probably with the upper part of the Eleana Formation of the Nevada Test Site.

SILICEOUS CLASTIC OVERLAP ASSEMBLAGE (OROGENIC SUITE) OF DEVONIAN AND (OR) MISSISSIPPIAN AGE

A thick sequence of dominantly siliceous clastic rocks of Devonian and Mississippian age crops out widely through northeastern Nye County and includes units mapped as Chainman Shale and Diamond Peak Formation, Eleana Formation, and limestone and shale, undifferentiated (pl. A1; fig. A27). Limestone lenses (pl. A1), of which the limestone of Dobbin Summit (pl. A1) may be an especially thick lens, are extensive and thick enough locally in the Hot Creek and Monitor Ranges and San Antonio Mountains to be mapped separately and are described in the next section (Limestone of Mississippian age). The siliceous clastic rocks, termed "overlap assemblage" by Roberts and Lehner (1955, p. 1661), represent an orogenic suite derived from the Antler orogen (Roberts and others, 1958, p. 2820–2821, 2838–2839).

Within and east of the Pancake Range, the siliceous clastic strata rest disconformably on Joana Limestone and are conformably succeeded by the Ely Limestone. In the Hot Creek Range the rocks lap across the Devonian Nevada Formation and Mississippian strata (limestone lenses, pl. A1) at one locality, but everywhere else are in fault contact with other rocks. The upper limit of the unit, which is assigned to the Eleana Formation, is not preserved there. Conglomerate in the Monitor Range south of Clear Creek Canyon is provisionally assigned to the Eleana and lies with possible disconformity above a thick section dominated by limestone (limestone and shale, undifferentiated, pl. A1). Some of the conglomerate occurs as massive lenses of cobble and boulder conglomerate similar to the conglomerate facies of the Joana Limestone in the Pancake Range and contains clasts of limestone. Other conglomerate and poorly sorted gritty beds, commonly brown weathering, bear some lithologic resemblance to the Pennsylvanian Wildcat Peak Formation of the Toquima Range. Clasts are shinglelike and subangular and consist of pebbles and sparse cobbles of limestone and brown and green chert. The gritty beds are composed of grains of quartz, chert, and feldspar(?) in a calcitic matrix. Chert in clasts and matrix appears to become less abundant upward, and the upper part of the section is pervasively silicified beneath rocks mapped as Pablo(?) and Diablo(?) Formations. Farther north at Dobbin Summit, clastic strata including several tens of feet of black clay shale and minor clastic limestone (mapped as limestone and shale, undifferentiated, pl. A1), compose the highest exposed part of the Paleozoic autochthon or parautochthon. Seemingly conformable underlying strata there consist of Lower Mississippian silty and sandy limestone (limestone of Dobbin Summit, pl. A1), described in the next section. A fault sliver of mudstone near Lime Mountain, north of Tonopah, is also provisionally assigned to the Eleana.

The clastic sequence appears to thin progressively eastward, although it is difficult to ascertain total thicknesses in many places owing to structural complexities and incomplete exposures. About 1500 feet (457 m) of Eleana Formation crops out in the southern Hot Creek Range, but the original thickness probably was several times greater because nearly 8000 feet (2440 m) that lies along sedimentary strike in southern Nye County has been reported from the Nevada Test Site (Poole and others, 1961). We estimate that between 3500 and 4000 feet (1068 and 1220 m) of Chainman Shale and



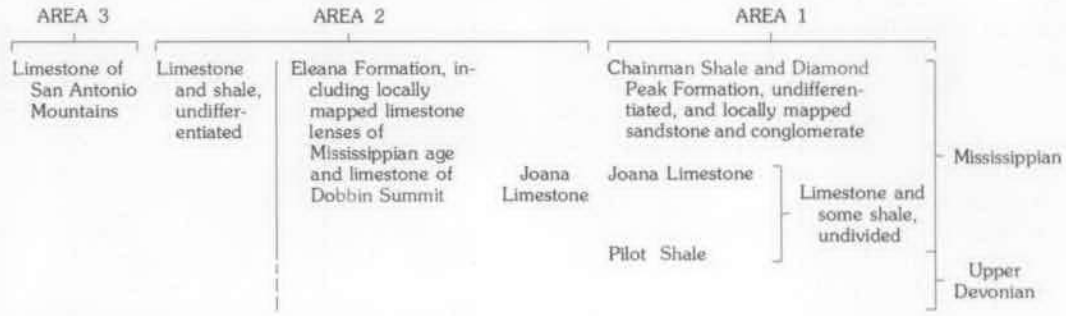


FIGURE A27. Map units used in various parts of northern Nye County for all Mississippian strata on the geologic map (pl. A1). Vertical line represents approximate age range of the units.

Diamond Peak Formation is present in the Pancake Range north of Moody Peak. Lumsden (1964, p. 87) reported 1415 feet (431 m) in the White Pine Range. Farther east, in the southern Egan Range (off the present map), a Mississippian clastic section of between about 1100 and 1400 feet (335 and 427 m) is indicated by Kellogg (1963, pl. 1).

The major components of the Mississippian clastic rocks are shale and siltstone. The former generally is nonresistant, fissile, black, carbonaceous, clay shale; less commonly, brown- to reddish-brown-weathering siliceous shale dominates. Slightly more resistant siltstone is intercalated with the shale in units of varied thickness.

Sandstone and conglomerate crop out as resistant, dark-brown- to reddish-brown-weathering ledges within the shale and siltstone. The conglomerate, composed mostly of pebbles and cobbles of chert in a siliceous matrix, forms massive beds as thick as 100 feet (31 m). The sandstone ranges from poorly sorted chert grit to well-sorted quartz arenite; it commonly is extremely well indurated. Graded bedding and cross stratification are locally developed, particularly in exposures in the Grant and Egan Ranges. Convolute bedding was noted locally in the Hot Creek Range.

Limestone beds and lenses, rarely more than 100 feet (31 m) in thickness, are dispersed as minor elements through the clastic sequence. Two types occur: dark-gray to black, dense, bituminous, aphanitic limestone; and lighter colored, medium- to coarse-grained calcarenite.

The Devonian and Mississippian clastic rocks display a systematic variation in relative proportion, coarseness, and stratigraphic position of constituent rock types across northeastern Nye County. Sandstone and conglomerate make up from 30% to 40% of the total exposed clastic section in the Hot Creek Range and are fairly uniformly distributed throughout the entire section. In the Pancake Range, less than 25% of the equivalent section is composed of sandstone, conglomeratic sandstone, or conglomerate, and these lithologies are almost entirely restricted to the upper one-third of the sequence. Nearly the entire sequence in the ranges adjacent to White River Valley is shale and siltstone;

conglomerate is absent and beds of sandstone, mostly fine to medium grained, occur only in the highest 300 feet (91 m) of Mississippian section.

Fossils typical of the Meramec series (Upper Mississippian) were collected from these clastic strata in the hills a few miles (about 3 km) north of Duckwater (field colln. 17324-26) and from limestone interbeds within the clastic sequence northeast of Morey Peak in the Hot Creek Range (U.S. Geol. Survey colln. 23200-PC).

In the San Antonio Mountains about 1.5 miles (2.4 km) southwest of Lime Mountain, a small outcrop of clastic strata is provisionally assigned to the Eleana Formation, but could be Permian(?) and part of the Pablo Formation, on the basis of lithology and paleontology. Here, black pencil shale and very dark gray mudstone that bears brachiopods and other organisms are faulted down on the north against a thrust plate of Upper Mississippian Limestone and are overlain unconformably by Tertiary volcanic rocks. Mackenzie Gordon, Jr., and W. J. Sando (written commun., Apr. 1968) examined and reported on fossil collection 15084-F16a (U.S. Geol. Survey loc. 23275-PC) as follows:

Coelenterate:
Conulariid, gen. ? sp. indet.
Brachiopods:
Orbiculoidea sp. indet.
Leiorhynchus carboniferum polypleurum Girty?
Indeterminate:
Rodlike bodies, phylum not recognized.

The age of this collection is Late Paleozoic. This could very easily be Mississippian Eleana Formation, but owing to poor preservation of the fossil material and the few long-ranging forms represented, one cannot be sure. The leiorhynchoid median septum in the brachial valve is visible in some of the brachiopods identified as *Leiorhynchus*. The presence of a conulariid precludes Mesozoic age. Permian is also a possibility, but Pennsylvanian is less likely.

If this collection is Mississippian in age, which seems reasonable, then Meramec age would be the most likely, Chester age the next most likely, and pre-Meramec the least likely. This is actually the sort of fauna I would expect to find in shales associated with the fossiliferous limestone of Meramec age that you found in the Hot Creek Range. In summary, I can only say definitely that this fauna belongs in the upper half of the Paleozoic. But, if field evidence is in agreement, the interpretation of this fossiliferous and somewhat altered shale as part of the Eleana Formation is certainly within reason. Additional fossils, of course, would be desirable to confirm or deny such an assignment.

The Mississippian clastic rocks of northern Nye County are equivalent to the combined Chainman Shale and Diamond Peak Formation of the Eureka and Ely districts. The Mississippian part of the Devonian and Mississippian Eleana Formation of southern Nye County extends into northern Nye County and correlates with the Chainman and Diamond Peak in the eastern part of the mapped region.

LIMESTONE OF MISSISSIPPIAN AGE

(limestone lenses of Mississippian age and limestone of Dobbin Summit)

Mississippian limestone of north-central Nye County commonly contains sandy to conglomeratic zones and ranges in age from Early to Late Mississippian. These strata, which generally compose thrust sheets, are partial correlatives of the Joana Limestone and Mississippian clastic rocks of northeastern Nye County.

Thin-bedded, light-gray-weathering, dark-gray, fine-grained cliffy limestone that contains quartz sand either as floating grains or as thin laminae occurs near Warm Springs in the southern Hot Creek Range. The rock is tightly folded and thrust over siltstone and chert of Middle Devonian age and over Upper Mississippian clastic strata. Conodonts that indicate an Early Mississippian (Kinderhook to lower Osage) age have been recovered from the limestone (field collns. 15095-6b, 17, and 24).

Several hundred feet (about 100 m) of thinly bedded quartz-sandy limestone with some chert-pebble horizons (limestone lenses, pl. A1) disconformably overlies the Devonian Nevada Formation in Hot Creek Canyon, Hot Creek Range. Siliceous clastic rocks of the Eleana Formation lap across the Nevada Formation and the cherty and sandy limestone, whose most probable correlative must be the Joana Limestone of Early Mississippian age.

An Upper Mississippian unit that is dominantly a medium-light-gray, very coarse grained, crinoidal limestone (limestone lenses of Mississippian age, pl. A1) is emplaced on a low-angle fault over siliceous clastic strata of the Eleana Formation about 6 miles (10 km) north-northeast of Morey Peak in the central Hot Creek Range. Subordinate lithologies in the thrust plate include light yellowish brown and brownish gray-weathering platy argillaceous or silty limestone. Grit and angular pebbles of black, brown, yellow-brown, and pale-greenish-gray chert are common and, at many places, float in a calcareous or silty matrix. Zones of chert pebbles are locally as much as several feet thick, and a marker zone of barite-cored nodules is near the top of the exposed section. Mackenzie Gordon, Jr., and Helen Duncan, in consultation with G. A. Cooper, made a careful study and assessment of an important fossil collection (U.S. Geol. Survey colln. 21410-PC, field no. 15310-F7) from the unit, and their summary is given below. Gordon later stated the collection was Meramec or lower Chester in age (oral commun., Sept. 1965).

USGS colln. 21410-PC (15310-F7)—Located 20,500 ft N. 74°40′ W. of Moores Station, Hot Creek Valley, in T. 10 N., R. 51 E., northern Nye Co., Nevada.

Bradyphyllum? sp.	*Inflatia* sp.
fistuliporoid bryozoan	*Inflatia?* sp.
Cystodictya sp. indet.	marginiferid n. gen. aff. *Inflatia* sp.
Fenestella sp.	dictyoclostid, indet.
crinoid columnals	*Ovatia* sp.
Rhipidomella sp. (juvenile?)	*Stenocisma* sp.
Schizophoria sp. indet.	*Spirifer*
Chonetes sp.	*Torynifer* sp.
Quadratia sp.	*Martinia* sp.
Avonia sp.	*Actinoconchus* sp.
Overtonia? sp.	*Beecheria* sp. indet.
Semicostella? sp. indet.	*Conocardium* sp.
marginiferid aff. *Desmoinesia* sp.	*Naticopsis* sp.

It has taken a rather careful examination of this assemblage, including painstaking preparation of some of the specimens, and consultation with G. A. Cooper of the U.S. National Museum to come out with a fairly firm age

designation for this very interesting faunule. Practically everything in this assemblage is new and as stated earlier in Gordon's letter to Kleinhampl, there are species that are reminiscent of forms ranging from Mississippian to Lower Permian.

Now, having done the preparation and consideration necessary to the present report, it is possible to state definitely that these fossils are Mississippian in age. Those genera arguing most strongly for Mississippian age include *Quadratia, Avonia, Semicostella, Inflatia, Stenocisma, Torynifer, Martinia* and *Actinoconchus*. These genera taken together indicate Late Mississippian age but probably not latest Mississippian. The locality should be revisited and the fauna studied.

Near Dobbin Summit in the Monitor Range, approximately 1000 feet (305 m) of strata (limestone of Dobbin Summit, pl. A1) that contain Kinderhookian conodonts (J. W. Huddle, written commun., 1964, of field colln. 19688-6b), as well as reworked Devonian conodonts, rest with probable thrust contact on the Lower Devonian Rabbit Hill Limestone. The upper plate sequence is composed chiefly of thin-bedded, platy to massive, fine-grained, black limestone that commonly is finely laminated with quartz-sand or silt streaks and weathers to light-gray and brownish-gray ledges and chip-strewn slopes. Pinkish to brownish quartz sandstone and thin conglomerate layers occur locally. Farther south in the range, between Tulle and Clear Creeks, a similar sequence of quartz-sandy limestone (limestone and shale, undifferentiated, pl. A1) greater than 1000 feet (305 m) thick has overridden the Roberts Mountains Formation along a thrust fault. Kinderhookian conodonts (USGS colln. 23892-PC) also have been obtained from these strata. R. K. Hose (oral commun. Aug. 1979), who recently examined the rocks at Dobbin Summit, stated that they resembled his informally named "Kinkead Spring Limestone" in the Antelope Range. There, the Kinkead Spring rests unconformably on the Devils Gate Limestone and contains Osagian foraminiferas.

Mississippian carbonate rocks are exposed at two localities in the San Antonio Mountains. Southwest of Lime Mountain (actually a promontory of basalt), highly contorted and silicified limestone is thrust upon presumed Cambrian or Ordovician slaty rocks; the limestone yields a coral and foraminiferal fauna dated as Late Mississippian (field colln. 15084-2 and 15084-6, examined by Helen Duncan and B. A. Skipp, written communs., 1964 and 1965, respectively). Northwest of Lime Mountain, near the Hall molybdenum property, a highly faulted, near-vertical carbonate sequence abuts metavolcanic rocks and associated volcaniclastic strata of the Pablo(?) Formation on the south. The Mississippian may be part of a thrust plate in an imbrication of Mississippian and Permian rocks related to the Sonoma orogeny and the Golconda thrust. Whether or not the near-vertical beds are overturned is unknown; it is assumed that the base of the section is at the south end of the thrust plate. There the dominant rock type of the Mississippian basal(?) strata includes several hundred feet of thin-bedded to massive, light-gray coral-bearing limestone with a quartz-sand lamination. Successively northward of these basal(?) beds in the plate lies a thick unit of medium-light-gray limestone interbedded with wavy beds of pinkish chert, several hundred feet of limestone(?)-cobble conglomerate with about 50 feet (15 m) of gray calcitic to siliceous argillite near its middle, about 100 feet (30 m) of brownish-gray calcareous quartzitic sandstone, and more limestone-cobble conglomerate that is chiefly silicified and contains scattered quartzite clasts. The age of these strata is in part uppermost Osagean (field collns. 12789-4 and 12789-4c) as indicated by corals and foraminifers examined by Helen Duncan and B. A. Skipp (written communs., 1964 and 1965, respectively).

Pennsylvanian System

ELY LIMESTONE

The Ely Limestone in northern Nye County is restricted as redefined by Steele (1960, p. 100) to limestone with abundant chert or comparable beds above Mississippian clastic rocks. The formation does not extend west of the Pancake Range, in which—west of Duckwater—the most complete section, about 3500 feet (1068 m) thick, crops out. The Ely Limestone is widely exposed along the eastern flanks of the Horse and Grant Ranges. Scattered incomplete outcrops of the unit also occur in the Golden Gate, Seaman, and Egan Ranges. Kellogg (1963, p. 704) reports slightly more than 3000 feet (915 m) of Ely in the Egan Range just east of the Nye County line.

The Ely Limestone forms prominent ledgy, light-yellowish-gray ridges that contrast strongly with the less resistant, dark-gray to brown, Mississippian clastic rocks that it conformably overlies. Alternate beds of massive resistant limestone and slabby slope-forming limestone characterize the formation. Organic detritus composes much of the rock, although pale-gray chert nodules and thin lenses that weather orangish brown are locally common and characteristic, as in the Golden Gate and Seaman Ranges.

We have mapped two units in the Ely Limestone: a lower, almost exclusively carbonate unit; and an upper unit containing significant amounts of terrigenous clastic detritus. The latter displays a marked decrease in amount and size of clastic material from the westernmost to eastern exposures of the Ely Limestone in northern Nye County.

The lower unit in the Pancake Range is about 2000 feet (610 m) thick. Gray to light-gray, coarsely crinoidal calcarenite; argillaceous limestone; and thin-bedded to laminated, massive to slabby, yellowish-brown, fine-grained limestone predominate near the base. These lithologies pass upsection into more massive cherty limestone. About 1700 feet (518 m) above the base, subspherical colonies of the coral *Chaetetes* compose a marker zone of known regional persistence. The upper unit, of which more than 1500 feet (457 m) is preserved, consists of limestone similar to that of the lower unit but is intercalated with brownish-weathering layers and lenses of quartz-sandy and chert-conglomeratic and gritty limestone. The proportion of clastic material increases upsection. Locally, nearly pure quartz sandstone and massive silica-cemented chert-pebble conglomerate are developed.

Only the lower part of the Ely Limestone crops out in the Horse and Grant Ranges, where its lithology is similar to that described above. In the Golden Gate Range, the upper unit is represented by an incomplete section of yellow-brown, fine-grained, calcareous sandstone with minor intercalated dark-gray, fine-grained limestone.

In the southern Egan Range, Kellogg (1963) reported that the lower 1355 feet (413 m) of the Ely Limestone is chiefly cherty limestone, with coarse-grained calcarenite and mudstone near the base. The upper unit of the formation, 1653 feet (504 m) thick, is yellowish- to brownish-weathering, laminated to thin-bedded, silty limestone. A persistent zone of *Chaetetes* occurs at its base.

Brachiopods and corals are moderately abundant throughout the formation and accurately document the age of the Ely Limestone here as Early and Middle Pennsylvanian. In the Pancake Range, the lower mappable unit ranges from Early Pennsylvanian to early Middle Pennsylvanian, whereas the upper clastic unit is Des Moinesian (Middle Pennsylvanian). Tschanz and Pampeyan (1970) reported occurrences of Middle Pennsylvanian fusulinids in the sandy upper unit in the Golden Gate Range just south of the Nye County line.

The Moleen and Tomera Formations of Dott (1955) in the Elko area are equivalent, both lithically and temporally, to the lower and upper parts, respectively, of the Ely of northern Nye County. The Ely is correlated with the lower third of the Bird Spring Formation of southern Nevada.

WILDCAT PEAK FORMATION

Pennsylvanian limestone and conglomerate that rest with angular discordance on Ordovician chert and volcanic rocks in the northern Toquima Range have been termed the "Wildcat Peak Formation" by Kay and Crawford (1964, p. 441). They described a type section of the south side of Mill Canyon, and McKee (1976, p. 21–22) described the section in more detail with modifications.

Initially, two units were said to compose the Wildcat Peak Formation. The lower, which ranges in thickness from 49 to 164 feet (15 to 50 m), comprises thin-bedded quartz-sandy and silty limestone. The upper unit, as much as 868 feet (265 m) thick, consists of chert- and limestone-pebble conglomerate intercalated and intertonguing with sandy and silty limestone. Locally, clasts of limestone as large as 2 feet (0.6 m) in diameter have been reported. McKee (1976, p. 22), dividing the formation somewhat differently, described three units in the same general type section. His lowest unit, 175 feet (55 m) of massive fossiliferous limestone, represents the greatest departure from the description of Kay and Crawford; and he measured a total thickness of more than 900 feet (275 m) for the formation. The upper contact of the formation has not been preserved, and the original total thickness of the strata is not known.

A Late Pennsylvanian fusulinid reported from the basal part of the formation at the head of Ikes Canyon (Kay and Crawford, 1964, p. 441) was considered by McKee (1976, p. 23) to be from strata of uncertain stratigraphic relation to strata of the type section. Other fossils, however, were listed and reported by Kay and Crawford to be from the type section and to be Late Pennsylvanian. Based on these fossils and Early Pennsylvanian (Atokan?) fossils from the basal part of the formation, McKee indicated that the formation spanned most of Pennsylvanian time (1976, p. 22–23).

The formation probably correlates with the Strathearn Formation and with the Antler Peak Limestone. McKee (1976, p. 23) stated that the Wildcat Peak Formation is typical of conglomerates of the overlap assemblage in central Nevada (Roberts and others, 1958), to which these formations belong, and which also includes the conglomeratic Brock Canyon and Garden Valley Formations.

Pennsylvanian and Pennsylvanian(?) Systems

Pennsylvanian and Pennsylvanian(?) strata were discovered in the Toiyabe Range, too late in the mapping to separate them everywhere from the lithologically similar Permian Diablo and Permian(?) Pablo Formations. They are variously included with the Diablo and Pablo. The Pennsylvanian and Pennsylvanian(?) strata may be confined to the area south of the Twin River mining district. Much of these strata consists of lenticular bioclastic limestone interbedded with mudstone, siltstone, arkosic chert-quartz grit, and minor clean quartzite.

The following fossil data, with locations of collections appearing in figure A28, represents the best available from our collections in these clastic strata of the Toiyabe Range:

> Colln. Z15324-9a. South slope of Boyd Canyon, near its mouth, approximately in middle of N½ of sec. 14, T.10N., R.42E. (unsurveyed) at roughly 6,700 feet elevation, east slope of Toiyabe Range, Nye Co., Nevada. Prominent cliff-forming bioclastic limestone which overlies rocks assigned to Ordovician Palmetto Formation by Ferguson.

Mackenzie Gordon, Jr. (written commun., Feb. 2, 1967) described the collection as follows:

> *Chonetid,* gen. and sp. indeterminate
>
> Although the preservation does not permit determining the nature of the surface sculpture in external molds of these shells, internal molds show some details of the internal structures of both valves. From this it can be seen that these fossils are post-Devonian. However, they could be anything from Mississippian through Permian in age.

J. W. Huddle (written commun., Apr. 12, 1968) reported the following conodonts in the collection:

	[no. of spec.]
Gnathodus bassleri bassleri (Harris and Hollingsworth)	3
G. pawhuskaensis (Harris and Hollingsworth)	22
Idiognathoides sinuatus Harris and Hollingsworth	1
Streptognathodus cf. *S. angustus* Dunn	3
fragments of conodonts and fish remains	

This fauna is probably Early Pennsylvanian in age.

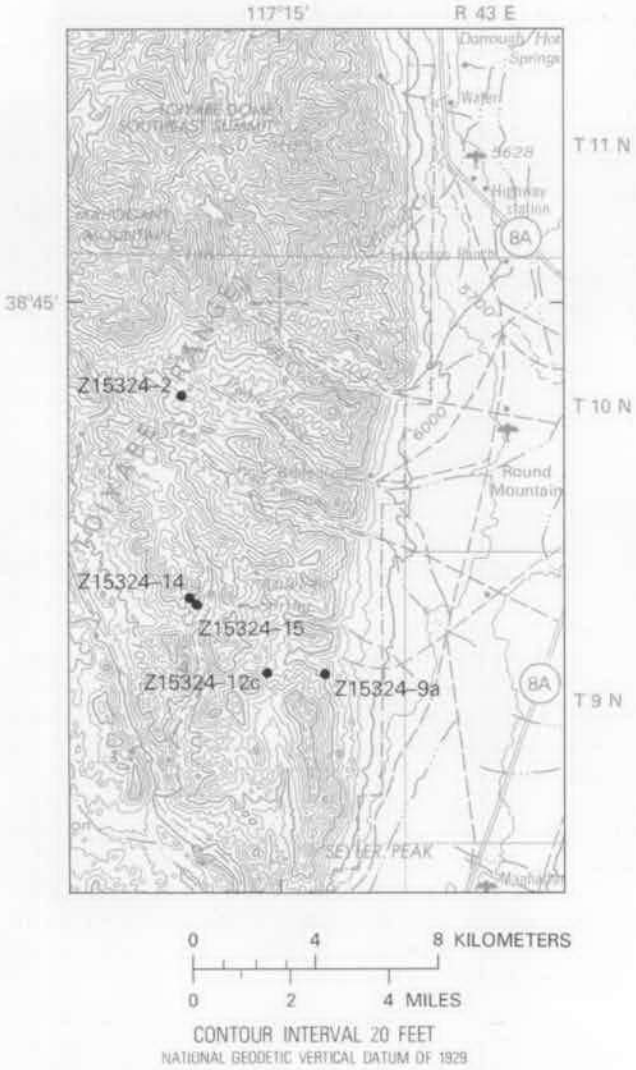


FIGURE A28. Locations of diagnostic fossil collections in upper Paleozoic clastic strata in the Toiyabe Range, northern Nye County. Base from U.S. Geological Survey, Tonopah 1x2° quadrangle, scale 1:250,000, 1971.

Little could be discerned from bryozoans in the collections, according to O. L. Karklins (written commun., June 23, 1975):

> Specimens in this collection are poorly preserved. The taxonomically and stratigraphically significant skeletal material is almost completely replaced or obliterated. The general shape of the colonies suggests the presence of at least two different trepostome forms. However, they are not identifiable and the age is indeterminable.

Thus, the best evidence is that the collection is Early Pennsylvanian.

> USGS colln. 23280-PC (Field Z-15324-14), bioclastic limestone interbedded with siltstone and grit in Horse Canyon, Toiyabe Range; northern Nye Co., Nevada.

J. W. Huddle (written commun., Apr. 12, 1968) has reported on the conodonts:

	[no. of spec.]
Adetognathus sp.	3
Gnathodus n. sp.	5
Gondolella bella Stauffer and Plummer	8
Idiognathodus meekerensis Murray and Chronic	140
bar fragments	

This collection is Pennsylvanian in age, probably Des Moines [Middle Pennsylvanian].

O. L. Karklins (written commun., June 23, 1975) noted a few specimens of fenestelloid and rhabdomesid bryozoans and stated that:

> Both taxa are typical of a late Paleozoic age. There appear to be present two different rhabdomesid genera. The material is too fragmentary for further taxonomic determination.

He also noted one specimen of *Rhabdomeson*(?), and stated:

> Specimen incomplete; this genus is known to range from the early Carboniferous into the Permian.

R. C. Douglass (written commun., June 24, 1975) reported on fusulinid fragments as follows:

> This sample is of a coarse limestone grit and the only fusulinids seen were fragments in the grit. The fusulinids confirm the late Paleozoic age and are probably no older than Middle Pennsylvania and no younger than Early Permian.

Thus, this collection is most likely Pennsylvanian in age, as is the nearby collection described below.

> USGS 23281-PC, field Z-15324-15, bioclastic limestone from Horse Canyon, Toiyabe Range, Nye Co., Nevada. Collected 1/2 mile downslope from 23280-PC.

J. W. Huddle (written commun., Apr. 12, 1968) has reported on conodonts in this collection as follows:

	[no. of spec.]
Gnathodus bassleri bassleri (Harris and Hollingsworth)	3
Gnathodus n. sp.	4
Idiognathoides sinuatus Harris and Hollingsworth	3
Idiognathodus meekerensis Murray and Chronic	126

This collection is Pennsylvanian in age, probably Morrow or Des Moines [Early or Middle Pennsylvanian, respectively].

Bryozoans were studied by O. L. Karklins, who reported as follows:

> Fenestelloids, several spec.
> Fragmented, indeterminate.
> Hexagonellids, three spec.
>
> This is a bioliate fistuliporoid somewhat similar to *Meekopora* or a genus like it. A different fistuliporoid might be also present. Material not sufficient for further identification.
>
> *Rhombotrypella* sp., 4 spec.
> A typical late Paleozoic genus whose known range is from the early Pennsylvanian into the Permian. It is a common genus in the Pennsylvanian and Permian strata of the USSR. It also appears to be abundant in the strata of similar age in the U.S.A., but it has been described only rarely and its distribution in the U.S.A. is not known.
>
> Stenoporids, 6 spec.

Probably two different genera; the material is insufficient for further determination.

Trepostome, one spec.

This might also be a stenoporid.

All taxa in this collection are typical of a late Paleozoic age. The known range of *Rhombotrypella* suggests a Pennsylvanian or younger age for the strata.

Thus, a Pennsylvanian age for the collection seems most likely on the basis of the conodonts. The study of bryozoans does not appear to conflict with this age assignment.

Pennsylvanian and Permian Systems

SEDIMENTARY STRATA IN HOT CREEK, PARK, AND REVEILLE RANGES

Scattered remnants of sedimentary rocks, probably all of Pennsylvanian and Permian age, are best preserved about several miles northwest of Morey Peak in the Hot Creek Range. Less extensive exposures in the Hot Creek Range lie about 4 miles (6.4 km) northwest of Tybo. Other outcrops are found at the extreme north end of the Park Range and northward in a string of isolated hills that merge into the Fish Creek Range of Eureka County and in a small solitary structural window in the Reveille Range west of the Gila mine.

The strata near Morey Peak in the Hot Creek Range form a discontinuous belt of southeast-dipping clastic beds that lap locally silicified Devonian carbonate strata with angular unconformity and are generally overlain unconformably by Cenozoic volcanic rocks or unconsolidated alluvium. At one place, not shown on the map, a Mesozoic or Tertiary conglomerate may unconformably lap the late Paleozoic beds. A well-indurated chert-pebble and chert-cobble conglomerate, about 50–100 feet (15–31 m) thick, lies at the base of the late Paleozoic clastic section and is succeeded by at least about several hundred feet of intercalated, locally gritty, maroon sandstone, conglomerate, siltstone, and minor pebbly limestone. A brachiopod fauna obtained from a siltstone interbed is considered to be of Pennsylvanian or Early Permian age, as reported by MacKenzie Gordon, Jr. (written commun., Dec. 1963):

USGS colln. 21492–PC (Z15310–F14) Located 34,500 ft S. 38°30′ E. of Fish Lake Ranch, in Hot Creek Range at approx. 38°42′ N. lat. and 116°17′ W. long.

Fragment of spinose shell, possibly a productoid
Wellerella sp.
Crurithyris cf. *C. planiconvexa* (Shumard)
Hustedia sp.
Beecheria? sp.

The preponderance of *Crurithyris* in a fine sandy matrix recalls some of our collections from the Rib Hill Sandstone (Lower Permian of the Ely District). *Crurithyris* is a long-ranging genus as are *Hustedia* and *Beecheria*. The fauna is one of these meager assemblages that is very hard to tie down stratigraphically. We can, however, eliminate Devonian age with certainty. I also believe that these are not Mississippian forms. Strictly on a faunal basis we will have to say at present that it could either be Pennsylvanian or Lower Permian. It will take further field work to narrow it down more.

Highly folded, thin-bedded to laminated, yellowish-brown limestone intercalated with soft, yellowish-brown to maroon siltstone and shale are exposed beneath a thrust plate of early to middle Paleozoic dolomite about 1 mile (1.6 km) northwest of the clastic section. The limestone layers are bioclastic, laminated, and display ripple marks and mud cracks locally. A few thin beds of quartz-sandy limestone and limestone-pebble conglomerate also occur within the section. Conodonts suggestive of a Pennsylvanian to Triassic age range have been recovered from the limestone by us and described by J. W. Huddle (written commun., Dec. 1967) as follows:

USGS 29611 (Mesozoic), field no. 15310–72a, T. 18 N., R. 50 E., Nye Co., Nevada.

	[no. of spec.]
This collection contains the following species:	
Gondolella cf. *G. navicula* Huckriede	2
Spathognathodus cf. *S. minutus* (Ellison)	24
Hibbardella sp.	1
Hindeodella sp.	1

All of the specimens are broken and I would like better specimens to be sure of my identifications. However, I think this collection is Triassic in age. *Gondolella* ranges from Middle Pennsylvanian to Triassic. *Spathognathodus* has a longer range. *S. minutus* was described from the Pennsylvanian. *Spathognathodus* cf. *S. minutus*, similar to the one in this collection, has been reported from the Triassic, Scythian from the Mediterranean region. *G. navicula* occurs in the Triassic of the Mediterranean region and has been found in Middle Triassic in Nevada.

Other collections from the same unit by H. W. Dodge, Jr. (USGS 23359–PC with field colln. MP–67–HWD–59; and USGS 23360–PC with field colln. MP–67–HWD–57) were later studied by Huddle and reported as more likely to be Pennsylvanian than Triassic (written commun., July 12, 1968, to H. W. Dodge, Jr., courtesy of Dodge). The relation between these rocks and the coarser clastic strata is unclear; possibly the former represent a stratigraphically higher part of the same succession as shown on the map.

Permian system

SEDIMENTARY ROCKS OF PANCAKE RANGE

Limestone and sandy limestone of Early Permian age crop out locally in the Pancake Range west of Duckwater. These rocks, which disconformably overlie Des Moinesian strata of the Ely Limestone, comprise several hundred feet of section. The lowest strata are light-gray sublithographic limestone that in places contains lenses and nodules of chert. Quartz-sandy and quartz-silty limestone, which weathers yellowish brown, constitutes the higher part of the sequence. Reddish-brown calcareous siltstone and sandstone are also associated with the latter lithology.

A brachiopod-bryozoan fauna from the base of the unit (field collns. 17327–2 and 17327–3, described by Helen Duncan and Mackenzie Gordon, Jr., 1963 and 1964, respectively) and fusulinids from near the exposed top (field colln. 17326–Z14) are considered to be Lower

Permian. The lowest strata probably correlate with the Riepe Spring Limestone of Steele (1960), and the remainder probably correlate with the Rib Hill Sandstone of the Ely district. The unit as a whole is believed to correlate with the lower part of the Arcturus Formation of the Confusion Range, western Utah, and the upper part of the Bird Spring Formation of southern Nevada.

DIABLO FORMATION

The Diablo Formation was first described from the Candelaria district near Mina in Mineral County (Ferguson and others, 1953; 1954). Subsequently, the name was applied by Ferguson and Cathcart (1954) to sedimentary rocks of supposed Permian age exposed along the east side of the southern Toiyabe Range and to small outcrops in the southern Toquima Range. In addition to these exposures, a lithologically similar sequence of rocks crops out near Clear Creek in the Monitor Range; we mapped this and other strata with Pablo(?) and Diablo(?) Formations (pl. A1), which are described elsewhere (see the section of this bulletin on Permian and Permian(?) systems, Undivided).

The most definitive description of the Diablo Formation is that by Speed and others (1977), who designated which outcrops of the Diablo were allochthonous and which were autochthonous. In addition to classifying and describing the outcrops, they proposed to restrict the formation name to autochthonous strata and to use the term "Diablo units" for allochthonous rocks until new formal names could be applied. We emphasize that we generally have mapped the Diablo Formation in its original sense, but we recognize that a different usage may be desirable. Serpentinite, for example, is excluded by us from the Diablo Formation and is described separately (see the section of this bulletin on Ultramafic Rocks of Paleozoic and (or) Mesozoic Age), although serpentinite outcrops generally lie within areas mapped as Diablo by Ferguson and Cathcart (1954). Speed and others (1977), likewise, described a serpentinite assemblage separately from the Diablo.

The Diablo Formation where autochthonous in the Toiyabe Range rests with angular discordance on folded slate and limestone of probable Ordovician age. At least 3000 feet (915 m) of section characterized by lithologic diversity and abrupt changes in facies occurs in the southern Toiyabe Range (Ferguson and Cathcart, 1954). Thicknesses ranging from about 131 feet (40 m) to more than 3280 feet (1000 m) are listed by Speed and others (1977) for eight outcrop areas in the Toiyabe Range. The formation is composed chiefly of soft, reddish-brown and yellowish-brown siltstone; subordinate gray to brown interbeds of pebble conglomerate, grit, and sandstone, all composed of chert detritus; and minor bioclastic limestone. Locally, such as in Jett Canyon in the Toiyabe Range, thick lenticular conglomerate containing boulders as much as 2 feet (.6 m) across is developed at the base of the unit; chert, volcanic rocks, and limestone are the major constituents of these clasts. Black shale and bedded chert are subordinate lithic elements. A few lenses of altered volcanic breccia are intercalated within the Diablo Formation northwest of Seyler Peak. Speed and others (1977) emphasized that "the Diablo units of the Toiyabe Range consist of entirely detrital rocks of which chert is a dominant or, at least, conspicuous component."

Several very small outcrops of fossiliferous "...coarse sandstone, with lenses of slate...of Permian(?) age... presumed...unconformably on the Ordovician..." (Ferguson, 1924, p. 25–26) appear at Black Mammoth Gulch, Toquima Range (near Manhattan). These Permian(?) rocks may represent landslide masses of Tertiary age and are so mapped (exotic slide blocks, pl. A1). A somewhat larger outcrop presents an abbreviated fossiliferous section 187 feet (57 m) thick near Willow Spring, about 7½ miles (12 km) southwest of Manhattan. The section is assigned to the Diablo(?) Formation and lies discordantly on lower Paleozoic clastic strata and intercalated(?) greenstone (mapped with shale and limestone, pl. A1), in part Cambrian in age. The Diablo(?) here consists of yellowish-brown, shaly to slabby, laminated to thin-bedded, alternating crinoidal silty limestone and calcareous siltstone, and minor silty to sandy detrital limestone that is especially common in the basal part of the section and that in the lowest 10 feet (3 m) alternates with layers and lenses of chert grit and conglomerate (Poole and Wardlaw, 1978).

Fossils collected from the Diablo Formation at two places in the Toiyabe Range (fig. A28) are described below. At one locality, in Pablo Canyon, a sparse megafossil assemblage is considered by Mackenzie Gordon, Jr., to be post-Wolfcampian Permian in age:

> USGS Colln. 22757-PC (field Z15324-2). Outcrop of orange-brown weathering fine-grained gray sandstone and reddish siltstone in bottom of upper Pablo Canyon, a few hundred feet NNE of Antimony prospect, approximately in SE¼ sec. 17, T. 10 N., R. 42 E. (unsurveyed) on east slope of Toiyabe Range, Nye Co., Nevada. Siltstone and sandstone. Mackenzie Gordon, Jr. (written commun., Feb. 2, 1967) reports the presence of

Kochiproductus? sp.	*Neospirifer* sp.
Megousia sp.	*Spiriferellina?* sp. indet.
Pugnoides? sp.	*Hustedia* sp.

and states that:

> Based on the range of *Megousia,* we generally think of this sort of assemblage as post-Wolfcamp Permian although, strictly speaking, *Megousia* in the west Texas section is now known to appear in uppermost Wolfcamp beds. G. A. Cooper has seen this collection and it was he who first positively identified the *Megousia* at a time when I was wavering between *Megousia* and *Anidanthus.* As he was coauthor of the genus with Muir-Wood it's hard to get a more authoritative determination.

No conodonts were recovered from this sample.

Another collection, Z15324-12C, made farther south in Boyd Canyon, from dirty siltstone and brown-weathering silty limestone of the Diablo Formation yielded brachiopods:

> Colln. Z15324-12c. Outcrop in western Boyd Canyon roughly in the NW¼ sec. 15, T. 9 N., R. 42 E. (unsurveyed), east slope of Toiyabe Range, Nye Co., Nevada.

Mackenzie Gordon, Jr. (written commun., Feb. 2, 1967) has reported the productoid *Anidanthus* or *Megousia* sp., and states:

This dirty siltstone contains very poorly preserved fossils, apparently all the same form. It is a small productoid with linoproductid sculpture, represented in this collection only by pedicle valves. It probably belongs in one or the other of the two genera cited above, which can be distinguished only by their brachial valves. Dr. Cooper has seen the collection and concurs in my identification. It is a different species from the *Megousia* in colln. Z15324-2, smaller and lacking a sulcus. The collection is considered Permian in age. The range of *Anidanthus* is about the same as that of *Megousia*.

J. W. Huddle (written commun., Apr. 12, 1968) identified the following conodont:

Gondolella sp. (small fragment)

and stated that:

Gondolella ranges from Pennsylvanian, Des Moines, through Triassic. This fragment could be a Permian species and does not contradict the age determined by brachiopods.

Thus, the collection is most likely Permian in age. Permian fossils also were collected from the basal coarse detrital member (field 11932-8d and -8x) of the several hundred-foot-thick section of the Diablo(?) Formation near Manhattan and reported on by Mackenzie Gordon, Jr., in consultation with E. L. Yochelson (written commun., Mar. 30, 1967):

USGS colln. 22807-PC (field 11932-8d). In westward drainage near south end of Toquima Range, on west side of Big Smoky Valley, 7 miles due south of Manhattan airport, near center of south line of sec. 8, T. 7 N., R. 43 E. From medium gray detrital silty to sandy limestone with lenses of chert rubble conglomerate, overlying phyllitic altered shale.

Bryozoans to Helen Duncan for report
Neochonetes sp. indet.
Yakovlevia sp. (*Muirwoodia*)
Megousia sp.
Rhynchopora? sp. indet.
Spiriferoid indet.

The limestone matrix contains brachiopods of Middle to Late Permian age.

USGS colln. 22808-PC (field 11932-8x). Same locality and bed as 11932-8d.

Corals to Helen Duncan for report
Neochonetes sp.
Echinauris sp.
Productoid indet., possibly *Megousia* or *Anidanthus*
Rhynchopora? sp. indet.
Spiriferoid indet.
Hustedia sp.
Aviculopecten? sp. indet.

This collection is likewise Permian in age. The two collections recall the fauna and lithology of the Permian collections from the Toiyabe Range that occur across the valley and 10 to 15 miles north-northwest.

Another collection (USGS colln. 22805-PC, field no. 11932-8A) from the same locality and same bed yielded the largest variety of all according to Mackenzie Gordon, Jr. (written commun., Apr. 4, 1967). He reported some of the same fossils listed in the above collections and the following:

Grandaurispina? sp. indet.
Camarotoechia? sp.
Spiriferellina? sp. indet.
Terebratuloid indet.

The Diablo in northern Nye County extends for about 35 miles (60 km) as a discontinuous series of outcrops in a narrow zone approximately along the long 117°15′. Speed and others (1977) indicated that this outcrop belt and another one, farther west outside the county, are along the northwestern margin of a region of widespread outcrop of Paleozoic rocks and coincide with the late Paleozoic continental margin. They described the Diablo as consisting of autochthonous neritic outer shelf (shallow marine) deposits and allochthonous deeper (bathyal) subsea fan and slope deposits. The shallow marine deposits are some of the youngest rocks that overlap the ancestral Antler orogenic belt (Speed and others, 1977, p. 307).

The Diablo Formation, where autochthonous, is similar in lithology and fauna to the Edna Mountain Formation of northern Nevada. It also is correlative with part of the Park City Group of western Utah and with the Phosphoria Formation of northwest Utah and southern Idaho.

The Garden Valley Formation and the Antler Peak Limestone are two more carbonate-chert clastic units in the overlap assemblage of Roberts and others (1958), cited by Speed and others (1977, p. 307) as being generally comparable in age and lithology to the autochthonous part of the Diablo Formation. They also called attention to the contemporaneity of the allochthonous bathyal rocks of the Diablo and the shelf deposits of the Pennsylvanian Wildcat Peak Formation farther east in the Toquima Range.

Permian(?) System

PABLO FORMATION

Ferguson and Cathcart (1954) designated as Pablo Formation a succession of altered volcanic and volcaniclastic rocks which they believed to overlie gradationally the Diablo Formation adjacent to Pablo Canyon in the Toiyabe Range. Speed (1973, p. 110; oral and written commun., 1970–1973) showed the Pablo to be discordant on the Diablo Formation and to represent the Golconda allochthon in the Toiyabe Range. Rocks believed to be of partly similar lithology to the Pablo and mapped with the Pablo by us crop out also in the San Antonio, Monte Cristo, and Shoshone Mountains, the Royston Hills, and the Paradise Range. Speed (1977a, p. 321), however, reported major lithogic differences between the type Pablo and the rocks at these other places and suggested that these strata not be named Pablo. He would restrict use of the name Pablo Formation to several outcrop areas in the southern Toiyabe Range approximately between lat 38°40′ (Wall Canyon) and 39° (Park Canyon).

There, a probable thickness in excess of 5000 feet (1524 m) was attributed to the formation (Ferguson and Cathcart, 1954), but Speed (1977a) indicated that a thickness estimate was not feasible because the strata are disrupted and deformed. The Pablo in this part of the Toiyabe Range has undergone low-grade regional metamorphism and, according to Speed (1977a), consists mainly of pelitic rocks and their derivatives, slate and hornfels, and chert and basaltic rocks. He observed

that the pelitic rocks (clayey and silty mudstone and siltstone) along with interbedded chert constitute more than half of the formation and that one-third is basaltic rock, including mostly pillow lava, some massive basalt, and basaltic (volcanogenic) sedimentary strata, such as mudstone and sandstone. Locally we mapped arkosic grit with the Pablo, but the grit should more properly be considered part of the Diablo Formation.

Summary descriptions of the rocks outside the Toiyabe Range mapped by us as Pablo or Pablo(?) Formation are given below. Because Speed (1977a) preferred not to use the name Pablo for these strata, his suggested correlatives are also given.

In the Shoshone Mountains, Speed (1977a, p. 320) measured 2625 feet (800 m) of chiefly volcanogenic beds that he termed the "sub-Grantsville rocks" and that Silberling (1959, p. 6) called Pablo and described as consisting of three members. The lower, with a minimum thickness of 1200 feet (366 m) is a heterogeneous unit made up of altered andesitic lava and tuff, sandstone, argillite, and pebble- and cobble-conglomerate. Although most of the detritus is derived from intermediate or basic volcanic rocks, the conglomerate contains clasts of granitic plutonic rocks, chert, and limestone. The middle member, about 200 feet (61 m) thick, is thick-bedded, fine-grained bioclastic limestone with tuffaceous and conglomeratic lenses. The upper greenstone member of Silberling is at least 1000 feet (305 m) thick and comprises massive, dark-greenish-gray andesitic lava and breccia. This member was described by Bonham (1970) in the Gold Park district as mainly meta-andesite breccia with minor lavas and lenses of slate and chert. The dominantly volcanic succession of the sub-Grantsville rocks is part of either an upper Paleozoic arc terrane or a younger (Triassic) succession interleaved at depth with rocks of a shelf terrane, according to Speed (1977c, p. 357–358). He also stated that if the volcanic rocks are so interleaved, they would likely have been the product of a collision of the upper Paleozoic arc terrane with the continent.

In the Paradise Range, there is a three-fold succession similar to that of the Shoshone Mountains (Vitaliano and Callaghan, 1963). The Pablo in the Paradise Range and adjacent Lodi Hills, according to Speed (1977a, p. 321), is part of a clastic and volcanic autochthonous assemblage of rocks of ill-defined age and kinship suggestive of the Dunlap Formation to the south and west. This correlation would eliminate a problem presented by the assemblage at and north of Alum Spring on the east side of the Paradise Range. There, the strata originally were shown to overlie Permian quartzite (Vitaliano and Callaghan, 1963). This quartzite was later questionably assigned to the Cambrian Gold Hill Formation (Kleinhampl and Ziony, 1967), and we here include it with the Jurassic Dunlap(?) Formation. This assignment requires the overlying rocks, if they are Pablo and pre-Jurassic, to have been tectonically emplaced onto the quartzite; however, field evidence does not strongly support this interpretation.

Elsewhere, rocks assigned to the Pablo Formation in the Royston Hills are well-stratified, light-gray to greenish-gray chert with subordinate greenstone lenses, much like the cherty middle part of the Pablo in Jett Canyon, Toiyabe Range. In the San Antonio Mountains, exposures of the Pablo are lithologically similar to those in the Toiyabe Range and include abundant dark-gray, fine-grained volcaniclastic strata. Speed (1977a, p. 321) suggested that these outcrops might be correlative with the Mina Formation of Speed (1977b) (see the section of this bulletin on Triassic System—Excelsior Formation). Strata mapped as Pablo(?) at the Hall molybdenum property are at least in part Mississippian. F. G. Poole (written commun., Oct. 1968) indicated that conodonts he collected from a site there (USGS Colln. 22283-PC) were described by J. W. Huddle (written commun., March 1968) as almost certainly a Middle or Late Mississippian and possibly Chester (Late Mississippian) fauna.

Until recently, the only diagnostic fossils known in the Pablo Formation came from the limestone member in the Shoshone Mountains. There, brachiopods and pelecypods are suggestive of a late Paleozoic age (Silberling, 1959, p. 9). Also, the Middle Triassic Grantsville Formation succeeds the Pablo in the Shoshone Mountains and, therefore, the Pablo could conceivably extend into the Lower Triassic. This possible younger age favors a proposal by Speed (1977c, p. 357–358) that the Pablo there could be part of a Triassic shelf terrane. His alternative proposal assigned this Pablo to late Paleozoic island arc terrane. That these strata correspond to the type Pablo is rejected by Speed (1977a, p. 320; 1977b, p. 327), however, and newly discovered radiolarians found by R. C. Speed and F. G. Poole in chert of the type Pablo were dated as Mississippian (D. L. Jones, oral commun., Aug. 1979). Thus, the Permian age of the Pablo Formation is more questionable now than when first defined, and we consider the Pablo to be Permian(?). Also, the unit has been shown not to be in depositional contact with the underlying Permian Diablo Formation in the Toiyabe Range, as was once supposed, but to be allochthonous (Speed, 1977a).

Ferguson and Cathcart (1954) correlated the Pablo and Diablo Formations with equivalents of the Early Triassic Koipato Formation of north-central Nevada. Stewart and Carlson (1974) assigned to the Koipato the rocks mapped by Silberling (1959) as Pablo near Ione in the Shoshone Mountains, although nearby rocks mapped as Pablo by Bonham (1970) were assigned by Stewart and Carlson to the Havallah sequence of Silberling and Roberts (1962). Speed (1977c, p. 357) indicated no specific correlation for the volcanic succession of the Pablo in the Shoshone Mountains but stated that these rocks were unrelated to the Pablo Formation in the Toiyabe Range. The Pablo was also correlated in part with the Excelsior Formation of western Nevada (Ross, 1961; Silberling and Roberts, 1962; Speed, 1973) but Speed (1977a, 1977b) later abandoned this correlation.

Permian and Permian(?) Systems, Undivided

Rocks of unknown age, but which compare lithologically with the Diablo and Pablo Formations of the

Toiyabe Range, crop out in the Monitor Range between Danville and Clear Creeks. These strata are grouped in an allochthon of undifferentiated Pablo(?) and Diablo(?) Formations on the geologic map (pl. A1). The strata at Danville Canyon, about 1000 feet (305 m) thick, consist chiefly of green and brown chert, minor zones of siltstone and gritty sandstone, and, near the uppermost exposures, argillite and argillaceous limestone(?). Some of the coarser clastic beds are phosphatic at Danville Canyon. There, near the base of the allochthon several feet of siltstone and sandstone are composed of grains of chert and quartz and pellets of apatite (Rogers and others, 1970, p. C57–C58). J. W. Huddle (written commun., 1965) reported reworked fragments of the late Paleozoic conodont *Gondolella* sp. from these phosphatic beds. The chert of the undifferentiated Pablo(?) and Diablo(?) unit extends northward from Danville Canyon to Sawmill Canyon, where it forms the cherty lower part of a probably more than 2000-foot (610-m)-thick unit whose thicker upper part consists of carbonaceous and siliceous shale, minor broadly lenticular bioclastic limestone, and greenstone.

Ultramafic Rocks of Paleozoic and (or) Mesozoic Age

Ultramafic rocks (pl. A1), rare in northern Nye County, compose no more than about a dozen small scattered outcrops from near Belmont on the east to the crest of the Toiyabe Range on the west. Some are so small that they had to be exaggerated in order to show on plate A1. One of the largest, in Pablo Canyon, Toiyabe Range, forms a very narrow sinuous body about 1 mile (1.6 km) long. The outcrops consist mostly of serpentinite; serpentinized peridotite(?) and diabase lie near Monarch Ranch south of Belmont. Chromite is visible in some of the serpentinites, and nickel-bearing deposits occur near serpentinite at Willow Spring, southern Toquima Range. The serpentinites, commonly sheared and fault-bounded, may have an emplacement age different from their genetic age. All are believed to have been derived from the upper mantle during tectonism at the continental margin and may have been emplaced some time between the Late Devonian and the Triassic (see the section of this bulletin on Major Structures of Pre-Tertiary Age).

Triassic System

CANDELARIA FORMATION

The Candelaria Formation was defined by Muller and Ferguson (1936, p. 243–244) as the lowest Mesozoic unit in the Hawthorne and Tonopah 30-minute quadrangles. They measured 3225 feet (983 m) of dominantly shale, sandy shale, and sandstone in an incomplete section in the type area in the Candelaria Hills, where the formation overlies, with progressively less angular discordance, Ordovician (Palmetto Formation) and Permian (Diablo Formation) units. Several small outcrops of the Candelaria were found by F. G. Poole (oral commun., May 1970; Poole and Wardlaw, 1978) in northern Nye County. Most of them are clustered about 7 miles (11 km) southwest of Manhattan near Willow Spring in the southwestern Toquima Range. These outcrops and another outcrop of possible Candelaria 16 miles (26 km) south-southeast near the Midway Mine, San Antonio Mountains, seem previously to have been assigned to the Ordovician Palmetto Formation (Ferguson and Cathcart, 1954; Kleinhampl and Ziony, 1967). Poole and Wardlaw (1978, p. 272) also reported finely clastic strata at Marysville Canyon, Toiyabe Range, containing a fauna similar in age to the fauna in the basal Candelaria near Willow Spring.

The formation at Willow Spring is best described by Poole and Wardlaw (1978), who measured as much as 805 feet (245 m) of flyschlike strata. The upper beds and generally the basal beds of the Candelaria are faulted out. The remainder are commonly pale yellowish brown and shades of brown and orange. In their measured section, about 50 feet (15 m) of silty and dolomitized limestone are overlain successively by about 65 feet (20 m) of quartzite and siltite that grade up through about 130 feet (40 m) of beds to 120 feet (37 m) of platy argillite, followed by a marker zone 80 feet (25 m) thick of quartzite and siltite, 295 feet (90 m) of siltite, and 50 feet (15 m) of argillite. A few dark-gray and brownish-gray recrystallized limestone lenses as much as 10 feet (3 m) thick are scattered in the shaly section and locally display ammonites, millimeter-size gastropods, and pelecypods. A locally carbonatized greenstone breccia (autobreccia?) lies disconformably beneath the Candelaria and possibly is intercalated in Cambrian strata, whereas nickeliferous silicified carbonate lenses associated with serpentine are exposed as northward-elongate faulted lenses adjacent to the Candelaria exposures. Clasts of serpentine occur in a conglomerate bed within the formation near here. The Candelaria at Willow Spring locally has been emplaced onto Cambrian and Ordovician strata along a low-angle fault (pl. A1). At one place, though, a basal silty limestone of the Candelaria appears to rest with probable unconformity on the Diablo Formation. The entire sequence is overlapped on the west by Quaternary alluvium (fanglomerate).

The type Candelaria Formation is assigned an Early Triassic age (Scythian Stage of Europe) on the basis of three pelecypod species of the genus *Claraia*, which have worldwide distribution, and a collection 40–50 feet (12–16 m) higher of ammonites, including *Meekoceras, Proptychites,* and *Grypoceras*, all of which suggest an age similar to that of the Woodside Shale of Utah and Idaho and part of the Moenkopi Formation of the Colorado Plateaus region (Muller and Ferguson, 1939, p. 1583–1586). *Claraia stachei* (Bettner) and gyronitid ammonites and *Proptychites* sp., collected by F. G. Poole from one Willow Spring locality, indicate an early Dienerian age and correlation with the lower part of the type Candelaria. Other collections near Willow Spring contain faunas similar to those in the type Candelaria; collectively, they represent late Griesbachian and early Dienerian time (Silberling, 1973). See Poole and Wardlaw (1978) for more complete faunal descriptions,

including some for conodonts, at the Willow Spring locality.

GRANTSVILLE FORMATION

Muller and Ferguson (1939, p. 1592–1594) proposed the name Grantsville Formation for the oldest clastic and carbonate rocks of Triassic age in the Shoshone Mountains. The only known outcrop of the unit is in that part of the range between Ione and Grantsville Canyon. The Grantsville Formation overlies the Pablo Formation with erosional disconformity but with an apparent angular discordance.

The Grantsville consists of a succession of shallow marine beds that record a beginning of marine transgression and sedimentation, which began somewhat earlier farther north according to evidence outside the county in the New Pass Range (Silberling, 1959, p. 13). Speed (1977c, p. 357) classed the Grantsville strata as shelf terrane. Muller and Ferguson (1939, p. 1592) and Silberling (1959, p. 10) have recognized two members of the Grantsville: a lower clastic unit about 400 feet (122 m) thick and an upper limestone unit about 350 feet (106 m) thick. The clastic member is composed of interbedded conglomerate and silty argillite which have undergone low-grade regional metamorphism. Conglomerate layers are massive, weather dark reddish brown, and consist of pebbles of gray and brown chert in a silicified, gritty chert-sandstone matrix. The argillite is purplish or brownish claystone that generally lacks slaty cleavage. The upper limestone member is silty and sandy near the base and contains thin shale intercalations; it grades upsection into more massive and relatively pure limestone. A thin, dark-brown fragmental and silicified zone, which has been interpreted as a pre-Luning Formation soil zone (Muller and Ferguson, 1939, p. 1593), marks the top of the Grantsville.

An abundant fauna of pelecypods and cephalopods is reported from the formation by Muller and Ferguson and by Silberling. The former tentatively considered the Grantsville to be of early Middle Triassic age. However, more recent fossil collections indicate that it is of latest Middle Triassic or perhaps earliest Late Triassic age (Silberling and Roberts, 1962, p. 31). The Grantsville Formation is probably correlative with the lower parts of the Augusta Mountain Formation of the New Pass Range and the Natchez Pass Formation of the Humboldt Range. Strata referred to the Excelsior Formation in the Gillis Range in Mineral County may also be partial time equivalents.

EXCELSIOR FORMATION

The Excelsior Formation (pl. A1) is a term that was first proposed for many thousands of feet of dark rocks chiefly of volcanic aspect in the Gold Range mining district, Excelsior Mountains, Mineral County (Muller and Ferguson, 1936, p. 244–245). These rocks are commonly regionally metamorphosed and consist of greenstone, felsite, and sedimentary strata that are dominantly chert and water-laid tuff (Muller and Ferguson, 1936, p. 245; 1939, p. 1586–1587). The formation was mapped over an extensive area of west-central Nevada by Ferguson and Muller (1949, pl. 1), who expressed reservations about the assignment of all these rocks to the Excelsior. Ross (1961, p. 21) also mapped extensive Excelsior outcrops in Mineral County but stressed even more strongly the stratigraphic problems involving the Excelsior and the somewhat similar Pablo Formation. Subsequently, Nielsen (1964) divided the Excelsior into two units of different age and restricted the name Excelsior to the lower unit. This consists of volcanogenic chert and argillite and andesitic tuff, minor dolomite, and tuff breccia. He named the upper unit the Gold Range Formation and designated the central Excelsior Mountains as the type locality. There, his Excelsior Formation (restricted) underlies the Gold Range with angular discordance. Thereafter, Speed (1973) noted that five discrete groups of rocks had been mapped as Excelsior, including allochthonous Permian andesite and rocks that are probably subunits of Dunlap Formation and as young as Jurassic. Later he defined two new formations, the Mina and the Black Dyke, and redefined the Gold Range Formation of Nielsen (1964); all were divided mainly from the Excelsior in Mineral County. He also locally divided the Excelsior into five units, including these three formations, with some units differing widely in age (Speed, 1977b, p. 325–327). In this last paper, he suggested abandoning the term Excelsior Formation but retaining the term "Excelsior rocks" for sequences not reclassified into new formations. The Excelsior Formation as mapped by us generally conforms to the usage of workers prior to Nielsen (1964) because the newer revised stratigraphy had not yet been sufficiently developed. Should one wish to adopt Speed's (1977b) suggested revision of the Excelsior, one would need only to substitute "Excelsior rocks" for much of what we show as Excelsior Formation (pl. A1). All the rocks shown as Excelsior in northern Nye County on plate A1 are of uncertain stratigraphic position; they resemble some of the rocks mapped as Excelsior by Ross (1961) in Mineral County.

We use the term Excelsior(?) Formation for scattered outcrops of dark siliceous strata and volcanic rocks in the Lodi Hills, Monte Cristo Mountains, and the Paradise Range. Rocks mapped in the Royston Hills as the Excelsior by Albers and Stewart (1972) are reassigned in the present report (pl. A1) to the Pablo Formation, but perhaps neither designation is entirely satisfactory. Speed considered the strata there to be the Mina Formation of Speed (1977b, fig. 1).

In the southwestern part of the Paradise Range about 5 miles (8 km) south of Gabbs, the Excelsior is a metamorphosed and sheared unit consisting of dark-greenish-gray to black andesitic flows and tuffs and fine to coarse volcaniclastic rocks and minor limestone (Permian or Triassic sedimentary and volcanic rocks of Vitaliano and Callaghan, 1963). Neither the base nor the top of the formation is exposed, and its thickness is not known.

Farther north in the Lodi Hills, perhaps as much as a few thousand feet of greenstone, quartz-feldspar porphyry, conglomerate, volcaniclastic beds, locally metamorphosed dark-gray, fine-grained siliceous clastic

strata, and minor chert and carbonate beds compose the Excelsior. These rocks underlie most of the northern and eastern part of the Lodi Hills in a belt from near the Illinois Mine to Quartz Mountain. Greenstone, conglomerate with clasts of volcanic rock, and quartzitic sandstone in the southeasternmost part of the belt were assigned originally to the Permian(?) by Vitaliano and Callaghan (1963) and subsequently combined with the Excelsior Formation by Kleinhampl and Ziony (1967). The conglomerate contains clasts of mostly dense aphanitic volcanic rocks and minor quartzite; the matrix is commonly pelitic and locally a siltite. Some of the fine-grained siliceous clastic strata includes thin beds and pods of dark-gray to black, locally dirty quartzite that is unique to the westernmost part of the county and possibly to the Lodi Hills. The quartzite is very fine grained and poorly sorted but contains well-rounded grains. Carbonate units are locally marmorized, commonly weather yellowish brown, and consist of light-gray to yellowish-gray, laminated, very fine to medium-grained dolomite or limestone. For reasons of map scale and expediency, outcrops of limestone and dolomite in the belt, some of which may be Luning Formation, are all included with the Excelsior.

The Excelsior in the Lodi Hills is faulted against and locally appears to be in depositional contact with the Upper Triassic Luning Formation. The Excelsior there remains part of a major stratigraphic problem. R. C. Speed (written commun., 1970) tentatively considered the rocks to be part of an autochthonous clastic, volcanic, and carbonate assemblage of undifferentiated Permian and Triassic age; he later (Speed, 1977a, p. 321; 1978, p. 262) indicated that the assemblage has a possible kinship with rocks of the Dunlap Formation to the south and west.

The Excelsior Formation of the Monte Cristo Mountains in Nye County is coextensive with rocks mapped as Excelsior by Ross (1961, pl. 1) in the same range in adjacent Mineral County and near Rawhide farther west. R. C. Speed (written commun., Nov. 1970) chose not to separate the Excelsior from the Luning Formation in these places and assigned both to a probable nearshore depositional assemblage of carbonate rocks and chiefly volcanogenic clastic rocks. The strata were shown by Ross (1961, fig. 4) as possibly consisting of predominantly intermediate to felsic flows and tuffs; he postulated that the section had been displaced along the inferred major Gillis thrust eastward onto Permian Pablo-equivalent rocks. According to this postulate, the dominantly volcanic section assigned to the Excelsior in the Gillis Range and near lat 39° N. in extreme western Nye County is part of the Gillis plate, but the concept of a regional Gillis thrust has been questioned (Speed, 1973, p. 110; 1977b, p. 327).

LUNING FORMATION

Muller and Ferguson (1936, p. 245–246; 1939, p. 1596) first described the Luning Formation, chiefly limestone and dolomite with subordinate clastic rocks, and established its type locality in the Pilot Mountains in Mineral County. The formation there is confined to a regionally extensive thrust sheet, the Luning allochthon above the Luning thrust (Ferguson and Muller, 1949; Oldow, 1975, p. 359; 1978, p. 223–225; Speed, 1977b, p. 326–328). Rocks assigned to the Luning Formation in northern Nye County crop out mainly in the Shoshone Mountains, Paradise Range, Lodi Hills, and Royston Hills. A nearly complete section of the Luning is present only in the Shoshone Mountains, where the Luning thrust and Luning allochthon were not recognized. There, the formation is about 3000 feet (915 m) thick and rests with erosional disconformity on the Grantsville Formation; the base of the formation is not exposed elsewhere in the county. Muller and Ferguson (1939, p. 1597) estimated the thickness of the unit to be more than 5000 feet (1525 m) in the Paradise Range. A minimum of 6000 feet (1830 m) of Luning strata crops out in the Cedar Mountains just west of the county line (Ross, 1961, p. 23).

Silberling (1959) divided the Luning of the Shoshone Mountains into four members: a basal clastic unit, about 645 feet (197 m) thick, composed of intertonguing chert-pebble and cobble conglomerate, sandstone, and argillite; thin-bedded shaly limestone and intercalated reddish-brown- and lavender-weathering shale and siltstone, totaling about 570 feet (194 m); light-reddish-gray-weathering calcareous shale, 550 feet (168 m) thick; and an upper unit of thick-bedded gray limestone and dolomite with an exposed thickness of 2000 feet (610 m).

Three units comprise the Luning of the southern Lodi Hills (Vitaliano and others, 1957). Thin-bedded, dark-gray limestone is succeeded by a dominantly clastic unit of dark-greenish-gray to black shale, slate, limestone, and conglomerate. The stratigraphically highest exposed member is a dense, dark-gray to black, cherty dolomite with subordinate thin-bedded black limestone. All these rocks have been affected by regional and contact metamorphism.

In the Paradise Range, altered and locally intensely recrystallized dolomite and limestone, probably equivalent to the upper carbonate unit of the Shoshone Mountains and the Lodi Hills, form the upper plate of the Paradise thrust. Hydrothermal alteration of this unit adjacent to a granodiorite body east of Gabbs may account for large resources of magnesite and brucite. Contrarily, it has also been proposed (see the section of this bulletin on Gabbs District) that the magnesite is a syngenetic chemical sedimentary deposit rather than a hydrothermal one. Under these circumstances, a bedded magnesite unit could be regionally extensive. Elsewhere in the Paradise Range, the Luning, represented by both carbonate and clastic lithologies, has not been divided from the Gabbs and Sunrise Formations because of poor exposures and structural complications.

The Luning Formation exposed in the Royston Hills exhibits a threefold lithologic division comparable to that of the Lodi Hills, although the rocks are much less affected by metamorphism. A lower unit of thin-bedded limestone with minor clastic components is succeeded by about several thousand feet of dark-greenish-gray to reddish-brown slaty shale, argillite, and chert-pebble conglomerate. The uppermost exposed Luning is made

up of medium- to thick-bedded, dark-bluish-gray bioclastic limestone with some dolomite.

Several hundred feet of limestone and minor amounts of slate in what Ferguson and Cathcart (1954) interpreted as a thrust plate of Luning Formation on Dunlap Formation crop out at the extreme south end of the Toiyabe Range (Rainier Mountain). The formation and its contact are largely covered by colluvium and talus, and affirmation of the contact and structural relations were difficult.

A considerable number of fossil collections from different parts of the Luning Formation throughout the region have been described (Muller and Ferguson, 1939; Silberling, 1959). Most faunas are distinctive of the upper Karnian and lower Norian Stages of the European Upper Triassic. Accordingly, the Luning Formation has been correlated with the upper parts of the Augusta Mountain and Natchez Pass Formations and with the Cane Spring, Osobb, Grass Valley, and Dun Glen Formations, all of which crop out in north-central Nevada. Speed (1978, p. 260) included only carbonate strata of a shelf terrane with the Luning Formation and indicated that Ferguson and Muller (1949) had assigned carbonate rocks of other terranes to the formation. Oldow (1978) and Speed (1977b; 1978) considered some of these other carbonate rocks to be parts of newly defined units that are partial age equivalents of the Luning, including the Pamlico Formation of Oldow (1978) and the Gold Range Formation of Speed (1977b).

Triassic and Jurassic Systems

GABBS AND SUNRISE FORMATIONS, UNDIVIDED

Muller and Ferguson (1936) designated the conformable sequence of uppermost Triassic and lowermost Jurassic rocks in the Gabbs Valley Range in Mineral County as the Gabbs and Sunrise Formations, respectively. The distinction between the two formations at their type locality is based almost entirely on paleontology. The units in northern Nye County cannot be separated on a lithologic basis; accordingly, we have mapped them as a single unit where they are exposed in the Shoshone Mountains and the Paradise Range (pl. A1).

The most complete section, about 2700 feet (823 m) thick, crops out in the Shoshone Mountains south of Milton Canyon. Although the base of the Gabbs Formation is not exposed there, Silberling (1959, p. 26) postulated that, by analogy with relations at the type locality, the contact with the underlying Luning Formation is conformable. Conformable relations between the Gabbs and Luning Formations can be observed in the Paradise Range east of Gabbs.

A monotonous sequence of interbedded shaly calcareous siltstone and silty limestone constitutes the Gabbs and Sunrise Formations. The siltstone is commonly dolomitic and carbonaceous and weathers black, lavender, and brown. The limestone occurs as thin-bedded to massive, argillaceous, gray to black units that weather brownish-gray to buff. Where massive, the limestone commonly is bioclastic and, in part, oolitic. Fine-grained calcareous sandstone and sandy limestone, locally conglomeratic, are minor elements in the succession. In the Paradise Range, the formations are extensively altered and silicified.

Both formations contain abundant and well-preserved fossils. The faunal evidence indicates that the Gabbs is Upper Triassic (Norian and Rhaetian European Stages) and that the Sunrise is Lower Jurassic (Hettangian, Sinemurian, and Pliensbachian European Stages). Silberling (1959, p. 29) suggested the possibility, however, that the uppermost part of the sequence in the Shoshone Mountains may be as young as Bajocian (early Middle Jurassic).

The Gabbs and Sunrise Formations in west-central Nevada show considerable overlap in age range with the autochthonous Gold Range Formation of Speed according to Oldow (1978, p. 231). He indicated, however, that the Gabbs and Sunrise are part of allochthonous terranes in the region and did not specifically describe the Mesozoic rocks of northern Nye County. Paleogeographically, the Sunrise-type strata are a product of an offshore marine subtidal environment and are considered to be part of an early Mesozoic volcanic arc terrane (Stanley, 1977; Speed, 1978, p. 260).

Jurassic System

DUNLAP AND DUNLAP(?) FORMATIONS

The name Dunlap Formation was assigned by Muller and Ferguson (1936, p. 250) to a sequence of coarse clastic rocks that overlies older Mesozoic rocks, commonly with angular discordance, in the Pilot Mountains in Mineral County. Stanley (1971) recently described the formation and emphasized its tectonic and sedimentary history. Strata assigned to the Dunlap and Dunlap(?) in northern Nye County have restricted exposures; they crop out in the Toiyabe Range near Ophir Canyon and at the extreme southern end of the range, locally along the west flank of the Shoshone Mountains, about 3 miles (5 km) northeast of Downeyville in the Paradise Range and locally along the east flank of the range, in the Lodi Hills, and in the central part of the Royston Hills.

Several hundred feet of Dunlap Formation unconformably overlies the Pablo Formation at the south end of the Toiyabe Range (Rainier Mountain). The rocks near the base of the succession are chiefly interbedded reddish-brown conglomerate, sandstone, and siltstone. The conglomerate is lenticular and contains well-rounded pebbles and cobbles of limestone and chert; some of the sandstone horizons display well-developed graded bedding. Greenish-gray conglomerate and gritty sandstone occur higher in the sequence. A thin but similar clastic sequence, commonly mildly metamorphosed and including conglomerate and quartzitic siltstone and sandstone, is assigned to the Dunlap(?) and is poorly exposed in a stripped and trenched area just west of Ophir summit. The formation here may be faulted against the Pablo Formation, with diorite intruded along the

faults; however, the contact is not well exposed and was not carefully examined.

In the Shoshone Mountains, more than 750 feet (229 m) of strata assigned to the Dunlap conformably succeeds the undivided Gabbs and Sunrise Formations near Milton Canyon, about 10 miles (16 km) south of Ione (Silberling, 1959). The basal unit, a thick, massive, brown, fine-grained sandstone, is overlain by purplish sandstone and siltstone; some of the grains are clearly volcanic in origin. The upper part of the Dunlap is composed of purplish-brown siltstone and sandstone with intercalated, light-gray dolomitic limestone and quartz-sandy laminated dolomite. Relatively common purplish to reddish-brown conglomerate interbedded with similar colored quartzite and minor quartzitic siltstone and argillite about 2.5 miles (4 km) northeast of Ione is assigned to the Dunlap(?). If not Dunlap, the outcrops are most probably Mesozoic. The strata, which form inliers surrounded by Tertiary volcanic rocks, were originally assigned to the Cambrian Gold Hill(?) Formation by Kleinhampl and Ziony (1967), but the conglomerate is coarser than and the purplish to reddish-brown color is different from the Gold Hill.

Another outcrop about 3/4 mile (1.2 km) east of Ione and other scattered outcrops along the east flank of the Paradise Range, however, more closely resemble the Gold Hill, even though they are mapped as Dunlap(?) Formation. They contain much less conglomerate than the other Dunlap(?) outcrops. The main constituent is a white to grayish-orange, very thick-bedded, faintly stratified quartzite that is about 1000 feet (305 m) thick at Ione, according to Silberling (1959, p. 5). These outcrops were all assigned to the Cambrian Gold Hill(?) Formation by Kleinhampl and Ziony (1967). The Ione outcrop was earlier assigned to the Cambrian(?) by Silberling (1959, p. 4–6, pl. 10), who said that the quartzite probably rested on a Cambrian(?) dolomitic unit more than 1000 feet (305 m) thick. We provisionally assign the dolomite to the Luning Formation, however, and a younger age than Cambrian for the quartzite seems certain even if the provisional assignment to the Dunlap is not sustained. Vitaliano and Callaghan (1963) assigned the quartzitic outcrops of the Paradise Range to the Permian. We cannot rule out a Permian age there, but other observations concerning the outcrops along the east flank of the range could favor a Jurassic assignment (see the section of this bulletin on Permian(?) System—Pablo Formation). Other quartzites in the Lodi Hills were mapped as Permian by Vitaliano and Callaghan (1963), but we place them with the Excelsior Formation along with other problematical strata. A few miles to the south in the Paradise Range, at the south end of Lodi Valley (NE/4 S6,T12N,R37E), another small exposure of reddish-brown siltstone, sandstone, and sandy limestone was mapped as Dunlap Formation by Ferguson and Muller (1949) and Vitaliano and Callaghan (1963), and we have retained their designation.

The Dunlap Formation in the Royston Hills, although surrounded by Tertiary volcanic rocks, probably rests unconformably on the Luning Formation in relations similar to those in the Cedar Mountains to the west as described by Ross (1961). The rocks are dark-brown to purple conglomerate, siltstone, and sandy limestone, in large part silicified. A few thin lenses of greenstone are intercalated with these clastic rocks. Indeterminate plant fossils are abundant in some of the sandstone horizons.

The Dunlap has been shown to be an orogenic deposit that developed with diastrophism beginning in the Early Jurassic. Muller and Ferguson (1939) considered the formation to represent a continental alluvial fan deposit. Stanley (1971, p. 467–471) indicated that the Dunlap consists dominantly of alluvial fan material of water-flow origin and intertidal red mud and carbonate beds that intertongue locally with the marine Sunrise Formation. The clastic strata include volcaniclastic, arkosic, and quartzose beds, and Stanley (1971, p. 473) determined that the depositing paleocurrents moved generally northward. He also considered the clastic parts of the Sunrise and Dunlap Formations possibly "...to represent a transitional zone between the volcanic suites on the west (eugeosyncline) and pure quartz sandstone (Nugget-Navajo-Aztec Sandstones) on the east (miogeosyncline)." In addition, he favored the view that a positive area did not exist in central Nevada in the Early Jurassic, and that a continuous miogeosynclinal environment extended across Nevada. The idea of a Mesocordilleran high (geanticline) in the Jurassic separating marine deposits in the west from continental or mixed continental and marine in the east (McKee and others, 1956) was also questioned by Stanley and others (1971, p. 16–17). Hallam (1965, p. 1499) mentioned the lack of evidence for a thinning or change to a littoral facies eastward across Nevada and Oregon. However, he accepted the concept of at least a local shoreline on the south in west-central Nevada as proposed by Ferguson and Muller (1949). Nielsen (1964, p. 69) interpreted the quartzose clastic beds to represent strandline deposits, a view adopted and applied by Speed and Jones (1969, p. 2551; also, see Speed, 1978, p. 263) to mature quartz sandstones of Jurassic age in west-central Nevada and, specifically, the Boyer Ranch Formation of northern Churchill County (Dixie Valley area).

The suggestion, mentioned above, that the Dunlap and Sunrise Formations are intertonguing facies (Stanley, 1971, p. 459) is unsupportable according to Speed (1978, p. 260, 263), who considered the formations to belong paleogeographically to different regional terranes. He assigned the Dunlap and Sunrise to orogenic and volcanic arc terranes, respectively, and, in the more classic sense, considered the clastic Dunlap to represent orogenic deposits that formed during major deformation and destruction of an early Mesozoic marine province.

Diagnostic fossils have not been obtained from rocks mapped as Dunlap or Dunlap(?) Formations in northern Nye County. Muller and Ferguson (1939, p. 1621) have assigned an Early Jurassic age to the Dunlap of the Excelsior Mountains and Garfield Hills in Mineral County. Silberling (1959, p. 30), however, suggested that Dunlap strata in the Shoshone Mountains might be assigned at least in part to the lower Middle Jurassic, because there is no marked stratigraphic break between them and the underlying undivided Gabbs and Sunrise Formations. Hallam (1965, p. 1488), contrarily, found

no paleontological evidence for an extension of the Dunlap into the Middle Jurassic, and Stanley (1971, p. 458) believed that the formation could be entirely Early Jurassic. Stanley (1971, p. 457–458) further stated that the Dunlap is partly the age equivalent of the Sunrise Formation as well as of the Gardnerville and the Sailor Canyon Formations farther west.

Cretaceous System

Strata assigned to the Newark Canyon Formation have been mapped west of Duckwater in the Pancake Range. The beds consist of generally reddish-brown to locally gray conglomerate, sandstone, shale, and some mudstone. Outcrops appear in relatively flat areas and subdued hills with local low ledges and cliffs. One dinosaur bone of nondefinitive type found as a cobble in a wash is attributed to the formation.

Mesozoic and (or) Cenozoic Erathems

Two small areas 17 and 19 miles (27 and 31 km) northwest of Duckwater are underlain by volcanogenic sedimentary rocks and tuffs (pl. A1), including white, locally porcelaneous, bedded tuff and light-gray tuffaceous sandstone. The age of these strata, based on the presence of volcanic material, is most likely Tertiary, but they are assigned to the Mesozoic and (or) Cenozoic.

Closer to Duckwater, in the W/2 S33,T13N,R56E, is an outcrop of a reddish-weathering limestone conglomerate assigned to the conglomerate and (or) breccia of the sedimentary rocks and tuffs unit. The outcrop could be a remnant of the Eocene Sheep Pass Formation.

Elsewhere in the Pancake Range, a partly silicified breccia and conglomerate unit mapped with the sedimentary rocks and tuffs, conglomerate and (or) breccia (pl. A1), crops out locally adjacent to Quaternary fanglomerate at the west base of Portuguese Mountain. The breccia and conglomerate contain pebble- to cobble-size and locally boulder-size clasts and fragments of Paleozoic dolomite, quartzite, and chert, and volcanic material. The volcanic component of the unit indicates a Tertiary age, and, as best we can determine, Quinlivan and others (1974) have assigned the sequence to an allochthonous(?) volcanic rocks unit of Oligocene(?) age. We show the strata as Mesozoic and (or) Cenozoic.

Other strata with the same age assignment (sedimentary rocks; fine to coarse clastic rocks; locally includes limestone, pl. A1) crop out in the low hills east of Indian Springs Ranch in Little Smoky Valley. There the beds consist of fine to coarse clastic rocks, especially shale, mudstone, and conglomerate.

Nearby, in the Park Range, 11.75 miles (19 km) due north of Pritchards Station, pale pastel (grayish-orange-pink, grayish-orange) outcrops consist of interbedded siliceous siltstone, shale, grit, conglomerate, and siliceous limestone (sedimentary rocks; fine to coarse clastic rocks; locally includes limestone, pl. A1). Clasts and fragments in the coarse detrital beds are composed of dolomite, limestone, and quartzite. Pelecypods, conifer needles, and bits of reeds and stems occur in the limestone, but J. A. Wolfe (written commun., Mar. 1962) indicated that the state of preservation of the plants prevented any useful identification. The unit is more likely to be Tertiary than Cretaceous because some lamina contain quartz grains that were possibly derived from volcanic rocks.

Farther south, a small outcrop 5 miles (8 km) northwest of Morey Peak, Hot Creek Range, consists of gently north-dipping, brown and gray, medium- to thick-bedded, chert-pebble and -cobble conglomerate whose clasts are subrounded to subangular. Nearby, float boulders of dolomite and vitreous quartzite may also have come from the conglomerate. The age of the unit could not be positively ascertained; however, the strata are included with those assigned to the Mesozoic and (or) Cenozoic (sedimentary rocks, conglomerate, pl. A1).

Mesozoic and Tertiary Plutonic Rocks

Plutonic rocks in northern Nye County have been divided into three general groups on plate A1: (1) granitic rocks including granite, quartz monzonite, and granodiorite; (2) dioritic rocks including diorite, quartz diorite, gabbro, and diabase (the latter mafic rocks occur mostly in the westernmost ranges and are subordinate areally); and (3) undifferentiated plutons in the western part of the county that include rocks of silicic to intermediate composition (older plutonic rocks, pl. A1).

Bodies of plutonic rocks range in outcrop area from less than 1 square mile (2.6 km^2) to as much as 60 square miles (155 km^2) (fig. A29). Most intrusive masses are irregularly circular to elliptical in plan view, but some larger ones are markedly elongate. The bodies generally have sharp, steep contacts with adjacent country rock, and in many cases the country rock has undergone contact with local development of thick contact aureoles. Most of the stocks are medium grained and relatively homogeneous, although a few appear to be composite masses. Porphyritic texture characterizes some of the bodies, and in the pluton at Belmont, a porphyritic zone forms such a wide continuous selvage that it was mapped separately (pl. A1). D. R. Shawe (oral commun. 1983) may consider the porphyritic zone to represent a separate sill-like body. Aplitic dikes and sills are abundant near the margins of some of the plutons, particularly those in the southern Toquima Range.

DESCRIPTION OF PLUTONIC ROCKS

Northeastern Nye County

Granitic Rocks

In northeastern Nye County, granitic rocks are exposed at three localities along the east side of Railroad Valley, and all have yielded mid-Tertiary radiometric ages (table A11).

Two stocks, the Railroad and Silver Spring stocks of Lumsden (1964), intrude Cambrian strata in the southern

TABLE A11. Radiometric ages obtained from plutonic rocks in northern Nye County, Nevada.

Map no. (see fig. A29)	Location	Rock name	Age in m.y.	Method	Mineral	I.D. no.	Collector	Analyst	Remarks
1	Southern White Pine Range, SE/4 S5,T11N,R58E	Quartz monzonite	27^{+4}_{-2} 31^{+5}_{-2}	K-Ar	Biotite	YAG 154	R. L. Armstrong, Yale University	R. L. Armstrong, Yale University	Cited in Schilling (1965); replicate analyses
2	Southern White Pine Range, S36,T12N,R57E	Quartz monzonite	36^{+5}_{-2}	K-Ar	Biotite	YAG 155	R. L. Armstrong, Yale University	R. L. Armstrong, Yale University	Cited in Schilling (1965, from same pluton as YAG 154
3	Southwestern Grant Range, Troy Canyon, SW/4 S29,T6N,R57E	Quartz monzonite	23^{+4}_{-2}	K-Ar	Biotite	YAG 74	R. L. Armstrong, Yale University	R. L. Armstrong, Yale University	Cited in Schilling (1965)
4	Northern Quinn Canyon Range, Willow Creek	Granodiorite(?)	26.8 ± 0.5	K-Ar	Biotite	15104-43 or USGS(M)-M3-13	F. J. Kleinhampl	M. L. Silberman and L. B. Schlocker, U.S. Geological Survey	Cited in Silberman and McKee (1971)
5	Northwestern Toquima Range, near Clipper Gap, S12,T15N,R45E (Lander County, near boundary with Nye County)	Quartz monzonite (Clipper Gap stock)	151 ± 3	K-Ar	Biotite	USGS(M)-M 275	E. H. McKee	E. H. McKee and L. B. Schlocker, U.S. Geological Survey	Cited in Silberman and McKee (1971)
6	Central Toquima Range, Northumberland Canyon	Quartz diorite or biotite—hornblende granodiorite	153 ± 8 156 ± 4	K-Ar	Biotite	19693-13	F. J. Kleinhampl and M. L. Silberman, U.S. Geological Survey	M. L. Silberman and L. B. Schlocker, U.S. Geological Survey	Replicate analyses
7	Southern Toquima Range, Shoshone Creek, about 2 miles east of Round Mountain	Porphyritic granitic pluton, Toquima pluton (see text)	73	Pb-alpha	Zircon	56-26-A	N. J. Silberling, U.S. Geological Survey	T. W. Stern, U.S. Geological Survey	
7	Southern Toquima Range, Shoshone Creek, about 2 miles east of Round Mountain	Sand derived from above	107	Pb-alpha	Zircon	56-26-B	N. J. Silberling, U.S. Geological Survey	T. W. Stern, U.S. Geological Survey	
8	Southern Toquima Range, Silver Creek about 5 miles west of Belmont	Porphyritic granite, Belmont pluton (see text)	78.4 ± 2.2 78.0 ± 2.5	K-Ar	Muscovite	12025-5	F. J. Kleinhampl and M. L. Silberman, U.S. Geological Survey	M. L. Silberman and L. B. Schlocker, U.S. Geological Survey	Replicate analyses
9	Southern Toquima Range, near NW corner, T9N,R45E; 38°39'06" N., 116°57'50" W.	Quartz monzonite porphyry, Toquima pluton	76.4 ± 2.8	K-Ar	Biotite	G-B0836/ NBM-AD19	Warren Ervine	Geochron Laboratories	Cited by Krueger and Schilling (1971); from small body intruded into AD11
9	Southern Toquima Range, close to above sample, 38°39'05" N., 116°57'49" W.	Porphyritic quartz monzonite, Belmont pluton	79.6 ± 2.0	K-Ar	Biotite	G-B0553/ NBM-AD11	Warren Ervine	Geochron Laboratories	Cited by Krueger and Schilling (1971)
10	Southern Toiyabe Range, area of Broad Canyon	Quartz monzonite dike, Broad Canyon pluton dike	29.4 ± 0.8	K-Ar	Biotite		R. C. Speed	E. H. McKee and L. B. Schlocker, U.S. Geological Survey	Cited by Speed and McKee (1976), who note that the dike intrudes the Darrough Felsite
11	Southern Toiyabe Range, near mouth of North Twin River	Granite, Ophir pluton	53.9 ± 1.5	K-Ar	Biotite		R. C. Speed	E. H. McKee and L. B. Schlocker, U.S. Geological Survey	Cited by Speed and McKee (1976)
12	Northwestern San Antonio Mountains, Hall molybdenum property, dump	Potassium-silicate altered rock	77.1 ± 2.2	K-Ar	Biotite			M. L. Silberman and L. B. Schlocker, U.S. Geological Survey	Data supplied by M. L. Silberman, 1974
13	Southwestern Paradise Range, NW/4 S2,T11N,R36E	Medium-grained biotite-hornblende granodiorite, Gabbs pluton	11.3 ± 1.2	K-Ar	Biotite	G-B0642/ NBM-AD13	J. H. Schilling	Geochron Laboratories	Age may reflect reheating; cited by Krueger and Schilling (1971)
14	Lodi Hills, NW/4 S13,T13N,R37E	Granite, Lodi Hills (Illinois) pluton	46.9 ± 2.0	K-Ar	Biotite	G-B0805/ NBM-AD17	J. H. Schilling	Geochron Laboratories	Cited by Krueger and Schilling, (1971)

White Pine Range about 8 miles (13 km) north of Currant. The larger body, the Railroad stock, is a medium-grained, xenomorphic, granular quartz monzonite and is generally concordant with the enclosing beds and elongate in a northeasterly direction (Lumsden, 1964). A pervasive network of quartz veins parallels the long axis of this stock and extends into the contact aureole.

Lumsden (1964) originally suggested that the domal structure of the White Pine Range is a result of emplacement of the two plutons, but more recently, he seems to have accepted a younger age for the major folding and uplift of the range (Moores and others, 1968).

Several granite or quartz monzonite bodies, which may coalesce at depth into a single northwest-trending pluton, crop out in the southwestern Grant Range between Irwin Canyon and Little Meadow Creek. These granitic rocks have intruded and metamorphosed strata of Cambrian to Ordovician age. The stock with the greatest areal exposure is typically medium-grained granite, but the texture varies from fine to coarse and locally exhibits evidence of cataclasis and recrystallization (Cebull, 1970, p. 1831, 1833). Younger plutonic rocks, distinguishable from the Troy body in not showing evidence of cataclasis and recrystallization, form very small exposures on the east side of the Grant Range, about 5 miles (8 km) east of Troy. The one body shown on the map (pl. A1) is younger than the thrust plate there because it intrudes the thrust (Cebull, 1970, p. 1833).

Three small bodies of quartz monzonite porphyry intrude Cambrian and Ordovician strata near the mouth of Willow Creek in the northern Quinn Canyon Range. The igneous rocks consist of medium- to coarse-grained, euhedral feldspar phenocrysts in a groundmass of fine- to very fine-grained quartz and feldspar.

Northwestern Nye County

Outcrops of plutonic rocks in northwestern Nye County are restricted to the ranges west of Monitor and Ralston Valleys, except for small exposures in the Monitor Range of diabase (near Monarch Ranch, fig. A29), quartz diorite and diorite porphyry in the Ellendale mining district 24 miles (39 km) east of Tonopah, fig. A29,

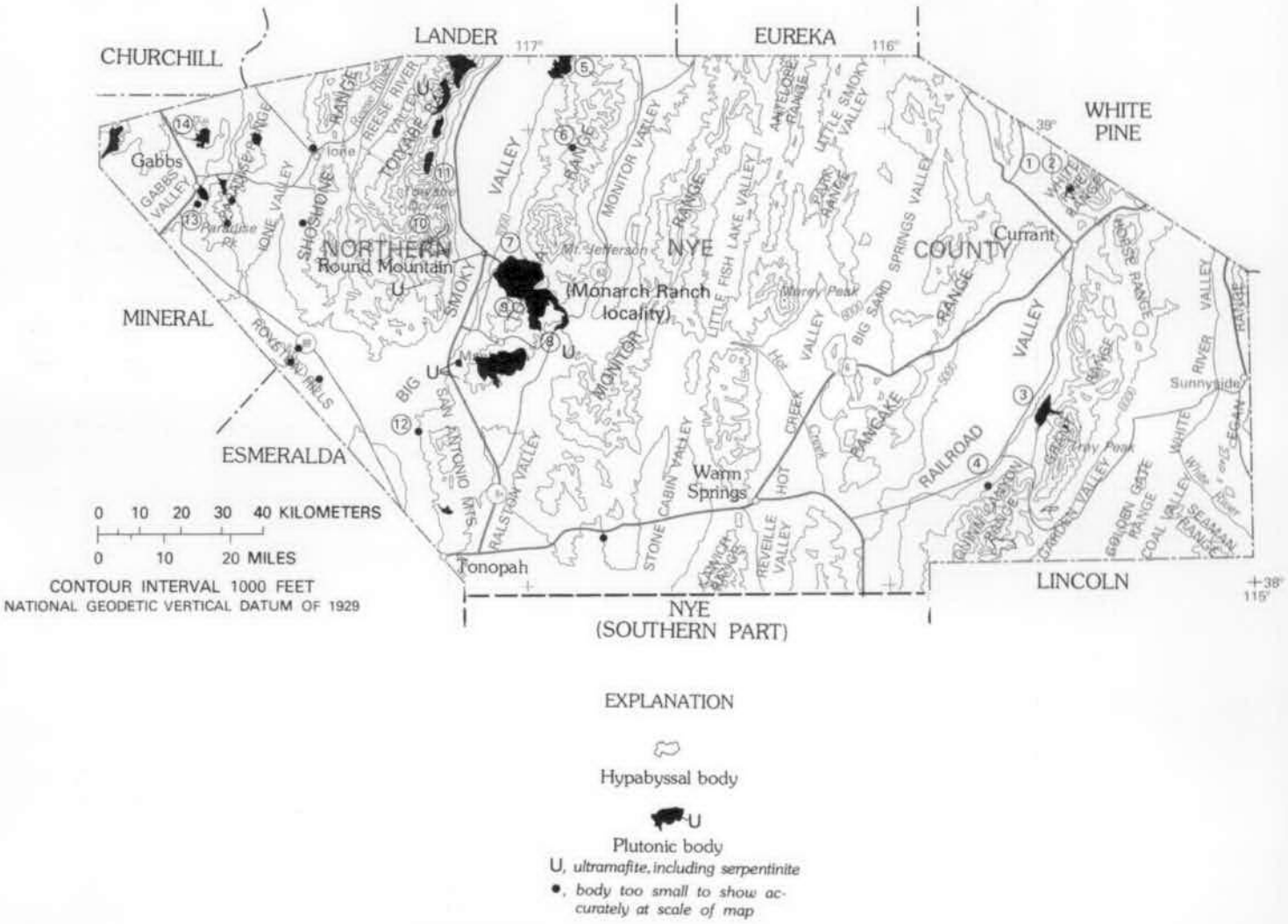


FIGURE A29. Map showing distribution of hypabyssal and plutonic rocks in northern Nye County. Numbers refer to dated samples in table A11.

and diorite near Stargo Spring, Dobbin Summit Area. Granite of probable Cretaceous age also forms large-boulder-size outcrops near Hat Peak, Monitor Range. These outcrops, components of partly exposed Tertiary slide blocks and therefore rootless masses, are included with other rocks in exotic slide blocks (pl. A1).

Granitic Rocks

The largest granitic plutons, Cretaceous in age (table A11), are in the southern Toquima Range and are described with the geology of the Belmont, Manhattan, and Round Mountain mining districts. The Toquima (Round Mountain) pluton, which is the westernmost of two adjoining stocks, has been variously called a microcline granite, grading into quartz monzonite or granodiorite (Ferguson, 1921, p. 387), and porphyritic quartz monzonite (Ervine, 1972, p. 49); it is a medium-grained hypidiomorphic rock. Its contact with the Cambrian and Ordovician country rock is steep and characterized by a wide zone of mixed sedimentary and granitic material. The stock is similar to the Belmont stock on the east, which it intrudes, except that the Belmont has a broad outer band of porphyritic microcline granite or quartz monzonite containing zoned feldspar crystals as much as several inches in length. The interior of the Belmont body is chiefly medium grained with rare scattered large phenocrysts of feldspar. The same rock as the Belmont pluton composes a third, partly unroofed stock south of Manhattan (Ferguson, 1924) and is considered to be a faulted part of the Belmont pluton. The contacts of all the plutons in the southern Toquima Range are approximately concordant with the bedding of the enclosing metamorphosed Cambrian and Ordovician strata, although crosscutting relations are common on a local scale. The bodies are moderately foliated locally, and the foliation is parallel to the margins. This is particularly true for the Toquima Range (Round Mountain) pluton. These structural features suggest that some doming may have occurred, although emplacement may have been partly controlled by preexisting anticlinal folds.

Near Round Mountain, a part of the Toquima pluton with dikes (rhyolite dike swarm [Oligocene] in marginal zone of granite [Cretaceous] [pl. A1]) is mapped separately and forms one of the most remarkable geological features in the range, because the entire unit is sheared to some extent and the dikes are altered (bleached). A dike in the swarm was dated at 34.3 ± 0.8 m.y. (D. R. Shawe, written commun., 1973). The geology in the vicinity of the dikes is described in the Mineral Deposits section of this bulletin on Round Mountain mining district.

West of Big Smoky Valley, medium-grained rocks that range from granite to granodiorite form several relatively large stocks that intrude Cambrian, Ordovician, and probable Permian rocks along the east side of the Toiyabe Range as far south as Broad Creek. Smaller plutons of granitic to dioritic composition are interspersed throughout, and two crop out as far south as near Boyd Canyon and Seyler Peak. The bodies in the Toiyabe Range probably are of quite diverse ages, but few have been radiometrically dated. The Broad Creek body (pl. A1) and parallel northeast-striking dikes in Jett Canyon (pl. A1) form a hypabyssal dike system dated at 29.4 ± 0.8 m.y. (Speed and McKee, 1976). The silicic Seyler Peak body may be of comparable age because it intrudes the Darrough Felsite, which Speed and McKee (1976) have determined to be Tertiary. These workers also obtained an early Tertiary radiometric age for the Ophir pluton, which extends for several miles from Ophir to North Twin River Canyons (no. 11, table A11). Some of the other plutons could be Mesozoic. The contacts of all but the Broad and Jett Canyon dikes are sharp, steeply inclined, and generally discordant with the structure of the enclosing rocks.

Granitic rocks that crop out in the San Antonio Mountains include a fairly large body near Red Mountain north of Tonopah and a small pluton associated with molybdenite at the Hall molybdenum property in the northwestern part of the range. The former body has yielded fission-track ages of 59 and 68 m.y. (Carlson and others, 1975) and is inferred to be Laramide. This pluton is porphyritic and ranges in composition from quartz monzonite to granodiorite (Broderick, 1949). Large microcline phenocrysts are scattered through the pluton, and xenoliths of gneiss are abundant locally. The other much smaller pluton, here named the Hall pluton, is an alaskitic granite that intrudes metamorphosed rocks provisionally assigned to the Pablo Formation. The body may be Cretaceous on the basis of a radiometric age determined from a sample of hydrothermally altered rock collected in the area (no. 12, table A11). This similarity in age and kind of mineralization (molybdenite) and geographic proximity to the plutons in the southern Toquima Range suggests a genetic relation between them, especially with the previously described Toquima pluton. These bodies may all be cupolas of an extensive, largely concealed Cretaceous batholith. The Ophir pluton in the Toiyabe Range also appears to be associated with molybdenite (described with the Twin River mining district), and, although the Ophir body yielded a younger apparent age (about 55 m.y.; no. 11, table A11), its crystallization age may be older (Speed and McKee, 1976).

Extensive exposures of granitic rocks occur in the vicinity of Gabbs. Granite porphyry, megascopically similar to that exposed in the southern Toquima Range, forms large stocks in the southern Lodi Hills (Illinois pluton, no. 14, table A11) and northeast of Sherman Peak in the Paradise Range, and smaller bodies farther south in that range. Just east of Gabbs, the Gabbs pluton (Krueger and Schilling, 1971), a large granodiorite mass elongate in a northwesterly direction, intrudes both plates of the Paradise thrust. Extensive deposits of magnesite and brucite occur along the digitated contact between the granodiorite and dolomite country rock of the Luning Formation. This pluton gave an extremely young radiometric age (late Miocene) that is believed by Krueger and Schilling (1971) to be the result of reheating during dike emplacement. Other small outcrops of monzonite are said to be late Tertiary and to cut Tertiary volcanic rocks near the mouth of Marble Canyon, about 2.5 miles (4 km) west-northwest of Fairview

Peak, Paradise Range (Vitaliano and Callaghan, 1963). We did not confirm this observation. Additional scattered bodies of granite and quartz monzonite occur widely in the Paradise Range, locally in the Shoshone Mountains, and locally in the small part of the Cedar Mountains that extends into Nye County.

Dioritic Rocks

Dioritic rocks are generally restricted to the westernmost ranges except for minor outcrops in the Monitor Range. The dioritic rocks of the Monitor Range are especially noteworthy because two of the three known bodies are altered and mineralized and the unmineralized body is Tertiary. An altered pyritized biotite hornblende diorite porphyry crops out in the eastern part of the Ellendale mining district, southernmost Monitor Range. Also, farther west in the district, an intense aeromagnetic anomaly is associated with an unmineralized Tertiary quartz diorite. Another pyritized dioritic body—fine- to medium-grained biotite diorite(?)—lies near Stargo Spring, Dobbin Summit area. Neither of the two altered mineralized dioritic units in the Monitor Range have yet been radiometrically dated and are considered to be Cretaceous and (or) Tertiary. A small east-striking diorite body about 2.5 miles (4 km) east of Round Mountain cuts rhyolite dikes believed to be part of the early Tertiary (34-m.y.-old) dike swarm in the peripheral part of the Toquima (Round Mountain) pluton (D. R. Shawe, oral commun., July 1976). Silberling (1959) reported that quartz diorite intruded the Pablo Formation just south of Ione in the Shoshone Mountains. In the Royston Hills south of Ione Valley, limestone of the Triassic Luning Formation is cut by a west-trending stock of fine- to medium-grained diorite.

A large dark pluton mapped by us as diorite in the Monte Cristo Range was recently described by Ekren and Byers (1978): the intrusive body plots in the granodiorite field of Johannsen (1939) and is generally medium-grained; very rich in hornblende, biotite, and clinopyroxene; and contains interstitial quartz. Medium- to coarse-grained diorite intrudes granite porphyry in the southern Lodi Hills and is injected into the tightly folded Luning Formation northeast of Gabbs. According to Vitaliano and Callaghan (1963), gabbro composes a small northwest-trending stock west of Ellsworth in the Paradise Range; the gabbro intrudes predominantly volcanic rocks assigned by us to the Pablo Formation.

An unusually coarse quartz-feldspar porphyry of unknown age, but mapped with the Triassic Excelsior Formation, is described in the Mineral Deposits section of this bulletin (Lodi district).

Older Plutonic Rocks

Two granitic stocks in the northern Toquima Range (nos. 5 and 6, table A11) are dated as Jurassic and mapped as older plutonic rocks (pl. A1). The larger of these two, straddling the Lander-Nye County line, is a medium- to coarse-grained biotite granite and quartz monzonite that intrudes Ordovician chert (pl. A1). The other pluton, a small body of quartz diorite or biotite hornblende granodiorite (no. 6, table A11), intrudes the Pogonip Group and transitional carbonate beds of Ordovician age farther south in Northumberland Canyon (Northumberland mining district).

AGE OF PLUTONIC ROCKS

A summary of isotopic mineral ages for fourteen plutons within northern Nye County is given in table A11. These data, of which the majority were determined by the potassium-argon dating method on biotite, suggest that the minimum ages of emplacement range from Mesozoic to Tertiary.

The oldest radiometric ages, about 150–155 m.y. (Jurassic), were obtained from stocks near Northumberland and Clipper Gap, Toquima Range. The youngest age was obtained from the Gabbs pluton (no. 13, table A11) and may have been reset during an episode of dike emplacement. The young age for the granitic pluton in Troy Canyon (no. 3, table A11) and possibly that of the Ophir pluton (no. 11, table A11) may also be apparent ages representing minimums, with the crystallization ages probably being older.

Cenozoic Erathem

TERTIARY SYSTEM

Introduction

The Tertiary rocks of northern Nye County include three major groups (arranged from greatest to least abundance by volume): (1) extrusive volcanic rocks, including ash-flow and air-fall tuffs, and lavas; (2) nonmarine sedimentary strata; and (3) intrusive rocks, including cumulo-domes, plugs, stocks, and dikes of plutonic and hypabyssal character. The igneous rocks range in composition from olivine basalt to rhyolite, but basalts are minor volumetrically and areally, except in the Pancake Range and locally in the western border region. Rhyolitic to quartz latitic ash-flow tuffs are the most abundant of the igneous rocks, followed by other tuffs of similar composition; dacitic to andesitic lavas are probably next most abundant. The sedimentary strata range from fine clastic beds to very coarse conglomerate and megabreccia. Composition of the detritus reflects the source areas and includes Paleozoic, Mesozoic, and Tertiary rocks. Many of the lacustrine deposits contain rhyolitic to quartz latitic material derived from the predominant Tertiary volcanic rocks, as well as discontinuous carbonate and, locally, diatomaceous strata. Intrusive rocks are mostly porphyritic and range in composition from rhyolite to andesite; a few are more or less equigranular and of granitic or intermediate composition.

All epochs of the Tertiary Period are represented in northern Nye County. The Paleocene is known from the Grant Range, but minor outcrops of sedimentary strata of uncertain age at or near the base of the Tertiary column and scattered throughout the eastern two-thirds of the region may belong to this epoch, and are designated as Cretaceous or Tertiary rocks on the map (pl. A1).

Documentation of the ages of these old units is difficult because diagnostic fossils are rarely present, and the absence of volcanic debris has ruled out application of isotopic dating techniques.

We chose to reference the age of the map units to the standard geologic time scale of Harland and others (1964), the standard which was in fairly general use when we first wrote the section on Cenozoic Erathem. This standard is today (1979) rivaled by that of Berggren (1972), who established slightly different absolute ages for the boundaries of some of the epochs of the Tertiary. The most significant differences are in the placement of the Oligocene-Miocene boundary: 26 m.y. by our usage versus 22.5 m.y. by Berggren, and the Miocene-Pliocene boundary: approximately 7 m.y. by our usage and 5.0 m.y. by Berggren.

Description of Map Units

For purposes of description, northern Nye County has been divided into five main parts or regions (fig. A30), from east to west, each of which is characterized by at least one generalized stratigraphic column. The five main parts and corresponding stratigraphic columns from east to west are hereafter referred to as: region 1, or eastern region and Grant Range column; region 2, or east-central region and column; region 3, or west-central region and main and supplemental (Hannapah and Ellendale) columns; region 4, or Toquima region and north and south columns; and region 5, or western region and main and supplemental (boundary) columns. The five main divisions of the county encompass the following mountain ranges, respectively: (1) Egan, South Egan, Golden Gate, Seaman, Quinn Canyon, Grant, Horse, and White Pine Ranges; (2) Pancake, Reveille, and Kawich Ranges; (3) Squaw Hills and Hot Creek, Park, Antelope, and Monitor Ranges; (4) Toquima Range; and (5) the entire area west of and including the San Antonio Mountains and the Toiyabe Range. The Tertiary rocks in parts of the west-central region (region 3), Toquima Range (region 4), and the western region (region 5) for special reasons required the introduction of supplemental sections. There are, therefore, eight general columnar sections that characterize the Cenozoic rocks of the mapped region; three are supplemental to the main sections and include the Hannapah and Ellendale mining districts section in the south part of the west-central region, the south section of the Toquima region, and the boundary section (adjacent to the county line on the west) in the western region.

Numerous map units (pl. A1) within each of the eight main and supplemental stratigraphic columns are combinations of a few to many units that have been defined by other workers in the region, as, for example, the young tuffs of the Pancake caldera complex (east- and west-central region stratigraphic columns, pl. A1), which includes six formations of ash-flow tuffs that are shown separately on published quadrangles within the region. The combinations were selected to unite rocks of similar mode of origin, rock type, and (or) geographic extent wherever possible; none of the map units includes strata that are continuous throughout the county. For this reason, the map explanation is extremely detailed, and the principal units included in the various groupings or combinations are listed. The units are also delineated in the following summary of correlations and in the detailed rock descriptions. In the descriptions that follow, there is some overlap from region to region because a few rock units are common to more than one region.

The reader is reminded that the map (pl. A1) is inconsistent in density of detail. For example, the southern Monitor Range and the area between Manhattan and Round Mountain in the Toquima Range have not been mapped in detail by us or others, and the Tertiary geology is considerably more complex than shown. The same applies, although perhaps to a lesser degree, to the Tertiary of the Quinn Canyon, Kawich, central Monitor, and Toiyabe Ranges. We endeavored to show at least enough detail everywhere to provide a base for additional studies and to show more detail in those places where such data was available, in order to more truly depict the complexities of the rocks.

General Correlations

The oldest known Cenozoic unit in northern Nye County is the Upper Cretaceous(?) to Eocene Sheep Pass Formation, of continental sedimentary origin, in the eastern part of the map area (regions 1 and 2, fig. A30). The Sheep Pass Formation in northern Nye County contains no volcanic detritus. Other continental beds lie at the base of the Cenozoic section in the Shoshone Mountains (a part of region 5). The beds were first noted by Vitaliano and Vitaliano (1972, figs. 2, 3) and are described in the present bulletin with the lower volcanic sequence of the western ranges (see the section of this bulletin on Western Region [region 5]—Oligocene Rocks). They are clearly not depositionally coextensive with the Sheep Pass and are here considered to be early Oligocene.

Cenozoic volcanism superseded the deposition of Sheep Pass Formation in the eastern region, and the oldest volcanic rocks are represented there and in regions 2 and 3 by silicic to intermediate lavas, their local vent tuffs and breccias, and intrusive bodies. These rocks are about 35–38 m.y. old. They are of minor areal extent and of small volume but are widespread geographically, being scattered across the eastern half of northern Nye County. On the basis of composition and other characteristics, they are variously delineated on plate A1. Their unequivocal correlatives farther west are not known, but the oldest lavas in the lower volcanic sequence of western ranges and some of the rocks in the Tonopah Formation could be the same age.

The intensive volcanism that began in the Oligocene about 35–38 m.y. ago appears to have been rather extensive throughout northern Nye County, except perhaps for the extreme western border region. During this epoch and continuing into the early Miocene when volcanism was, if anything, more general, continental sediments were intermittently deposited in restricted basins. Minor sedimentary strata in the eastern half of the mapped region are intercalated with and locally overlie some of

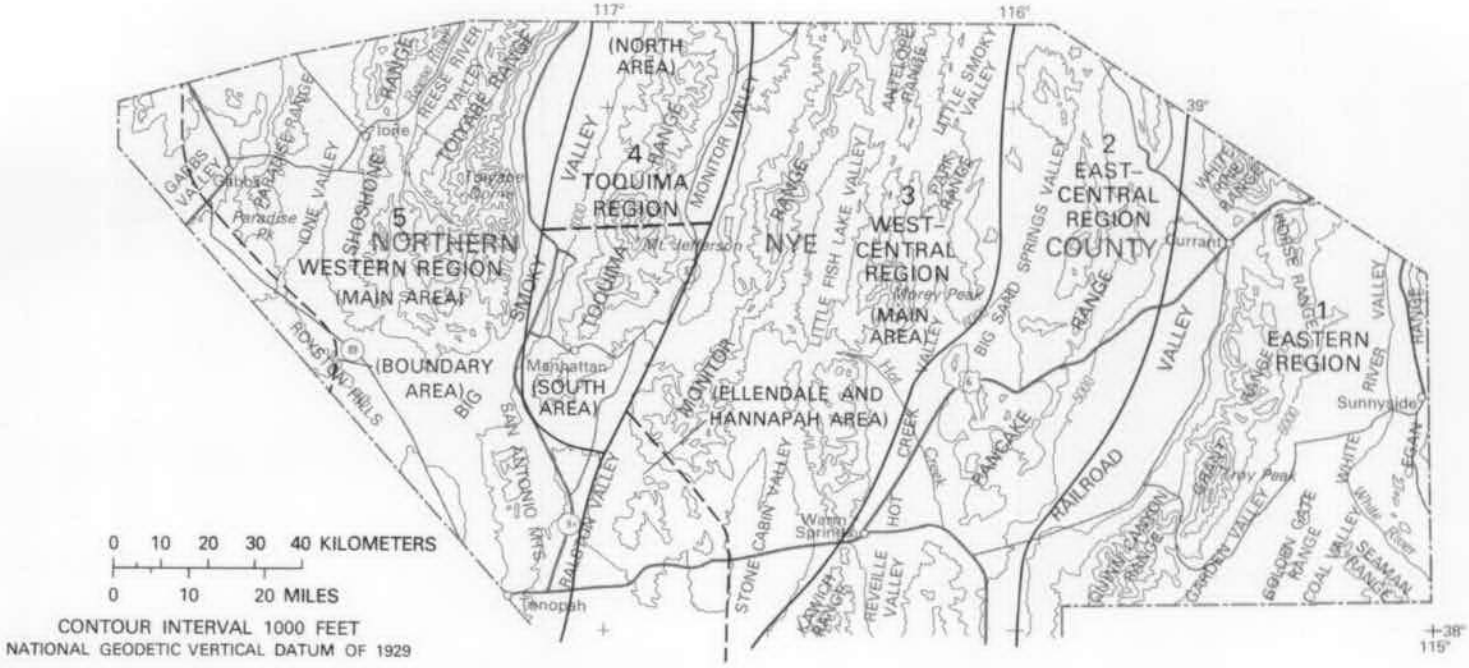


FIGURE A30. Geographic divisions of Cenozoic rocks, northern Nye County.

the old fluidal volcanic rocks (mentioned above) from which they are partially derived. The sedimentary strata include the Blind Spring Formation of Scott (1966) and undifferentiated and unnamed beds in regions 2 and 3 (see map explanation, pl. A1). Basinal deposits comparable in age may also exist farther west, but for the most part they are not identified separately on the geologic map. They are mapped with the overlying ash-flow tuffs and lavas.

Extensive exposures of thick silicic Oligocene ash-flow tuffs form the next younger grouping of stratigraphic units in regions 1 through 4 (west through the Toquima Range). These tuffs are, in general, crystal rich and quartz bearing in the lower part and are rhyolitic and quartz latitic in composition. The upper part displays more variations in both crystal content and chemical composition. Each of the two parts is many thousands of feet thick in some areas, and many individual units in the lower part attain thicknesses of several thousand feet locally. The geographically most extensive of these older individual units are the Stone Cabin and Windous Butte Formations of E. F. Cook (1965) in regions 1, 2, and 3 and the partial time correlative of the latter, the tuff of Williams Ridge and Morey Peak, in regions 2 and 3. Some of these units, as well as other ash-flow tuffs that are more restricted areally, are variously combined in each of regions 1 through 4 into an undifferentiated unit (pl. A1).

Several ash-flow sheets present near the top of the crystal-rich lower rocks of the Oligocene series are, in part, less silicic and range in composition from rhyodacite to dacite. The most noteworthy of these are the Needles Range and Needles Range(?) Formations in regions 1 through 3 and the Monotony Tuff in regions 2 and 3. Ash-flow tuffs ranging in age from about 23 to 25 m.y. form localized very thick piles of rhyolitic to rhyodacitic material in the Pancake, Hot Creek, Reveille, and possibly the Kawich Ranges. The Shingle Pass and Bates Mountain Tuffs, two lithologically very distinctive units, are widely distributed in the eastern and central parts of northern Nye County, commonly cap the tuff sequences, and make extremely useful marker horizons. Although they are, in general, quartz poor and phenocryst poor, they are highly silicic and highly differentiated (Noble, 1972).

Ash flows younger than the Bates Mountain and Shingle Pass Tuffs are locally important. These include, principally, the Fraction Tuff at Tonopah and the very thick and widespread Toiyabe Quartz Latite in region 5. Less important areally are localized tuffs in the Reveille Range, and, possibly, part of the tuffs of Peavine Canyon in the Toquima and Toiyabe Ranges could be included here. Other young tuffs, probably in the age range of 10–16 m.y. and unimportant volumetrically, are not shown separately on the map. These are mostly included with sedimentary strata and intercalated tuffs (pl. A1) and probably, in the main, represent ash falls into lakes. These economically important sedimentary strata and other beds were deposited in restricted but nearly contemporaneous basins across the western half of northern Nye County, from the Monitor Range west, during sporadic intervals from Miocene to middle or late Pliocene. The sedimentary rocks are chiefly volcanogenic and include fluviatile (piedmont slope to flood plain), deltaic, and lacustrine strata composed of very fine (clay) to very coarse (conglomerate) clastic material. Diatomite and limestone are also present.

A conspicuous threefold division of ash-flow tuffs in the western part of northern Nye County is made on the basis of composition and color, with the middle mostly white, rhyolitic rocks (middle volcanic unit, pl. A1) separating the dark-hued, generally less silicic, lowest rocks (lower volcanic unit, pl. A1) from the cliffy reddish-brown rhyolitic to quartz latitic upper part consisting mostly of the Toiyabe Quartz Latite and related tuffs. The tripartite division is best displayed in the Shoshone Mountains and, to a lesser degree, the Paradise Range but is more equivocal in the Toiyabe Range, where the division depends on the recognition of the Darrough Felsite as the lowest part of the Tertiary section. The Darrough Felsite was considered to be pre-Tertiary by Ferguson and Cathcart (1954), but recent K-Ar data (Speed and McKee, 1976) indicate a middle Tertiary age for the unit.

The tripartite division based principally on color cannot be discerned in the San Antonio Mountains, where the oldest Tertiary volcanic rocks—the Tonopah Formation (pl. A1)—do not appear to be lithologically distinct from the middle division rocks farther north. The Tonopah is thus best considered as a partial lithic, if not temporal, equivalent of the middle volcanic sequence.

Several other widely scattered map units not now considered part of the tripartite division of Tertiary rocks are exposed in the western region. One of these is the Fraction Tuff, which (at about 17 m.y. in age) represents the only major late extensive outpouring of tuffs in the western third of the mapped region.

Lavas and intrusive bodies are especially difficult to combine into meaningful map units for an area as large as northern Nye County. The reasons are obvious: they are not regionally continuous, and lithologically similar rocks may vary widely in age. Intermediate and silicic lavas, for example, occur at various stratigraphic levels throughout the county, although rhyolitic lavas are commonly the earliest Tertiary volcanic rocks and, in places, probably the youngest. Some lavas and intrusive bodies, therefore, are locally included with wastebasket map units in which ash-flow tuffs may predominate. An example of such a unit is the middle volcanic sequence (pl. A1) of the western region.

One of the more extensive intermediate lava sequences is that which overlies the Stone Cabin Formation and underlies the Windous Butte Formation in the central region and is variously labelled on the map (pl. A1). This series is commonly a thousand or more feet thick and forms very dark gray ledges and broken cliffs near the foot of the mountains. Other large, irregularly shaped bodies of silicic and intermediate composition, including chiefly lavas and domes, are widely scattered throughout northern Nye County and in general are Oligocene in age. Examples include the 25–27-m.y.-old rhyolite of Big Sand Springs Valley in the east- and west-central regions, early Oligocene rhyolitic lava of the east-central region, and undifferentiated bodies included with ash-flow tuffs in map units such as the Tonopah Formation and in the middle volcanic sequence of the western region.

Volcanism ceased in about the eastern one-third of northern Nye County with the local emplacement of basaltic rocks in the late Tertiary and (or) Quaternary. The extent of the basalts is limited to minor outcrops except for the large basalt field in the southern Pancake and northern Reveille Ranges. Basaltic cones and associated lavas in the Reveille area are about 6 m.y. old (Ekren, Rogers, and Dixon, 1973), whereas at least some of the flows, composite cones, and maars of the adjacent southern Pancake Range may be as young as Pleistocene(?).

There seems to be no obvious geographic pattern to the composition of the late Cenozoic lavas and intrusive bodies in about the western two-thirds of the mapped region. Rocks ranging in composition from rhyolite to basalt are all present and sporadically distributed. Detailed studies, including many absolute age determinations, will be necessary to permit a more detailed assessment of the situation. Work of M. L. Silberman and others in west-central Nevada (summarized in Silberman and others, 1976) tends to show that andesitic lavas there range in age from about 26 to 10 m.y.; therefore, the andesites of northern Nye County predictably will yield similar ages. In general, Pliocene lavas, plugs, and domes, and volcanoes of intermediate and basic composition are the youngest preserved extensive Tertiary rocks in northern Nye County. They commonly intrude and locally are intercalated with siliceous tuffs and sedimentary rocks.

Despite the occurrence of a few extensive lava sequences, such as the sequence between the Stone Cabin and Windous Butte Formations, most of the intermediate and rhyolitic lava piles are restricted to one or two mountain ranges or to only part of a range. In contrast, the ash-flow sheets have very wide areal distribution. With few exceptions, the lavas are localized in and near areas believed to be major vent or source areas. These locally coincide with vent areas for ash-flow tuffs. Regional studies also tend to indicate that mineralized areas are spatially related to Tertiary volcanic centers (Albers and Kleinhampl, 1970, p. C1–C10).

The maximum total composite thickness of the Tertiary section in any one mountain range probably ranges from several thousand to as much as 23,000 feet, measured in the Tybo quadrangle, Hot Creek Range) (Quinlivan and Rogers, 1970). Sections on the order of 5000–15,000 feet (1525–4570 m) thick are not uncommon, as in the Quinn Canyon, Pancake, and Toiyabe Ranges. The figures cited are extreme values because they incorporate maximum thicknesses of temporally correlative lenticular units, many of which never overlapped. At any one locality the thickness of strata is generally much less, on the order of a few score feet to several thousand feet. Thicknesses easily approach 10,000–15,000 feet (3050–4570 m), however, within some major calderas, of which good examples are found in the Toquima, Hot Creek, and the Pancake Ranges. Other as yet ill-defined structures are present in the southern Quinn Canyon, southern Monitor, and the southern Toiyabe Ranges; and a postulated domical structure apparently underlies the Tonopah area (Nolan, 1935b,

p. 10–11). Tertiary rocks are inordinately thick in most of these places.

Eastern Region (Region 1)

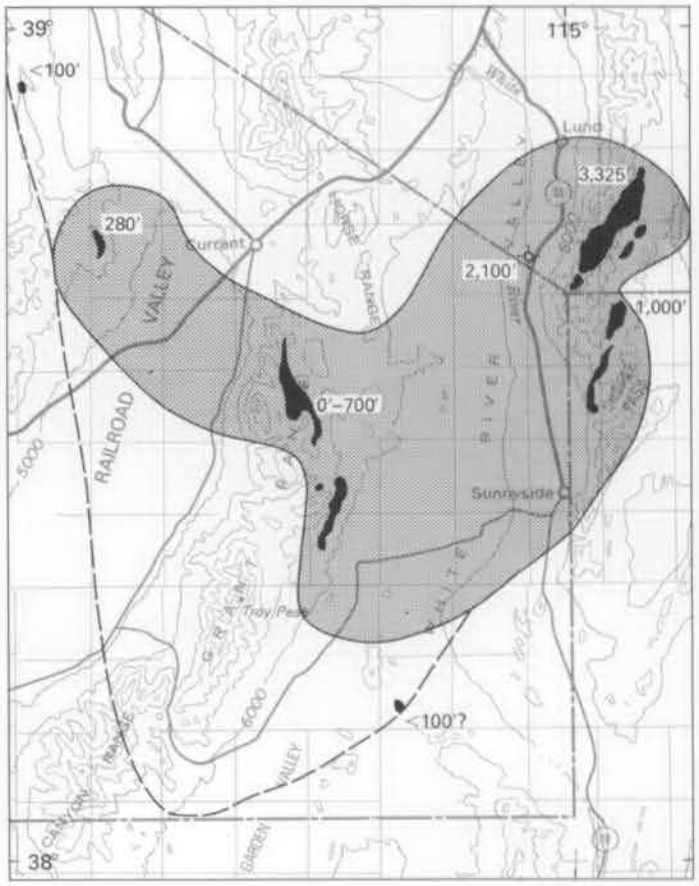
Sheep Pass Formation

The Sheep Pass Formation is a predominantly lacustrine sedimentary unit whose type locality is in Sheep Pass Canyon, Egan Range, White Pine County (Winfrey, 1958). The formation crops out in several ranges in northern Nye County and probably lies discontinuously in the subsurface beneath Railroad and White River Valleys (Murray and Bortz, 1967, p. 2134, 2136), with the latter supposition supported by limited subsurface data from scattered drill holes (Murray and Bortz, 1967, p. 2136). The Sheep Pass Formation is important because it contains the only documented Paleocene and Eocene sedimentary rocks in central Nevada and is an aid in determining early Tertiary structural events. Also, the Sheep Pass forms much of the reservoir rock and is the source rock for oil in the Eagle Springs oil field in Railroad Valley.

The depositional basin of the Sheep Pass encompasses an area of at least 1100 square miles (2849 km²) (Winfrey, 1960, p. 131) and very likely more than 1800 square miles (4662 km²) (fig. A31; also Scott, 1965, pl. 3). The basin appears to have been topographically low when the earliest ash-flow sheets were erupted, as indicated by the unusually thick sections of Calloway Well, Stone Cabin, and Windous Butte Formations in the Grant Range. These great thicknesses appear to be anomalous for ash-flow units deposited outside a caldera or a volcano-tectonic depression.

The Sheep Pass is thickest in its type locality, and the approximately 3000 feet (914 m) of section wedges out southward near Shingle Pass. The outcrop distribution in the Grant and Quinn Canyon Ranges, Nye County, indicates that the depositional basin was quite broad here, and the approximate northern and southern limits may be exposed. Other outcrops in the Pancake and the Golden Gate Ranges are also probably close to the margin of the depositional basin (fig. A31). Locally within the basin, the strata are absent by truncation, as in the Eagle Springs oil field, where a formation thickness of 875 feet (267 m) is truncated within about 1/2 mile (0.3 km) (Murray and Bortz, 1967, p. 2139–2140). Scott (1965, p. 12, app. D) measured several sections more than 400 feet (122 m) thick in the Grant Range and stated that the Sheep Pass there is as much as 700 feet (213 m) thick. Some of these and other thicknesses of the formation are indicated on figure A31.

The type Sheep Pass Formation contains no Tertiary volcanic detritus whatever, and the coarse clastic debris at its base is derived exclusively from the underlying Paleozoic sedimentary rocks. Six members constitute the formation at its type locality (Winfrey, 1960, p. 128–130) and generally appear in attenuated sections in the Grant Range and in the subsurface of the Eagle Springs oil field in Railroad Valley. Member A at the base is a calcareous-cemented conglomerate-breccia. Member B, overlying A, is composed of interbedded limestone,



0 10 20 30 40 KILOMETERS

0 10 20 MILES

CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

1,900'

Outcrop of Sheep Pass Formation, showing approximate thicknesses

Outline of Sheep Pass Basin (from Winfrey, 1960, fig. 3)
Probable extension of basin dashed. That part of basin known from subsurface data east of the Egan Range is not shown

2,100'

Drill hole, showing thickness of Sheep Pass Formation (from Winfrey, 1960, fig. 4)

FIGURE A31. Outline of Sheep Pass basin, northern Nye County.

shale, and mudstone; in clastic member C, predominating sandstones are interbedded with siltstone, shale, and conglomerate; member D is a white, siliceous, locally calcareous, very fine grained siltstone; member E is a resistant lithographic limestone; and member F, at the top of the formation, is composed of nonresistant siltstone-claystone beds. Scott's (1965, p. 12–14, app. D) measured sections of the Sheep Pass Formation in the

Grant Range are composed largely of limestone with conglomerate at the base; Winfrey's member designations were not utilized and the sections appear to be deficient in the finer grained clastic strata such as mudstone and shale. A more detailed study of the formation might confirm the presence of all six members originally noted by Winfrey. Outside the Grant Range in northern Nye County, outcrops assigned to the Sheep Pass reveal chiefly conglomerate that is tentatively correlated with member A of the type section. In the Pancake Range a limestone member overlies the conglomerate (Winfrey, 1960, p. 132), and some red mudstone is intercalated with the conglomerate.

The Sheep Pass Formation unconformably overlies Paleozoic strata generally with very slight angular discordance, and in Nye County it is unconformably overlain by Oligocene volcanic rocks. Murray and Bortz (1967, p. 2136) mentioned that the volcanic rocks locally rest with angular discordance on the Sheep Pass. Stratigraphic position and invertebrate fossils were used originally to establish a probable Eocene age for the formation (Winfrey, 1960, p. 130), which was widely accepted (Kellogg, 1964, p. 955; Scott, 1965, p. 12; Tschanz and Pampeyan, 1970, p. 68). On the basis of biostratigraphic studies, the Sheep Pass at its type locality is Late Cretaceous(?) to middle Eocene and is Paleocene and Eocene in the Grant Range (Fouch and others, 1979).

When Winfrey (1958) defined the Sheep Pass Formation, it had not been clearly established whether widely separated outcrops of the Sheep Pass represented separate small basins of contemporaneous accumulation or remnants of a once-continuous body (Winfrey, 1960, p. 130). The persistence of some of its members over long distances (Winfrey, 1960, p. 130, 132, 133; Kellogg, 1964, p. 951, pl. 1; Tschanz and Pampeyan, 1970, p. 68) suggests the original continuity of at least parts of the Sheep Pass. Continuity of the Sheep Pass is suggested also by continuity of the earliest ash-flow tuffs in the region of the Grant Range, which confirms low relief even after the disappearance of the lake. Basin-and-range structure had not yet developed in the early Tertiary. Over all of the Sheep Pass basin, however, there is some evidence of local high topography and the presence of early Tertiary positive structures, for example, in the Egan Range east of Nye County (Kellogg, 1964, p. 951–955, 966). Thus, for the entire region, there may have been lateral discontinuities in the Sheep Pass basin, but for the Grant Range area itself, evidence favors accumulation of sediments in a single topographic low.

Winfrey states that the Sheep Pass Formation correlates with the Green River, Flagstaff, and Wasatch Formations of Utah and the White Sage Formation of Nevada (1958, p. 82; 1960, p. 133). Fouch and others (1979) generally sustained the correlations with the Green River and Flagstaff, indicated detailed refinements, and correlated the lower part of the type Sheep Pass with the upper part of the Newark Canyon Formation in the Pinon Range (near Carlin). Winfrey also suggested a possible correlation with the Horse Spring Formation near Las Vegas, but the Horse Spring has been dated as Miocene(?) in the Moapa Valley (Longwell and others, 1965, p. 44, 48). Tschanz and Pampeyan (1970, p. 68) were unable to correlate the Sheep Pass with other Tertiary sedimentary rocks in Lincoln County. In White Pine County, Hose and Blake (1976) correlated the Sheep Pass with the Kinsey Canyon Formation of Young (1960). Fouch and others (1979) restricted this correlation to the strata mapped as Sheep Pass near Ely; the unit there and the Kinsey Canyon contain tuffaceous strata.

Rocks Younger than the Sheep Pass Formation

Stratigraphic Setting and Grant Range Columnar Section. Cenozoic rocks of the eastern region (area east of Railroad Valley) that are younger than the Sheep Pass Formation are best characterized by the section in the Grant Range and vicinity (summarized below and in table A12) mentioned by Winfrey (1958, p. 79), first described by Cook (1960, fig. 4; 1965, figs. 4, 5, p. 12–21), and later augmented and modified by Scott (1965). Scott's modification of Cook's Grant Grange columnar section is the standard because it is the most complete, and many rock units of this section have become firmly established in the literature (Lumsden, 1964, p. 104–109; Moores and others, 1968, p. 1709, fig. 2; Kleinhampl and Ziony, 1967). Elements of the section extend southeastward into the Golden Gate and Seaman Ranges, where, however, the volcanic rocks were not mapped in detail and in the present bulletin are left largely undifferentiated. This practice is followed in the Quinn Canyon Range, where many elements of the Grant Range section are missing or the section is so different or poorly known that several units there have been grouped together (pl. A1).

The approximately fifteen major rock units of the idealized Grant Range Cenozoic section totals nearly 24,000 feet (7315 m) in thickness; that is, where the maximum developed thickness of each unit is considered. Most units are broadly or abruptly lenticular, and because of the differing thicknesses or local absence of individual units, the total thickness of the Cenozoic volcanic section at any one place generally does not exceed about 5000 feet (1525 m). In the idealized section, lavas constitute about one-sixth (3900 ft or 1200 m) of the total, and two-thirds of the lavas are rhyolitic and one-third are intermediate in composition. Ash-flow tuffs constitute about one-third (7300 ft or 2225 m) of the section. Sedimentary strata make up the remaining half (12,400 ft or 3780 m), most of which is composed of basinal deposits of fluvial and lacustrine origin but also includes landslide and air-fall tuff members. The sedimentary units are mainly intercalated with the Tertiary volcanic units except for the previously described Sheep Pass Formation. The Sheep Pass is unconformably overlain by Oligocene rocks, at the base of which are localized accumulations of rhyolite and less silicic lavas and their feeders, and above which are thick quartz latitic and rhyolitic ash-flow tuffs that range in age from Oligocene to early Miocene. Ash-flow tuff eruptions may have nearly ceased with deposition of the youngest mapped tuffs about 22–23 m.y. ago. Ash-flow tuffs younger than 22 m.y. are apparently absent and may have been eroded away. The time interval between

TABLE A12. Tertiary composite section, Grant and Quinn Canyon Ranges, northern Nye County.

Age	Grant Range (Scott, 1965) Formation	Thickness (feet)	Grant and Quinn Canyon Ranges (This bulletin) Map Unit	
QUATERNARY	Alluvial valley fill, fans, and terraces	0-5000	Alluvium, colluvium, talus, fanglomerate, terrace deposits	
	Local breccia sheets	0-?		
(approximate stratigraphic order)	Deer Park Andesite	0-500?	Basalt, andesite, and latite	Rhyolite to latite
	Perish Spring Dacite	0-400?		
	Local breccia sheets	0-?		
MIOCENE and PLIOCENE	Horse Camp Formation	0-10,000	Horse Camp Formation of Moores (1964)	
			Rhyolitic welded ash-flow tuffs. Age ~22-23 m.y.	
			Sedimentary rocks and tuffs	
	Shingle Pass Formation	0-1700	Shingle Pass Tuff. Age 25.1 ± 1.0 m.y.	Shingle Pass(?) and Needles Range Formations and other ash-flow tuffs
29 m.y.	Needles Range Formation	0-1000	Needles Range(?) Formation. Age 26-29 m.y.	
	Forest Home Ignimbrite	0-400		
33 m.y.	Windous Butte Formation	300-1200	Windous Butte Formation. Age 30.7 m.y.	
	Currant Tuff	0-1000?	Currant Tuff. Age 31.7 ± 1.2 m.y.	Chiefly crystal-rich welded ash-flow tuffs of rhyolitic to quartz latitic composition
OLIGOCENE	Local andesite flows	0-20	Andesite	
	Stone Cabin Formation	0-2400	Stone Cabin Formation. Mean age 34.1 m.y.	
	Saddle Mountain Andesite	0-250	Andesite	
	Calloway Well Formation	0-600	Calloway Well Formation of Scott (1965, 1966). Mean age 33.2 ± 0.7 m.y.	
	Blind Spring Formation	0-700	Sedimentary rocks	
36 m.y.	Railroad Valley Rhyolite	0-2700	Rhyolite and dacite. Age ~35 m.y.	
PALEOCENE to EOCENE	Sheep Pass Formation	0-700	Sheep Pass Formation	

late Miocene and Pliocene was marked by localized eruptions of lavas of intermediate composition, by the deposition of discontinuous sedimentary rocks, and by widespread erosion. The older Oligocene volcanic rocks do not crop out in and east of Garden Valley (pl. A1), where limited available descriptions indicate that much of the exposed volcanic section includes only the later Oligocene and younger welded ash-flow tuffs (Needles Range Formation and Shingle Pass Tuff) (E. F. Cook, 1965, figs. 11, 14, 15, 16, 17; Armstrong, 1970, table 3).

Oligocene Rocks. Rhyolite flows form the oldest volcanic unit, the Railroad Valley Rhyolite of Scott (1966), and are confined mostly to the area near Currant in proximity to their feeders, which are not identified on the map (pl. A1). The flows in general consist of about 2500 feet (762 m) of aphanitic to porphyritic, light-brown-weathering, gray rhyolite, some of which is altered to green, red, yellow, and purple (Scott, 1965, p. 14-16). Other parts are autobrecciated. The rhyolite locally intertongues with red to green sedimentary beds that were derived largely from the rhyolite, and they are overlain by similar strata that are assigned to the Blind Spring Formation by Scott (1965, p. 16-17; 1966). Armstrong (1970, table 3) dates the rhyolite at 33.4 ± 0.7 m.y., an age which seems too young when compared with the ages of overlying units. A somewhat older age for the Railroad Valley Rhyolite (34.0 ± 1.3 m.y.) came from a nearby locality in White Pine County (sampled by Blake, *in* Marvin and others, 1973, p. 17). Other rhyolites that lie at the same stratigraphic horizon farther west (region 3) are 37 m.y. old. Lavas of similar stratigraphic position but dacitic to latitic in composition (pl. A1) crop out in the Horse and White Pine Ranges. Similar intermediate lavas and associated tuffs,

all with a characteristic high-potassium content, are widely scattered throughout east-central Nevada. They have been reported as far east as White Pine County by Hose and Blake (1976) and in the vicinity of Eureka on the northwest by Nolan and others (1974) and Blake and others (1975). The rocks of the Eureka locality represent an assemblage that formed at a volcanic center during an interval from 38 to 33 m.y. ago and thus are approximately coeval as well as compositionally similar to the lavas around Currant, Nevada, in regions 1 and 2.

The Blind Spring Formation of Scott (1965, p. 16–17) (pl. A1), consisting of conglomerate, sandstone, shale, and minor lenses of limestone and mainly derived from the Railroad Valley Rhyolite of Scott, is not differentiated from younger sedimentary beds on the map (pl. A1) but is in general restricted to outcrops adjacent to the rhyolite.

The overlying very thick and extensive series of crystal-rich, chiefly rhyolitic Oligocene ash-flow tuffs has at its base the Calloway Well Formation of Scott (1965, p. 18–20) (pl. A1). The unit is known only from a few outcrops in the Grant Range. Scott described the Calloway Well as being rhyolitic in composition, containing 30% crystals, and consisting of from one to nine cooling units separated by thin layers of sedimentary rocks. He attributed thickness variations and pinchouts to irregularity of the underlying topography; two measured sections 7 miles (10 km) apart are 225 and 750 feet (69 and 229 m, respectively) thick. Armstrong (1970, table 3) obtained a mean K-Ar age of 33.2 ± 0.7 m.y. from biotite in the formation, which satisfies the stratigraphic order based on his determinations of younger ages for higher ash-flow tuffs in the Grant Range.

Thin andesite flows (part of andesite in flows, pl. A1) and green sediments derived from them lap the Blind Spring and Calloway Well Formations of Scott and are overlain by the thick but discontinuous Stone Cabin Formation (pl. A1), whose type locality is about 8 miles (13 km) southeast of Currant, Nevada (E. F. Cook, 1965, p. 12). The Stone Cabin, as described by Scott (1965, p. 21–24), is a rhyolitic crystal-rich (43% crystals) unit that forms a single cooling unit with more than five discrete flows. The bulk of the unit consists of dense lithoidal to poorly welded (frothy) rock at the top and is grayish orange pink to pinkish gray or white and weathers to shades of brown. The unit is discontinuous in the Grant Range because of erosion and nondeposition during the Oligocene; it commonly ranges in thickness from 110 to 2500 feet (33 to 762 m). The latter thickness, however, is probably excessive due to repetitive faulting, according to E. B. Ekren (written commun., Sept. 4, 1975). The formation apparently never extended south of the Grant Range or east of Garden Valley but is well represented in the central region, west of the Grant Range. Its mean radiometric age is 34.1 m.y. with a standard deviation of ± 0.9 m.y. (Gromme and others, 1972, tables 5, 6); Armstrong (1970, table 3) obtained a radiometric age of 32.4 ± 0.7 m.y. on the formation in the Grant Range.

Minor andesite lava or the successively younger Currant Tuff and the Windous Butte Formation locally unconformably overlie the Stone Cabin (Scott, 1965, p. 24). The Currant Tuff, a water-laid tuff (Faust and Callaghan, 1948, p. 15–26, 33–46), is not differentiated from other Tertiary sedimentary strata on the map (pl. A1). Small outcrops northeast of Currant form a whitish to pale-yellowish-gray marker zone beneath the darker brown, cliff-forming Windous Butte Formation. Epiclastic volcanic rocks including massively bedded tuffaceous sandstones, derived from the surrounding underlying tuffs, compose most of the Currant Tuff; and limestones are present locally in the Grant Range (Scott, 1965, p. 25) and elsewhere (Faust and Callaghan, 1948, tables 1, 2). Firby has obtained an age of 31.7 ± 1.2 m.y. on biotite near the base of the formation stratigraphically close to fossils of the Chadronian (early Oligocene) land-mammal stage (Marvin and others, 1973, p. 17–18).

One of the thickest (300–1200 ft or 91–366 m) and most continuous rhyolitic and quartz latitic welded ash-flow tuffs of the eastern one-third of the mapped region is the Windous Butte Formation. It was first defined by E. F. Cook (1965, p. 14–16) at a type locality just northeast of Currant and noted here even earlier as porphyritic quartz latite flows and latite crystal tuff by Faust and Callaghan (1948, p. 46–49). Scott's (1965, p. 25–27) description of the formation is summarized below. The unit contains about 33% crystals with quartz, sanidine, and plagioclase nearly equally abundant. It weathers to brownish cliffy outcrops not readily distinguishable from the Stone Cabin Formation and consists of two flows in a single cooling unit in the Grant Range. The formation extends well into the Egan Range on the east (off the map, pl. A1) and possibly into the Quinn Canyon Range on the south, where, if present, it would be relatively thin and mapped with undifferentiated crystal-rich, welded ash-flow tuffs (pl. A1). A radiometric age of 32.8 m.y. was obtained by Evernden and others (1964, p. 175), and younger ages (30.2 ± 0.6, 30.6 ± 0.6, and 30.7 ± 0.6 m.y.) were obtained by others (Armstrong, 1970, table 3; Gromme and others, 1972, tables 5, 6).

The thin rhyolitic Forest Home Ignimbrite of Scott (1965, p. 27–28; 1966), identified by him in two sections in the Grant Range, is included with the Windous Butte Formation on the present map (pl. A1).

The Needles Range Formation (pl. A1), whose type locality is on the east side of the Needle Range in southwestern Utah (Mackin, 1960, p. 99), overlies the Windous Butte in the Grant Range section, according to Scott (1965, fig. 4, p. 28–29). Maximum thickness of the Needles Range Formation is about 1000 feet (305 m), and locally it is absent by pinchout. Scott (1965, p. 28–29) described five cooling units ranging from dacite to rhyolite in composition, with all but one unit absent to the north near Currant. The cooling units contain 28%–43% crystals, and the formation is classed as moderately crystal rich and as less silicic than the underlying and overlying ash-flow tuffs. Plagioclase is generally most abundant, followed by quartz; sanidine is extremely sparse in most cooling units. Mafic crystals, including biotite, hornblende, and pyroxene, constitute a noticeable percentage of the total crystals (up to about 25%), thus serving to darken and to distinguish the formation

from surrounding tuffs. Armstrong (1970, p. 208–211, 223) gave 29.7 m.y. as the best value for the age of the Needles Range and suggested an age span of about 2 m.y. (about 29.7–27.2 m.y.b.p.) between lower members and an upper member (the fifth and highest of Scott [1965, p. 28–29] in the Grant Range). Ages as old as 30.7 ± 0.6 and 30.6 ± 0.9 m.y. have been obtained on the basal member of the formation by Armstrong (1970, p. 208–211). Similar ages—mean 30.0 m.y.—were obtained on samples from rocks questionably identified as the Needles Range in the southern Egan and northern Seaman Ranges by others (Marvin and others, 1970, p. 2671, table 6).

The Needles Range Formation extends into the Seaman and South Egan Ranges, according to E. F. Cook (1965, fig. 14), who measured thicknesses of 1055 feet (322 m) and more than 370 feet (133 m), respectively. It may also extend into the Golden Gate Range. In these places, the formation is undifferentiated on the map (pl. A1) and is apparently the thickest of the exposed Tertiary units. Other workers have concluded that Cook's assignment of the rocks to the Needles Range Formation is reasonable even though there is some confusion with the lithologically similar Monotony Tuff (Marvin and others, 1970, p. 2671–2672). This problem has not been fully resolved, however, especially in the Quinn Canyon Range, where a unit questionably identified as the Needles Range Formation also crops out. Rocks in the latter range are described with the Shingle Pass Tuff, below.

The Shingle Pass Tuff, whose type locality lies just east of Nye County in the southern Egan Range (E. F. Cook, 1965, p. 20), is probably the most extensive ash-flow tuff in the eastern region (region 1). It crops out in the Grant, Golden Gate, Seaman, and southern Egan Ranges but thins southward. Cook (1965, fig. 15) gave thicknesses of 160 feet (49 m) and approximately 160 feet (49 m) in the latter two ranges, respectively. The formation does not crop out in the Horse Range or the White Pine Mountains but probably extended across the area of the Horse Range. Its existence in the Quinn Canyon Range is questioned, and rocks there are described on later pages. In the Grant Range section, Scott (1965, p. 31) measured a thickness of as much as 1600 feet (488 m) and recognized ten cooling units in the formation, noting that only the lowest corresponded to Cook's unit at Shingle Pass. Farther north, near Currant, Scott recognized only three cooling units and measured less than 500 feet (152 m) of total thickness. The thickness, extent, and number of cooling units outside the Grant Range in region 1 generally have not been established. Bedded ash and conglomerate locally separate the cooling units. The Shingle Pass is a more highly differentiated rhyolite than the rhyolites in the older Oligocene ash-flow tuffs and differs from them by containing noticeably fewer crystals; it generally weathers more colorfully—to pale purples, reds, and oranges. Scott (1965, p. 31) noted 12% crystals in the lowest of ten members (cooling units) and about 25% in the upper cooling units. Quartz is typically absent from the crystal mode. The principal phenocrysts are sanidine and lesser amounts of plagioclase. An absolute age for the Shingle Pass Tuff comes from workers elsewhere: Sargent and McKee (1969, P. E12) listed a range of dates—24.5–25.1 ± 1.0 m.y. Thus, the age is considered to be earliest Miocene, possibly straddling the Oligocene and Miocene boundary.

The Oligocene section in the Quinn Canyon Range, described in more detail by Sainsbury and Kleinhampl (1969, p. C3, C4, pl. 1) is notably different from that in the Grant Range. One such difference is the great thickness of welded tuff that has been tentatively assigned to a map unit designated the Shingle Pass(?) and Needles Range Formations, undivided (pl. A1) in the Quinn Canyon Range from Cherry and Cottonwood Creeks on the east to Big Creek and Water Canyon on the west. As mapped on plate A1, the unit may also include the Monotony Tuff, which crops out extensively farther west in the Hot Creek, Pancake, and Reveille Ranges and in southern Nye County. The undifferentiated unit in the Quinn Canyon Range probably is at least 3000–5000 feet (914–1520 m) thick and consists of much thicker rocks than its possible correlatives in the Grant Range. The great thickness and other features led Sainsbury and Kleinhampl (1969) to conclude that the range was an eruptive center, but detailed studies are necessary to determine which ash flows in the region were vented from the center. Some of the thick welded tuffs in the Cottonwood Canyon and Pine Creek-Badger Gulch drainages are intensely altered, commonly to pervasively propylitized rocks, and weather greenish to brownish gray. Others, containing much quartz and sanidine, are only incipiently altered. The abundance of quartz is dissimilar to most Shingle Pass units, and the abundance of sanidine is totally unlike cooling units that have been assigned to the Needles Range Formation. Thus, it appears likely that much of the section in the Quinn Canyon Range is not related to either the Shingle Pass or the Needles Range.

Outcrops of quartz latitic(?) welded tuff west of Quinn Canyon are provisionally assigned to an undifferentiated welded tuff unit (pl. A1) because they do not readily correspond to any known formations. The rocks are characteristically platy to slabby, pale brown to pale purplish gray weathering, and crystal poor. In this respect the tuff resembles the cooling unit in the Shingle Pass Formation at Shingle Pass in the Egan Range. Penecontemporaneous flowage of the welded tuffs is locally evidenced by greatly elongated and extremely flattened pumice fragments (10:1 length to width is common) that impart lineation characteristics superficially resembling those of rhyolitic lava.

Miocene and Pliocene Rocks. Rhyolitic welded tuffs 22–23 m.y. old that crop out locally in the Quinn Canyon Range form one of the youngest ash-flow units in the eastern region (pl. A1, table A12). The unit consists chiefly of reddish-brown- to orange-brown-weathering lithoidal welded tuff of moderate crystal content, with quartz and sanidine predominant in the crystal mode. Tuffaceous sedimentary strata (pl. A1), including air-fall and water-worked ash, pumice, sand, and conglomerate, underlie and probably intertongue with the last-described ash-flow tuff unit and were deposited in fluviatile and lacustrine environments. Fossil plants

(grasses) are preserved locally in some of the lacustrine beds west of Quinn Canyon. We found no additional fossils. The youngest ash-flow tuff in the eastern region is the 21.3 ± 0.5 m.y.-old Bauers Tuff Member of the Condor Canyon Formation (undifferentiated on pl. A1), dated in the Golden Gate Range by Armstrong (1970, table 3). E. F. Cook (1965, p. 23–25) described the formation and indicated that it may extend into the Seaman Range as well, except that the outcrops there are close to its northwestern limit of distribution.

The Horse Camp Formation of Moores (1968) is a fluviolacustrine sedimentary deposit that unconformably overlies the Oligocene and Miocene volcanic rocks of the Grant Range and that is restricted to a basin about 5 x 10 miles (8 x 16 km) across (now deformed) near Currant. Thickness of the formation ranges from a wedge edge on the periphery of the basin to as much as 10,000 feet (3050 m) (Moores, 1968, p. 89–93). Fluviatile beds and fanglomerate intertongue with lacustrine strata composed of vitric ash, sandstone, conglomerate, limestone, and some zeolite. Clastic detritus was derived from both Paleozoic sedimentary rocks and Tertiary volcanic rocks. Gravity slide blocks and monolithologic breccias, as much as thousands of feet across and composed of Paleozoic and Tertiary rocks, are common at different horizons in the Horse Camp. Their significance has been discussed by Moores (1968) and Moores and others (1968). The probable Miocene and Pliocene age of the formation given by Moores (1968, p. 96) appears to be based on faunal evidence cited by Van Houten (1956, p. 2803, 2812), who used the mammalian correlations and nomenclature established by Wood and others (1941). The dated Barstovian and Clarendonian ostracodes and snails do not furnish limiting ages, however, and leaves of probable pre-Miocene age were reported in the basal part of the formation (Van Houten, 1956, p. 2812). According to the timescales of the Geological Society of London (1964), the age of the formation would most likely be confined to the Miocene.

Discontinuous basaltic, andesitic, dacitic, and quartz latitic lavas, as much as several hundred feet thick, are scattered throughout the upper Tertiary of the Grant Range and Currant area. Scott (1965, p. 33–34) applied the names Deer Park Andesite and Perish Spring Dacite to two such units. None has been dated precisely. Their ages probably range from Miocene to Pliocene. The only known age for possibly similar rocks is 20.1 ± 0.5 m.y. for a trachytic basalt in the Golden Gate Range just south of the mapped region (Armstrong, 1970, table 3). Rhyolitic dikes and irregular bodies of rhyolite and quartz-latite porphyry, as much as several miles across, intrude parts of the ash-flow tuff section in the Quinn Canyon Range and are probably Miocene. The rhyolitic dikes are spatially and in part perhaps genetically associated with fluorite deposits (Sainsbury and Kleinhampl, 1969).

Quaternary Deposits. Fanglomerate aprons border the mountain ranges of the Eastern Region and intertongue valleyward with alluvium and, finally, with eolian and beachbounded lacustrine deposits. Together these deposits form a valley fill as much as several thousand feet thick (Smith, 1960, pl. 2; McJannet and Clark, 1960, p. 245–246). The deposits consist of material derived from Paleozoic and Tertiary rocks. Induration of these deposits varies considerably; where indurated, calcium carbonate is the most common cement. Quaternary deposits disconformably and locally unconformably overlie late Tertiary strata that are somewhat similar in origin except for the occurrence of beds of volcanic ash and more abundant volcaniclastic rocks in the older strata. Extensive terraces of thick caliche-cemented gravels in and adjacent to the White Pine and Grant Ranges indicate the former presence of large amounts of water and, thus, a probable direct relationship to a Pleistocene interglacial epoch. The terraces form bajadas on pedimented surfaces, and locally remnants extend well up into the higher valleys of the ranges. Glacial deposits were not specifically identified (see the section of this bulletin on Glacial Geology). The valley-fill deposits wedge out or, in some cases, terminate against fault-bounded bedrock. In places the peripheral valley-fill deposits form a discontinuous thin cover over pedimented bedrock surfaces. Magnificent exposures of beach and nearshore lacustrine features in Railroad Valley are described in the section of this bulletin on Geomorphology.

East-Central Region (Region 2)

Stratigraphic Setting

The lower (Oligocene) part of the composite section (pl. A1) generally resembles that in the eastern region (region 1). There are a number of striking differences, but they are not so common as between the corresponding Miocene and Pliocene parts of the sections in each region. The similarity between the Oligocene parts is apparently mainly in the general progression upward from a basal sedimentary unit derived from nonvolcanic rocks (Sheep Pass Formation, pl. A1) through a series of predominantly lavas and intrusive bodies into a thick pile of crystal-rich silicic ash-flow tuffs. Certain major marker units of great areal extent, such as the Stone Cabin and Windous Butte Formations and the Shingle Pass Tuff, persist over much of the central and eastern parts of northern Nye County and serve to emphasize remaining differences between the sections in regions 1 and 2. A major difference is the presence of a great thickness of intermediate lavas (pl. A1) between the Stone Cabin and Windous Butte in region 2 and their almost total absence in region 1. The differences between the post-Shingle-Pass parts of the two composite sections, although real, may not be so pronounced as appears at first glance, because a few units differently named or placed in each section may prove to be partly correlative (pl. A1).

Oligocene Rocks

The oldest Tertiary volcanic rocks in this region are rhyolitic and andesitic lavas with minor welded and nonwelded tuffs (older volcanic rocks, pl. A1). These older rocks appear to be localized in two places. In the

Pancake Range about 7 miles (11 km) south of Portuguese Mountain they are as much as 1000 feet (305 m) thick and have been described in considerable detail by Quinlivan and others (1974). Other outcrops in the Duckwater Hills include tuffs and tuffaceous sedimentary strata.

The Stone Cabin Formation, previously described, has the same general characteristics as it does in region 1. The formation is thicker, however, in region 2. Between Portuguese Mountain and Railroad Valley, it is as much as 3000 feet (915 m) thick, and its upper surface is an unconformity (Quinlivan and others, 1974).

Rhyolitic lava of Portuguese Mountain (pl. A1) includes both crystal-rich and quartz-rich rhyolite and crystal-poor rhyolite and rhyodacite and is restricted to the vicinity of Portuguese Mountain. The unit intertongues with the Stone Cabin Formation, according to Quinlivan and others (1974), and is therefore in part equivalent to the Stone Cabin in age.

Other discontinuous rhyolitic flows containing sparse to abundant phenocrysts lie at different stratigraphic positions within the Oligocene near Portuguese Mountain. Most of these flows span a narrow time interval (about 31-34 m.y. ago) between the Windous Butte and Stone Cabin Formations (Quinlivan and others, 1974) and, therefore, are grouped together as a single unit on the accompanying map (rhyolite lava, pl. A1).

Lavas of dacitic, quartz latitic, and, locally, basaltic andesite composition overlie the Stone Cabin Formation and crop out as prominent dark-gray broken cliffs capped by high cliffs of brown-weathering ash-flow tuffs. These and similar lavas extend over a vast part of the east-central and west-central regions (rocks of intermediate composition, pl. A1). In places, the lavas are 1000 feet (305 m) or more thick. They appear to be thickest in the vicinity of Moody Peak, which undoubtedly is the location of one of the main vents for the lava sequence. The stratigraphic position of the lavas between the Stone Cabin and the Windous Butte Formations indicates an age of about 31-33 m.y.

Several major ash-flow tuffs overlying the pile of intermediate lavas complete the series of Oligocene rocks. The most widespread of these is the Windous Butte Formation, but other units are locally important and will be briefly described. The Pancake Summit Tuff and the tuff of Cottonwood Canyon are widespread in the northern part of region 2. These two units are combined (pl. A1) because of their thinness, possible intertonguing character, and their similarity of source. The Pancake Summit Tuff (Gromme and others, 1972; Nolan and others, 1974; McKee, 1976) consists of a salmon-colored, cliffy, crystal-rich, rhyolitic, welded ash-flow tuff with conspicuous smoky quartz crystals. Quartz, sanidine, and plagioclase are nearly equal in the crystal mode (Gromme and others, 1972, p. 1624). It extends into the region from the north and terminates at about lat 39° N. in Nye County. It probably does not attain the maximum thickness of 420 feet (140 m) noted by Gromme and others (1972, p. 1625) north of Nye County. The tuff of Cottonwood Canyon of Dixon and others (1972) is similarly distributed. The ages of the two units are about 32 m.y. (Gromme and others, 1972, table 5) and 30 m.y., respectively, and they are overlain by the Windous Butte Formation, whose mean age is 30.7 m.y. and which is similarly confined to the northern part of region 2. The seeming incongruity between the ages and stratigraphic positions may be due to errors in the dating method and the fact that samples were obtained from partly intertonguing and overlapping ash-flow tuffs.

The Windous Butte Formation in region 2 is a densely welded cliff former that weathers to a conspicuous reddish brown. It thins southward in the region to only between a wedge-edge and 100 feet (0 and 31 m) near Portuguese Mountain and was not recognized farther south (Quinlivan and others, 1974). The thickest outcrops in the region are near Moody Peak, where exposures attain a thickness of several hundred feet. The formation is more widely distributed and locally much thicker in regions 1 and 3. It is rhyolitic and moderately crystal rich (20%-50% crystals), with abundant quartz and an even greater content of feldspar crystals and visible mafic minerals. The Windous Butte appears to have erupted from a giant caldron complex centered on Hot Creek Valley in regions 2 and 3. (Ekren, Hinrichs, Quinlivan, and Hoover, 1973; Ekren, Bath, Dixon, Healey, and Quinlivan, 1974, p. 108). E. F. Cook's (1965, p. 14-15) wide distribution for the Windous Butte was made more restrictive in Nye County by Gromme and others (1972, fig. 1, and p. 1625-1628) and by Ekren and others (referenced previously). Its initial distribution may have encompassed all of regions 1, 2, and 3, as suggested by Cook (1965, p. 15), but if so, deep erosion prior to succeeding volcanic events in the southern parts of regions 2 and 3 has led to its obliteration there.

The tuff of Williams Ridge and Morey Peak of Ekren, Hinrichs, and Dixon (1972) has proven to be one of the major units of the central Nevada region (U.S. Geol. Survey, 1970, p. A39-A40; Ekren, Bath, Dixon, Healey, and Quinlivan, 1974; Ekren, Quinlivan, Snyder and Kleinhampl, 1974). It underlies a large area in regions 2 and 3 of northern Nye County, its greatest thickness centering approximately from Morey Peak (Hot Creek Range) eastward to the vicinity of Williams Ridge in the western Pancake Range about 5 miles (8 km) north of Sandy Summit on U.S. Highway 6. At Williams Ridge the total thickness probably exceeds 6500 feet (1980 m) based on outcrop and drill-hole measurements (Ekren, Hinrichs, Quinlivan, and Hoover, 1973; Ekren, Quinlivan, Snyder, and Kleinhampl, 1974). The formation thins and pinches out eastward near the east edge of the Pancake Range and is absent north of about lat 38°45′ N, where other temporally equivalent ash-flow tuffs are prevalent.

The tuff of Williams Ridge and Morey Peak was provisionally identified and mapped as far south as the Reveille Range, where it forms the base of the Tertiary section (Ekren, Rogers, and Dixon, 1972a, 1972b, 1973). The following description of the tuff is taken largely from three published sources (Ekren, Rogers, and Dixon, 1973; Ekren, Hinrichs, Quinlivan, and Hoover, 1973; Quinlivan, Rogers, and Dodge, 1974). Composition ranges from rhyolite to quartz latite in two

or more compound cooling units with very thick, densely welded devitrified zones. Vent breccias occur locally in the upper part of the formation. Crystal content is moderate to high (25%–55%); crystals are conspicuous and commonly several tenths of a millimeter across. Quartz, plagioclase, and hornblende attain a crystal size of more than 1.5 cm in a few rare outcrops. The crystals include quartz and alkali feldspar in about equal amounts and plagioclase equal to their total. Mafic minerals, particularly biotite, are common. The relatively fresh rock is gray and weathers to dark or light grays and browns. Where altered, the unit may be dark purplish to greenish gray (commonly propylitized) or light or very light grays and browns (lightest where most oxidized and argillized). Its age range averages between 30.5 and 32.7 m.y. and overlaps the ages of the three ash-flow tuffs described above; this overlap tends to confirm their partly intertonguing relationships. The formation is directly correlated with the upper quartz latitic part of the Windous Butte Formation by Ekren, Bath, Dixon, Healey, and Quinlivan (1974, p. 108). The tuff of Pritchards Station of Dixon and others (1972), an ash-flow tuff up to 700 feet (214 m) thick between Portuguese Mountain and Wood Canyon in the main part of the Pancake Range, is combined with the tuff of Williams Ridge and Morey Peak because G. L. Dixon (oral commun., 1974) has suggested such a correlation. The tuff of Pritchards Station, however, was shown to have a distinct crystal mode and to lie directly beneath the tuff of Cottonwood Canyon and above the Stone Cabin Formation (Quinlivan and others, 1974).

The tuff of Black Rock Summit of Ekren, Hinrichs, and Dixon (1972) is of local importance near U.S. Highway 6 in the southern Pancake Range. It is informally named for excellent exposures of predominantly rhyolitic welded tuffs and minor overlying intermediate lavas at Black Rock Summit on U.S. Highway 6. Its thickness ranges from a wedge edge to more than 1450 feet (440 m) over a distance of several miles. The unit is generally grouped with undifferentiated tuffs in a volcanic rocks unit (pl. A1); locally, it may have been included with the old tuffs of the Pancake caldera complex. The tuff of Black Rock Summit is distinctive because, although it has a quartz latitic or rhyodacitic phenocryst assemblage, it is rhyolitic in composition (Ekren, Quinlivan, Snyder, and Kleinhampl, 1974). The range in color is from light grays through bluish and pinkish grays to browns, and the overall effect locally is of a faintly variegated pastel unit. There are at least two cooling units of somewhat similar lithology. Crystal content is low, and crystals consist mainly of plagioclase feldspar, noticeably lesser quartz, and minor amounts of other minerals with a considerable scattering of biotite. The unit lies stratigraphically above the tuff of Williams Ridge and Morey Peak and below two other distinctive silicic ash-flow tuffs that for purposes of the present report are combined into a single map unit termed "old tuffs of the Pancake caldera complex" (pl. A1).

The old tuffs of the Pancake caldera complex is a map unit formed of thick ash flows that are conspicuous in the southern Pancake Range and include the tuff of Halligan Mesa (30.3 m.y.) and the overlying tuff of Palisade Mesa (29.9 m.y.). These components are multiple-flow simple cooling units, and as many as twelve flows can be seen in the cliffy exposures on the south side of Sandy Summit. The tuff of Halligan Mesa is locally, but not everywhere, less cliffy than the tuff of Palisade Mesa and forms massive lighter gray to buff outcrops beneath the reddish-gray to brown-weathering cliffs of the latter. The combined thickness of the two tuffs is somewhat more than 1000 feet (305 m), and the younger is somewhat thinner than the older. Their crystal content is generally moderately high (about one-fifth to one-half of the entire rock); the crystals, as much as several millimeters across, consist of nearly equal amounts of quartz, alkali feldspar, and plagioclase with a noticeable scattering of mafic minerals.

Two other ash-flow tuff units of considerable importance in region 2 are the Needles Range Formation and the Monotony Tuff (pl. A1). The Needles Range Formation, which is so widespread in region 1 to the east, underlies only the northern Pancake Range in region 2. Minor outcrops that attain a maximum thickness of about 50 feet (15 m) were mapped by Dixon and others (1972) in the Pritchards Station quadrangle and more recently by G. L. Dixon (oral commun., 1974) in the Brown Summit quadrangle, northern Pancake Range. Ekren, Rogers, and Dixon (1973) divided the Monotony Tuff into extracaldron and intracaldron facies in the Reveille Range and vicinity. They described the intracaldron Monotony (the tuff of Goblin Knobs) as the least typical and least extensive variety, but by far the thickest (5000+ ft or 1520+ m), and they infer that it filled the caldera that formed after the widespread extracaldron facies was vented. The tuff of Goblin Knobs contains fewer crystals (about 32%) than the extracaldron Monotony and is quartz latitic in composition. The extracaldron Monotony is in large part rhyodacitic in composition and generally contains about 50% crystals consisting of about 10%–32% quartz, 3%–12% sanidine, 46%–63% plagioclase, 8%–22% biotite, and about 4%–12% hornblende and clinopyroxene. One to three simple cogenetic cooling units characterize the extracaldron variety of the formation everywhere except for the compound cooling unit in the Reveille Range. The typical extracaldron rock closely resembles the Needles Range Formation in phenocryst habit, chemistry, and weathering characteristics. The tuff typically weathers dull brown or rusty brown and forms slopes or rounded hills. In a few places where the rock is unusually fresh, it weathers to light gray or pale brown.

Lavas and intrusive bodies ranging in age from the middle Oligocene to about the Oligocene-Miocene boundary are widely distributed in the region. The nearly aphyric 25.8 ± 1.3-m.y.-old rhyolite of Big Sand Springs Valley (Ekren, Hinrichs, and Dixon, 1972; pl. A1) forms several large piles in the vicinity of Lunar Crater, and this unit is shown separately on plate A1. Several other large lava flows and piles are not singly differentiated (pl. A1). Some of these are rhyolitic; others are intermediate in composition. They crop out in the Kawich and Reveille Ranges and in the central part of the Pancake Range. Most of the rhyolites in-

cluded in the undifferentiated unit are crystal poor. The phenocrysts are small (less than 2 mm) and consist mainly of quartz. Small bodies of intermediate composition in the northern Kawich Range, not examined by us, may include some rocks that more properly correlate with the older dacitic and latitic lavas of the region. Ferguson (1916) described some of the andesitic rocks of the Clifford mining district nearby (about 7 miles or 11 km southwest of Warm Springs), where propylitic alteration is fairly pervasive. A large intrusive body of quartz latite porphyry (Cornwall, 1972; Gardner and others (1980) called it rhyodacite of Bellehelen Lakes) underlying the highest part of the Kawich Range in northern Nye County is mapped with intermediate to silicic lavas and intrusive bodies (pl. A1). The body was dated at 26.4 ± 1.3 m.y. (Gardner and others, 1980); it is probably related to a late (resurgent) stage of caldron development.

Miocene and Pliocene rocks

The rhyolitic Shingle Pass Tuff has been described in considerable detail in the description of map units for region 1, and only a few pertinent facts will be enumerated here. The Shingle Pass is a major unit in region 2. It includes several units of very similar lithology, locally including the ignimbrite of E. F. Cook (1965) that crops out at Shingle Pass in the Egan Range (Sargent and McKee, 1969; Ekren, Hinrichs, and Dixon, 1972). The thickest Shingle Pass unit in region 2 is the approximately 750 feet (229 m) in the southern Pancake Range. As many as three cooling units are present at that locality and in parts of the Hot Creek Range. The units included in the Shingle Pass in region 2 are all crystal poor, especially the lowermost unit. Dixon, Hedlund, and Ekren (1972) and Ekren, Rogers, and Dixon (1973) quoted the 24.5 ± 1.0 and 25.1 ± 1.0 m.y. ages for the formation obtained by Sargent and McKee (1969, table 6) in a section in the Hot Creek Range (region 3 of this report). Ages of 21.8 ± 0.7 m.y. and 27.4 ± 0.9 m.y., also given by Ekren, Rogers, and Dixon (1973), do not permit a good fit with stratigraphic relations. Ekren, Hinrichs, and Dixon (1972) suggested that the Shingle Pass Tuff may be the distal end of the tuff of Orange Lichen Creek of Ekren, Hinrichs, Quinlivan, and Hoover (1973), which in the present report is included with the young tuffs of Moores Station area (pl. A1) in region 3.

The tuff of Bald Mountain (Ekren, Rogers, and Dixon, 1973; pl. A1) in the extreme southern part of the Pancake Range is of rhyolitic composition and overlies debris, containing blocks of Shingle Pass Tuff, that formed between 18.5 and 26 m.y. ago. Exposures are very limited and represent some of the northernmost known outcrops of the ash-flow tuff, which, according to the above authors, had its origin south in the Bald Mountain caldera, about 55 miles (89 km) south-southwest in the Groom Range, Lincoln County.

Six other ash-flow tuffs that are differentiated on various maps (see sources of data, pl. A1) are included in the young tuffs of the Pancake caldera complex (pl. A1) because of their geographic proximity and partial consanguinity. The tuffs total as much as 1500 feet (457 m) in thickness, but few are regionally significant. They are rhyolitic to rhyodacitic in composition and generally contain moderate amounts of crystals. The units weather to pale to moderate browns, reddish browns, and pink to purplish grays in a series of steplike cliffs. The most regionally important of these units is the widely distributed approximately 25-m.y.-old tuff of Lunar Cuesta (up to 400 feet or up to 122 m thick) (Snyder, Ekren, and Dixon, 1972; Ekren, Quinlivan, Snyder, and Kleinhampl, 1974).

The young tuffs of the Pancake caldera complex vented from a caldera complex that underlies the southern Pancake range; they are among the youngest ash-flow tuffs that vented in the eastern half of northern Nye County. The Bates Mountain Tuff, for example, which is 22.8 ± 0.9 m.y. old and described with rocks of the west-central region (region 3), erupted in Lander County (Stewart and McKee, 1968b; McKee, 1969). The Bates Mountain outcrops in region 2, however, are limited to very small patches in the northern part. Rocks forming the map unit welded tuffs and miscellaneous rocks of the Reveille Range (pl. A1) are of close age affinity and represent an aggregation of predominantly rhyolitic ash-flow and air-fall tuffs and tuffaceous sedimentary strata derived from the tuffs. Several of the younger tuffs composing this map unit may have been deposited only in the vicinity of their present-day limited outcrops and were never regionally extensive. An exception is the basal rhyolitic tuff of White Blotch Spring of Ekren and others (1971), which is about 21–25 m.y. old, consists of several ash flows, and is extremely widespread in southern Nye County (Ekren and others, 1971, p. 32–33; Cornwall, 1972, p. 17).

The major pulse of volcanism that yielded the numerous middle and late Oligocene lavas and intrusive bodies extended into the Miocene and generally concluded with the emplacement of quartz latite dikes in the Reveille Range about 18.7 ± 0.8 m.y. ago. (Ekren, Rogers, and Dixon, 1973). Bodies spanning the younger part of this broad age range are grouped into two map units: (1) rocks of the Reveille Range (pl. A1) (24–25 m.y. old) and (2) silicic to intermediate lavas and intrusive bodies (pl. A1) (as old as 22–24 m.y. and as young as 18.7 ± 0.8 m.y.). The former unit underlies parts of the Reveille Range in scattered bodies of irregular shape and size. Its various members are believed to be of local origin and include some tuffs and sedimentary strata—mainly the informally named (Ekren, Rogers, and Dixon, 1973) rhyolite and tuff of Steuben Knob and tuff of northern Reveille Range.

The debris unit (pl. A1) mapped and studied by Ekren, Rogers, and Dixon (1973) at the extreme southwestern edge of the Pancake Range, east of Twin Springs Ranch, is essentially a melange that formed during a period of intense strike-slip faulting between 18.5 and 26 m.y. ago. The debris is inferred to have been shed from a western fault block as it moved past an eastern block that now forms the southern terminus of the Pancake Range (E. B. Ekren, written commun., 1975). Movement along the strike-slip faults ceased prior to about 18 m.y. ago, because quartz latite dikes

of that age (pl. A1) are undisturbed where they are intruded along faults of the strike-slip system. Intrusion of the dikes concluded the silicic volcanism in the Reveille Range area.

Basaltic Rocks

Basaltic andesite and basaltic flows from localized volcanos and fissures are scattered throughout the Duckwater Hills and the southern half of the east-central region (region 2). Divisions of basaltic rocks as late Tertiary, Tertiary or Quaternary, and Quaternary (pl. A1) are provisional because very few of the rocks have been dated. The youngest dates so far obtained are those in the Reveille Range (pl. A1), where an olivine-bearing basalt flow yielded a date of 5.7 ± 0.2 m.y. (Ekren, Rogers, and Dixon, 1973). The basalts of the Reveille Range, although they flowed out over faulted and eroded terrane, are faulted themselves, and locally they are deeply eroded. These facts suggest strongly that basalts of the Reveille Range are much older than most, if not all, of the basaltic rocks in the Lunar Crater area, which are little faulted and eroded. More detailed work may show the Tertiary or Quaternary basaltic rocks (basalt, andesite, and latite, pl. A1) of the Duckwater Hills to be part of the nearby much older pile of Tertiary lavas (rocks of intermediate composition, pl. A1).

The extensive basaltic field in the Lunar Crater area (pl. A1) is an impressive sight with its widespread lava, cinder, and ash deposits and its many volcanic cones, mounds, and craters aligned along fissures (Scott and Trask, 1971, pl. 1; Kleinhampl and Ziony, 1967; and quadrangle maps covering this region—see sources of data, pl. A1). Vitaliano and Harvey (1965) made the first petrographic descriptions of the basalts, and a report by Scott and Trask (1971) details the geology of the basalt field. Both reports are used for the following summary of the geology of the basaltic field. The basalts are alkaline basalts, commonly vesicular and porphyritic with phenocrysts of olivine, plagioclase, and pyroxene ranging in size from microphenocrysts to phenocrysts several inches across. The youngest basalts contain abundant xenoliths of lherzolite, wehrlite, dunite, and gabbro and xenocrysts of olivine, pyroxene, and plagioclase (Scott and Trask, 1971, p. I6). The cones in the basaltic field are commonly cratered and most are quite symmetrical. They may exhibit a breached portion of perimeter from whence flowed lava. Many of the cones are composites of ash, cindery and blocky ejecta, and lava. Three closely spaced episodes of basaltic volcanism, older, intermediate, and younger, were recognized by Scott and Trask (1971); we think these episodes Pliocene and younger. Basalt flows of the older and intermediate episodes, totaling 100 feet (31 m) in thickness are exposed in the walls of Lunar Crater. The presence of tuffaceous (ashy), friable, snail-bearing lacustrine beds on the floor of this crater is useful in defining the upper age of the flows. It is likely that the fossiliferous strata were deposited during a pluvial interglacial period; thus, the lavas in which the crater is formed are most likely to be at least as old as Pleistocene. As many as four flows, including rocks of the youngest episode of Scott and Trask (1971), have erupted successively from vents along a fissure zone north of U.S. Highway 6 just east of Big Sand Springs Valley. All four flows appear to be fairly young, but the last one is of the youngest episode and so fresh in appearance as to make it one of the most conspicuously young lavas in the region. Madison Locke, whose father homesteaded Lockes Station just east of the Pancake Range, related (oral commun., 1960) that an old Indian had told Locke's father of a taboo on travel to the locality in his grandfather's time because the volcano smoked. It is certainly possible that the most recent flow is no older than several hundred or a few thousand years. R. L. Smith examined this flow in late 1967 and concluded that it was probably less than 2000 years old (oral commun., 1967). Holocene cinder mounds on talus along the base of cliffs of ash-flow tuffs several miles eastward may be even younger than the basalt flow described above (Scott and Trask, 1971, p. 14).

Tertiary and (or) Quaternary Deposits (exclusive of basaltic lavas)

Tertiary and (or) Quaternary deposits exclusive of basaltic lavas and consisting principally of unconsolidated to weakly consolidated fluviolacustrine deposits are widespread in region 2, chiefly in the broad valleys. The alluvial deposits have been categorized as a single map unit of Quaternary age (alluvium, colluvium, talus, pl. A1), but they undoubtedly include Tertiary strata. The unit, not described in detail here, includes a wide variety of deposits that are typical of the Basin and Range physiographic province. They include fanglomerate, fine to coarse alluvium, lake beds, minor wind-blown sand and silt, and clay in playas.

Volcanogenic clastic rocks (pl. A1) underlie a small area in the northern Pancake Range north of Moody Peak. Sandstone and conglomerate derived from Tertiary volcanic rocks are the most abundant constituents.

Landslide deposits are important features locally and are shown as three separate units on the map (pl. A1). The time of sliding of the various masses is in considerable doubt. Most of the masses are probably very late Tertiary or younger and related to basin and range faulting; these are not silicified or otherwise altered. Landslide deposits included in exotic slide blocks (pl. A1), however, are commonly altered and require special mention. The large exotic slide block in the Pancake Range west of Duckwater is chiefly a monolithologic mass of crystal-rich, quartz-rich welded tuff assigned by G. L. Dixon (oral commun., 1974) to the Stone Cabin Formation. The rock is highly silicified, as are other blocks of Stone Cabin that occur 11 miles (18 km) southwest of Lockes Station; these may have had a similar history. The blocks at Duckwater and near Lockes may have been altered by waters of once-active hot springs, modern-day relics of which are aligned along the west side of Railroad Valley near the slide masses. More abundant exotic slide blocks are clustered near Moores Station in region 3 to the west. Geologists who mapped there consider some of these blocks to be related to volcano-tectonic subsidence; others are

related to strike-slip fault movements (E. B. Ekren, oral commun., 1975).

Exotic slide blocks of middle Paleozoic carbonate rocks, plainly visible from U.S. Highway 6 north of Black Rock Summit in the Pancake Range, are not distinguished on the map (pl. A1) from typical thrust plates because of their massive size, general cohesiveness, and considerable age. The interpretation that they formed during collapse of the Williams Ridge cauldron (Quinlivan and others, 1974) is reasonable and readily acceptable to the present authors. Some of the Paleozoic masses near Highway 6 are intercalated with the tuff of Williams Ridge and Morey Peak and are late Oligocene.

Tufa deposits (pl. A1) are relatively more abundant in the east-central region than elsewhere in northern Nye County. They consist mostly of pale-brown, grayish-brown, or yellowish-brown calcareous material that formed around springs. Many such springs are still flowing, and most are depositing various amounts of calcium carbonate. Irregular to nearly circular tufa mounds with one or several active and extinct orifices characterize the localities of many springs in Railroad Valley (see the section of this bulletin on Springs and Fault Scarps). Some of the tufa forms coalescing mounds (Warm Spring, 3 miles [5 km] south-southwest of Lockes Station), and some form broad terrace aprons (Big Springs, near Duckwater) that give evidence of having formed partly under water, with tufa enclosing casts of reeds or algae. It is not uncommon for tufa to contain recemented tufa debris.

West-central Region (Region 3)

For purposes of description, this region has been divided into two parts—a main part that encompasses most of the region and the Hannapah-Ellendale area in the southern Monitor Range. The latter area has undergone extensive hydrothermal alteration and contains a distinctive assemblage of volcanic strata that warrant separate description. Much of the Cenozoic section described in region 2 on the east is recognizable and mapped in parts of region 3. Therefore, the rock descriptions below chiefly elaborate on those map units unique or nearly so to region 3.

Main Area

Oligocene Rocks. The oldest Tertiary rocks with volcanic affinities are mapped as tuffaceous rocks, sedimentary strata, and rhyolitic bodies, undifferentiated (pl. A1). These strata crop out mainly in scattered patches in the northern half of the main area. Phenocryst-poor rhyolite bodies predominate near Dobbin Summit in the Monitor Range and near Luther Waddles Wash in the Hot Creek Range. Some of the uppermost flows in the Hot Creek Range are less rhyolitic and contain abundant phenocrysts (Ekren, Bath, Dixon, Healey, and Quinlivan, 1974, p. 107–108). Bedded rhyolitic tuff, rhyolite bodies, and tuffaceous sedimentary strata, including lacustrine limestone, are all common in a section up to 500 feet (152 m) thick east of Moores and Pritchards Stations (Dixon and others, 1972). The rocks weather to pastel grays, browns, yellows; the tuffaceous sedimentary strata include fluviatile and lacustrine sandstone and siltstone, derived chiefly from tuffaceous rocks, and commonly argillized bedded tuff. Imprints of pine needles and a fern leaf were found in the strata east of Red Ring Mountain but were not definitive of age according to J. A. Wolfe (written commun., 1962). Some rhyolite near Moores Station was dated at 37.2 ± 1.3 m.y. (Dixon and others, 1972), which is the oldest unequivocally dated Tertiary volcanic rock in northern Nye County. These rhyolites are overlain by rocks of intermediate composition in the Monitor and Antelope Ranges.

The rocks of intermediate composition (pl. A1) crop out over much of the northern part of region 3 in sections as much as several thousand feet thick and consist mainly of lavas, intrusive masses, and very minor tuffs. Intermediate lavas are locally not distinguished from ash-flow tuffs in a volcanic rocks unit (pl. A1) in the Monitor Range west of Antelope and Dry Valleys because time did not permit their separation. The lava outcrops typically weather to moderate slopes and cliffs that are variously colored dark gray, black, brown, and moderate red and in most places contrast markedly with overlying and underlying units. The rocks range in composition from andesite to quartz latite, and propylitized zones are common locally. A lenticular outcrop of rhyodacite lavas up to 900 feet (274 m) thick between Empire and Keystone Canyons, Hot Creek Range, was mapped as unconformably overlying late Paleozoic strata and unconformably underlying the 30.0 ± 0.9-m.y.-old tuff of Hot Creek Canyon of Quinlivan and Rogers (1974). The intermediate lavas were dated at 35.2 ± 1.1 m.y. by R. F. Marvin (written commun., Sept. 1965) near Ninemile Peak in the Antelope Range, just north of where similar lavas overlie the 37-m.y.-old rhyolites described in the preceding paragraph, which lends support to the considerable age of the rhyolite. However, farther east near Pritchards Station, comparable intermediate lavas may be somewhat younger because they overlie the 34.1-m.y.-old (mean age) Stone Cabin Formation. Here the intermediate lavas are as much as a few thousand feet thick and are broadly subdivided by Dixon and others (1972). This stratigraphic position corresponds to that of rocks of intermediate composition (pl. A1) that crop out still farther east in region 2. Thus, the rocks of intermediate composition, taken in their entirety, straddle the stratigraphic interval of the Stone Cabin, and the intermediate rocks in regions 3 and 2 erupted from different centers. Several major eruptive centers for these rocks are recognizable in the northern part of the mapped region; they include Ninemile Peak (Antelope Range) and the high area north of Dobbin Summit (Monitor Range). Rocks of intermediate composition underlie almost the entire 2500-foot (762-m)-high mass of Ninemile Peak, and contorted flow laminations are common here and locally at the Dobbin Summit locality. Local sources gave rise to the thinner, less continuous lavas in the southern Hot Creek Range and vicinity. Another volcanic center near Eureka, Nevada, gave rise to the Richmond Mountain Andesite,

which is an approximately synchronous unit (Blake and others, 1975).

The intermediate lavas are directly overlain in the Monitor and Antelope Ranges by moderately to densely welded rhyolitic ash-flow tuff (included with volcanic rocks—ash-flow tuffs, undifferentiated, pl. A1) that contains abundant crystals of quartz, sanidine, and plagioclase. This welded tuff was sampled in Long Canyon, Monitor Range (east of Potts Ranch), where the section is thick and was dated at 33.1–35.2 m.y. (extremes of averages of biotite and sanidine dates) by R. F. Marvin (written commun., 1965) and R. W. Kistler (written commun., 1967). The welded tuff is lithologically similar to the 34.1-m.y.-old mean age Oligocene Stone Cabin Formation.

The Stone Cabin Formation (pl. A1), however, is generally much thinner in region 3 compared to region 2, which suggests that its source is in the eastern part of the county. The formation crops out only near Moores and Pritchards Stations, where Dixon, Hedlund, and Ekren (1972) describe the unit as ranging laterally in thickness from a wedge edge to 700 feet (213 m). They note that it forms a single cooling unit weathering to pastel colors which contrast with generally darker weathering outcrops farther east.

The Cenozoic sections of the Hot Creek Range and vicinity are particularly important because they include excellent exposures of major units that have wide distribution in central Nevada. Ferguson's (1933) pioneering Cenozoic stratigraphy there at Tybo, however, has been so modified by later workers that it is best disregarded, although the early lithologic descriptions are still useful. Also, his definition of the Tertiary sedimentary Gilmore Gulch Formation still stands. Although the Gilmore gulch lies between ash-flow tuffs, it is described first below because of its historic importance and because it seemed unwise to interrupt and possibly confuse the description of the ash-flow tuffs that follows.

The Gilmore Gulch Formation was named for an incomplete 400–500-foot (122–152-m)-thick section of sedimentary rocks with unexposed base in Gilmore Gulch, a southern tributary to Tybo Canyon near Tybo (Ferguson, 1933, p. 21–22). The formation is restricted to the Hot Creek Range, and later mapping has demonstrated that the broadly lenticular unit ranges in thickness from a wedge edge to a maximum thickness of about 2000 feet (610 m) (Kleinhampl and Ziony, 1967; Quinlivan and Rogers, 1974). The Gilmore Gulch weathers to brown and yellow-brown steep slopes and ledges. Strata are chiefly tuffaceous sandstone and siltstone and dark-gray shale and lesser amounts of thin-bedded to laminated limestone, bedded tuff, and pebble and cobble conglomerate. As mapped, the formation includes some welded tuff and andesitic lava of minor extent (Ferguson, 1933, p. 22; Quinlivan and Rogers, 1974). Platy to slabby calcareous argillitic siltstone locally contains several nondiagnostic types of fossils, such as millimeter-size rod-shaped forms and carbonized plant remains (*Stigmaria* of Ferguson, 1933, p. 22). Samples collected and examined for pollen and spores yielded no such material (E. B. Leopold, written commun., 1964). Additional collecting for this purpose is justified, however, because only a very minor part of the section was tested. Tertiary fresh-water ostracodes collected about 6 miles (9 km) up Sixmile Canyon from calcareous strata assigned to the Gilmore Gulch also proved to be undiagnostic. I. G. Sohn (written commun., Oct. 6, 1964) stated that they were smooth forms and probably nonmarine. The age of the Gilmore Gulch is not firmly established; Ferguson (1933, p. 21–22) questionably assigned the strata to the Tertiary and appears to have been correct in further suggesting that an age older than Miocene was likely. Kleinhampl and Ziony (1967) considered the formation to be the earliest Tertiary rock with volcanic affinities in the Hot Creek Range, but detailed work by Quinlivan and Rogers (1974) showed that the formation is younger than tuffs dated at about 30 m.y. and older than tuffs dated at 28–30 m.y. The formation therefore is Oligocene. The Gilmore Gulch south of Tybo in the Hot Creek Range lies locally on megabreccia (pl. A1). Similar scattered patches of fine to coarse sedimentary clastic strata and megabreccia masses extending northward from Tybo to Morey were assigned to the Gilmore Gulch by Kleinhampl and Ziony (1967) but are here mostly reassigned to the separate megabreccia unit (megabreccia and welded tuff, pl. A1). The ostracode-bearing calcareous unit in Sixmile Canyon is an exception to the reassignment.

Many unique or otherwise distinctive tuffs of the central and southern parts of the Hot Creek Range were first named by H. E. Cook (1968, p. 111–118). Several of Cook's units, however, are regional in extent and had previously been named by other geologists working in adjacent areas; therefore, we will not follow Cook's terminology but use the nomenclature of the recently published quadrangle maps by geologists of the U.S. Geological Survey (see sources of data, pl. A1). Many of the quadrangle map units, however, are grouped (see ash-flow tuffs, undifferentiated, pl. A1). In places, the thicker and more widely distributed units are separately shown, for example, the tuff of Hot Creek Canyon and the tuff of Kiln Canyon (pl. A1). The tuffs outside the Hot Creek and Park Ranges were not so intensively studied and are less finely divided. In a general way the ash-flow tuffs of the main area of region 3 are many thousands of feet thick and are even more extensive than the underlying thick stack of lavas and minor tuffs (rocks of intermediate composition, pl. A1).

Because the tuff units are so thoroughly described on the published quadrangle maps of region 3, the descriptions herein are very brief and limited to the units that are thick and widespread.

Ash-flow tuffs (pl. A1) include three very extensive units of Oligocene age: the Pancake Summit Tuff, the Windous Butte Formation, and the tuff of Williams Ridge and Morey Peak. The Pancake Summit Tuff and the Windous Butte Formation are described with region 2 rocks. The tuff of Williams Ridge and Morey Peak, previously described with region 2 rocks, has great thickness in the subsurface beneath parts of Hot Creek and Big Sand Spring Valleys. It composes the spectacular, high (4000 ft or 1220 m), roughly domical massif of Morey Peak, where the unit is most homogeneous, ex-

tremely thick (at least 3000 ft or 915 m), and deuterically altered (propylitized). This combination of features suggests that there was resurgence in the Morey area of part of a large collapse structure (caldron complex) that is inferred to underlie much of the central Hot Creek Range and adjoining area (U.S. Geol. Survey, 1970, p. A39–A40; Ekren, Bath, Dixon, Healey, and Quinlivan, 1974, p. 108). Lithologic and structural aspects of the unit within the Morey Peak massif have been studied by W. J. Carr (unpub. data, 1974) and are unique. We noted that pumice is either much less abundant or much less readily recognizable here than elsewhere, probably because of pervasive alteration and dense welding. Here, too, there are irregular clots of crystals to several centimeters across in addition to pervasively scattered crystals. The clots are suggestive of palimpsest structure and may represent completely destroyed (devitrified and otherwise altered) pumice. Rarely seen compaction foliation represented by flattened pumice is parallel to well-developed sheeting joints in the thick tuff of the Morey massif. The joints dip in a manner consistent with a deformation related to resurgence (Kleinhampl, 1967). It has been suggested that the tuff of Williams Ridge and Morey Peak and the upper part of the Windous Butte Formation are genetically related; both are quartz latitic and they are similar in age. The former tuff may have filled a very large caldera that formed upon eruption of the Windous Butte (U.S. Geol. Survey, 1970, p. A39–A40; Ekren, Bath, Dixon, Healey, and Quinlivan, 1974, p. 108). The Windous Butte Formation is rhyolitic welded tuff in its lower part and grades upward into quartz latitic tuff; its greatest thickness is attained in the Park Range (1800+ ft or 549+ m) (Dixon and others, 1972; Ekren, Bath, Dixon, Healey, and Quinlivan, 1974, p. 108). It is nearly as thick (1600+ ft or 488+ m) in the Hot Creek Range and thins westward to a wedge edge in the Monitor Range, where the formation has a maximum thickness of only about 200 feet (61 m) (Ekren, Bath, Dixon, Healey, and Quinlivan, 1974, p, 108).

Another thick ash-flow tuff, the tuff of Hot Creek Canyon of Quinlivan and Rogers (1974), is shown separately (pl. A1). Descriptions by Quinlivan and Rogers (1974) and Ekren, Hinrichs, Quinlivan, and Hoover (1973) are summarized below. The formation is confined largely to the central part of the Hot Creek Range, where thicknesses exceed 2000 feet (610 m) and range up to 1500 feet (457 m) east of Moores Station. The unit wedges out westward from the Hot Creek Range and is not present in the Monitor Range west of Little Fish Lake Valley (Ekren, Bath, Dixon, Healey, and Quinlivan, 1974, p. 108, fig. 2). An abrupt termination north and east of the Moores Station locality may be explained by a restriction during the emplacement of the ash flow against a caldera wall that predated the flow (Ekren, Hinrichs, Quinlivan, and Hoover, 1973). The white to gray rhyolitic to quartz latitic welded tuff weathers to mostly brown and some brownish-yellow and gray steep slopes and cliffs. Crystal content is moderate to large (30%–50%); the crystals consist of subequal quartz, sanidine, and plagioclase and scattered biotite and hornblende. An average radiometric age of 30.0 ± 0.9 m.y. was obtained from biotite and sanidine (Ekren, Hinrichs, Quinlivan, and Hoover, 1973).

The middle tuffs of Moores Station area (pl. A1) is a series of rhyolitic to quartz latitic ash-flow tuffs that were mapped to include sedimentary strata and breccia. The sequence contains as many as seven separate ash-flow tuff cooling units estimated to be about 6000 feet (1800 m) thick in a composite section. Most of these units are confined to the caldron complex (Ekren, Hinrichs, Quinlivan, and Hoover, 1973, cross sections A–A′, C–C′). Some of the tuffs composing the middle tuffs of Moores Station are localized in The Needles area southeast of Moores Station, and others are present west of Morey Peak, where they are not differentiated from the underlying tuff of Hot Creek Canyon on the present map (pl. A1). Locally persistent brecciated and faulted tuffs (pl. A1), composed of exotic masses and blocks of older tuffs, form the basal part of and intertongue with the middle tuffs of Moores Station. The brecciated and faulted tuffs formed chiefly as talus and landslide masses that slid off the caldera wall that delimits the unit on the northeast (E. B. Ekren, oral commun., 1973); see additional description of the breccias in the section of this bulletin on Landslide Deposits and Breccias). Locally the basal and uppermost parts of the middle tuffs of Moores Station area are composed of sedimentary strata (fluviolacustrine) and air-fall tuffs, the basal part ranging from a wedge edge to 300 feet (90 m) thick and the upper (tuffaceous rocks of Slanted Buttes of Ekren, Hinrichs, Quinlivan, and Hoover, 1973) ranging from a wedge edge to 300 feet (90 m) thick. Some of the ash-flow tuffs within the middle tuffs of Moores Station yielded radiometric ages in the range of about 29.4–31.4 m.y. The map unit is underlain by the tuff of Hot Creek Canyon of Quinlivan and Rogers (1970) and overlain by the Monotony Tuff and other younger tuffs (Ekren, Hinrichs, Quinlivan, and Hoover, 1973).

The young tuffs of Moores Station (pl. A1) consist of several chiefly rhyolitic ash-flow tuffs informally named and described by Dixon, Hedlund, and Ekren (1972; Ekren, Hinrichs, Quinlivan, and Hoover, 1973), that in part have geographic proximity and probable consanguinity. Two, the tuff of Orange Lichen Creek and the tuff of Pott Hole Valley, are named informally for good exposures in the vicinity of Moores Station, where they overlie the Monotony Tuff and underlie the Shingle Pass Tuff. A third unit, the tuff of Crested Wheat Ridge, underlies the tuff of Pott Hole Valley farther northwest just west of Park Range, where it rests on the Windous Butte Formation. The young tuffs of Moores Station area extend westward into the Monitor Range at least to near the Dougherty Ranch at the mouth of Willow Creek (Ekren, Bath, Dixon, Healey, and Quinlivan, 1974, p. 106–107), where they are included with the Shingle Pass Tuff and stratigraphically adjacent rocks (pl. A1). The ash-flow tuffs are rhyolitic except for an upper cooling unit of the tuff of Crested Wheat Ridge, which is quartz latitic, and of low to moderate crystal content. The tuffs are generally pastel in color and weather to slopes and cliffs. Dixon and others (1972) give a date of 28.6 ± 1.0 m.y. for the tuff of

Crested Wheat Ridge and show the tuff of Pott Hole Valley and the overlying tuff of Orange Lichen Creek as Oligocene(?).

The Needles Range and Monotony Tuffs (previously described) are both present in region 3. The Needles Range, however, is thin (less than 200 feet or 61 m) and includes only the Minersville Member (E. F. Cook, 1965). It is confined to small areas east and west (not shown on pl. A1) of Pritchards Station (Dixon and others, 1972). The Monotony, however, is extensive in the central and southern part of the Hot Creek Range, where it attains a thickness of as much as 3000 feet (914 m) (Quinlivan and Rogers, 1974). It is particularly well exposed in the rugged spurs along much of the eastern range front south of Tybo Canyon and to the west in successive north-trending fault blocks. Another unit known as the tuff of Kiln Canyon (pl. A1) is rhyolitic to rhyodacitic(?) in composition. This tuff crops out extensively along the west flank of the Hot Creek Range south of the head of Empire Canyon, where the formation weathers to steep slopes and cliffs monotonously colored in pastel grays and buff. Its extent farther west is not known, but it may underlie some of the area near the Dougherty Ranch at the mouth of Willow Creek (Monitor Range) (Ekren, Bath, Dixon, Healey, and Quinlivan, 1974, p. 106–107). The formation, a compound cooling unit, contains 30%–50% crystals that include plagioclase, quartz, and sanidine, in decreasing order of abundance, and minor amounts of biotite and hornblende, with a trace of sphene (Quinlivan and Rogers, 1974).

Many Oligocene tuffs and tuffaceous rocks, some of which are unnamed and others informally named on the U.S. Geological Survey quadrangle maps (see sources of data, pl. A1), are undivided in the present report (volcanic rocks—ash-flow tuffs, undifferentiated, pl. A1) and may range widely in age. The reader is referred to the above maps for detailed descriptions of these units. The up to 600-foot (183-m)-thick tuffs of Chaos Creek of Ekren, Hinrichs, Quinlivan, and Hoover (1973) east of Moores Station, the tuff of Sixmile Canyon of W. J. Carr and H. W. Dodge, Jr. (unpub. data, 1974) west of Morey Peak, and the up to 3000-foot (914 m)-thick tuff of Twin Peaks of Quinlivan and Rogers (1974) near Tybo are three such units. Significantly, Ferguson (1933, p. 24–25, pl. 1) considered the latter to be a quartz latite lava flow or intrusive mass that was possibly genetically related to quartz latite porphyry hosting the main ore deposits at Tybo. Quinlivan and Rogers (1974) stated that the tuff of Twin Peaks is a rhyolitic to rhyodacitic(?) welded tuff with 30%–50% crystals, thus correcting Ferguson's observations. The tuff of Twin Peaks forms distinctive gray, purple, and locally greenish cliffs and very steep slopes that contrast with the unconformably underlying brownish Gilmore Gulch Formation. The unit is particularly thick and widely distributed south of Tybo. Crystals consist mainly of plagioclase and lesser and subequal amounts of quartz and sanidine with scattered but conspicuous biotite as the main mafic constituent. The absolute age of the tuff of Twin Peaks has not been established; however, the unit lies beneath the Monotony Tuff (age 26.5–27.0 m.y.) and overlies the Gilmore Gulch Formation, which in turn overlies the 30.5–32.7-m.y.-old tuff of Williams Ridge and Morey Peak of Ekren, Hinrichs, and Dixon (1972) (Quinlivan and Rogers, 1970). The tuff of Sixmile Canyon of W. J. Carr and H. W. Dodge, Jr. (unpub. data, 1974) forms dark-gray, brown, and purplish cliffy exposures west of Morey Peak and consists chiefly of quartz latite to rhyodactitic welded tuffs. Pervasively propylitized zones are common within this unit, and it is overlain by the altered 30.0 ± 0.9-m.y.-old tuff of Hot Creek Canyon of Quinlivan and Rogers (1974). The unit appears to lie directly on the tuff of Williams Ridge and Morey Peak near Sixmile Canyon (W. J. Carr, oral commun., Aug. 1974).

Ash-flow tuffs and minor intermediate lavas, undifferentiated (pl. A1), includes great thicknesses (thousands of feet) of extensive Oligocene welded ash-flow tuffs and minor intercalated air-fall tuffs and tuffaceous sedimentary strata in the central and southern parts of the Monitor Range. Their correlatives elsewhere, particularly in the Hot Creek Range, have not been well established. These rocks vary considerably in composition and weather to cliffs of light to dark pastel grays and browns and, less commonly, to such pale-colored slopes that they appear white in contrast to the cliffs. Much of the upper part of the range is capped by deeply dissected, resistant welded tuffs that form a series of buttes and mesas interconnected by steep-sided spurs and locally fringed with pinnacles. A small part of the range bordering Little Fish Lake Valley has been the most carefully studied of all the Monitors, and Tertiary rocks here were subdivided by Ekren, Bath, Dixon, Healey, and Quinlivan (1974, p. 108–109). The subdivisions are not shown on the present map but include the tuff of the Monitor Range (Oligocene and Miocene) and the tuff of the northern Monitor Range, each of which consists of several cooling units. A mafic-rich tuff just beneath the cap rock on the Monitor Range south of Tulle Creek has been dated at 26.5 ± 0.7 m.y. By inference, the main mass of Oligocene ash-flow tuffs farther south near Big Ten and Hat Peaks (south of Belmont) probably is in the age range of about 26–31 m.y. Several cooling units in at least one thick welded tuff sheet are present here, and some of the oldest exposed rocks contain abundant boulder-size debris of pre-Tertiary rocks, including granite, quartzite, schist, and dark-gray argillite and chert. Larger masses of debris, most of which are shown on plate A1 as exotic slide blocks, commonly are monolithologic and composed of Cambrian quartzite and phyllite. These exotic masses are described separately in the section of this bulletin on Landslide Deposits and Breccias. Smaller fragments of dark-colored argillite and (or) chert are common and impart a distinctive aspect to these tuffs. The tuffs weather to pastel grays and yellowish to brownish, bluish, and greenish grays and generally contain a moderate quantity of crystals. Welded tuffs farther east near Pinon Peak commonly form massive cliffs. These tuffs are characterized locally by numerous ash flows, each of which is bounded at base and top by horizontal laminations, but few of which are separated from others by cooling breaks, so that only a few cooling units are

present. Southward toward the Hannapah and Ellendale area of the west-central region (fig. A30 and pl. A1), the older ash-flow tuffs are faulted against and lapped by younger (Miocene) ash-flow tuffs. At one place, near Warm Spring southeast of Pinon Peak, the older ash-flow tuffs appear to have been tilted, eroded, and lapped by tuffs and tuffaceous and sedimentary strata prior to deposition of the younger (Shingle Pass Tuff) tuffs.

Intrusive bodies designated as silicic rocks (pl. A1) in region 3 are abundant about 4–6 miles (6–10 km) east of Moores and Pritchards Stations and in the vicinity of Morey Peak; they include rhyolite and quartz latite lavas and feeder dikes. Quadrangle map descriptions (see sources of data, pl. A1) indicate that both phenocryst-poor and phenocryst-rich (to 50%) rock types occur. Phenocryst-rich quartz latite locally intrudes compositionally similar tuff of Williams Ridge and Morey Peak.

Lavas and intrusive bodies of intermediate composition are scattered adjacent to U.S. Highway 6 in the southern Hot Creek Range and Kawich Range. These rocks were not carefully examined and, in some cases, were mapped only from aerial photographs. They have been included on the map (pl. A1) with the unit termed "intermediate to silicic lavas and intrusive bodies," and a brief description is given with the region 2 rocks (east-central region).

Intrusive rocks, undifferentiated (pl. A1) are restricted to the Tybo quadrangle. The unit is important because it includes the host rock for most of the ore found to date at Tybo. Rhyolite, rhyodacite, minor andesite, and the ore-bearing quartz latite porphyry dikes of Ferguson (1933, p. 23–25, 44, 48–49) are included in this map unit. The latter porphyry is synonymous with the rhyolite and rhyodacite of Quinlivan and Rogers (1974). The rocks are pervasively propylitized and locally silicified and sericitized except where they intrude the tuff of Kiln Canyon. Ferguson offers a good description of the ore-bearing dikes, which commonly are localized along north- and east-trending faults. A particularly large swarm of dikes fills faults near Keystone and Old Dominion Canyons. Some of the silicic rocks mapped separately (pl. A1) just north of the Tybo quadrangle in the Morey Peak quadrangle intrude similar faults and, therefore, may be the same age as the dikes at Tybo.

Miocene and Pliocene Rocks. The Shingle Pass and Bates Mountain Tuffs and the tuff of Clipper Gap of Gromme and others (1972, p. 1633–1636), from oldest to youngest, are the chief Miocene ash-flow tuffs in the main part of region 3. They are easily confused because of their similar lithology and appearance in the outcrop, particularly where the formations are thin and densely welded. The Shingle Pass Tuff is shown separately in places (pl. A1), whereas in others it is included with subjacent or superjacent strata. Units grouped together in these combinations range in age from about 23 to 29 m.y. and thus are not everywhere restricted to the Miocene and Pliocene (see the head of Hot Creek Canyon, pl. A1). Grouped units locally include the above-mentioned Bates Mountain Tuff and the tuff of Clipper Gap, which form good exposures near Butler Creek and cap the range. The tuff of Clipper Gap is differentiated on the map only in region 4, where it reaches maximum thickness. Some of the northernmost outcrops of tuff included in the tuff of Saulsbury Wash (Hannapah and Ellendale area) may inadvertently include tuff of Clipper Gap.

The Shingle Pass Tuff has been described previously in some detail. Its lithology is unchanged in region 3 and the formation wedges out northward and westward. It is as much as 600 feet (183 m) thick in the Tybo quadrangle, where four cooling units are present locally (Quinlivan and Rogers, 1974).

The Bates Mountain Tuff (pl. A1) is a rhyolitic welded tuff defined by Stewart and McKee (1968b) in Lander County. Sargent and McKee (1969) have described the formation in detail and defined its limit of distribution. It is widely distributed in scattered outcrops primarily in the region north of about lat 39° N. and thickens northward toward a possible vent in Lander County (Gromme and others, 1972, p. 1633). Excellent exposures of the formation have been described by McKee (1972; 1976) in the Toquima Range in region 4 to the west. The scattered outcrops in region 3 in most respects resemble the orange-red to red-brown, densely welded, crystal-deficient thinner parts of the Shingle Pass Tuff. The color and paucity of crystals impart a distinctive bricklike appearance that accentuates the Bates Mountain in spite of its thinness, which ranges from a wedge edge to 150 feet (46 m) thick in the Pritchards Station quadrangle (Dixon and others, 1972). An age of 22.8 ± 0.9 m.y. was obtained for the formation in region 3 near the location of the dated previously cited Shingle Pass sample. Other ages range down to as old as 24.7 ± 0.7 m.y. (McKee and Silberman, 1970; Gromme and others, 1972, table 7).

The tuff of Clipper Gap covers 3914 square miles (6300 km^2) in central Nevada and according to these workers apparently forms most of the capping welded tuff from about lat 39° N. south to about lat 38°15′ in the Monitor Range. We believe, however that the tuff of Clipper Gap may have been misapplied in the southern Monitor Range, where other welded tuffs, like the tuff of Saulsbury Wash, are present and locally cap the range. The only other outcrops of the formation in Nye County extend over several square miles near the head of Stoneberger Creek at the summit of the Toquima Range in region 4 to the west, where the formation was mapped with the Bates Mountain Tuff. The tuff of Clipper Gap is a crystal-poor, rhyolitic ash-flow tuff and was once considered to be the upper unit (no. 5) of the Bates Mountain Tuff (Sargent and McKee, 1969, p. E5–E8 and McKee, 1976, p. 39). Crystal content is about 5% and consists of quartz, sanidine, and plagioclase (McKee, 1972). The natural remanent magnetization is barely inclined, and this serves to distinguish the formation from the Bates Mountain Tuff, which has moderately steeply inclined natural remanent magnetization (Gromme and others, 1972, figs. 7, 8; McKee, 1972). The absolute age of the tuff of Clipper Gap is about 22.1–22.2 ± 0.6–0.9 m.y. (Gromme and others, 1972, p. 1635–1636; Sargent and McKee, 1969, p. E11). The age spread between the formation and the

successively underlying Bates Mountain and Shingle Pass Tuffs is only 1–5 m.y. Such closeness along with similarity of lithology for the three formations is perhaps indicative of some similarity of evolution of the parent magmas and venting stages, even though the vents apparently are widely separated.

Miocene and Pliocene lavas and intrusive rocks are less varied but as extensive as those of the Oligocene. The oldest ranges in thickness from a wedge edge to 500 feet (152 m) and crops out in a broad belt in the upper reaches of Empire Canyon, Hot Creek Range, where it was studied and mapped by Quinlivan and Rogers (1970). They stated that the predominantly rhyolitic unit is locally a quartz latite or rhyodacite(?) and has intruded their tuff of Kiln Canyon. In this report, the rhyolite is mapped with the 25.8 ± 1.3-m.y.-old rhyolite of Big Sand Springs Valley (pl. A1), with which it may be approximately coeval.

Rhyolite in lavas and associated domes crops out extensively in the southern part of the Monitor Range in section- to township-size bodies. Those in the vicinity of Hunts Canyon are mapped as rhyolite (pl. A1), and others, some of which are similar, are abundantly scattered to the south in the Hannapah and Ellendale area of region 3. The latter (rhyolites, undifferentiated, pl. A1) are described more fully with rocks of that area. The rhyolites nearly everywhere are resistant and weather to cliffy caprocks and crudely conical bodies that are conspicuous because of their pastel hues (yellowish browns and pinkish grays) and a paucity of vegetation on the outcrops. The large mass at the south end of Monitor Valley is a nearly aphyric body at least 700 feet (213 m) thick with locally frothy pumiceous base and margins. It locally caps the Monitor Range and overlies Oligocene(?) welded tuffs. The approximately 1500-foot (457-m)-high pluglike rhyolite at Hat Peak is more typical in size, lithology, and weathering habit of several bodies farther south. It tends to be devoid of vegetation, and its base is ringed by fine talus.

Mafic rocks (pl. A1; also locally mapped with basaltic and andesitic rocks) of Tertiary or Quaternary age are rare in the main area of region 3. One small body crops out near Indian Spring Ranch in the Antelope Range; another equally small outcrop—basalt lying 6 miles (10 km) southeast of Moores Station—was studied and dated (10.2 ± 0.9 m.y.) by Ekren, Hinrichs, Quinlivan, and Hoover (1973), whose description is summarized here. They noted up to 100 feet (31 m) of porphyritic lavas and dikes of olivine-bearing basalt, whose largest phenocrysts are labradorite that attain a maximum size of 1 cm. Other lavas (mafic rocks, pl. A1) that unconformably overlie ash-flow tuffs crop out in small faulted exposures just southwest of Fish Lake and at the head of Hot Creek Canyon. H. E. Cook (1968, p. 118) described the latter rocks as olivine basalts and named them the Little Fish Lake Formation.

Quaternary deposits. The Quaternary deposits of the main area in region 3 are similar to Quaternary deposits throughout northern Nye County. The deposits consist mainly of unconsolidated to semiconsolidated fluviolacustrine material in the main valleys. Mountainward, the deposits are coarser and include chiefly fanglomerate, alluvium, and colluvium, particularly talus. Sand deposits border parts of the Hot Creek and Monitor Ranges. Geomorphologic aspects of some of the Quaternary deposits should prove useful in deciphering Quaternary geologic and climatologic history, but they were not comprehensively studied. A little information about terraces and drainage features in the valleys surrounding the Hot Creek Range appears in the section on geomorphology.

Hannapah and Ellendale Area

The Cenozoic rocks of this area are mostly undated radiometrically. The oldest unit, termed "volcanic rocks of Hannapah and Ellendale mining districts" (pl. A1), includes an assemblage of rocks which have not been identified outside the southern Monitor Range and may partly have local source areas. The assemblage includes principally undifferentiated rhyolitic to quartz latitic(?) welded ash-flow tuffs, vent tuffs, pumice flows (cold), air-fall tuffs, and tuffaceous sedimentary strata. The fresh and weathered rocks in most exposures are light pastel, with pale yellow, pale brown, and gray predominating. The assemblage has been subdivided locally into several major mappable components, including andesitic to dacitic rocks, and two younger and volumetrically much greater units: the tuffs of Hannapah and probable vent rocks and the younger, areally peripheral, tuffs of McKinney Tanks.

Andesitic to dacitic rocks include flows(?) and small intrusive bodies; dikes appear to have intruded the welded tuffs and locally to have been emplaced along faults cutting the welded tuffs. Other andesitic to dacitic bodies, possibly from the same magma chamber as the dikes, lie at or near the base of the ash-flow tuffs in the volcanic rocks of Hannapah and Ellendale. These lavas have not been dated directly but are at least 25 m.y. old because they underlie an approximately 24.5-m.y.-old ash flow dated from a sample near Murphy's Camp, 11 miles (18 km) northeast of Hannapah (H. F. Bonham, Jr., oral commun., Oct. 1979). The old lavas and (or) dikes are pervasively propylitized and weather to dark brownish or greenish black and, locally, to reddish browns. Any feeder dikes for the basaltic and andesitic rocks shown at the top of the stratigraphic column (pl. A1) would have been mapped with this older dike and flow complex.

The most extensive and voluminous rock included in the tuffs of Hannapah is a relatively homogeneous quartz latitic(?) welded tuff that centers approximately on what may be its vent area—the 8032-foot (2448-m) hill north of Cedar Corral Spring. This welded tuff is commonly pervasively propylitized and argillized. It is characterized by abundant flattened pumice and dark lithic fragments of slate and siliceous siltstone that locally attain large pebble size. It may be the main mineralized unit in the Hannapah mining district; the tuffs of McKinney Tanks, peripheral to and younger than the tuffs of Hannapah, are probably not mineralized. We eventually mapped the welded tuff exposed at the McKinney Tanks (fig. B34), meant originally to be the type locality of the tuff of McKinney Tanks, as the

tuff of Saulsbury Wash. Therefore, air-fall tuff and sedimentary strata 6 miles (9.6 km) to the northeast are the only outcrops still mapped as tuff of McKinney Tanks.

Miocene and Pliocene Rocks. The tuff of Saulsbury Wash (pl. A1) is one of the more widely distributed units in the extreme southern part of the Monitor Range, but it was not recognized outside the area. It is informally named for excellent exposures of rhyolitic welded tuff adjacent to Saulsbury Wash, where the unit is thickest and north of which it thins abruptly and crops out in scattered, thin erosional remnants for about 6-8 miles (10-13 km). A maximum exposed thickness is estimated at 800-1500 feet (244-457 km) in the mountainous terrain east of Saulsbury Wash, but here and elsewhere the upper part of the formation is eroded away. The formation characteristically forms a brownish cliffy caprock that overlies the lighter hued volcanic rocks of Hannapah and Ellendale (pl. A1). A black vitrophyre and associated lithophysal zones commonly lie close to the base of the formation, and crystal content is moderate and consists chiefly of quartz, sanidine, plagioclase, and fresh black biotite. A eutaxitic structure with densely compacted pumice fragments that are as much as several centimeters long is well preserved. This structure and local faint broad color bands are commonly the most distinctive features of the rock. The bands possibly represent separate ash flows, but these and variations in cooling units were not studied. The vitric base of the unit exhibits reversed moderately strongly inclined remnant magnetization with a declination of approximately N. 15°-20° E. A sample of the black vitrophyre from this place (S32,T4N,R46E) was dated at 21.6 ± 0.6 m.y. by M. L. Silberman (written commun., 1968). The formation is, therefore, similar in age as well as lithology to the tuff of White Blotch Spring of Ekren and others (1971), which is widely distributed in southern Nye County in the Cactus, Kawich, and Reveille Ranges. The White Blotch averages about 23 m.y. old and ranges in age from about 21-25 m.y., with younger and older parts not only reflecting different times of eruption but also different sources. One of the younger sources could be in or near the Cactus Range, where a sample yielded young dates averaging about 22 m.y. (Ekren and others, 1971, table 5). The virtual restriction of the tuff of Saulsbury Wash to the Hannapah and Ellendale area of northern Nye County and its abrupt thinning northward support a possible correlation of the tuff with the thick, widely distributed tuff of White Blotch Spring and the likelihood of a source to the south rather than to the north. The tuff of Saulsbury Wash lies with slight angular discordance on a surface of low to moderate relief (50-100 ft or 15-30 m) cut into the rocks of Hannapah and Ellendale. A small outcrop about 5.5 miles (9 km) west-southwest of Fivemile Spring lithologically resembles the tuff of Saulsbury Wash but differs in polarity and may be assignable to the Fraction Tuff.

Lavas and intrusive rocks of middle to late Cenozoic age are very abundant and widely distributed in the Hannapah and Ellendale area. They are included with rhyolites, undifferentiated (pl. A1) and basaltic and andesitic rocks. Outcrops of rhyolite range from several yards to about 4 miles (6.5 km) across; many are about 1 mile (1.6 km) across, and because they are resistant, commonly form distinctive hills and conical peaks. Massive rhyolite is abundant, but flow-laminated rhyolite prevails locally and weathers to chips and plates. Fresh and weathered rhyolites are mostly pastel grays, browns, yellows, and pinks, with a particular color characterizing a specific mass. The rhyolites are commonly aphyric; some bodies, however, are sparsely and finely porphyritic, and several south of U.S. Highway 6 contain a moderate amount of phenocrysts, some as much as a few millimeters across. Phenocrysts in most bodies are quartz and feldspar with or without biotite, but quartz or feldspar may be absent in some masses. None of the rhyolites were dated by radiometric methods, but by analogy with similar bodies in the surrounding region, they may be of more than one age and probably range from about 26-16 m.y. old. The oldest are considered to be coeval with the rhyolite of Big Sand Springs Valley (25.8 ± 1.3 m.y.) to the east, and if any are younger, they may well be coeval with the Oddie Rhyolite (16 m.y.) of Tonopah. One of the late volcanic events only 20 miles (32 km) south of Ellendale in the Cactus Range was rhyolitic volcanism that could have occurred as recently as 18 m.y. ago. The rhyolitic volcanism there probably predated the emplacement of the Fraction Tuff and postdated the tuff of White Blotch Spring of Ekren and others (1971, p. 43; Cornwall, 1972, p. 32-33). Bonham (1970) has also suggested that rhyolites near South Shoshone Peak in the Shoshone Range are only slightly younger than the 21-24-m.y.-old Toiyabe Quartz Latite, a welded tuff that they intrude. The preceding attention to ages of rhyolites should be helpful to mining exploration because of a close stratigraphic and structural relationship of the rhyolites to ore deposits in the southern part of the Monitor Range and possibly elsewhere. A rhyolite mass at Ellendale is the host for precious-metal vein deposits, especially the gold at the Ellendale mine. Rhyolites at Hannapah may also be mineralized or at least related to mineralization, although the main host rocks appear to be the tuffs of Hannapah (pl. A1).

Basaltic and andesitic rocks that are classed as Quaternary or Tertiary (pl. A1) include altered and relatively fresh-looking aphanitic dikes and irregular bodies at Hannapah, feldspar porphyry flows nearby, and coarse hornblende porphyry at Ellendale that cut the volcanic rocks of Hannapah and Ellendale. The basaltic and andesitic rocks also include small late aphanitic to porphyritic dacitic to andesitic plugs and dikes that intrude rhyolite at Ellendale. Excellent exposures of coarse porphyritic hornblende andesite occur in roadcuts and in hills adjacent to U.S. Highway 6 in the NE/4 T3N,R46E and the NW/4 T3N,R47E. Phenocrysts of the intermediate rocks consist mostly of hornblende and plagioclase in varying proportions. The rocks are dark gray to black and commonly weather to brown and gray cliffs and ribs, except where propylitized, in which case they weather to olive-colored slopes and ledges. Much of the map unit basaltic and andesitic rocks (pl. A1) is probably post-ore in age, except possibly for some of the

more intensely altered parts including dikes like that in S5,6,T3N,R45E. A radiometric age of 18.9 ± 1.5 m.y. for the uppermost of the thick series of olivine trachyandesite flows at Thunder Mountain (Armstrong and others, 1972) is believed to be too old by Bonham (oral commun., May, 1974), who thinks that the lavas are not more than about 15 m.y. old. Their topographic expression at Thunder Mountain as a relatively flat capping of a steep-sided butte is not unlike the 10.2 ± 0.9-m.y.-old basalt southeast of Moores Station in the main area of region 3. Some basaltic andesite flows in the extreme southern part of the area are unaltered and believed to be the youngest of all the flows.

These rocks or the small partly altered aphanitic to porphyritic dacitic to andesitic plugs and dikes that intrude the rhyolites at Ellendale and east of Cedar Corral Spring are probably the youngest of all the volcanic rocks in the Hannapah-Ellendale area.

Quaternary Deposits. Extensive sand deposits border the extreme southern part of the Monitor Range. The sand is fine to medium grained and consists predominantly of quartz and feldspar derived from Tertiary volcanic rocks. These deposits and small calcareous tufa and (or) sinter deposits near Ellendale are described in the Ellendale mining district section of this report. In general, other unconsolidated deposits are similar to those in the rest of region 3.

Landslide Deposits and Breccias

Cenozoic landslide deposits, breccias, megabreccias, and exotic slide blocks (pl. A1) are as abundant and significant in region 3 as in any of the other regions of northern Nye County. As in region 2, they are described separately because they span a wide range of ages and because some have unique importance in deciphering the geologic structure. They may serve as guides to features like caldera margins and major transcurrent faults, which are believed to be genetically related to the formation and emplacement of the blocks. The numerous landslide deposits and megabreccias are clustered in about four main areas: (1) east of Moores Station, (2) near Pritchards Station, (3) at several localities in the Hot Creek Range, for example, just south of Twin Peaks (south of Tybo), in Hot Creek Canyon, at localities on the flanks of the Morey Peak massif, and in a broad swath across the Range about 6–12 miles (9.7–19.4 km) north of Morey Peak, and (4) the southern Monitor Range, south of Belmont near Big Ten and Hat Peaks and in the Ellendale and Hannapah mining districts. Also, several areas within the Tertiary ash-flow tuffs high in the Monitor Range about 9 miles (14.5 km) north-northeast of Dobbin Summit exhibit topography suggestive of landslide deposits and are so designated (pl. A1). This interpretation is based solely on an examination of aerial photographs.

Landslide deposits mapped as Quaternary or Tertiary (pl. A1) are especially abundant and large near the head of Hot Creek Canyon, and morphology in some is well displayed. The debris in the deposits is composed of Tertiary ash-flow tuffs including the Shingle Pass Tuff and the tuff of Lunar Cuesta of Snyder and others (1972). Some of the landslide deposits may be as young as Pleistocene, whereas others may be Pliocene or possibly even older. The younger ones appear to have slid into the valley and to have contributed to its form, but all are now being eroded.

A monolithologic exotic slide block (pl. A1) about 1 mile (1.6 km) down Hot Creek Canyon and on the north wall consists of partly brecciated light-gray Silurian or Devonian dolomite and a little Eureka Quartzite. The block appears to have slid onto the tuff of Hot Creek Canyon and to have been downfaulted against this tuff and other tuffs of similar age by basin-and-range faults.

The scattered megabreccias in the Hot Creek Range at and south of the Morey mining district are somewhat similar to one another and were originally included chiefly with the overlying Gilmore Gulch Formation by Kleinhampl and Ziony (1967); later, they were in part separately mapped by Quinlivan and Rogers (1974) and by W. J. Carr and H. W. Dodge, Jr. (unpub. data, 1974). Megabreccia and intercalated welded tuff in the locality just south of Twin Peaks have a maximum thickness of about 1000 feet (305 m) and wedge out within 1/2 mile (0.8 km) (Quinlivan and Rogers, 1974). The welded tuff separates two broadly lenticular units of breccia that they describe as composed mostly of angular pebbles and boulders of conglomerate, sandstone, siltstone, and shale in an indurated matrix of similar material. The detritus was derived from the Paleozoic Eleana Formation, and the megabreccia unit rests on the 30.5–32.7-m.y.-old tuff of Williams Ridge and Morey Peak. Similar megabreccia at the mouth of Sixmile Canyon is locally associated with some tuffaceous fluviolacustrine beds, light-gray calcareous siltstone with distinctive herringbone marks of inorganic origin, and exotic slide blocks hundreds of yards in length, mapped separately (pl. A1) consisting of Silurian dolomite and Devonian and Mississippian Eleana Formation. These masses may have originated in any one or a combination of three ways: (1) blocks of basement material brought up during a postulated resurgence of the tuffs in the Morey massif, (2) landslide masses associated with caldron collapse, or (3) breccia masses associated with tectonism during development of transcurrent faults. W. J. Carr and others (unpub. data, 1974) mapped and described these scattered outcrops as slide blocks and debris and tuffaceous sediments intertonguing with the tuff of Sixmile Canyon (that is included in volcanic rocks—ash-flow tuffs, undifferentiated, pl. A1). This stratigraphic position tends to confirm their gross contemporaneity with the megabreccia underlying the Gilmore Gulch farther south in the range.

Breccias and landslide masses which occur in great abundance east of Moores Station consist of material derived chiefly from some of the older Oligocene ash-flow tuffs and lavas, principally the Windous Butte Formation, and to a lesser extent from middle and upper Paleozoic strata. Paleozoic blocks commonly are surrounded by tuffs. Some of the masses are spatially and probably genetically associated with an inferred caldron collapse (Ekren, Hinrichs, Quinlivan, and Hoover, 1973), whereas other masses probably are related to transcurrent

fault zones (Dixon and others, 1972; Ekren, Bath, Dixon, Healey, and Quinlivan, 1974).

The exotic slide blocks south of Belmont in the Monitor Range are chiefly monolithologic and composed mainly of deformed and faulted quartzite, phyllite, and schistose shale of the Cambrian Gold Hill(?) Formation and (or) Zabriskie Quartzite. Quartzite blocks are commonly shattered; however, these and other blocks generally retain their bedding and other predeformation characteristics and therefore are difficult to distinguish from the pre-Tertiary bedrock in the area. Some blocks consist of Cambrian or Ordovician rocks metamorphosed to marble and molybdenite-bearing tactite. Such exotic material may have been prospected at claims in the Mine Canyon area (Longstreet mining district). The time of emplacement of the blocks here is uncertain, but they probably are Oligocene or very early Miocene. The blocks are related to caldera formation and the culminating deposition of the enclosing ash-flow tuffs of late Oligocene or very early Miocene age. One indurated resistant brown-weathering breccia mass about 1½ miles (2.4 km) northeast of Big Ten Peak, mapped as a landslide block of Tertiary or Quaternary age (pl. A1), has a unique composition and may have a unique origin compared to the other slide blocks in the vicinity. The mass is composed of polymictic clasts that consist predominantly of, and are characterized by, spotted schist (Mayflower? Schist) and granite. White quartzite clasts are also abundant but less conspicuous; other clasts are marble. The mass may be an erosional remnant of a Tertiary lahar or may be correlative with or at least comparable in origin to the Hedwig Breccia at Manhattan, which is described with region 4 rocks.

The inferred Tertiary or Quaternary landslide blocks at Ellendale are as much as 1000 feet (305 m) across. They are essentially monolithologic and are composed of quartzite (Zabriskie?) and cherty dolomite of probable Late Cambrian or Early Ordovician age. Most of the masses are surrounded by Tertiary andesitic lavas, and all are approximately positioned along the northern base of an east-trending high (7281 ft or 2219 m) mountain. The landslide masses were not examined closely; consequently, their origin is unclear. They probably are related to tectonism along a major but concealed Tertiary fault rather than having simply slid onto the andesite from a topographically higher position on the south in the Quaternary period.

Several isolated brecciated masses of Paleozoic rocks, including white quartzite, crop out close to the inferred longest east-striking fault mapped at Hannapah (fig. B41). These blocks may have originated in a manner similar to those at Ellendale (see Mineral Deposits section of this bulletin on Hannapah District.

Toquima Region (Region 4)

The Toquima region includes only the Toquima Range, where the Cenozoic volcanic rocks are largely distinct from those to the east and west. The Toquima region is divided into areas north and south of Mount Jefferson (fig. A30), the highest point in the range, and both areas are partly underlain by the volcanic rocks of the Mount Jefferson massif. The north area also contains volcanic rocks mapped by McKee (1972; 1976) in the Wildcat Peak and part of the Dianas Punch Bowl quadrangles. Because the northern section is the best studied and the most subdivided, it is considered to be the main section characterizing the Toquima region. Tertiary rocks of part of the south area were studied by Ferguson (1933) prior to the present-day understanding of ash-flow tuffs, and none of the area has been mapped in detail since. The following descriptions of the north and south areas are drawn liberally from those of the above-mentioned workers and combined with our own reconnaissance observations.

North (Main) Area

The oldest Cenozoic rocks mapped in the north area are included in a single map unit termed "Northumberland Tuff and other old tuffs" (pl. A1). Megabreccia of Paleozoic debris (pl. A1) within the Northumberland Tuff is mapped separately in local areas. The basal part of the map unit includes the tuff of Iron Spring of McKee (1976), formerly the Tuff of Dry Creek of McKee (1972) when first described from small outcrops in the Wildcat Peak quadrangle (S/2 S34,T15N,R45E [unsurveyed]). McKee described the tuff of Iron Spring as a pink to red, crystal-poor, mostly densely welded, probably rhyolitic ash-flow tuff that rests unconformably on Mesozoic and Paleozoic rocks. A long period of erosion removed most of this unit and perhaps some younger rocks as well prior to deposition of the overlying 30.4-m.y.-old tuff of Hoodoo Canyon of McKee (1972; 1976). As a consequence, outcrops are scarce. The Tuff of Iron Spring closely resembles the 34-m.y.-old tuff of Dry Creek of the Simpson Park Mountains, Lander County, and the two welded tuffs may be parts of the same unit (McKee, 1976, p. 29).

The much more abundant Northumberland Tuff was first defined by McKee (1972; 1974, p. 35–41). It corresponds with a prior informally named map unit, tuffs of Moores Creek (Kleinhampl and Ziony, 1967). The type section near Northumberland Canyon is sited within a mass of intracaldron material where at least 2000 feet (610 m) of ash-flow tuff is preserved. McKee (1974, p. 36) stated that the extracaldron part of the Northumberland Tuff is 100 feet (31 m) thick or less; however, at least several times that thickness is present in the vicinity of Moores Creek to the south. The rhyolitic formation has a crystal content of 20%–35% composed mostly of equal amounts of quartz and sanidine and much less but, nevertheless, ubiquitous plagioclase and biotite. A bleached appearance and the occurrence of numerous lithic fragments (Paleozoic chert and silicified argillite), of very large size in the upper part of the formation, are its most distinguishing macrofeatures. Much of the intracaldron material is relatively structureless and could be mistaken for a porphyritic intrusive body, whereas compaction foliation features are well developed and best seen outside McKee's hypothesized caldera. A K-Ar are of 32.3 ± 1 m.y., obtained by McKee (1974, p. 41) for the formation, is suggested by him to be a median age, with the upper limit defined by

the disconformably overlying 30.4-m.y.-old tuff of Hoodoo Canyon. The age and composition of the formation is not unlike several other tuffs in region 3 to the east, for example, the Stone Cabin and the Windous Butte Formations.

The Pancake Summit Tuff and overlying tuff (pl. A1) includes the widespread Pancake Summit Tuff and the localized tuff of Stoneberger Canyon of McKee (1972; 1976). These are crystal-rich rhyolitic ash-flow tuffs and tuff breccia. The Pancake Summit Tuff, described with the rocks of region 2 (also, see McKee, 1976), apparently wedges out southwestward and does not appear west of the divide in the Toquima Range nor south of about Stoneberger (formerly Wilson) Creek (McKee, 1972). The much more restricted tuff of Stoneberger Canyon was mapped only over about a township-size area near the southwestern fringe of the disconformably underlying Pancake Summit Tuff and extends several miles southwestward beyond the limit of the latter. McKee (1976) has described the unit as 31.1-m.y.-old tuff and tuff-breccia about 800 feet (250 m) thick and a typically massive, weakly welded to nonwelded, punky tuff breccia; locally half the formation consists of angular lithic fragments that are chiefly chert and were probably derived from the immediate basement rock, the Vinini Formation. He postulated that the extremely lenticular unit erupted from within its area of accumulation. These ash-flow tuffs and the Northumberland Tuff are unconformably and discontinuously overlain by white to gray slope-forming tuffaceous fluviolacustrine beds (tuffaceous sedimentary rocks, pl. A1). Coarse clastic detritus, including exotic masses of dark-gray Paleozoic chert and argillite, are characteristic of parts of the sedimentary section, which is thickest (several hundred feet) in Northumberland Canyon. Searches for fossils proved fruitless, although carbon-bearing layers are present locally. Similar strata crop out discontinuously between Moores and Barker Creeks on the lower flank of the Mount Jefferson massif, where they are included with the Northumberland Tuff. Their discontinuity appears to stem from a combination of depositional and erosional factors. The beds in the vicinity of Northumberland Canyon were deposited within the collapse zone of the Northumberland caldera, to which they exhibit a circumferential distribution today (McKee, 1974, p. 36). The sedimentary strata and older rocks are lapped by the unconformably overlying tuff of Hoodoo Canyon of McKee (1972). The following description of this tuff is from McKee (1972; 1974, figs. 5, 8, p. 41; 1976).

The tuff of Hoodoo Canyon is a quartz latite welded tuff that probably had an initial distribution broader than the present discontinuous outcrops that cross the Toquima Range and form much of the broad upland near White Rock Mountain and the minor but conspicuous white hoodoo topography below the peak of the mountain. As mapped on plate A1, the formation includes minor lenticular clastic sedimentary rocks. The formation is thickest (greater than 400 ft or 122 m) in a possible source area just north of the mouth of Northumberland Canyon, thins northward to several hundred feet at White Rock Mountain, and becomes discontinuous in Lander County. It lapped across the Northumberland Tuff and clastic sedimentary debris filling the Northumberland caldera and was subsequently eroded away except for small areas northeast of the caldera and possibly farther west, where it could be faulted down and buried beneath alluvium in Big Smoky Valley. Whether or not the formation extends into the south area of region 4 and constitutes part of the old undifferentiated volcanic rocks there is uncertain. Lithologically, the tuff of Hoodoo Canyon is crystal rich and contains crystals of plagioclase and sanidine. A high biotite content distinguishes the unit from other tuffs in the area. Sanidine has yielded a K-Ar age of 30.4 m.y.

The tuffs of Mount Jefferson include rhyolitic to quartz latitic welded tuffs and form much of the Mount Jefferson massif. The 24.7–26.1 m.y.-old formation is described with rocks of the south area of region 4.

Ash-flow tuffs included in the Shingle Pass(?) Tuff and some other tuffs map unit (pl. A1) crop out chiefly in intricately faulted blocks between Red Rock and East Northumberland Canyons, where the tuffs overlie lower Paleozoic cherty strata. More of the unit crops out in low hills near Potts Ranch and Dianas Punch Bowl Spring. The rocks there were mapped as undifferentiated ash-flow tuffs by McKee (1972; 1976) and are gray to reddish-brown with scattered crystals of quartz(?), sanidine, and black biotite. Our assignment was made prior to the work of Sargent and McKee (1969, fig. 2), which indicated that the Shingle Pass does not extend even as far west as the Monitor Range—at least in the vicinity of Butler Creek. However, the rocks in the Toquima Range included with this map unit may occupy a time-stratigraphic position very close to that of the Shingle Pass, and the map unit, therefore, is a useful subdivision.

Lavas and intrusive bodies in the north area of region 4 are of minor extent and probably are mostly early Miocene in age. They include rhyolitic intrusive rocks and lavas and possibly intrusive bodies of intermediate composition, all mapped with intrusive and extrusive volcanic rocks (pl. A1). The rocks of intermediate composition crop out about 1 mile (1.6 km) north of the mouth of Ikes Canyon. Small swarms of felsite and diorite dikes cut the large granitic pluton and bordering Paleozoic strata in the northwestern part of the range. The dikes may range in age from Jurassic to Tertiary (McKee, 1972), but most are probably Cretaceous, and one of these was dated at about 93 m.y. (McKee, 1976, p. 27). A rhyolite dome has intruded the Northumberland Tuff about 6 miles (9.7 km) south of the mouth of West Northumberland Canyon. This rhyolite is characterized by well-developed columnar jointing, weathers to nearly white hues, and forms a low but distinctive conical hill about 500 feet (152 m) high. Sparse phenocrysts of quartz, black biotite, and feldspar in the rhyolite average a few millimeters across and rarely are as much as 1 cm across. McKee (1974, fig. 5) dated the rhyolite at 26 m.y. Other rhyolite in low hills southeast of Dianas Punch Bowl Spring is thought to be approximately correlative because it clearly overlies welded tuffs and is therefore younger than other older rhyolites

near Dobbin Summit farther east (region 3). There, older rhyolites are close to the base of the Cenozoic ash-flow tuff section and are mapped with the unit tuffaceous rocks, sedimentary strata, and rhyolitic bodies, undifferentiated.

The uppermost ash-flow tuffs and the youngest of the Cenozoic volcanic rocks are termed the "Bates Mountain Tuff and other young tuffs" (pl. A1). This unit includes both the Bates Mountain Tuff and the overlying tuff of Clipper Gap, which are lithologically similar. Both units were described with rocks of region 3. Here in the Toquima Range, however, McKee (1972) noted as many as three cooling units in the Bates Mountain, whereas the tuff of Clipper Gap appears to consist of a single cooling unit (Gromme and others, 1972, p. 1633). These formations are crystal-poor, rhyolite welded tuffs that form nearly flat-lying, conspicuous, resistant erosional remnants capping the high northern part of the Toquima Range. Those who have studied the two formations indicate that they evolved from separate volcanic centers with component cooling units having erupted sequentially at a rate of one every 0.8 m.y. (Gromme and others, 1972, p. 1636). Bates Mountain Tuff and tuff of Clipper Gap are about 23-24.7 ± 0.7 m.y. old and about 22 ± 0.6 m.y. old, respectively.

South Area

Cenozoic rocks in this area are less well known and thus more uncertainly correlated and more grossly subdivided than are those in the north area. Nevertheless, we can broadly subdivide the rocks. One anomalous map unit which combines a rhyolite dike swarm about 34 m.y. old east of Round Mountain with Cretaceous granite (rhyolite dike swarm [Oligocene] in marginal zone of granite [Cretaceous], pl. A1) is described in the section of this bulletin on Mesozoic and Tertiary plutonic rocks—Northwestern Nye County—Granitic rocks. Welded tuffs near the mouth of Meadow Creek Canyon are assigned to the rhyolitic Northumberland Tuff, but this correlation is somewhat doubtful and is queried (pl. A1). The Northumberland(?) Tuff in Meadow Creek Canyon weathers yellowish brown to olive gray and is locally bleached. Crystal content is moderate to large, and crystals locally attain a size of about 0.5 cm and average about 0.5-1.0 mm. Crystals consist of abundant quartz, somewhat less(?) feldspar (sanidine?), and scattered but noticeable black biotite (thin books and flakes). The biotite is similar to that in the tuffs of Mount Jefferson. The relation of the Northumberland(?) Tuff to other old rocks in the south area is uncertain. Some of the latter rocks are designated "old volcanic rocks" (pl. A1) and consist chiefly of rhyolitic ash-flow tuffs of uncertain stratigraphic position. This unit composes most of a large fault block on the southeast flank of Mount Jefferson and crops out mainly between Corcoran Creek and Andrews Canyon. The old volcanic rocks thus include mainly the informally named tuffs of Corcoran Creek and Andrews Canyon, which designation may be changed when correlations with nearby units are established. The tuffs of Corcoran Creek and Andrews Canyon are deeply dissected and form yellowish- to brownish-gray outcrops that weather to steeply sloping mountain ridges and peaks. Welding of the rocks is moderate to intense, and shard-rich subglassy zones are common. Crystal content is small to moderate, the crystals averaging 1-2 mm across and consisting of abundant quartz, feldspar in subequal or lesser amounts, and biotite, scattered to sparse but fairly ubiquitous. Lithic inclusions are not especially common. Irregular altered bleached zones are common, and locally along fault zones the rocks are crushed. The ash-flow tuffs are overwhelmingly more abundant than scattered thin lenses of air-fall and water-laid tuffs and tuffaceous sedimentary strata. The old volcanic rocks appear to underlie the Shingle Pass(?) Tuff and some other tuffs (pl. A1) and are Oligocene to Miocene. Scattered small patches of ash-flow tuff in the extreme southern part of the range are questionably assigned to the old volcanic rocks but were not carefully examined. At least two cooling units were noted in a section southwest of Baxter Spring. Ferguson (1924, p. 46) commented that these minor outcrops resembled his Esmeralda Formation north of Manhattan. There, his Esmeralda is clearly older than Esmeralda-type rocks and is assigned by us to the volcanic rocks, undifferentiated (pl. A1).

A great pile of volcanic rocks, included in volcanic rocks, undifferentiated (pl. A1), covers most of a township-size area just north of Manhattan and some of the components may have erupted from and filled a caldron there (D. R. Shawe, oral commun., Oct. 1979). The pile, at least 2000-3000 feet (610-914 m) thick, was correlated with the type Esmeralda Formation by Ferguson (1924, p. 42-50) and later by Ferguson and Cathcart (1954). Extension of the name to the Toquima Range at Manhattan was shown by Kleinhampl and Ziony (1967) to be erroneous, and in our opinion the name Esmeralda should be restricted from the range. Ferguson's divisions of the assemblage consisted of five members, including the basal Hedwig Breccia Member and the successively overlying Round Rock Member (welded tuff), Diamond King Member (bedded and ash-flow tuffs), Bald Mountain Lake Beds Member, and the quartz latite member that caps Bald Mountain, but except for the Bald Mountain Lake Beds Member, the members are believed to be mainly pyroclastic rocks consisting chiefly of ash-flow tuffs. The Bald Mountain Lake Beds Member contains tuff beds intercalated with sedimentary strata that were probably derived chiefly from pyroclastic rocks. The member, shown separately on the present map, may represent a caldron-fill deposit that at Bald Mountain is in a resurged part of the caldron. The Hedwig Breccia Member (pl. A1), was originally described as containing only nonvolcanic pre-Tertiary detritus and possibly as being fossil talus. D. R. Shawe (oral commun., Oct. 1979), however, has found clasts of Tertiary volcanic rocks in the Hedwig and considers the unit to be a volcanic breccia. It may be related to an ash-flow tuff eruption, but its basal (or peripheral?) position in the volcanic pile indicates a possible relation to caldron margin tectonics. The overall aspect of the massive pile of rock is one of monotonous pastel terrain. It is composed chiefly of rhyolitic to quartz latitic ash-flow tuffs and generally younger tuffaceous sedimen-

tary strata, including air-fall tuffs, and rests unconformably on deformed lower Paleozoic strata and Cretaceous plutonic rocks. Some of the ash-flow tuffs composing the unit may possibly correlate with the Oligocene ash-flow tuffs north of Mount Jefferson, and the map unit, in general, may contain time and rock correlatives of rocks in the southern part of the Toiyabe Range mapped with the middle volcanic sequence (pl. A1).

Minor outcrops of tuffs and sedimentary rocks about 2–4 miles (3.2–6.4 km) north of the paved road into Manhattan along the west front of the Toquima Range are mapped with the tuffs of Peavine Canyon (pl. A1), a unit named for excellent exposures in the southern part of the Toiyabe Range (see region 5). Similar rocks elsewhere in the southernmost Toquima Range may inadvertently have been included with volcanic rocks, undifferentiated (pl. A1). Where mapped near Manhattan, the tuffs of Peavine Canyon include rhyolitic to quartz latitic(?) ash-flow tuffs rich in lithic fragments, and minor tuffaceous sedimentary strata. The tuffs are light- to moderate-hued grays, pinks, and oranges on fresh and weathered surfaces. Crystal content is low to moderate, and most crystals average about 1 mm in size, with some as large as several millimeters. Crystals consist of clear to smoky quartz and lesser amounts of plagioclase and sanidine(?). Much potassium feldspar occurs in the groundmass. Most of the ash-flow tuff outcrops are massive; one variety however, weathers to distinctive hackly plates and chips. The latter type forms a thick unit about 3 miles (4.8 km) up Peavine Canyon in the Toiyabe Range and is described with the rocks of region 5.

Rhyolitic rocks (pl. A1) include rhyolites of several ages, probably ranging in age mostly from about 16(?)–26 m.y. Some are possibly as old as 34 m.y. and may correlate with dikes in the rhyolite dike swarm (Oligocene) in marginal zone of granite (Cretaceous) (pl. A1) east of Round Mountain. Rhyolite dikes intrude lower Paleozoic strata about 3 miles (4.8 km) south of Round Mountain and the Northumberland(?) Tuff in Meadow Creek Canyon. Dikes at the former locality are porphyritic, containing quartz and feldspar phenocrysts averaging about 1–2 mm across. Dikes at the latter locality are rhyolite porphyry containing quartz, feldspar, and biotite crystals to 0.5 cm across. All the dikes are conspicuous because they are bleached even lighter than their original light shades of color. They may be comparable in age to dikes of the map unit rhyolite dike swarm (Oligocene) in the marginal zone of granite (Cretaceous) or possibly to a large bulbous rhyolitic mass, the porphyry of Kanrohat, in the Jefferson Canyon mining district, 4 miles (6.4 km) east of Round Mountain. The brown to gray porphyry consists of rhyolite dikes and (or) sills and welded tuff, much of which is altered and silicified but not so sheared or bleached as the dikes in the rhyolite dike swarm east of Round Mountain. Therefore, because of less shearing, the porphyry of Kanrohat is believed to be somewhat younger than the dikes of the dike swarm east of Round Mountain and could be coeval with the small 26-m.y.-old rhyolite dome north of Mount Jefferson. The youngest rhyolites in the south area of region 4 were originally named Maris Rhyolite (Ferguson, 1924, p. 50–51) and later mapped as the Oddie Rhyolite (Ferguson and Cathcart, 1954), the name that has precedence. The Oddie intrudes the volcanic rocks, undifferentiated near Manhattan and is commonly pale pink to purple, fine grained, and locally autobrecciated and porphyritic. Phenocrysts consist of small crystals of quartz and feldspar (orthoclase, oligoclase, and albite), and a few rhyolites contain biotite and magnetite. The ones that contain biotite may be younger (Ferguson, 1924, p. 51). The Oddie-like rocks here were probably assigned to the Oddie because Ferguson (1924, p. 42–43) and later Ferguson and Cathcart (1954) considered the rhyolitic rocks to have intruded the Siebert and Esmeralda Formations. It is clear that the host rocks are not Esmeralda or Siebert; therefore, the correlation of the rhyolites with the Oddie is tenuous. Their absolute ages are unknown but would approximate 16 m.y. if they correlate with the Oddie. The distribution of the Maris Rhyolite on Ferguson's (1924) map indicates that the unit may define the southern limit of a caldera: the rhyolite having been emplaced along an inferred caldron-bounding fault during a late stage of caldron development. In summary, the range in age of the rhyolites combined in a single unit on the map is most probably from about 16–26 m.y., with some possibly as old as about 34 m.y. The important mineralized porphyry of Kanrohat in the Jefferson mining district is most likely no younger than about 26 m.y.

The name "tuffs of Mount Jefferson" (pl. A1) is applied here to the pile of rhyolitic to quartz latitic ash-flow tuff resembling a thick stubby lens and composing the top and western bulk of Mount Jefferson. The tuffs attain a maximum thickness of at least several thousand feet and were definitely recognized only at Mount Jefferson. At this time, this geographic restriction must be construed as real but may only reflect our inability to identify the unit elsewhere. Densely welded tuff predominates in the formation and weathers to shades of grayish red and brown cliffy outcrops. Homogeneity characterizes the formation from its lowest outcrops on the western flank of the massif to well up toward the summit, whereas cooling breaks high on the south flank of the massif are marked by zones of very dark gray vitrophyre and pastel-colored, less welded material. The formation has a moderate crystal content. In some units, quartz and feldspar are abundant and subequal in amount; but in the unit sampled for dating purposes, plagioclase is most abundant, and the rock contains much less quartz and scattered black biotite. Biotite forms thin books and flakes and is ubiquitous and conspicuous. Pumice is devitrified, well flattened, mainly about 1 cm long, and common in scattered zones. An approximately due-north azimuth and a moderate to strong normal polarity characterize the remanent magnetization of the formation at a spot about 1/2 mile (0.8 km) east of the mouth of Slaughter House Canyon. Samples from an upper cooling unit north of the divide between Jefferson and Meadow Creeks yielded a K-Ar age of 24.7–26.1 m.y. (R. F. Marvin, written commun., Sept. 1965, and R. W. Kistler, written commun., Apr. 1967). The formation overlies the Northumberland Tuff on the north flank of the massif and is mostly faulted against Paleozoic strata

on the south. Younger Tertiary rocks have been removed by erosion from most of Mount Jefferson, except on the southeast flank—where units included in Shingle Pass(?) Tuff and some other tuffs (pl. A1), are faulted down against the tuffs of Mount Jefferson. Nearby, in another downfaulted block along the range front at Meadow Creek Canyon, these same younger tuffs conformably overlie rocks questionably assigned to the tuffs of Mount Jefferson.

The Shingle Pass(?) Tuff and some other tuffs (pl. A1), are thickest, 1000–1500 feet (305–457 m) thick, on the southeast flank of Mount Jefferson. Much smaller discontinuous outcrops cap old volcanic rocks near Willow and Baxter Springs in the extreme southern part of the range. The lower part of the mapped unit at Meadow Creek consists of very light gray, massive to bedded, pumiceous, nonwelded to slightly welded tuff, ash-fall tuff, and minor locally interbedded tuffaceous sedimentary strata and forms conspicuous, light-hued, locally hoodoo-weathering steep slopes. Densely welded, reddish to orangish-brown, crystal-poor and locally intervening, moderately crystal-rich, rhyolitic welded tuffs form cliffy resistant cap rocks. The cooling units are locally separated by lenses of tuffaceous sedimentary strata, one of which is several hundred feet thick. The map unit may include distal parts of the Shingle Pass (but see description of this unit in north area of region 4), the Bates Mountain, and other tuffs that are petrographically similar to and possibly correlative with the tuff of Clipper Gap of McKee (1972).

An even younger ash-flow tuff, the 21–24-m.y.-old Toiyabe Quartz Latite, which is most extensive in and described with rocks of the western region, may extend into the Toquima Range. Glassy porphyritic dacite with small but numerous phenocrysts of feldspar, biotite (flakes), and minor quartz caps an 800-foot (244-m)-high hill about 2 miles (3.2 km) northwest of Manhattan. The capping unit was mapped originally by Ferguson (1924, p. 53), who considered the rock to comprise lava and related intrusive masses of Pliocene(?) age. He stated that the unit intruded and unconformably rested on the Esmeralda Formation that here is tilted and is cut by rhyolitic and andesitic dikes. Ferguson and Cathcart (1954) later correlated the capping rocks with their newly named "Toyabe (now spelled "Toiyabe") Quartz Latite" in the Toiyabe Range (region 5) but noted that the former were more dacitic. We did not examine the hill of Toiyabe(?) Quartz Latite, but recently D. R. Shawe (oral commun., May 1980) indicated that the unit in question was not a tuff; its age, moreover, is unknown.

Andesitic rocks (pl. A1) crop out mainly west of Silver Creek drainage near Bald Mountain and farther west along the range front. They occur as numerous narrow dikes and sills and less abundant larger masses, some of which have irregular shapes and dimensions measured in thousands of feet (~1000 m). Andesite porphyry and hornblende and biotite andesite porphyry have been described by Ferguson (1924, p. 51–53). Most of the andesitic rocks are propylitized to varying degrees, and according to Ferguson (1924, p. 52, 53, 55), some appear to cut the rhyolitic rocks but are older than the dacite of Ferguson that is presently mapped as the Toiyabe(?) Quartz Latite. The andesites would thus be more than 21–24 m.y. old on the basis of this relation. Ferguson (1924, p. 52, 55), however, noted the similarity of the andesite porphyry to the Divide Andesite of the Divide district (Esmeralda County) and commented that all the andesites at Manhattan were probably intruded during the same epoch. Later, Ferguson and Cathcart (1954) assigned the andesitic rocks to the Gilbert Andesite, whose type locality is in the Monte Cristo Range, Esmeralda County, and for which a Pliocene age had long been inferred. The Gilbert Andesite, however, is unequivocally Miocene as indicated by a K-Ar age of 15.1 ± 0.6 m.y. (McKee, *in* Silberman and McKee, 1972, p. 21). The Divide Andesite also may be Miocene (H. F. Bonham, Jr., oral commun., 1974). Plainly, until such time as the andesites near Manhattan are directly dated, correlations with andesites elsewhere are presumptuous, and the possibility of error is great. Complex problems concerning ages of the various andesites in western Nevada are briefly described in the section on the western region (region 5).

Several exotic slide blocks crop out about 1½ miles (2.4 km) northwest of Manhattan. These masses were combined and are shown on plate A1 as a single 325-foot (0.2 km)-long block. The outcrops were first described by Ferguson (1924, p. 25–26). They consist of coarse sandstone and slate of Permian age. Ferguson did not attempt to account for the position of the Permian rocks here, which he showed as inliers surrounded by the Hedwig Breccia Member of his miscorrelated Tertiary Esmeralda Formation. The inliers of Permian rocks may be extremely large exotic constituents within the Hedwig, which D. R. Shawe (oral commun., Oct. 1979) considered to be a Tertiary volcanic breccia. Another possible interpretation is that the Permian blocks constitute partly exposed monoliths of a more extensive but buried Permian terrain. The size of the Permian masses and the scarcity of fragments of this lithology in the Hedwig favor this interpretation.

In general, the Quaternary deposits of region 4 are similar to those that have been described in other parts of Nye County. Several unusual deposits, however, deserve special mention. These are shown separately (pl. A1) and include Pleistocene glacial deposits, a travertine dome, and very coarse fanglomerate. The last-named unit crops out in several places on the southwest edge of the region. All these deposits are described in the section of this bulletin on Geomorphology.

Western Region (Region 5)

Three key Cenozoic stratigraphic sections in region 5 have been established by previous workers: one at Tonopah, another in the southern Shoshone Mountains, and a third in the southern Toiyabe Range. Most of the Cenozoic rocks of the main area of region 5 correlate wholly or in part with these sections, which are combined and generalized for the present bulletin. Some very extensive units are common to more than one of the sections. Along the boundary of Nye and Mineral Counties (boundary area of western region, fig. A30), however, volcanic rocks occur that were not recognized

elsewhere in Nye County, except possibly in the southern Shoshone Range section. These rocks are described separately. The stratigraphic section at Tonopah has been the most thoroughly studied and evolved from one first described by Spurr (1905b, p. 31–72). Successive summaries, modifications, and additions were supplied chiefly by Burgess (1909), Nolan (1930, p. 8–23; 1935b, p. 13–28), Broderick (1949, table 1, p. 18–29, 40–72), and H. F. Bonham and L. J. Garside (1974). Part of the section for the southern Shoshone Mountains was initially described by Vitaliano (1963) and later enlarged upon by Vitaliano and Vitaliano (1972), who also described the rocks in the Paradise Range. Bonham (1970) described a complementary section just to the north of that in the southern Shoshone Mountains. The section in the Toiyabe Range was defined by Ferguson and Cathcart (1954), more recently studied in Lander County by Stewart and McKee (1977), and partly changed in Nye County by Speed and McKee (1976). Kleinhampl and Ziony (1967) combined, generalized, and modified the earlier described sections for the preliminary version of the county geologic map, which has been somewhat altered for the present report.

Two map units, the middle volcanic sequence and the Toiyabe Quartz Latite (pl. A1), are without question areally and volumetrically the most extensive Cenozoic units in the western region, but the Toiyabe consists of a much simpler series of rocks. This suggests strongly that the ash flows included herein in the Toiyabe Quartz Latite probably originated from a single eruptive center or caldera. In this regard, a statement made by Vitaliano and Vitaliano (1972, p. 3277) about correlations between Tertiary rocks of the Paradise Range and the Shoshone Mountains is pertinent for the entire western region:

> Many of the volcanic rocks present undoubtedly are the products of small local eruptions and by their very nature cannot be traced over large areas. Their relative position in the stratigraphic sequence can only be determined on the basis of their relation to more extensive and readily identifiable units.

This is not to say that major eruptive centers and corresponding eruptive rocks older than the Toiyabe Quartz Latite are not present, but that there is greater heterogeneity to the older rocks and that the many lavas, in particular, are more localized than the tuffs with which they are associated. Specific sources for the ash-flow tuffs in the western region have only recently begun to be identified. One source, described by Ekren and Byers (1977), is the westernmost known caldron in the boundary area of region 5. They have defined part of the western boundary of the caldron in the Monte Cristo Mountains and some of the ash-flow tuffs related to the caldron. Another segment of an inferred caldera, the Peavine caldron, crops out in the extreme southeastern part of the Toiyabe Range. A possible caldera or volcanotectonic depression must lie just to the north in order to account for the presence of the Darrough Felsite (fig. A32; see Darrough Felsite). Other Cenozoic volcanic centers, but not necessarily calderas, are scattered throughout region 5 and are denoted by clustered intrusive bodies. Tonopah is one such center; others include the Cimarron camp of the San Antone mining district, Goldyke (see the section of this bulletin on Fairplay district), and the Bruner mining district.

Oligocene Rocks

This report considers the Tonopah Formation and the lower volcanic sequence of western ranges (pl. A1) as partial time correlatives and as the oldest Cenozoic units in the western region. Problems concerning this correlation and the stratigraphic positions of the units are outlined following the lithologic descriptions of the two units. The Tonopah Formation is mapped to include various exposures from about 1 mile (1.6 km) north of Tonopah northward to the tip of the San Antonio Mountains. Assignment of rocks in the northern end of the San Antonio Mountains (Cimarron camp) is somewhat uncertain, because the section there was not carefully studied. The southernmost outcrops of the Tonopah Formation mapped by Broderick (1949) near the King Tonopah shaft at Tonopah are very small and are not shown on the present map. The formation is present in all the mines at Tonopah examined by Nolan (1930, p. 10; 1935b, p. 14) and is the oldest formation found there. Broderick (1949, p. 19–20) concisely summarized the evolution of the definition of the formation:

> Spurr [1905b, p. 43] first described the formation in the Tonopah mines and named it the Tonopah rhyolite-dacite. He believed it to be a post-andesite intrusion in its occurrences underground and correlated it with large areas of what he called intrusive rhyolite-dacite that he found on surface north of Tonopah.
>
> Burgess [1909] called the underground occurrences the 'Lower rhyolite' and recognized the pyroclastic nature of most of the formation. Spurr's surface 'Tonopah rhyolite-dacite' was also correctly determined by Burgess as a surface accumulation of similar materials of later age (Fraction breccia).
>
> Locke [1912] reported that he found abundant evidence that proved to his satisfaction that the 'Lower rhyolite' is a pre-Mizpah andesite accumulation of pyroclastic material. This evidence is: the upper contact is planar over a large area, stratified material is abundant, the veins pass without diminution from the andesite above into the 'Lower rhyolite' below.
>
> Spurr revisited Tonopah and reaffirmed [1915] his opinion that the 'Tonopah rhyolite' was intrusive into the Mizpah andesite and also into the Fraction breccia.
>
> Nolan [1930, p. 10–13; 1935b, p. 13–16] and [Ian] Campbell [1931], on the basis of their underground mapping agreed with Burgess and Locke that the 'Lower rhyolite' is the result of the surface accumulation of pyroclastic material and flows. The term Tonopah formation was proposed by Nolan and Campbell for this sequence in order to divorce it from the confusion that had grown up because of various workers' usages of the previous terms, 'Tonopah rhyolite-dacite,' 'Lower rhyolite,' 'Tonopah rhyolite,' 'Glassy trachyte,' all of which applied to parts of or all of the formation.

The Tonopah Formation attains a maximum thickness in the Tonopah mines (its type locality) of about 1000 feet (305 m) (Nolan, 1935b, p. 16), but the base is not exposed. Farther north, it rests unconformably on pre-Tertiary rocks and is credited with a thickness of at least 2500 feet (762 m) (Broderick, 1949, p. 18). Interbedded volcanic breccia, massive tuff, porphyritic

and banded flows, and water-laid deposits compose the formation (Nolan, 1935b, p. 14). Many of the pyroclastic rocks are ash-flow tuffs (see Campbell, in Nolan, 1935b, p. 15; Broderick, 1949, p. 18), and the section is believed to be predominantly rhyolitic. Broderick (1949, p. 18) mentioned rhyolitic, dacitic, and keratophyric compositions. Andesitic flows totaling 500 feet (152 m) in thickness are interbedded with other rocks in the formation and were separately identified as the Sandgrass Andesite by Spurr (1915, p. 729–733). Argillic alteration, which is pervasive underground and in many surface localities, accounts for much of the bleached appearance of the formation. The strata unconformably overlie pre-Tertiary rocks and conformably underlie the Mizpah Trachyte, an andesite which intertongues with the formation in local areas.

Thick sections of variegated volcanic rocks that lithologically resemble the Tonopah Formation are present in the Toiyabe and Shoshone Ranges, where they have been mapped as the middle volcanic sequence (pl. A1). Each of these sections includes numerous lithic units, some of which are unquestionably of limited areal extent, such as the lavas and, especially, the lavas of silicic composition. Some of the ash-flow tuffs, however, probably are common to both ranges. Also, it is clear that similar volcanism affected much of region 5, virtually simultaneously and continuously for an unknown but fairly long time prior to the eruption of the Toiyabe

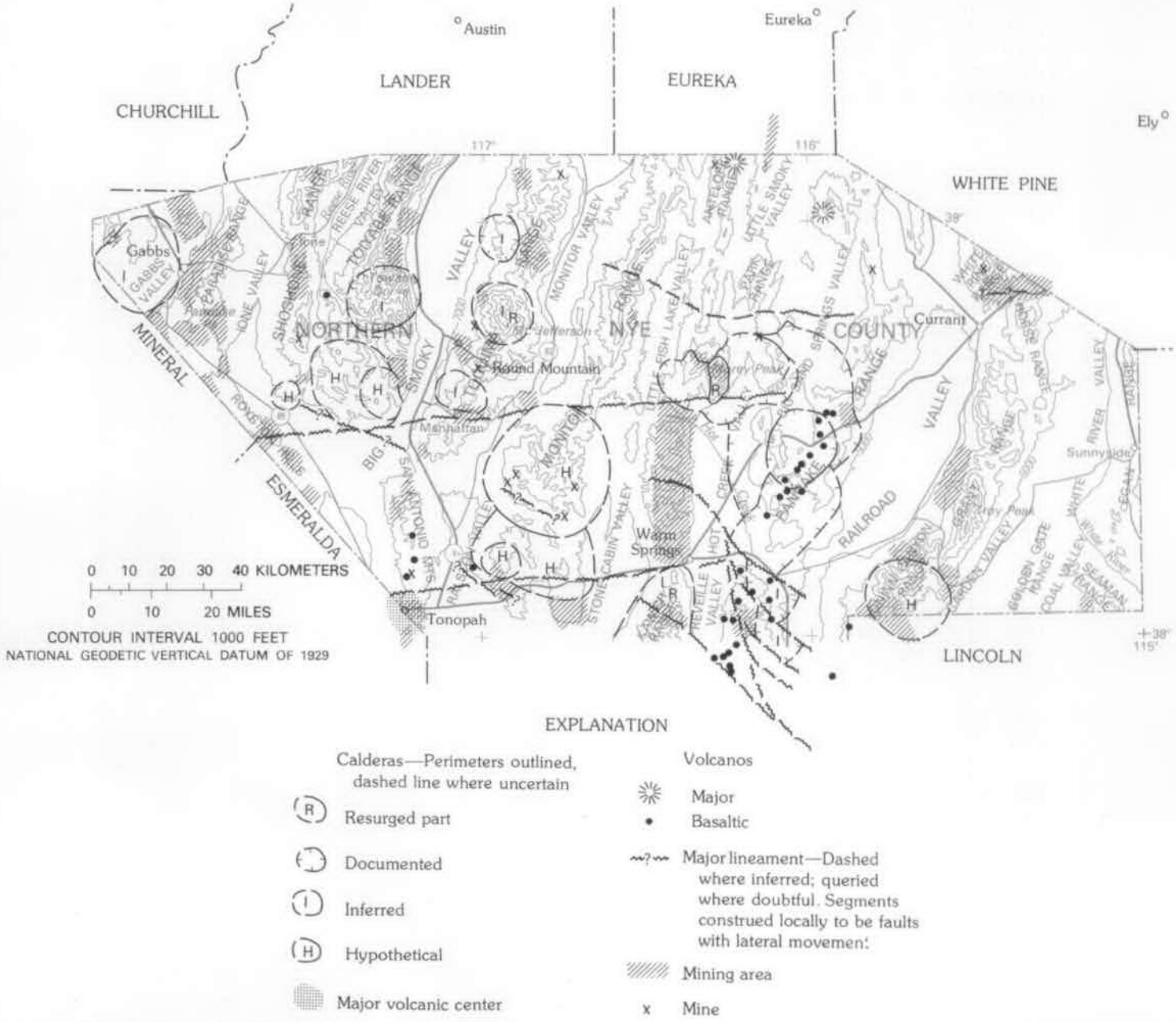


FIGURE A32. Areal relations of major volcanic centers, major lineaments (shear zones?), and mining districts, northern Nye County. Caldera and lineaments from various sources (see text).

Quartz Latite, which has been dated at about 21–24 m.y.

The lower volcanic sequence of western ranges (pl. A1) crops out in the Shoshone Range from near Mount Ardivey northward to the county line; it occurs also in the southern Paradise Range and in a minor outcrop in the Monte Cristo Mountains (boundary area of western region). It probably is present in the southern Toiyabe Range as small erosional remnants. The map unit north of 39° includes the Underdown Tuff of Bonham (1970) and rocks mapped and described in the Ione quadrangle by Vitaliano (1963) that were subsequently divided into two formally named units: the Mission Spring and Third Canyon Formations (Vitaliano and Vitaliano, 1972, p. 3270–3271). The latter authors believe that the Third Canyon Formation extends into the Paradise Range. The stratigraphic position of the Mission Spring and Third Canyon Formations with respect to the Underdown Tuff has not been determined.

Rocks in the lower volcanic sequence of western ranges weather to generally dark-hued slopes and cliffs that are difficult to distinguish from the underlying pre-Tertiary sedimentary strata, but they contrast markedly with the light-hued overlying rocks. The thickest (about 2550 ft or 780 m) and most complete exposures of welded tuff (lower volcanic sequence, pl. A1) lie south of Grantsville in the Shoshone Mountains between Mission and Spanish Canyons; in contrast, only about 400 feet (120 m) of the Third Canyon Formation is present in the Paradise Range (Vitaliano and Vitaliano, 1972, p. 3271, 3275), and probably only 50 feet (15.2 m) occurs in the Monte Cristo Mountains.

The Underdown Tuff attains a thickness of 1600 feet (490 m) in the Shoshone Mountains, but its base is not exposed (Bonham, 1970). Unlike the Mission Spring and Third Canyon Formations, the Underdown is restricted to a single rock type and consists of two lithologically similar cooling units of extremely crystal-poor, densely welded, rhyolite welded tuff, the lowest of which is characteristically foliated and lineated and contains flattened, greatly elongated pumice fragments. The Underdown is light brownish gray and contains about 2% crystals and 2%–3% rock fragments; crystals consist mainly of quartz, perthitic alkali feldspar, sparse biotite, and oligoclase. Bonham (1970) suggested that the Underdown was deposited with a steep initial dip against a ridge of pre-Tertiary strata, thus accounting for the conspicuous foliation and lineation in the lower cooling unit. The Underdown is overlain unconformably by the middle volcanic sequence (pl. A1), which here includes mostly the Bonita Canyon Formation of Bonham (1970). The Bonita Canyon Formation (see below) is considered to be Oligocene and probably is no younger than about 26 m.y. (Bonham, 1970).

South of about lat 39° N. the lower volcanic sequence of western ranges (pl. A1) is composed entirely of the Mission Spring and Third Canyon Formations, and each formation contains a wide variety of volcanic rocks. The following descriptions of the strata included in the two formations is taken from Vitaliano (1963) and Vitaliano and Vitaliano (1972, p. 3270–3271, 3275, and 3277). Three subdivisions in the Mission Spring were recognized: a lower aphanitic to slightly porphyritic rhyolite (about 591 ft or 180 m thick), a middle rhyodacite tuff (about 443–492 ft or 135–150 m thick), and an upper porphyritic trachyte lava and tuff (394 ft or 120 m). Interbedded tuffaceous sedimentary strata mentioned by Vitaliano as occurring south of Mission Canyon and volcaniclastic sandstone that overlies the pre-Tertiary basement rocks (Vitaliano and Vitaliano, 1972, fig. 3) are not differentiated from the lower volcanic sequence of western ranges on plate A1. The Mission Spring was deformed prior to deposition of the Third Canyon and commonly exhibits strongly sheared rock and associated quartz-sericite schist that are only sparingly present in the Third Canyon. The Third Canyon Formation in the Shoshone Mountains lies on the deformed and eroded Mission Spring, but farther west in the Paradise Range, it forms the base of the Cenozoic section. In the Shoshone Mountains, the Third Canyon consists of amphibole-plagioclase porphyritic rhyodacite lava (180 ft or 55 m thick) at the base that is overlain by about 246 feet (75 m) of trachytic and siliceous tuffs interbedded with minor dacite lava and about 656 feet (200 m) of capping rhyodacite and minor trachyandesite lavas. Propylitic alteration has imparted a greenish cast to much of the Third Canyon Formation, which tends to characterize the formation. Propylitized lavas are especially common in the capping rhyodacites. Sheared rocks occur locally but, as mentioned above, are not nearly so abundant as in the underlying Mission Spring. The Third Canyon in the Paradise Range was described as consisting of about 300–675 feet (120–205 m) of pyroclastic rocks (tuff and tuff breccia) and lavas of intermediate composition. The dark-hued but characteristically greenish lavas are a porphyritic andesite with phenocrysts (as much as 5 mm long) of plagioclase, biotite, hornblende, augite, and a little olivine. Locally, for example, adjacent to the large rhyolite mass at the Davis Mine (near Goldyke), the andesite is bleached, argillized, silicified, and, presumably, mineralized. We believe that minor outcrops of chiefly augite andesite mapped by Ferguson and Cathcart (1954) near the heads of Jett and Pablo Canyons, Toiyabe Range, are similar in age and stratigraphic position to the above-described andesites of the Third Canyon Formation in the Paradise Range; therefore, they belong with and are included with the lower volcanic sequence (pl. A1).

The rocks described above unconformably overlie pre-Tertiary rocks, and they are unconformably overlain by the middle volcanic sequence (pl. A1) of probable Oligocene to early Miocene age. Unequivocal lower and middle volcanic sequences have not been dated by absolute methods; the former is considered to be Oligocene, chiefly because of its stratigraphic position beneath the latter, which underlies the dated 21–24-m.y.-old (avg. 22.8) Toiyabe Quartz Latite. The andesite assigned to the queried lower volcanic sequence of western ranges (pl. A1) in the Toiyabe Range apparently unconformably overlies Mesozoic and Paleozoic rocks and unconformably underlies rocks of the middle volcanic sequence. The andesite probably also underlies the Darrough Felsite, occurring as erosional remnants as much as 300 feet (91 m) thick (Ferguson and Cathcart,

1954; and Speed and McKee, 1976). Speed and McKee have not clearly demonstrated the pre-Darrough age of the andesite, but have reported that granitic dikes dated at 29.4 ± 0.8 m.y. cut the andesite. Porphyritic rhyolite lavas (base of the Mission Spring Formation) may be approximately coeval with rhyolites that crop out much farther eastward near Dobbin Summit (Monitor Range) and at Pritchards Station (Park Range), where the rhyolite at Pritchards Station was dated at 37.2 ± 1.3 m.y. (Dixon and others, 1972). Rhyolite lavas occurring at the base of the Tertiary section in many localities across northern Nye County, including the Grant Range, probably are nearly the same age. If so, the dacite and rhyodacite lavas at the top of the Mission Spring Formation possibly are time equivalents of the widespread intermediate lavas that overlie the 34.1-m.y.-old Stone Cabin Formation in the eastern part of the county.

The middle volcanic sequence (pl. A1) is an extremely heterogeneous unit. The principal lithologic units included in this sequence are the Bonita Canyon Formation of Bonham (1970) in the northern Shoshone Mountains; the tuffs of Grantsville and Union Canyons in the southern Shoshone Mountains (Vitaliano and Vitaliano, 1972); and possibly two formations from the southern Desatoya Mountains given unpublished names there by Barrows (1971) and which may extend into the Paradise Range. Also included are sedimentary strata and lavas that are very local in extent and, in places, thick ash-flow tuffs that have not been named or correlated with units elsewhere. The wide variety of tuffs and lavas in the sequence were undoubtedly fed from widely dispersed centers, and the strata probably vary considerably in age. The unit is thickest in the Shoshone Range where one section near Grantsville Canyon was found to be 5350 feet (1630 m) thick (Vitaliano and Vitaliano, 1972, p. 3271–3272). The unit is on the order of 2000 feet (610 m) thick in the Toiyabe Range but possibly only several hundred feet thick in the Paradise Range. The initial distribution of the rocks included in the middle unit (pl. A1) probably covered much of region 5 and the surrounding territory.

Although the rocks are very heterogeneous, they consist chiefly of silicic, largely devitrified air-fall and ash-flow tuffs. Volcanogenic sedimentary rocks, including sandstone, conglomerate, and epiclastic volcanic breccia, are also common but are greatly exceeded in volume by the tuffs, except locally. The map unit commonly weathers to starkly lighter slopes and cliffs than the cliffy underlying and overlying strata. Where Bonham (1970) adopted the name Bonita Canyon Formation for the middle volcanic sequence (pl. A1) north of lat 39° N. in the Shoshone Mountains, the formation is 1200–1600 feet (366–488 m) thick. Its pyroclastic units, on the basis of phenocryst mineralogy, range in composition from dacite to rhyolite and are principally rhyodacite. Silicic lavas are intercalated with the tuffs locally, although none were mapped in the part of Nye County studied by Bonham. The formation is commonly mildly argillized and locally silicified, mineralized, and hydrothermally altered.

The middle volcanic sequence as mapped probably includes rocks in a few places that are as young as the Toiyabe Quartz Latite. For example, sanidine from rocks believed by Speed and McKee (1976, no. 4 of table 1) to belong to the middle volcanic sequence was dated at 22.7 ± 0.8 m.y. In addition, the separately mapped (pl. A1) tuffs of Peavine Canyon, silicic volcanic rocks, volcanic rocks, undifferentiated (region 4), and the Tonopah Formation probably include rocks that are partially time—if not lithic—equivalents of the middle volcanic unit. A 25.3 ± 1.3-m.y.-old formation and an underlying formation mapped by Barrows (1971) about 30 miles (48 km) northeast of Gabbs in the southern Desatoya Mountains are also believed to be correlatives of at least part of the middle volcanic sequence of the present report.

The Darrough Felsite was originally named and described by Ferguson and Cathcart (1954). The type section lies due west of Darrough Hot Springs near Cove Canyon, along the east flank of the Toiyabe Range, where the unit is relatively unbroken by faults. Speed and McKee (1976) stated that the Darrough in the type locality exceeds 9842 feet (3000 m) in thickness. Outcrops of the Darrough have been recognized only in the southern one-third of the range, where they form typically somber, very steep, rough cliffs colored moderately dark shades of gray on fresh and weathered exposures. The extreme hardness of much of the unit and scattered veinlets of epidote and chlorite give a decided aged appearance to the rock and undoubtedly influenced Ferguson and Cathcart to conclude that the unit was of pre-Tertiary (Permian?) age. Details of the formation reported below are from Speed and McKee (1976). The quartzofeldspathic Darrough is subtly layered and consists of rhyolitic to rhyodacitic tuff and tuff breccia and lesser amounts of lava, sedimentary breccia, and volcanogenic sandstone—totalling more than 9842 feet (3000 m) in exposed thickness. The densely welded ash-flow tuffs contain 20%–60% crystals and average 40%. The major crystal assemblage is quartz with lesser amounts of sanidine and equal amounts of zoned plagioclase of An_{10} to An_{20} composition. Widespread flow banding and abundant inclusions were also noted and emphasized, as was a local tendency toward a coarser texture that resembles granite. A shard matrix is holocrystalline. Lithic fragments, which comprise as much as 50% of the volume of some tuff units, are generally less than 10 cm in diameter and consist of aphanitic felsic igneous rocks, granitic rocks, and rocks representative of the pre-Mesozoic strata found in the area. The hard dense character of the Darrough is due to pervasive silicification. Speed and McKee stated that the Darrough truncates folded pre-Tertiary rocks along an approximately planar surface. They presented evidence, based partly on work of Speed (1971), indicating that the formation was not intensely codeformed with rocks assigned to the Permian Pablo and older formations and is not genetically related to the type Pablo, as suggested by Ferguson and Cathcart (1954). Potassium-argon determinations on sanidine and hornblende from the Darrough give a range in age of from about 22–27 m.y., with the horn-

blende yielding the oldest date. Speed and McKee (1976) concluded that the Darrough is middle Tertiary. Despite these seemingly unequivocal data, the present authors and McKee (oral commun., 1974) believe that the appearance of the formation is so unlike other middle Tertiary ash-flow tuffs of the Great Basin, including altered units, that an older Tertiary age cannot be completely excluded. Any possible refutation of the K-Ar data, however, must await further study of the formation.

The great thickness and areal restriction of the Darrough, together with its unusual pervasively altered state, suggest strongly that the formation is confined to a volcanotectonic depression or caldera (Speed and McKee, 1976). These authors noted a siliceous dike swarm in the underlying pre-Tertiary that they suggest might represent a feeder system for the very thick ash flows in the Darrough. The largest dikes are in the area of Broad and Jett Canyons, respectively, and quartz monzonite porphyry in one of the large dikes yielded a biotite K-Ar age of 29.4 ± 0.8 m.y. (Speed and McKee, 1976; table A11). They also speculated (p. 4, 5) that much of the 23-m.y.-old volcanic unit (included in our middle volcanic sequence, pl. A1) overlying the Darrough might be genetically related to the Darrough.

The tuffs of Peavine Canyon (pl. A1) are somewhat arbitrarily differentiated from the middle volcanic sequence (pl. A1) and crop out primarily in and near the mouth of Peavine Canyon in the Toiyabe Range. Minor outcrops tentatively assigned to this unit also crop out to the east, along the west front of the Toquima Range. The largest part of the unit may be concealed beneath alluvium in Big Smoky Valley. Long after the reconnaissance mapping, a decision was made to differentiate the unit from the middle volcanic sequence (with which it has strong lithologic and stratigraphic affinities) because of the belated recognition along the west side of Peavine Canyon of a distinctive section of ash-flow tuffs that contain much lithic material. The upper two of three units here were not traced into the surrounding main mass of the middle volcanic sequence, and it was decided that the study of a caldera hypothesized for this area would be aided by the recognition of the distinctive members of the tuffs of Peavine Canyon. The formation is composed of basal massive white tuffs consisting chiefly of rhyolititic ash-flow material and is overlain by about 700 feet (213 m) of pale-brown to red-brown cliff-forming platy and chippy, hackly weathering, densely welded tuff that is capped by unconformably overlying, massive lithic and quartz crystal-rich quartz latitic(?) ash-flow tuff. The lithology of the lower member closely resembles that of the middle volcanic sequence (pl. A1) and might very well correlate with it. The 700-foot (213-m)-thick densely welded tuff of the middle member superficially resembles that part of the Fraction Tuff at the television repeater antennas north of Tonopah. The similarity encompasses color and weathering characteristics and high content of small lithic inclusions; however, H. F. Bonham, Jr., and L. F. Garside (oral commun., Oct. 1971) noted much more biotite in the Fraction. This member of the tuffs of Peavine Canyon is the most distinctive and, therefore, the most readily recognized in the Toquima Range, where some of the rocks have a pinkish coloration and contain abundant smoky quartz. Characteristic features of the upper member are its propylitized massive appearance and its large content of lithic inclusions. The member bears a resemblance to a thick pile of altered, welded ash-flow tuffs in the East Golden area (Cloverdale mining district) west of Cloverdale Canyon, where the rocks were included with the middle volcanic sequence (pl. A1). Each of the three members probably had a different source, and together they may represent a fairly long span of time. As mapped in Peavine Canyon, the tuffs of Peavine Canyon may partly intertongue with the middle volcanic sequence, but southwest of the mouth of the canyon, the latter appear to lie with angular discordance beneath the former. Both relations are possible since the age span of both formations is construed to be great and since each formation is composed of at least several units. The bracketing absolute ages of the tuffs of Peavine Canyon have not been determined; the rocks are more likely to be older than the Toiyabe Quartz Latite, rather than partly older and partly younger as depicted in the map explanation (pl. A1). The higher position shown allows for the less likely possibility that some of the rocks may be equivalent to the Miocene Fraction Tuff.

Miocene and Pliocene Rocks

Rocks overlying the middle volcanic sequence (pl. A1) are mostly ash-flow tuffs of the Toiyabe Quartz Latite. Andesite flows that locally intervene in the Toiyabe Range are discontinuous because of erosion. They were correlated with the Gilbert Andesite by Ferguson and Cathcart (1954), who stated that they thickened westward and southwestward (toward the Gilbert district) into a section of andesite flows, breccias, and agglomerates. The andesites of the Toiyabe Range, however, are clearly older than the approximately 21–24-m.y.-old Toiyabe Quartz Latite, and they are, therefore, probably older than the main mass of the Gilbert Andesite. The source of the flows in the Toiyabe Range may be an andesite complex of dikes and possible vent rocks that cut the middle volcanic sequence several miles southwest of the mouth of Peavine Canyon. One 2-mile (3-km)-long outcrop of intermediate lavas in Jett Canyon is provisionally assigned to the lower volcanic sequence of western ranges (pl. A1). This and a more northerly outcrop in North Twin River Canyon were mapped by Ferguson and Cathcart (1954) as isolated erosion remnants (300 ft [91 m] or less thick) of older lavas, chiefly augite andesite. The northern exposure apparently would be intercalated with the middle volcanic sequence, according to our assessment of mapping by Speed and McKee (1976), and cannot be as old as the lavas in Jett Canyon. More details about andesites in general and those of the western region in particular are given in the section of this bulletin on Other Rocks of Intermediate to Mafic Composition, which includes two of our map units (pl. A1): dacitic to basaltic rocks and andesitic to basaltic rocks, including Mizpah Trachyte.

The Toiyabe Quartz Latite, a rhyolitic to rhyodacitic ash-flow tuff, is one of the best known and most conspicuous Tertiary units in central Nevada. It was named

and described by Ferguson and Cathcart (1954), who established the type locality on the crest and west flank of the Toyabe (now spelled Toiyabe) Range (misnamed Toquima Range in one place in their text); however, many aspects of their original definition have since been modified. Their spelling of "Toyabe" was changed to "Toiyabe" by a 1971 decision of the Geologic Names Committee of the U.S. Geological Survey to conform with the spelling of the range adopted in 1930 by the Board of Geographic Names (from files of Geologic Names Committee, 1974). Ferguson and Cathcart's (1954) descriptions of the lithology and stratigraphic position of the formation have also been modified. As originally described the formation was considered to be mostly lava. Later studies have shown that most of the rock is densely welded tuff.

The Toiyabe Quartz Latite is widely distributed in region 5 of northern Nye County and locally extends northward into Lander County in the Shoshone Mountains and Toiyabe Range (Bonham, 1970; Stewart and others, 1977). Its present extent probably closely delineates its original distribution, because sections in the peripheral outcrops are appreciably thinner than elsewhere. The formation rests unconformably on older rocks and, where not affected by erosion, is overlain by lavas of intermediate composition. Thickness in Lander County, near the Jackson (Gold Park) mining district in the Shoshone Mountains, is 1500 feet (460 m) (Bonham, 1970); and nearly 2000 feet (600 m) in three cooling units was described in the Ione quadrangle (Vitaliano, 1963; Vitaliano and Vitaliano, 1972, p. 3272–3274). The unit thins westward, and outcrops of the formation in the Paradise Range probably are no more than several hundred feet thick. Ferguson and Cathcart (1954) stated that the thickness may exceed 1500 feet (460 m) in the Toiyabe Range, and we believe that the section there is on the order of 2000 feet (600 m) thick. The formation in places probably originally extended well eastward across the area of Big Smoky Valley, and an erosional remnant on a ridge 3 miles (4.8 km) northwest of Manhattan is questionably assigned to the formation. At least several hundred feet of section here was first described as dacite by Ferguson (1924, pl. 1, p. 53) and later as Toyabe (now Toiyabe) Quartz Latite by Ferguson and Cathcart (1954). D. R. Shawe (oral commun., May 1980) believes that the unit is not a tuff. One outcrop in the northern San Antonio Mountains exposes less than about 100 feet (30 m) of the formation; elsewhere in the range, near the Liberty and Hall mines, several other outcrops are questionably assigned to this formation. Conceivably, they could have been thin when deposited there and could have later mostly eroded away.

In addition to original (outdated) descriptions by Ferguson and Cathcart (1954), recent descriptions have been made by Vitaliano (1963), Bonham (1970), Vitaliano and Vitaliano (1972), and Stewart and others (1977). These observations are summarized below. The rhyolitic to rhyodacitic ash-flow tuffs where thickest weather reddish brown and brownish gray and form a broad, deeply eroded upland topography or caprock in the mountain ranges. The strata weather to persistent, conspicuous high cliffs, and cooling breaks in the ash-flow tuffs are well displayed. Columnar jointing is especially characteristic of the sections in the Shoshone Mountains and the Toiyabe Range. The ash-flow tuffs are moderately crystal rich (about 50% crystals) and contain crystals of quartz, feldspar, biotite, and hornblende—as much as several millimeters across. Feldspar includes both plagioclase (sodic plagioclase to oligoclase) and sanidine. Quartz, commonly smoky, and feldspar are the most conspicuous megascopic crystals in the formation approximately north of the latitude of Ione; farther south, biotite in flakes and thin books becomes conspicuous, and the quartz loses its smoky color. These differences probably relate to differences in the mineralogy of individual cooling units, that have not been separately mapped. Vitaliano and Vitaliano (1972, p. 3272–3274) described characteristics of three cooling units in the Ione quadrangle, where each consists of virtophyre and poorly welded and densely welded devitrified zones. The basal cooling unit is 650 feet (250 m) thick, and the successivly overlying cooling units are 1050 feet (320 m) and 260 feet (80 m) thick. Lithic fragments are generally small and sparse in the Toiyabe Quartz Latite compared to older tuffs in the underlying middle volcanic sequence, but locally, as in the headwaters of the Reese River, some parts of the ash-flow tuffs contain a high proportion of lithic material. Remanent magnetism of the Toiyabe Quartz Latite is characterized by relatively strongly inclined normal (positive) polarity and an azimuth of about 310°–320°. Measurements were made with a portable fluxgate magnetometer at localities about 2 miles (3.2 km) and 11 miles (18 km) above the mouths of Cloverdale and Peavine Canyons, respectively, in biotite-bearing tuffs near the base of the formation.

Age of the Toiyabe Quartz Latite ranges from about 21 to 24 m.y. and probably reflects as yet unstudied variations in age among the different cooling units. This range of ages approximately encompasses the 22.1 ± 0.6–23.7 ± 1.0 m.y. span of ages of the geographically separated and lithologically different Bates Mountain Tuff and tuff of Clipper Gap of McKee (1972), which probably erupted from separate centers. The above-mentioned ages are generalized from determinations made by R. L. Armstrong and R. W. Kistler and reported by Armstrong (1970, p. 212–213), Kleinhampl and Ziony (1967), McKee and others (1971, p. 26) and Silberman and McKee (1972, p. 22). The center for the Toiyabe Quartz Latite could possibly lie in region 5 of northern Nye County. Mapping is too inconclusive to determine whether the great thickness of the formation in the Shoshone Mountains and Toiyabe Range reflects the vent area for the formation or the collapsed vent for older tuffs over and into which the Toiyabe Quartz Latite flowed. Localization of the vent area for the Toiyabe Quartz Latite near the thickest part of the formation in the Shoshone Mountains is suggested by the occurrence there of numerous intrusive rocks that are lithologically similar to the tuff. For example, rhyolitic plugs near the Jackson (Gold Park) mining district (Shoshone Mountains) that intrude the Toiyabe Quartz Latite are very similar mineralogically to the country rock, according to Bonham (1970), who suggested that

they may have had the same magmatic source. The approximately 550 feet (165 m) of lavas that disconformably overlie the ash-flow tuffs and are mapped with the Toiyabe are quartz latitic to rhyodacitic and trachyandesitic in composition, and they are also mineralogically similar to parts of the tuff sequence. The lavas were noted and described primarily by Vitaliano and Vitaliano (1963, p. 3274 and 3278), who indicated that these possibly were erupted in such rapid succession after the ash flows that they cooled and crystallized in continuum with the underlying tuff. The Toiyabe Quartz Latite in the Paradise Range is mapped locally, as in the thick cliff near Sherman Peak, to include a somewhat older phenocryst-poor, reddish ash-flow tuff that is a cooling unit in a sequence of tuffs mapped separately farther west in the Monte Cristo Mountains (silicic volcanic rocks—chiefly rhyolitic welded ash-flow tuffs, pl. A1).

Volcanic Rocks at Tonopah

Introduction. Many of the mapped units in the western region that are younger than the Toiyabe Quartz Latite are represented in the Tonopah area and constitute the greatest part of the section there. The Tonopah section as used in the present bulletin is a generalization of the sections described by Spurr (1905b, p. 31–56) and later modified by Burgess (1909, p. 687–709), Spurr (1915, p. 717–747), Nolan (1930, p. 10–23; 1935b, p. 13–28), Broderick (1949, p. 18–72), and Bonham and Garside (1974, p. 43–46; 1979). Rock units seen only underground and described by these workers are either not mentioned or only briefly mentioned in the present bulletin, and the reader is referred to the earlier reports. The section exposed at the surface at Tonopah is distinctive and includes, above the previously described Tonopah Formation, the Mizpah Trachyte and the successively overlying Fraction Tuff, Siebert Tuff, and Oddie Rhyolite (mapped with rhyolitic rocks, pl. A1), which is coeval with the Brougher Dacite (mapped with dacitic and quartz latitic rocks, pl. A1). The Siebert Tuff in the Tonopah area is mapped and described with sedimentary strata and intercalated tuffs (pl. A1), and it intertongues extensively with basaltic rocks that are locally shown separately on plate A1. The Oddie and Brougher are described farther on with young silicic volcanic rocks of the western region.

Mizpah Trachyte. The Mizpah Trachyte (pl. A1) was named and defined by Spurr (1911, p. 560–561; 1915, p. 719–724), who pointed out that the unit was the principal ore-bearing formation at Tonopah. Nolan (1930, p. 15–17) retained the name Mizpah Trachyte and added to Spurr's descriptions. Broderick (1949, p. 26–28) further enlarged the description and changed the name to Mizpah Andesite, a term not widely used but which more correctly identifies the composition of the unit according to Bonham and Garside (1974, p. 43). The formation crops out over a limited area at and near Tonopah, conformably overlies the Tonopah Formation, and is unconformably overlain by the Fraction Tuff. A thickness of at least 2000 feet (600 m) is indicated underground at Tonopah (Nolan, 1930, p. 17), whereas Broderick (1949, p. 26) reported about 1000 feet (300 m) in drill holes about 1 mile (1.6 km) to the north. The Mizpah Trachyte has been described as an albitized andesite or keratophyre (Nolan, 1935b, p. 19; Broderick, 1949, p. 27). Chemically, it is a calc-alkaline andesite (Bonham and Garside, 1974, p. 43) that is rather pervasively albitized and commonly hydrothermally altered to bleached quartz-sericite-adularia rock in the central part of the Tonopah district. It is less intensely altered outward from the main district to grayish-green propylitized and pyritized andesite. Conspicuous phenocrysts of plagioclase, hornblende, and biotite set in a fine-grained felsitic groundmass typify the fresh rock. Pleochroic apatite, a constituent noted by Ian Campbell (Nolan, 1935b, p. 22) is a conspicuous accessory mineral (Bonham and Garside, 1974, p. 43). Accessory pleochroic apatite phenocrysts like those of the Mizpah also occur in the Midway Andesite (Spurr, 1915, p. 743–744) according to Nolan (1935b, p. 22) who (1930, p. 16) found the Midway to be inseparable from the Mizpah and therefore abandoned the name Midway Andesite. Broderick (1949, p. 40–46) comprehensively summarized the problem of correlating andesites at Tonopah and appeared to conclude that minor andesites of post-Mizpah and pre-Siebert Tuff age may exist. It is possible that the Midway as originally defined partly represents lava flows of the Mizpah and partly includes the dikes and plugs of Mizpah Trachyte mentioned by Bonham and Garside (1974, p. 43) as intruding extrusive phases of the Mizpah. Unaltered Mizpah Trachyte collected by Bonham and Garside has yielded biotite with a K-Ar age of 20.4 ± 0.6 m.y. (Silberman and McKee, 1972, p. 23).

Fraction Tuff. The term Fraction Tuff (pl. A1) as used in this bulletin is derived through complex nomenclatural changes and redefinitions of Spurr's (1905b, p. 39–40) original Fraction Dacite Breccia at Tonopah. As used herein, however, the Fraction Tuff includes not only the original unit but also the Tonopah Rhyolite–Dacite and the Heller Dacite, units that are now known to be distinctive ash flows in the tuff unit (see Bonham and Garside, 1974).

Outcrops of the Fraction Tuff at Tonopah (pl. A1) are the farthest west known for the formation. Aside from the outcrops at Tonopah, where the Fraction Tuff is estimated to be about 2000–3000 feet (610–914 m) thick, the formation lies mainly south of lat 38° N., where it is widely distributed to as far east as the Belted Range and attains a maximum thickness of about 7200 feet (2200 m) (based on a composite section) in the southern Kawich Range (Ekren and others, 1971, p. 50; Cornwall, 1972, p. 20–21).

The Fraction Tuff at Tonopah is classed as a rhyolitic unit by Bonham and Garside (1974, p. 19), who divided the Fraction into six members informally labelled "a" through "f." In the Kawich Range and other places to the southeast in southern Nye County, chemical and normative studies show the formation to be calc-alkalic and to consist of rhyolite and quartz latite close to the rhyolite field (Ekren and others, 1971, p. 52; Cornwall, 1972, p. 20). A modern description of the Fraction Tuff summarized below is chiefly from the report of Bonham and Garside (1974, p. 43–44) and discussions with them;

the reader is also referred to the earlier mentioned district reports that provide detailed lithologic descriptions made, however, without the insight of the ash-flow origin of the rocks. All six of Bonham and Garside's informal members are rhyolitic ash flows with variable but moderate to abundant crystal content. Biotite is abundant in two of the members; however, quartz, plagioclase, and alkali feldspar are generally most abundant. The degree of welding varies from member to member. Accessory minerals include hornblende, zircon, apatite, magnetite, and lesser amounts of sphene and allanite. Lithic inclusions ranging from sand size to very large boulder size include Tertiary welded tuffs, rhyolitic rocks, andesites, some vein quartz, and lesser amounts of pre-Tertiary material, such as Mesozoic(?) granite and Paleozoic sedimentary rocks. The informal members correspond to the original units named by Spurr (1905b, p. 37–43) at Tonopah as follows: member "f," the oldest, corresponds to part of the old Tonopah Rhyolite-Dacite; member "e" corresponds at least in part to the Fraction Dacite Breccia of former usage; member "d" to the Heller Dacite also of former usage; member "c" corresponds to part of the Tonopah Rhyolite-Dacite, some later dacite, and the Fraction Dacite Breccia; member "b" corresponds to part of the Tonopah Rhyolite-Dacite; and member "a," the youngest, corresponds to that part of the Tonopah Rhyolite-Dacite west of the Belle of Tonopah shaft in the main mining district (H. F. Bonham, Jr., and L. J. Garside, oral commun., 1974). Much of the Fraction weathers to very low hills and flats that in places gently rise to higher subdued hills and ridges. Several of the thick lower units in the formation form extensive areas of subdued topography that appear white or pastel (like the overlying Siebert Tuff), in contrast to the underlying Mizpah Trachyte. The excellent exposures at the town's television repeater antennas northeast of Ararat Mountain consist of at least 500 feet (152 m) of densely welded ash-flow tuff, designated the "a" (youngest) member by Bonham and Garside (1974, fig. 2), and form a distinctively colored, pastel reddish to brownish terrain of low rolling hills and somewhat higher subdued hills and ridges. At least six rhyolitic ash-flows (cooling units?), the thickest greater than 984 feet (300 m) thick, compose the Fraction Tuff and exhibit different degrees of welding ranging from nonwelded and little compacted to densely welded. Vitrophyre is common in member "d" and in member "a." The postore Fraction Tuff rests unconformably on the older rocks, especially the Mizpah Trachyte, and is overlain unconformably by the predominantly sedimentary Siebert Tuff. A Miocene age for the Fraction is based on stratigraphic and radiometric evidence: K-Ar ages of about 17 m.y. have been obtained from the Fraction (16.9–17.1 ± 0.3 m.y.), reported by Silberman and McKee (1972, p. 24) from a sample collected at Heller Butte, and is the only date directly from the Tonopah district. Another sample from far to the southeast in the Kawich Range yielded a biotite age of 17.8 ± 0.48 m.y. (Ekren and others, 1971, table 5; Cornwall, 1972, p. 21). However, table 5 in the report by Ekren and others (1971) listed three other samples for which biotite or sanidine ranged in age from 15.0 ± 0.55–16.4 ± 0.5 m.y. These came from localities at least 25 miles (40 km) southeast of Tonopah; currently the 17-m.y. age is the best available age of the Fraction Tuff at Tonopah. An age of 20.4 ± 0.6 m.y. for the Mizpah Trachyte, which underlies the Fraction as mapped by Bonham and Garside (1974, fig. 2), and an age of about 16 m.y. for the Oddie Rhyolite, which intrudes the youngest member, serve to bracket the age span of the Fraction (dates from, respectively, Bonham and Garside, 1972, p. 6, and M. L. Silberman, oral commun., Oct. 1974). The recognition of the Fraction Tuff by Ekren and others (1971, p. 50–52) and F. M. Byers, Jr. (written commun., 1975) as far southeastward as Yucca Flat is based on considerable petrographic evidence; we accept their correlation. Contrarily, Ferguson's (1924, p. 42–43) proposed correlations of rocks at Manhattan with the Fraction, as well as with the Esmeralda Formation, should be disregarded. Ferguson proposed correlating a low unit, the Round Rock Member, of the Esmeralda Formation with the Fraction Breccia of Tonopah; later, he and Cathcart (1954) noted a lithologic similarity between this member and the Fraction Breccia. However, in both papers, they miscorrelated the Esmeralda, and the Manhattan rocks in question predate the Fraction Tuff. The Fraction seems to represent a series of discrete eruptions without counterparts in the surrounding region. Data of Ekren and others (1971, p. 50–55) appear to indicate that its source was the Cathedral Ridge caldera between Gold Flat and Kawich Valley near their 7200-foot (2100-m)-thick measured section.

Most earlier workers regarded the Fraction to be a postore unit; however, sparse ore minerals were found locally, as in the rocks formerly termed "Tonopah Rhyolite-Dacite" at the Ohio Tonopah shaft (Spurr, 1905b, p. 202–204), which rocks are now included by Bonham and Garside (1974, fig. 2) and us in the Fraction Tuff. Also, the Fraction is the main host for the precious-metal ore deposits only 5 miles (8 km) to the south at the Divide district (Albers and Stewart, 1972, p. 65; Bonham and Garside, 1974, p. 47).

Sedimentary Strata and Intercalated Tuffs. The map unit sedimentary strata and intercalated tuffs (pl. A1) includes economically important and paleontologically significant strata. The map unit groups widely distributed beds of diverse ages that cluster primarily at about 10–16 m.y. old. The strata commonly are buried beneath Quaternary valley fill in the intermontane valleys and crop out in the foothills and pediments of many of the mountain ranges, in particular the Cedar and San Antonio Mountains, the southern parts of the Shoshone Mountains and the Toiyabe Range, the Royston Hills, and in Gabbs Valley and vicinity. Minor outcrops also appear north of the Lodi Hills. The thickest sections are in the boundary area of the western region (Gabbs and Ione Valleys) and in and adjacent to the San Antonio Mountains, at the south end of which Spurr (1905b, p. 51–54) named the strata the Siebert Tuff for exposures at Siebert Mountain, 1 mile (0.6 km) southwest of Tonopah. Diatomite beds are common locally in the boundary area sections, and although many have been prospected, there appears to have been little or no pro-

duction to date (1979). The Siebert, which also contains some diatomites, is described below and serves to typify the map unit sedimentary rocks and intercalated tuffs (pl. A1).

Spurr (1905b, p. 53) assigned about 600 feet (183 m) of white stratified tuffs and other continental sedimentary rocks to be Siebert Tuff and noted that neither the base nor the top were seen at the type locality. The thickness is probably at least as great at the north end of the San Antonio Mountains and across the broad expanse of Big Smoky Valley to the Toiyabe Range. Near Tonopah, the formation "...consists of water-reworked volcaniclastic rocks ranging from epiclastic volcanic conglomerate to tuff and tuff-breccia" (Bonham and Garside, 1974, p. 45). Pumiceous blocks, lapilli, and ash along with grains of quartz and feldspar are the main constituents of the strata. Other constituents are clasts of Tertiary andesitic rocks and welded tuff(?). The better stratified parts of the section include beds of tuffaceous siltstone and mudstone, and lesser amounts of diatomite, shale, sandstone, conglomerate, and minor limestone. Weak cement characterizes most of these beds. Poorly sorted conglomerates and gravels occur locally. The limestones commonly are punky or porous and, locally, pisolitic. The finer grained rocks are locally so silicified as to be called chert or porcelanite. Opaline and chalcedonic silica bodies are also scattered in similar strata in the Gabbs and Ione Valleys region farther northwest, where some of the material has been mined. The predominant rock near Tonopah and in many sections elsewhere in the region is massive and thick bedded and includes irregular lenses of reworked tuff breccia. Broderick (1949, p. 50) stated that at the latitude of Tonopah the well-stratified section gradually disappears eastward and is largely replaced by the more massive rocks. Well-stratified beds and massive rocks are intercalated and common at the north end of the range. Here, plant leaves and needles are preserved in abundance in the ashy, well-bedded, thinly stratified rocks. It is believed that the plant remains were blown and (or) washed into ephemeral lakes and settled in quiet water. Crushed and fragmented fossil fish skeletons were also noted in the area, but they are not directly associated with the leaves. The well-bedded rocks of the formation are in general the most fossiliferous. In addition to the plant and fish remains, diatoms, pelecypods, and gastropods are locally abundant. An important Miocene (Barstovian) mammalian vertebrate locality, about 9 miles (14 km) north of Tonopah, has been described by Henshaw (1942). It lies close to diatom- and fish-bearing shale and is near a locality where invertebrates were identified as Eocene by W. H. Dall (Spurr, 1905b, p. 66–67); all of these strata, however, must be part of the younger Tertiary section at the vertebrate locality. Many workers, starting with Spurr (1905b, p. 51), have emphasized lacustrine and deltaic environments of deposition for the Siebert. Broderick's (1949, p. 51–52) description, quoted in part here, is the most informative:

> ...except for the well-bedded and finely laminated portions along the western side of the range [vicinity of Tonopah?], which are undoubtedly largely lake deposits, the rock is the result of piedmont slope accumulation of ....tuffs, breccias, mud flow breccias and stream gravels with minor flood plain deposits in the central and eastern part of the range; of delta and shallow, possibly saline, lake deposits in the western part of the range.

Considerable support comes from Henshaw (1942, p. 93), who is quoted by Broderick (1949, p. 51–52):

> The abundance of grazing horses...indicates without question that the environment was one of grassy, perhaps shrub-covered plains.... Summarizing...we find that the fossils occur in delta deposits along the shores of a large saline lake.... A saline lake and a plains fauna suggests aridity of climate....

A rhyolitic tuffaceous bed in the Siebert Tuff yielded an age of 15.5 ± 1.6 m.y. (no. 84 reported by L. J. Garside, *in* Silberman and McKee (1972, p. 24). The Siebert lies unconformably on the approximately 17-m.y.-old Fraction Tuff and intertongues with and is overlain by andesitic to basaltic lavas at the north end of the San Antonio Mountains, which give radiometric ages of some disparity. These last range from about 16 to 19 ± 2 m.y.; the younger ages (approximately post-17 m.y.) seeming to make better sense stratigraphically. This is borne out also by the age of the Oddie Rhyolite (about 16 m.y.), which locally intrudes the Siebert, and the age of the Brougher Dacite (included in dacitic and quartz latitic rocks, pl. A1), which locally intrudes the Siebert and was dated at 16.2 ± 0.4 m.y. (Albers and Stewart, 1972, p. 36; no. 86, *in* Silberman and McKee, 1972, p. 24). Broderick (1949, p. 53) and Bonham and Garside (1974, p. 45) have suggested that most of the volcanic material found in the Siebert came from explosive volcanism associated with vents that later erupted the Brougher.

Elsewhere, off the east-central flank of the Cedar Mountains (S19,T8N,R38E), radiometric ages of 10.7 and 11.5 m.y. were obtained on tuff beds assigned to the Esmeralda Formation by G. H. Curtis and J. F. Evernden (*in* Silberman and McKee, 1972, p. 21–22). These ages for the Esmeralda correspond well with ages of 10.5–12.7 m.y. in Esmeralda County cited for sedimentary strata formerly assigned to the Esmeralda Formation (Albers and Stewart, 1972, p. 36). All these beds are mapped with the sedimentary strata and intercalated tuffs (pl. A1). The general youthfulness of all the rocks included in this unit is indicated by the presence of mostly undeformed to mildly deformed strata. Horizontal to gently dipping beds are common; the steepest dips measured in open-folded strata at and near the mammalian fossil locality in the San Antonio Mountains were no more than 15°–20°, and such dips are not uncommon elsewhere. The only severely deformed strata are localized near some of the intrusive bodies at Tonopah.

Many of the late Tertiary rocks assigned to the sedimentary map unit were commonly considered by past workers to be part of the Esmeralda Formation, whose type locality is in the Silver Peak Mountains in Esmeralda County (Turner, 1900, p. 197–208; Ross, 1961, p. 45–46). The reader is referred to Ross (1961, p. 45–46) and Albers and Stewart (1972, p. 32–34 and 36) for a resume of the complex history of usage of the term Esmeralda Formation. Although the present writers are sympathetic to Ross's (1961, p. 45) retention of the

name Esmeralda Formation for all the late Tertiary sedimentary strata of Mineral County and to the usage of Robinson and others (1968, p. 581–582), which follows the original definition of Turner, we have accepted the definition adopted by Albers and Stewart (1972, p. 34). This definition restricts the Esmeralda to approximately 10- to 13-m.y.-old deposits of a single intermontane basin that existed near the Weepah Hills in Esmeralda County. One reason for this is the possibility of locally misapplying the formation name to various strata of widely different ages, as was done by earlier workers in the Toiyabe and Toquima Ranges (Ferguson, 1924, p. 43–50, 54–55, pl. 1; Ferguson and Cathcart, 1954). Thus strata similar to the restricted Esmeralda, with an age span possibly as wide as from about 10–16 m.y., are grouped together as sedimentary strata and intercalated tuffs (pl. A1). We feel that these strata generally were not deposited in a single continuous basin but represent separate basinal deposits, although some of the basins in northern Nye County may have been connected during stands of high water. The Esmeralda as originally defined in the limited region of the central part of Esmeralda County was also deposited in several basins that crudely coincide with the present valleys (Robinson and others, 1968, p. 608). Other units elsewhere in west-central Nevada that are correlative in part with the sedimentary strata and intercalated tuffs (pl. A1) include parts of the Aldrich Station, Coal Valley, and Morgan Ranch Formations west of the Wassuk Range (Axelrod, 1956, p. 19–87; Gilbert and Reynolds, 1973, p. 2493–2502, table 1) and similar strata mapped in scattered localities throughout Esmeralda and Mineral Counties.

Young Silicic Intrusive Rocks. Young silicic intrusive rocks in the western region are shown on the accompanying map as: (1) rhyolitic rocks and (2) dacitic and quartz latitic rocks (pl. A1). Resistant steep-sided masses characterize most of the young silicic intrusives. The rhyolitic rocks form dikes, plugs, cumulo-domes, and minor associated flows that commonly are less than 1 mile (0.6 km) across, except for one mass about 3 miles (4.8 km) across in Ione Canyon. Unstudied, narrow but long dikes near the Blue Gem Mine in the Royston Hills are included with the rhyolitic rocks but may be considerably older. Many of the presently exposed rhyolite cumulo-domes and volcanic plugs probably originally extended to the surface. Small porphyritic bodies near Tonopah were termed Oddie Rhyolite by Spurr (1905b, p. 49) for outcrops at Mount Oddie. These bodies are white to pale reddish brown and contain megascopically conspicuous bypyramidal quartz phenocrysts. Thin sections show phenocrysts of mainly quartz, sanidine, rare plagioclase, sparse biotite, and accessory magnetite and sphene (Spurr, 1905b, p. 50; Broderick, 1949, p. 54; and Bonham and Garside, 1974, p. 45). The Oddie, like some of the rhyolites near the Jackson (Gold Park) district (Shoshone Mountains), is locally silicified, sericitized, and argillized (kaolin), all of which has given it a bleached appearance (Spurr, 1905b, p. 50; Bonham, 1970). Flow layering is commonly well developed peripherally, and flow breccias are present locally. The large rhyolitic body in Ione Canyon is characterized by even more pronounced flow laminations and partings.

The Oddie is about 16 m.y. old (M. L. Silberman, oral commun., Oct. 1974), that is Miocene, and as previously mentioned intrudes rocks as young as the Siebert Tuff (part of sedimentary strata and intercalated tuffs, (pl. A1). North of Ione, rhyolite plugs are believed to be just slightly younger than the 21–24-m.y.-old Toiyabe Quartz Latite (Bonham, 1970), but absolute ages are not known. These occurrences suggest, however, that older rhyolites inadvertently may have been locally included with rhyolitic rocks (pl. A1). Some of the rhyolitic masses mapped near the northeasternmost point of Mineral County may also be in this category. One 800-foot (244-m)-long body there is presumably overlain by the sedimentary strata and intercalated tuffs unit (pl. A1). The rhyolite is pinkish gray, flow banded, poorly porphyritic, and has a conspicuous perlitic selvage. It appears to be relatively unaltered, but other unstudied bodies in region 5 are of critical importance to understanding spatially related ore deposits because the bodies appear to be altered by mineralizing solutions. Examples of these are (1) the hydrothermally altered rhyolite plug north of Idlewild Creek in the Shoshone Mountains about 5–6 miles (8–10 km) south of the Jackson (Gold Park) district; (2) rhyolitic rocks of the Bruner district; (3) the rhyolite cumulo-dome(?) at Goldyke in the Fairplay district, extreme southern Paradise Range, and numerous dikes near Goldyke (see especially the Davis mine locality); (4) numerous rhyolite dikes that cut copper-mineralized Mesozoic strata in the extreme southern Toiyabe Range; and (5) rhyolite in the northern San Antonio Mountains.

Dacitic and quartz latitic rocks (pl. A1) in the San Antonio Mountains form flows, dikes, cumulo-domes, and plugs, the most extensive body of which is a biotite-hornblende dacite porphyry that crops out in the northern part of the range. The rock is classed as a lava flow but has some features suggestive of a welded tuff, and locally welded tuff may be included with the unit. The lava, a cliff-former as much as 1500 feet (457 m) thick, weathers to shades of brown, red, gray, and, especially, reddish brown. It is characteristically flow laminated and lineated, and locally parts readily along the laminations. Lenses and layers of agglomerate and autobreccia(?) are common. Fresh rock predominates and glass phases are common; local zones are bleached (argillized and silicified) or propylitized. Phenocrysts in the trachytic groundmass average about a millimeter or so across, approach 1 cm in maximum size, and consist chiefly of feldspar laths and smaller but conspicuous amounts of biotite in thin books and flakes, a few scattered grains of hornblende, and very rare green pyroxene(?). Mafic constituents yielded a radiometric age of about 17 m.y. (biotite, 16.7 ± 0.5 m.y.; hornblende, 16.8 ± 0.5 m.y. [Silberman and McKee, 1972, p. 23]). The dacitic lava appears to lie unconformably on rhyolitic ash-flow tuffs included in the Tonopah Formation (pl. A1) and to underlie andesitic to basaltic lava flows that cap the range. Genetic relations to other intermediate volcanic rocks of the San Antonio Mountains

have not been determined. Scattered smaller quartz latitic bodies in the Tonopah region include the 16.2 ± 0.4 -m.y.-old Brougher Dacite (rhyolite), the largest body of which extends east-southeast from Golden Mountain (Tonopah mining district) for about 4 miles (6.4 km) and forms a series of hills as much as 600 feet (183 m) high. The pastel gray and grayish-brown Brougher Dacite, like the Oddie Rhyolite, nearly everywhere is resistant to erosion and forms steep hills. Typically, it is flow laminated and glassy (perlitic), especially in the margins of bodies; vesiculated layers to several centimeters thick may parallel the flow laminations. The rock is fine grained and porphyritic, containing phenocrysts of quartz, sanidine, plagioclase, biotite, and sparse hornblende and augite and accessory zircon in a glassy or finely crystalline matrix of quartz and sanidine (Spurr, 1905b, p. 48; Broderick, 1949, p. 59–60; Bonham and Garside, 1974, p. 45). Bonham and Garside (1974, p. 45) stated that the Brougher Dacite is a rhyolite in composition, and they probably base this on chemical data, because Spurr (1905b, p. 44, 48) and Broderick (1949, p. 59) classed the rock as a dacite and quartz latite, respectively, on the basis of thin-section mineralogy. Many outcrops purportedly represent domes and plugs of magma that solidified in their vents; they are circular or elliptical in plan view. Brougher, Brock, Golden Mountains, and Mount Butler are categorized as protrusive domes (cumulo-domes) of Brougher Dacite by Bonham and Garside (1974, p. 45). Spurr (1905b, p. 46) noted the absence of lava flows around the plugs or necks at Tonopah, but some lavas are present (Broderick, 1949, p. 61–63). Also, a classic well-developed extensive lava is associated with a plug of Brougher about 8½ miles (14 km) north of Tonopah.

Other Rocks of Intermediate to Mafic Composition

Other rocks of intermediate to mafic composition in region 5 have been divided into two map units: (1) andesitic to basaltic rocks, including Mizpah Trachyte, and (2) dacitic to basaltic rocks (pl. A1). These map units include some of the youngest volcanic rocks in region 5 and probably also volcanic rocks of a wide age range, extending back as far as latest Oligocene. We felt constrained to use this two-fold grouping without further subdivision because these rocks commonly form discrete and discontinuous bodies and are lithologically indistinguishable in the field. Problems of subdivision are especially severe with andesite and trachyandesite in region 5 and elsewhere in west-central Nevada. Current studies by M. L. Silberman (oral commun., Oct. 1974) along the Walker Lane just west of Nye County indicate that andesitic volcanism was essentially continuous there from about 25–10 m.y. ago, with a peak of activity approximately 17–12 m.y. ago (Silberman and others, 1976). One even older andesite near Nye County adjacent to the Broken Hills mining district of Mineral County was dated at 27 m.y. (no. 19, *in* Silberman and McKee, 1972, p. 14). Andesitic volcanism may have been nearly as continuous in Nye County.

Rocks of the map unit andesitic to basaltic rocks, including Mizpah Trachyte, the latter previously described and mapped only at Tonopah, are thick and most extensive in the San Antonio Mountains, where they cap the range and locally intertongue with Siebert Tuff. Conspicuous but somewhat less extensive outcrops elsewhere include a basaltic volcano (Black Mountain) south of Reese River Valley, and basaltic flows in the Shoshone Mountains, especially the up to 800-foot (244-m)-thick pile of flows west of South Shoshone Peak. The latter flows were classed as basalt on the basis of phenocryst mineralogy by Bonham (1970), who suggested that they might chemically be trachyandesite. Bonham also tentatively considered them to be Pliocene upon noting that "...the flows are moderately deeply eroded." McKee (1968) assigned them to the Pliocene or Pleistocene. Vitaliano and Vitaliano (1972, p. 3274–3275) confirmed that the basaltlike lavas are in part trachyandesites and considered them to be as young as Quaternary(?). The most westerly outcrop of the andesitic to basaltic rocks (pl. A1) is just north of the Lodi Hills, where the unit has intruded and baked nearly flat-lying, white tuffaceous sedimentary strata (included with sedimentary strata and intercalated tuffs (pl. A1). Some of the andesitic to basaltic rocks of region 5, and especially those in the San Antonio Mountains, are undoubtedly coeval with the basaltic and andesitic rocks of the southern Monitor Range. For example, in the former range two trachyandesitic flows, one 15.8 ± 2 m.y. old and the other 17.9 ± 3 m.y. old (nos. 11 and 12 in Armstrong and others, 1972), could correspond in age with an olivine trachyandesite flow at Thunder Mountain, in the Hannapah mining district. There the flow was dated at 18.9 ± 1.5 m.y. (no. 13 in Armstrong and others, 1972), but H. F. Bonham (oral commun., 1974) has questioned the age and believes that the flow is younger and possibly as young as about 15 m.y. old.

Rocks of the map unit dacitic to basaltic rocks, composed of subunits 1) intermediate lavas and intrusive bodies of widespread age span and 2) younger(?) mafic rocks (pl. A1), common in the boundary area of region 5, crop out as far east as the central San Antonio Mountains. There, the distinction between these rocks and another unit, andesitic to basaltic rocks (pl. A1), could not be positively drawn during our reconnaissance mapping. Near the Orizaba Mine (S2,T7N,R38E), at least a few hundred feet of andesitic lava (subunit intermediate lavas and intrusive bodies of widespread age span, pl. A1) rests on sheared Tertiary volcanic rocks of unknown age (silicic volcanic rocks, pl. A1). The andesitic lava contains conspicuous acicular hornblende phenocrysts like those in the 25-m.y.-old andesite, dated by M. L. Silberman, Merton and others, 1977, at the Lindsey (Gunmetal) Mine in the Pilot Mountains to the west and could be of comparable age. However, E. B. Ekren (written commun., 1975) stated that acicular hornblende characterizes rocks 12–26 m.y. old.

The younger(?) mafic rocks, subunit of dacitic to basaltic rocks (pl. A1), occurs as erosional remnants of relatively flat-lying lava flows capping buttes in scattered outcrops between the Cedar Mountains and the Paradise Range and in the Royston Hills. These may be the youngest volcanic rocks of the boundary area, possibly including the youngest in region 5. An age

range from about 5 or 7 to 15 m.y. is postulated by analogy with other intermediate to basaltic rocks in western Nevada and on relations with underlying sedimentary rocks (Silberman and McKee, 1972; Silberman, Bonham and Osborne, 1975; Silberman, Noble, and Bonham, 1975). Near the Orizaba Mine, for example, basaltic lavas as much as several hundred feet thick lap across mildly warped(?) sedimentary strata and interbedded tuffs (pl. A1) and underlying andesitic lavas (intermediate lavas and intrusive bodies, pl. A1). Nearby, other andesitic or basaltic rocks may also lie on or intrude fluviolacustrine beds of the map unit sedimentary strata and interbedded tuffs (pl. A1), two tuffs of which were dated at about 11 m.y. by G. H. Curtis and J. F. Evernden (reported as nos. 68 and 69 in Silberman and McKee, 1972, p. 21-22).

Silicic Volcanic Rocks

There are scattered silicic volcanic rocks of uncertain age in the boundary area of region 5 that could not be definitely correlated with rocks elsewhere; they are shown separately (silicic volcanic rocks, pl. A1). Most of these rocks are rhyolitic ash-flow tuffs, and several individual cooling units are represented, none studied in detail. The rocks include welded tuffs of low to moderately high crystal content that are commonly devitrified and locally somewhat sheared and (or) altered. In the Athens (Pactolus camp) and the southern part of the Fairplay (Atwood camp) districts, many of the ash flows are moderately to intensely altered and bleached, argillized, and silicified. Where the welded tuffs extend southwestward from the high part of the Monte Cristo Mountains into Mineral County, they are quite fresh and glassy. There, they have been termed the "tuffs of Gabbs Valley" (Ekren and Byers, 1978). These are rhyolite in composition and typically weather reddish (conspicuous pale and moderate shades of orange pink, red, reddish brown, and locally, brown). Densely welded tuffs predominate and contain abundant readily visible shards and pumice. The pumice is commonly less than 1 cm in length, but in the high part of the mountains where two cooling units appear to merge, pumice fragments as much as 5 cm long were noted. Crystal content ranges from low to moderately high; crystals to several millimeters across consist of quartz, sanidine, sodic plagioclase, and very sparse scattered biotite. Centimeter-size lithic clasts other than pumice are common and appear to be composed of other welded tuffs and flow-laminated rhyolite. The tuffs of Gabbs Valley of Ekren and Byers may be the youngest in the boundary area, and it, and possibly other tuffs mapped with the silicic volcanic rocks (pl. A1), is believed to be mostly about 20–26 m.y. old.

Ekren and Byers (1977; 1978) have shown that the tuffs of Gabbs Valley are intercalated with hornblende- and augite-rich intermediate lavas in the Monte Cristo Mountains (boundary area of western region). They reported a K-Ar date of about 26 m.y. for one of the phenocryst-poor tuffs and showed that in adjacent parts of Mineral County, near the Nye County line, other cooling units are about 25 m.y. old. One cooling unit of the phenocryst-poor tuffs extends eastward into the Paradise Range, where it was mapped with the Toiyabe Quartz Latite. Phenocryst-poor reddish welded tuffs also extend into the Gillis and Gabbs Valley Ranges, Mineral County, where they are thin and discontinuous and intercalated with much thicker calc-alkaline tuffs and lavas of intermediate composition (Ekren and Byers, 1977). Ekren and Byers (1977) inferred that the tuffs were vented from a nearby buried caldera in western Gabbs Valley.

Domes, plugs, and breccias ranging in composition from rhyolite to trachyandesite (pl. A1) crop out in the Monte Cristo Mountains. These dark-brownish-gray to gray rocks are light brownish gray where locally altered and intrude and are intercalated with the rhyolite ash-flow tuffs described above. All these rocks are localized in and adjacent to the inferred caldera of Ekren and Byers (1977); some may be confined to and may define the caldron margin by having been emplaced along a caldron-margin fault.

STRUCTURAL GEOLOGY

General Statement

The rocks of northern Nye County bear the imprint of a succession of late Paleozoic, Mesozoic, and Cenozoic tectonic episodes. Folds and thrust faults, with large eastward-directed displacements which commonly juxtapose rocks of diverse facies, characterize most of the older orogenies. The more recent episodes of deformation are dominated by high-angle normal faulting that has produced north-northeast-trending ranges and valleys that dominate the present-day topography. Ancillary calderas and caldron complexes marked by circular and elliptical collapse zones, landslide and breccia units, and locally resurged interiors are also scattered throughout the region in areas of Cenozoic rocks.

Chronologic positioning of the major thrust faults is the most difficult problem in the interpretation of the tectonic history of the region. Continuity of the larger thrust masses must be inferred from similar geologic relations in successive ranges because the actual surface of a thrust commonly can be traced for only a few miles before it is covered by younger rocks. The tectonic complexities caused by overprinting of structures of varied ages and origins make difficult the task of distinguishing separate tectonic events, particularly where folds or faults may have been reactivated by subsequent orogenies.

Regional Tectonic History

Central Nevada during most of Paleozoic time was the site of a broad geosyncline within which diverse rock assemblages were concomitantly laid down, according to Roberts and others (1958). This geosyncline more properly may be considered as a geocline—here a gentle westward-sloping feature bordering a protocontinental margin in central Nevada (Stewart, 1972; Stewart and Poole, 1974). Nevertheless, strata east of approximately

long 117° W. are chiefly carbonate in composition, including minor amounts of siliceous shale and quartzite, and grade through a transition zone on the west into coeval chert, fine- to coarse-grained siliceous clastic strata, and volcanic rocks. The transitional assemblage contains elements of both the carbonate and the siliceous and volcanic assemblages.

The first major orogeny to have involved Paleozoic rocks occurred at the end of the Devonian and in the Early Mississippian and led to the development of the Antler orogenic belt (Roberts and others, 1958). This belt, which extended north-northeast across the middle of Nevada, was the locus of intense folding and low-angle faulting. The Roberts Mountains thrust, a thrust of great magnitude (Merriam and Anderson, 1942), carried rocks of the siliceous and volcanic assemblage eastward as much as 100 miles (161 km) across a terrane of correlative carbonate-assemblage strata. In north-central Nevada, this thrust was propagated in latest Devonian or earliest Mississippian time (Roberts and others, 1958; Smith and Ketner, 1968).

During and after the Antler orogeny, a great thickness of shallow-water marine detrital sediments was shed eastward and westward from the orogenic belt. In west-central Nevada, siliceous clastic and volcanic rocks of Pennsylvanian, Permian (Diablo Formation), in those few places where they are unfaulted, and the allochthonous Permian(?) (Pablo Formation) rest with angular discordance on highly deformed lower and middle Paleozoic rocks. East of the Antler belt, however, the Mississippian, Pennsylvanian, and Permian rocks of the so-called overlap assemblage (Roberts and others, 1958) were deposited with essential concordance on carbonate-assemblage strata.

Sedimentation and crustal instability continued intermittently through the late Paleozoic. Epeirogenic movements within much of the eastern Great Basin are indicated by disconformable relations between Lower Permian and underlying Middle Pennsylvanian strata in the Pancake and Diamond Ranges.

Farther west, the Permian Diablo and Permian(?) Pablo Formations and other late Paleozoic clastic strata were deposited as a thick sequence of neritic and oceanic, volcanic, and volcaniclastic rocks in western Nevada. Locally the Diablo was disconformably overlain in the marine basin by the Lower Triassic Candelaria Formation (west-central Nevada, including Nye County). The Sonoma orogeny (Silberling and Roberts, 1962, p. 36; Silberling, 1973), which was characterized by folding and by eastward displacement of some of the late Paleozoic volcanic and volcaniclastic rocks (allochthon) along low-angle faults, subsequently affected a large part of western Nevada and northern Nye County, possibly as far east as the Monitor Range, during the Late Permian and Early Triassic.

By Middle Triassic time, marine deposits, including chiefly limestone and shale of shallow-water origin of the Luning, Winnemucca, and Augusta sequences of Silberling and Roberts (1962), accumulated adjacent to the western edge of the Antler orogenic belt. Concurrently, volcanic and clastic rocks (part of the Excelsior Formation of old usage) were deposited farther west in the orogen. Sedimentation was essentially continuous during Late Triassic and earliest Jurassic time.

The major period of diastrophism termed the Nevadan orogeny began in western Nevada in the late Early Jurassic, concomitantly with the deposition of the coarsely clastic Dunlap Formation (Ferguson and Muller, 1949, p. 13). During the early part of this orogeny, folding and minor thrusting were directed toward the south. Later, major thrusts, recognized west of northern Nye County and once postulated to include the generally discredited Gillis thrust (Ferguson and Muller, 1949; Ross, 1961; Speed, 1973; 1977b) and including the Pamlico and Luning thrusts (Ferguson and Muller, 1949; Speed, 1977b; Oldow, 1978), advanced eastward, juxtaposing rocks of diverse terranes (facies). The early Mesozoic marine province was deformed and destroyed. The last stages of the late Mesozoic orogeny were accompanied by some high-angle faulting and by widespread emplacement of granitic bodies, presumably satellites to the Sierra Nevada batholith, through southwestern Nevada.

In eastern Nevada, deformation of regional extent followed the withdrawal of the Early Triassic sea. As envisaged by Roberts and others (1965) and Hose and Danes (1967), the Paleozoic and lower Mesozoic rocks of the eastern Great Basin compose a large and complex allochthonous mass that moved eastward with respect to basement during the late Mesozoic. Attenuation of this stratigraphic section by low-angle faults, which generally emplaced younger strata on older, characterizes eastern Nevada. Farther east, the northeast-trending Sevier orogenic belt (Armstrong, 1968) was the locus of folding and thrusting of older rocks on younger during latest Jurassic and most of Cretaceous time. Large-scale folding and thrust faulting during Late Cretaceous or earliest Tertiary time are recorded in the Pancake and Antelope Ranges.

The Tertiary and Quaternary Periods are characterized by widespread eruption of volcanic rocks and the scattered intermittent deposition of nonmarine sediments. During Oligocene and early Miocene time, ash-flow tuffs were widely dispersed, chiefly from calderas. Intrusion and extrusion of rhyolitic to basaltic dikes, domes, and lava occurred spasmodically before, during, and after the episodes of ignimbrite eruption and, in some cases, invaded the subsidence structures like the Lunar Lake caldera (Ekren, Quinlivan, Snyder, and Kleinhampl, 1974). After the formation and collapse of the Williams Ridge caldron in the central part of the mapped region, resurgence produced the Morey Peak massif in the Hot Creek Range. Resurgence within other calderas may have occurred, but this has not been documented. Megabreccia and landslide units within the Tertiary volcanic section formed as a result of landsliding from, and collapse of, portions of caldron walls.

Several northwest- to west-striking lineaments and left-lateral strike-slip faults known to have been active in the middle Tertiary have been traced for as much as tens of miles in the central part of northern Nye County (Moores and others, 1968, p. 1716; Ekren, Rogers, and Dixon, 1973; Ekren, Bath, Dixon, Healey, and Quinlivan, 1974; and Ekren, Bucknam, Carr, Dixon, and

Quinlivan, 1976), and other such features, as yet unrecognized, may be present. Movement of Miocene age has been demonstrated at Reveille and in the Hot Creek and Monitor Ranges. These features commonly affect the surficial geology in subtle ways and are not unequivocal, but their existence is borne out by studies of the Las Vegas Valley and Soda Spring Valley shear zones. Near Las Vegas (Anderson, 1971) and in the Gillis and Gabbs Valley Ranges (Stewart and Carlson, 1974), low-angle (detachment) faults mapped at and near the base of the Tertiary section suggest Tertiary thin-skin tectonics. Movement on these low-angle faults may be related to Tertiary strike-slip faulting along the Walker Lane.

Basin-and-range normal faulting along north- to northeast-trending breaks marked the final phase of the structural evolution of the region. Major movement along most of these faults apparently postdates the Oligocene and early Miocene welded tuffs; movement on many faults has continued to the present, as evidenced by fresh scarplets in late Pleistocene and Holocene valley fill. Gravity slides and low-angle faults of limited extent accompanied the uplift of some ranges (see the sections of this bulletin on Geology and Structure of the Ranges—Grant, Horse, and White Pine Ranges).

Major localized tilting, uplift, and folding to produce the Horse and White Pine Ranges is considered by some (Moores and others, 1968, 1970) to have taken place in the middle to late Miocene. Others (Drewes, 1970) favor the view that the more conventional older and more broadly time-spanning Sevier event produced the main structures in the Horse and White Pine Ranges.

Major Structures of Pre-Tertiary Age

Major structures of pre-Tertiary age include fold belts and fault zones and associated structural basins. Most of the fold belts and fault zones are described elsewhere (see the sections of this bulletin on Geology and Structure of the Ranges and on mining districts—geologic setting), and only their salient features are summarized below. The major fold belts and fault zones are grouped according to age into four major deformational realms that are to a large degree separated geographically. The Sevier realm (Armstrong, 1968) lies mainly in the eastern third of the mapped region and is supplanted in the central part of northern Nye County by the middle Paleozoic Roberts Mountains thrust and Antler realm. These realms overlap areally to some degree. The third or early Mesozoic Sonoman realm, characterized by the Golconda thrust, lies mainly in and west of the Toiyabe Range. Small outcrops of the Golconda plate as far east as the Monitor Range indicate that the influence of the deformation extended over nearly the entire western half of the mapped region. The Jurassic Nevadan realm is approximately coextensive areally with the Sonoman in the mapped region, but it is a precursor of the Sevier in a continuum of orogenic events. These deformational realms, although defined mainly by the ages of the involved rocks, are partly defined by characteristic styles of folding and faulting that, however, are not unique to any one realm.

Tectonics of continental margins and global plate movements have been utilized since the late 1960's in interpretations of structural evolution of the Basin and Range province in general and of central Nevada specifically by various workers, including Armstrong (1968), Christiansen and Lipman (1972), K. L. Cook (1966), Gilluly (1963; 1969), Hamilton and Myers (1966), Lipman and others (1972), Menard (1961), Moores (1970), Poole and Desborough (1973), Roberts (1972), Stewart (1971), Stewart and Poole (1974), Wise (1963), Speed (1977a; 1977b; 1977c), and Speed and others (1977). The general hypothesis of continental margin plate tectonics has evolved especially rapidly during about the past 10 years as an outgrowth of oceanographic and geophysical research on a global scale. Applications of the hypothesis to the Great Basin are dependent upon the syntheses and detailed geologic mapping of everyone involved in the study of Cordilleran geology, which means scores of workers, including those referenced in the present report and, in particular, C. A. Anderson, H. G. Ferguson, J. F. Gilluly, Marshall Kay, C. W. Merriam, T. B. Nolan, B. M. Page, R. J. Roberts, N. J. Silberling, and R. C. Speed.

An activated north-trending continental margin through central Nevada figures prominently in the paleogeographic plate-tectonic models postulated for the Western United States. Stewart (1972, p. 1345–1360; also see Stewart and Poole, 1974) has suggested that separation along the western margin of the North American continent in late Precambrian time initiated the Cordilleran geosyncline. Tectonism persisted sporadically along the activated continental margin in the region at least into the Triassic, and erosion gave rise to a westward-thickening prism of sediments that extends from the craton successively across the continental shelf, slope, and rise. Lithologic differences within this prism (geocline of Dietz and Holden, 1966; Dietz, 1972) are generally ordered into three assemblages of strata: from east to west, the carbonate, transitional, and volcanic and detrital assemblages. An older synonymy referred, respectively, to eastern carbonate or miogeosynclinal, transitional, and western siliceous and volcanic eugeosynclinal assemblages. Such westward progressions of suites of rocks, with variations, persisted from at least the Ordovician through the Triassic; the Jurassic ended major deposition in the Cordilleran geosyncline (Armstrong, 1968, p. 432). On the basis of the present and restored geographic order of the assemblages, the continental margin trended generally northward across Nevada, placing northern Nye County within the geocline associated with the continental shelf and slope. The plate-tectonic models generally depict a marginal sea and associated basinal deposits extending out (west) from the continental margin, with or without a positive area (island arc?) on the west. The continent as presently constituted in the west includes the preexisting continental mass as well as an accreted part of the marginal sea floor (oceanic crust and wedge of overlying sediments) of Paleozoic and Mesozoic age. The mechanics generally proposed for the rifting of the proto-continental margin involve various obductive and subductive plate movements that provide the forces necessary to deform the

wedge of sedimentary rocks lapping the continental margin and generate heat and magma for plutonism and volcanism associated with deformation of the Sonoma and Sevier events. Forces necessary to have decoupled and translated plates of some of the major allochthonous rocks, such as the Roberts Mountains thrust plate in central Nevada, are attributed to interacting movements of oceanic and continental plates along the protocontinental margin (G. A. Davis, oral commun., May 21, 1975). Such a driving mechanism could be used to establish the eastward gradients hypothesized by others (Kay and Crawford, 1964, fig. 9) as necessary to induce major thrust-sheet gliding during the Antlerian and Sonoman events. However, the precise plate-movement mechanisms along the western Cordillera are still controversial. While the accumulation of geologic and geophysical data in the Western United States seems to favor the plate-tectonic hypothesis, the actual sequence of events may have been even more complicated than indicated.

Scattered small ultramafic bodies, especially serpentinite, cropping out in the Toiyabe and Toquima Ranges and vicinity are most significant in this regard (see section on ultramafic rocks). Most were tectonically emplaced into and thereafter deformed along with "...allochthonous Paleozoic oceanic sedimentary and mafic volcanic rocks...," according to Poole and Desborough (1973), who described these and other serpentinites in Nevada as alpine-type serpentinites derived from the Paleozoic or older upper mantle. They inferred that these rocks had been detached and raised into a crustal position during the "...Paleozoic lithospheric plate convergence." They considered that emplacement was mostly related to the Late Devonian and Early Mississippian Antler orogeny, and that serpentinite bodies in the early Mesozoic Golconda allochthon (common in northern Nye County) could have been formed during the Sonoman orogeny either by remobilization from the older Antler terrane or by derivation of new material from the upper mantle.

Calderas and Other Early Tertiary Structures

Scattered northwest-to-west striking faults of early Tertiary age, oriented transverse to the dominant basin-and-range fault pattern, are exposed in many of the ranges. Locally, these faults appear to predate and to have controlled the margins of some calderas (see figure A32). Several lineaments of regional extent, representing zones of possible left-lateral displacement, have been proposed to connect the transverse faults of adjacent ranges (Ekren, Rogers, and Dixon, 1973; Ekren, Bath, Dixon, Healey, and Quinlivan, 1974; Ekren, Bucknam, Carr, Dixon, and Quinlivan, 1976; Quinlivan and Rogers, 1974). These Tertiary faults may be the latest manifestation of movement on hypothetical major deeper seated structures that have been active since before the Tertiary. The most carefully studied of these transverse faults, in Hot Creek Valley between the Reveille and Hot Creek Ranges, displaces late Oliogene ash-flow tuff but is intruded by middle Miocene (about 19 m.y. B.P.) dikes (Ekren, Rogers, and Dixon, 1973). The Pritchards Station lineament, extending between the Hot Creek and Monitor Ranges, post-dates the 23 m.y. Bates Mountain tuff and is older than sediments of late Miocene or early Pliocene age (Ekren, Bath, Dixon, Healey, and Quinlivan, 1974; Ekren, Bucknam, Carr, Dixon, and Quinlivan, 1976). Farther east, the west-striking Currant Summit fault has been interpreted as having offset the Grant and Horse Ranges in a left-lateral sense (Lumsden, 1964; Moores and others, 1968).

East-striking faults scattered through northern Nye County are more common in some ranges than others; in the main high part of the Reveille Range, a series of such faults have broken outcrops of Paleozoic rocks into major topographic blocks. In the Hot Creek Range, just north of Hot Creek Canyon, a major east-striking lineament mapped in part as a fault serves to define a segment of a caldera margin. Several other similar faults in the Toiyabe Range may also delimit part of caldera walls, as, for example, near Boyd Canyon (south part of range) and North Twin River (near Darrough hot spring).

The area in northern Nye County lying adjacent to the long county border extending northwestward from Tonopah lies close to a paralleling zone of maximum flexure defined by sigmoidal bends, or oroflexes, and right-lateral faults described by Albers (1967) adjacent to the Walker Lane. He stated that major deformation in this zone did not end until early or middle Miocene, as indicated by the apparent absence of bends in Tertiary rocks as old as middle Miocene. Some effects of displacement along the belt clearly extend into northern Nye County and account for the lack of general parallelism between the basins and ranges in the western part of the mapped region, where, unfortunately, extensive alluviated valleys make structural studies difficult.

Calderas, large partly collapsed volcanic vents (see R. L. Smith, 1960, p. 818–820 for classification), and caldera complexes represent a major structural type in northern Nye County and account for most of the Cenozoic tuffaceous rocks that blanket much of the mapped region. All the calderas have not been defined, however, and except for one of the youngest, the late Tertiary Lunar Lake caldera, they do not lend themselves to easy delineation. The distinguishing features of older calderas are commonly modified or obscured to differing degrees by younger calderas and their associated volcanic rocks and by basin-and-range structures and Quaternary valley-fill deposits. Mapping was in most cases only sufficiently detailed to suggest the possible loci of calderas within broadly defined areas of thick ash-flow tuffs. In one broad area centering on Hot Creek Valley, several calderas or caldron complexes were documented and more precisely located by U.S. Geological Survey geologists studying the northern test site of the Atomic Energy Commmission. These workers partially outlined the Hot Creek Valley and Williams Ridge caldron complexes and the Lunar Lake and Pancake Range caldrons on geologic maps of the 15-minute topographic quadrangles cited on plate A1 (Lunar Crater, Moores Station, Portuguese Mountain, Pritchards Station, and The Wall). The Lunar Lake caldera

and spatially associated structures were also described in detail in a report by Ekren, Quinlivan, Snyder, and Kleinhampl (1974), and McKee (1974, p. 35–41) described the Northumberland caldera in the northern Toquima Range. Another caldera in the Toiyabe Range (for want of a better name termed the "Darrough caldera") is alluded to by Speed and McKee (1976). Stewart and Carlson (1976) recompiled these data, and their compilation is shown on figure A32, along with other data.

Several especially noteworthy features of the Cenozoic calderas in northern Nye County are enumerated below, because of their importance to structural evolution of the region and their possible control of mineral deposition. Successive calderas of different dimensions commonly formed in the same general areas through Cenozoic time, and several appear today as a series of nested, coalescing, or partly overlapping calderas. The crudely circular to elliptical boundaries of all of the calderas are seen to be or are inferred to be marked in the classical sense by a major fault or fault zone. Pre-Tertiary rocks may even be exposed outboard of the faults and, besides providing a strong contrast to the Tertiary volcanic rocks, indicate considerable throw measurable in thousands of feet of subsidence within the caldron. Good examples of the effects of the faults are visible along the eastern edge of the Lunar Lake caldera, the southwestern and northwestern peripheries of the Williams Ridge and Hot Creek caldera complex, the northern and southern limits of the Darrough caldera, and the presumed northern edge of the more problematical Peavine caldera. The faulted arc-segments on the north of the latter three calderas delimit Tertiary ash-flow tuffs downdropped on the south against markedly contrasting Paleozoic or Mesozoic rocks on the north. The bounding fault zones commonly serve as conduits for postcollapse gas and magma effusions like the dike system in Broad and Jett Canyons, Toiyabe Range, along the inferred southern edge of the Darrough caldera. Other examples are the silicic lavas and intrusive bodies along marginal parts of the Lunar Lake Caldera and another caldron in the southern Monitor Range informally referred to by some as the Big Ten Peak caldera. These emanations appear locally to give rise to ore deposits, whereas the thicker initial ash-flow tuffs erupted from the vents are commonly barren, particularly where least disturbed by the later structures and emanations. The Horse Canyon mercury mine is associated with one such mineralized, highly sheared, and fractured zone presumed to bound the Peavine caldera on the north. Uranium and other metallic deposits are also close to a marginal fault bounding on the west the caldera in Gabbs Valley postulated by Ekren and Byers (1978). Figure A32 diagramatically illustrates the proximity of known mineralized areas to calderas and, particularly, to their bounding structures and associated effusive and intrusive rocks. The lack of correspondence of many mineralized areas to calderas in the western part of northern Nye County is due in part to limited knowledge concerning the loci of calderas. This is not meant to deemphasize the spatial and genetic correspondence of ore deposits to other features, such as plutonic bodies, which commonly occur in the western part of northern Nye County.

Resurgence after collapse within the Williams Ridge and Hot Creek caldron complex has formed the Morey Peak massif, which represents another feature commonly associated with calderas. Uplifted deformed blocks, such as this one, are commonly intensely fractured and faulted and, as a result of the fracturing and prior deep burial, are also commonly mineralized and pervasively altered. This does not seem to be generally true of the resurgent(?) core of the Mount Jefferson caldera (plotted just northeast of Round Mountain on figure A32), but the margin of the dome is locally altered, mineralized, and intruded by rhyolite.

Basin-and-Range Structure

Alternate mountain ranges and alluvial basins, each about 15 to 20 km wide, characterize the Great Basin province. The origins of this distinctive topographic configuration has been debated in the geologic literature for many years. Geologists generally agree that this structure resulted from large-scale crustal extension along normal faults of late Cenozoic age, although the driving mechanism and timing of the extension is not well understood. The reader is referred to Stewart (1978) for a modern review of the character and evolution of basin-and-range structure.

North- and northeast-striking, range-bounding normal faults are a conspicuous feature of the structural fabric of northern Nye County. These faults have surface traces that are straight to curvilinear and that form distinctive segments 5–30 km in length. Although generally coincident with the range fronts, these normal faults in places extend diagonally into adjacent valleys (for example, Little Fish Lake Valley) and even cross from one range front to another (for example, across the north end of Monitor Valley). Although commonly expressed as relatively wide zones of short, echelon ruptures in the thick alluvium of the valleys, most of the faults presumably are narrow continuous fractures in the bedrock at depth.

The earliest models for basin-and-range faulting in the region assumed that the range-bounding faults invariably are steep (greater than 60° dip), but later models have ascribed the structure to tilting of beds along downward-flattening (listric) fault surfaces. Recently, analysis of seismic-reflection profiles across representative parts of the Great Basin suggests that three modes of basin formation may be present (Anderson and others, 1983): (1) relatively simple asymmetric sags bounded by one or more steep, planar, normal faults; (2) sedimentary prisms above tilted bedrock ramps that are displaced by moderately deep, listric, normal faults; and (3) complexly deformed subbasins associated with sharply curved listric faults and planar faults that at depth are terminated by a gently dipping detachment fault surface.

Published seismic-reflection profiles are only available in northern Nye County for Railroad Valley. These

data have been interpreted by Anderson and others (1983) to indicate that Railroad Valley is bounded on the east by a steep normal fault, rather than by a listric fault. However, until similar profiles are available for other parts of Nye County, listric faulting also should be considered as a possibility for basin-and-range formation.

The time of initiation of basin-and-range structural development is known only approximately and apparently varied across the western United States (McKee and Noble, 1974; Stewart, 1978). For the western Great Basin, crustal extension began in the early to middle Miocene, about 21 m.y. to 16 m.y. ago. Kellogg (1964) concluded for the Egan Range that, although there is evidence of localized uplift from Oligocene and Miocene normal faults, the present basin-and-range fault structure was initiated in the Pliocene. For the White Pine and Grant Ranges, Moores and others (1968) constrain the beginning of large-scale, high-angle normal faulting to between 20 m.y. and 10 m.y. B.P. Most of the displacement on the high-angle faults of the region, however, took place during the past 7 m.y. (McKee and Noble, 1974). Evidence of scattered mountain glaciation in the Toiyabe and Toquima Ranges suggests to us that these ranges had risen nearly to their present elevation by late Pleistocene time.

Geologically recent tectonic activity along many of the basin-and-range faults is demonstrated by the abundance of displaced late Quaternary alluvial deposits that flank the ranges in the study area. Although conspicuous fault scarps in alluvium occur along range fronts across the entire map area, the freshest scarps appear to be concentrated in the west.

Westernmost northern Nye County is within the central Nevada-eastern California seismic zone (VanWormer and Ryall, 1980; Wallace and Whitney, 1984), which extends southward from Winnemucca. This seismic zone has been the site of numerous historical earthquakes as large as magnitude 7.6 that have been accompanied by surface faulting. One event, the magnitude 7.2 1932 Cedar Mountain earthquake, produced surface fault rupture along a 61-kilometer belt that included part of the frontal fault bounding the Paradise Range in southern Gabbs Valley (Gianella and Callaghan, 1934). On December 16, 1954, two earthquakes of magnitude 7.1 and 6.8, respectively, formed fault scarps totalling about 98 km in length in the Dixie Valley–Fairview Peak region (Wallace and Whitney, 1984); surface faulting apparently extended southward into northern Nye County along the west front of the Monte Cristo Range (Ekren and Byers, 1978). Seismometer networks operated in western Nevada since 1969 by the University of Nevada Seismological Laboratory have recorded a spatially complex pattern of small earthquakes that cluster within the aftershock zones of the major historical earthquakes and are scattered across western and central Nevada (Ryall, 1977; VanWormer and Ryall, 1980).

The presence of late Quaternary faults throughout northern Nye County implies that large earthquakes can occur along many of the range-bounding normal faults. Recent studies of fault-scarp morphology in north-central Nevada (Wallace and Whitney, 1984) suggest, however, that the repeat times for large earthquakes along individual faults in the region are approximately 2800–7600 years.

Geology and Structure of the Ranges

EGAN, SOUTH EGAN, SEAMAN, AND GOLDEN GATE RANGES

Parts of the Egan and South Egan Ranges, a sinuous mountain chain that extends more than 100 miles (161 km) through east-central Nevada, are included within northern Nye County. These ranges are structurally simple blocks bounded by steep normal faults on the west; the arcuate traces of frontal faults, which cut deposits as young as Pleistocene or Holocene, are well exposed along the east side of White River Valley. The segments of the ranges that lie within the county are composed principally of an east-dipping homoclinal sequence of Cambrian to Pennsylvanian strata overlain by Tertiary volcanic rocks. This sequence is disrupted by high-angle faults, which parallel the range front and commonly are downdropped on the west, and by several shallow- to steeply dipping, west-northwest-trending transverse faults. Where the South Egan Range terminates in White River Valley, the Paleozoic strata dip southwestward into the valley, and such transverse faults are particularly well developed.

The small part of the Seaman Range extending into Nye County from Lincoln County trends northwesterly and merges with the Golden Gate Range, which trends north-northeasterly, at the north end of Coal Valley. Paleozoic rocks ranging from the Devonian Sevy Dolomite through the Pennsylvanian Ely Limestone crop out beneath middle Tertiary welded ash-flow tuffs, which in the northern Golden Gate Range are succeeded by basalt of Tertiary or Quaternary age. The two ranges are sharply divided into a series of diversely tilted blocks by normal faults that either parallel the ranges or strike westerly to west-northwesterly. In comparison with the Grant Range, however, the structure appears to be relatively simple and bears a closer affinity to that of the Egan and South Egan Ranges.

Two isolated hills of Paleozoic strata occur near the White River. At one, near the Forest Moon Ranch, an east-dipping succession of Pogonip Group through Sevy Dolomite is exposed. About 6 miles (9.7 km) farther north, east-dipping Simonson(?) Dolomite crops out. The two hills probably represent the same structural block, now nearly buried by valley fill, and are presumably bounded on the west by a concealed normal fault of large displacement.

WHITE PINE RANGE

Nye County contains the southernmost part of the White Pine Range, which is approximately 50 miles (80.5 km) in length. Summit elevations are generally between 9000 and 11,000 feet (2743 and 3353 m); the highest point is Currant Mountain (11,513 ft or 3509 m) astride the county line.

Cambrian to Pennsylvanian sedimentary rocks, which locally are intruded by Mesozoic or Tertiary granitic to dacitic stocks and northeast-trending dikes, are the chief rocks exposed. East of Currant Creek, mid-Tertiary volcanic rocks lap upon the upper Paleozoic strata.

The southern White Pine Range is an easterly tilted block elevated along faults on the west and south. The dominant structure within the block is a north-northwest-trending asymmetric anticline whose steeper eastern flank has dips of 30°-60°. North- and northeast-striking high-angle faults of small displacement disrupt the fold. Erosion has removed most of the post-Cambrian strata from the core and west flank of the anticline, and part of the west flank is downfaulted and buried beneath the valley-fill deposits of Railroad Valley. Moores and others (1968, p. 1723, table 2; 1970, p. 325) consider the fold to have formed in the middle to late Miocene, 20(?)-10 m.y. ago, subsequent to the major volcanism.

Several low-angle faults that emplace younger strata on older are exposed along the southwestern and southern margins of the range. These decollement-type faults generally are subparallel to the bedding and have resulted in large-scale attenuation of the Paleozoic stratigraphic section. Lumsden (1964) believed that these faults formed in response to gravity sliding during the major uplift (block-faulting) of the range, and that the large anticline developed earlier concurrently with and in response to the emplacement of the mid-Tertiary granitic stocks (see the section of this bulletin on Currant District). Drewes (1970) believes that the data of Moores and others (1968) are inconsistent with their conclusions and that the more conventional conclusions about the Sevier orogenic belt favoring a complex structural history encompassing a broad time period from Mesozoic to Tertiary are more acceptable.

Two faults delineate the White Pine Range on the west. The Blackrock fault (Lumsden, 1964) is a west-dipping range-front fault that strikes northeastward and places Pennsylvanian against Cambrian strata near its southern terminus. The fault lies close to the eastern limit of the broad alluvial apron marked chiefly by fanglomerate that borders the range on the west. This Pleistocene and Holocene alluvial material laps the fault trace over most of its course. Farther basinward is a north-south fault, the Railroad Valley fault, that has had late Pleistocene or Holocene movement, as evidenced by truncated terrace spurs. This fault joins the Blackrock fault at the southwest edge of the White Pine Range and continues southward, where its trace marks the western margin of the Grant Range.

The abrupt terminations of the southern White Pine Range and part of the northern Horse Range form a prominent west-northwest-trending topographic discontinuity that almost certainly is structurally controlled. The exact nature of the fault or faults that give rise to the discontinuity, however, is obscured by extensive areas of Quaternary deposits and by the presence of several low-angle, younger-on-older faults that presumably were generated after the uplift of the range. A major concealed transverse fault, termed the Currant Summit fault, has been postulated by Moores and others (1968). The dominant movement along this inferred fault is considered to be left-lateral strike slip, because equivalent parts of the Paleozoic section in the White Pine and Horse Ranges show a map separation of several miles. However, conclusive evidence for strike-slip displacement is not available; comparable map patterns could have resulted from large oblique-slip or dip-slip movements.

QUINN CANYON RANGE

The Quinn Canyon Range forms a topographic and geologic entity with the southern Grant Range, although separated from the latter by the prominent canyon of Cherry Creek. Rugged mountainous terrain, with elevations locally exceeding 10,000 feet (3050 m), passes into low rolling hills southward in Lincoln County. Steeply dipping normal faults that cut both Tertiary rocks and Quaternary alluvium outline the range on the west and locally on the east.

Rocks exposed include lower Paleozoic siliceous clastic strata and dominant lower to middle Paleozoic carbonate assemblage strata intruded by a small Mesozoic or Tertiary granitic stock, minor locally preserved conglomerate and freshwater limestone possibly correlative with the lower Sheep Pass Formation, and widely exposed welded ash-flow tuff and rhyolite of middle and late Tertiary age. These are intruded by a quartz-latite porphyry hypabyssal pluton and by numerous leucocratic (rhyolitic) dikes and sills. Dikes of intermediate composition are present locally.

The Quinn Canyon Range is divided into several structural blocks by basin-and-range-type faults; major exposures of Paleozoic strata are confined to blocks east of Big Creek Canyon. These rocks form gently folded or homoclinal sequences disrupted by an imbricate low-angle fault that has placed older rocks on younger. This fault, exposed south of Bordoli Ranch and near the heads of Badger Gulch and Pine Creek, brings Cambrian to Ordovician strata over Devonian rocks. One segment near the Uhalde Ranch brings younger over older strata. The correlative segment of this major plate is probably one that extends for nearly 15 miles (24 km) along the crest of the southern Grant Range and there exhibits both older-on-younger and younger-on-older relations. The age of the low-angle faulting is not well defined, except that such deformation must predate the Tertiary sedimentary and volcanic rocks that lie on upturned and eroded Paleozoic strata and lap across the trace of this low-angle fault.

Thick sections of Tertiary volcanic rocks crop out adjacent to Cherry Creek and southwest of Big Creek Canyon. Moderate to gentle dips toward the southwest characterize the attitude of the Tertiary rocks except in the vicinity of the basin-and-range-type faults. Because the Tertiary stratigraphy is not well known, nor mapped in detail, it is likely that many high-angle faults in the southern and western part of the range were not recognized. An unmapped major northwest-striking fault or fracture zone postulated in pre-Tertiary rocks by Sainsbury and Kleinhampl (1969, p. C18) may control secondary gash fractures in Tertiary rocks along which are local-

ized some of the range's fluorite deposits. The postulated concealed major break lies 3.5 miles (5.6 km) southwest of and parallel to the North Fork of Cottonwood Creek and extends across a series of prospected fluoritized zones for at least 4.5 miles (7.2 km).

The postulated fault may in part represent a caldron-margin fault; at least one major center of Tertiary volcanism probably impinges on the Quinn Canyon Range and is suggested by the thick character of the Tertiary section, by the locally sharp abutment of these rocks with the Paleozoic strata, and by the presence of numerous volcanic plugs and flows along the southwestern flank of the range. Propylitic and silicic alteration, as well as broad zones of brecciation in the volcanic rocks near the Lincoln County line, indicate loci of structural weakness, but these features have not yet been related to a definite volcanic center.

Numerous dikes in the central part of the range strike northeast to east across the strike of Paleozoic and Tertiary units and across the trend of major low-angle faults and fold structures. The dike trend also subparallels that of the alteration zones in the volcanic rocks near the Lincoln County line.

GRANT RANGE

The Grant Range, about 40 miles (64 km) long, is one of the most impressive mountain ranges in Nevada, rising more than 6500 feet (1980 m) from its west base in Railroad Valley to the highest point: Troy Peak, 11,312 feet (3450 m). The range north of Sherwood Wash is about 10 miles (16 km) wide and is markedly asymmetric, with a steep western slope incised by numerous deep canyons and a gentle eastern slope; farther south, where the range narrows to about 5 miles (8 km), both flanks are equally steep.

In general, the oldest rocks are exposed in the southern Grant Range, whereas progressively younger rocks crop out toward the northern and eastern flanks. The most complete sequence of Paleozoic rocks in northern Nye County—more than 25,000 feet (7625 m) of Lower Cambrian to Pennsylvanian strata—is preserved. This Paleozoic section is succeeded by as much as 5000 feet (1525 m) of Paleocene to Eocene lacustrine strata and Oligocene to Miocene ash-flow tuff. A Miocene and Pliocene continental basin-fill deposit, locally exceeding 10,000 feet (3050 m) in thickness, overlies the Paleozoic and Tertiary rocks in the north. In the southern part of the range, stocks of quartz monzonite that yield a Miocene radiometric age intrude Cambrian and Ordovician rocks.

The Grant Range has been uplifted and tilted to the east along a major normal fault that bounds Railroad Valley. This fault and its subsidiary breaks cut alluvial and fanglomerate deposits as young as Pleistocene or Holocene. Subsurface data from the Eagle Springs oilfield indicated to Horton (1968) that the main fault dips at least 57° westward and probably has had a total minimum vertical displacement of about 12,000 feet (3760 m). Murray and Bortz (1967, p. 2140–2141), however, interpreted the subsurface data as suggesting 11,000–16,000 feet (3350–4850 m) of vertical offset along a series of step faults—composing a fault system rather than a single fault. South of Sherwood Wash, segments of the east side of the range are markedly linear, suggesting that the range is separated from Garden Valley by a series of en echelon basin-and-range normal faults.

The internal structure of the Grant Range is dominated by low-angle faults, subparallel to bedding on the small scale but imbricate and crosscutting over a large area, that divide an otherwise continuous Paleozoic stratal sequence. In general, younger rock is emplaced on older; however, older strata are thrust on younger in the Horse Spring Hills and along the east side of the range south of Murphy Wash. The faults separate plates hundreds to a few thousand feet thick and commonly several miles long which generally are in approximate stratigraphic order but are tectonically thinned. Several of the sheets contain large north-trending folds. Within some plates, units of different ages have been juxtaposed by high-angle faults. Minor folds associated with many of the fault surfaces are overturned toward the east, suggesting tectonic transport in that direction.

The age of the low-angle faults is in dispute. Kirkpatrick (1960a, 1960b), Ptacek (1962), Hyde and Huttrer (1970), and Cebull (1970) ascribed such deformation to a Mesozoic episode, possibly contemporaneous with that which produced similar features elsewhere in the eastern Great Basin. In contrast, Scott (1965) and Moores and others (1968; 1970) propose a tectonic chronology which emphasizes Tertiary deformation and contend that the major folding and low-angle faulting in the Grant Range occurred during Miocene time.

Geologic studies during the past two decades have delineated a belt extending between southern Canada and northwestern Mexico that contains more than 25 scattered terranes of metamorphic and igneous rock to which the term "metamorphic core complex" recently has been applied (Davis and Coney, 1979; Coney, 1980; and Davis, 1983). In Nevada, such complexes have been identified in the Ruby Range (Howard, 1971) and in the Snake Range (Coney, 1974). All these complexes typically display two distinctive structural and petrologic levels: a lower, older terrane of foliated and lineated metamorphic and igneous basement rocks; and an upper level of unmetamorphosed sedimentary rocks that are attenuated and sliced by subhorizontal extensional faults that emplace younger strata on older. Separating these levels is a relatively thin zone of "decollement" (dislocation) having a rock fabric indicative of sliding and detachment. Plutonic rocks as young as early to middle Tertiary age are deformed in the basement terranes of many of the complexes, and some of the deformed upper-level rocks are nonmarine Tertiary sedimentary and volcanic rocks. Metamorphic core complexes are believed to result from regional-scale crustal extension in the western Cordillera during early to middle Tertiary time.

Our evaluation of the mapped geology of the Grant Range identifies distinctive structural levels and suggests that a metamorphic core complex probably is present within the southern part of the range. Although several lines of evidence described below support this interpretation, additional detailed field and petrologic

investigations are necessary to prove that this structural model is indeed correct.

Because of its structural complexity, the Grant Range will be described in greater detail than other ranges. For convenience of description, three segments or structural blocks can be discerned. These are from south to north: the southern Grant Range, from Cherry Creek to Grant Canyon and Sherwood Wash; the north-central Grant Range, between Sherwood Wash and Ragged Ridge; and the Horse Camp Basin.

Southern Grant Range

Mostly Cambrian to Devonian sedimentary rocks are exposed in this part of the range. The Paleozoic rocks are lapped and intruded by Tertiary volcanic rocks near Cherry Creek Canyon and are overlain by Tertiary conglomeratic sediments adjacent to Little Meadow Canyon.

Cebull (1970) recognized two structural levels having distinctive deformational and metamorphic styles in the pre-Tertiary of the southern Grant Range. The lower level, exposed on the west side of the range between Little Meadow and Irwin Canyons, consists of strongly folded and metamorphosed Lower to Middle Cambrian strata, chiefly Prospect Mountain Quartzite. These strata compose a large north-trending anticline that has been recumbently overturned toward the east. According to Cebull, penetrative synkinematic metamorphism characterizes the lower structural level; it is of chlorite-zone grade and has produced chiefly schistose fabrics.

Small plutons of quartz monzonite intrude the rocks of the lower structural level and locally have superposed thermal metamorphic effects on preexisting schistosity. The largest body crops out along the range front between Troy and Irwin Canyons. The rock ranges from nonfoliated to highly cataclastic and porphyroclastic. A sample has yielded a potassium-argon radiometric age of about 23 m.y. (Armstrong, 1970), but this date may not represent the time of igneous intrusion. Generally, north-trending dikes and sills of granophyric porphyry cut the quartz monzonite in places. Emplacement of the plutonic rocks apparently occurred both before and after low-angle faulting of the higher structural level. For example, northeast of Irwin Canyon the quartz monzonite has been mylonitized and sheared by the low-angle Grant Canyon fault (Hyde and Huttrer, 1970, p. 514). In other places, such as at the head of Irwin Canyon, plutonic rocks reportedly form a zone of lit-par-lit injection with the adjacent sedimentary rocks. A small intrusive body on the east side of the range (Cebull, 1970, p. 1833) apparently penetrates the Grant Canyon fault.

The upper structural level consists of nonmetamorphosed or only weakly metamorphosed Upper Cambrian and younger Paleozoic strata that are not strongly folded. At least five low-angle faults can be mapped within this level. These faults bound relatively thin sheets which mantle the lower structural level; all have produced marked cataclasis of adjacent rocks and are considered to be younger than the metamorphism and recumbent folding of the lower level. Local eastward overturning of strata near some of the faults suggests relative movement in that direction.

The structurally lowest fault in the Grant Range, termed the "Grant Canyon Fault" by Hyde and Huttrer (1970, p. 515) and "thrust I" by Cebull (1970), is exposed between Grant and Little Meadow Canyons. North of Irwin Canyon it emplaces moderately inclined Middle Cambrian strata on sheared quartz monzonite and highly folded, metamorphosed Prospect Mountain Quartzite. The fault east of Timber Mountain separates the Pogonip Group above from strongly deformed Middle Cambrian strata below; similar relations occur where it is exposed between Little Meadow and Troy Canyons. North of Troy Canyon, a klippe of Pogonip strata has overridden sheared Lower Cambrian strata and quartz monzonite. The latter remnant of the Grant Canyon fault is unconformably overlain by Tertiary ash-flow tuff.

The Grant Canyon fault can be mapped as far south as Troy Peak, where it apparently is truncated by a series of imbricate sheets that mantle the south part of the range. Faults that bound these plates dip slightly eastward. The lower one emplaces Middle Cambrian rocks on Pogonip Group between Troy Peak and Scofield Canyon. A structurally higher low-angle fault south of the Scofield Canyon puts Ordovician and Silurian dolomite on Cambrian strata.

The highest exposed low-angle fault in the southern Grant Range is designated in this report as the "Troy Peak fault," because it underlies Troy Peak and can be mapped for more than 15 miles (24 km) to the south. Map relations indicate that the fault surface is approximately planar and dips slightly toward the west. Rocks in the sheet above it form a broad south-plunging syncline. Immediately southwest and southeast from Troy Peak, the fault attenuates the section, placing the Pogonip Group on Middle and Upper Cambrian strata; however, farther south, the Troy Peak fault truncates lower faults that dip eastward and displays older-on-younger relations. The most conspicuous exposures are along the east side of the range between Scofield Canyon and Spring Creek where the Pogonip Group has overridden Silurian and Devonian dolomite. South of the latitude of Cherry Creek Summit, the upper plate, of Upper Devonian and Mississippian rocks, has been displaced along high-angle faults, which are truncated downward by the Troy Peak sole fault, so that locally strata as young as Chainman Shale are faulted on Ordovician rocks.

An elongate, east-trending Tertiary dacite body cuts across the Troy Peak fault at Bruno Creek. The fault is lapped east of Cherry Creek by ash-flow tuffs assigned to the Shingle Pass(?) and Needles Range(?) Formations (pl. A1) of late Oligocene age. Latest movement on the Troy Peak fault and the other faults that it truncates, therefore, must have occurred prior to about late Oligocene.

North-central Grant Range

Structural relations in this part of the range are exceedingly complex. Both low- and high-angle faults and

some large-scale folds characterize the area. Despite relatively detailed geologic mapping by Kirkpatrick (1960a), Scott (1965), Moores and others (1968), Hyde and Huttrer (1970), and ourselves, the structure is not yet fully understood.

The dominant structural feature of the north-central Grant Range appears to be an east-dipping low-angle fault whose sinuous trace extends between Ragged Ridge and the Horse Spring Hills. This fault, here referred to as the Blue Eagle fault because a segment of it was recognized at Blue Eagle Mountain by Kirkpatrick, divides the rocks into two distinct structural terranes. West of and below this fault are moderately to steeply inclined Middle Cambrian to Devonian strata that, in places, form large folds. The structural terrane above and to the east of the Blue Eagle fault is a generally eastward-dipping succession of Upper Devonian to Pennsylvanian strata, Paleocene to Eocene lacustrine beds, lower Tertiary volcanic rocks, and upper Tertiary coarse clastic sediments. The Paleozoic and Tertiary rocks are cut by relatively closely spaced, steep, north- and west-striking faults that exhibit horizontal and vertical separations of a few hundred to many thousands of feet. Mapping by Scott (1965) and Moores and others (1968), locally confirmed by our own work, indicates that such separations are not present below the Blue Eagle fault and that the high-angle faults, which cut rocks as young as Tertiary, are truncated at depth by the low-angle fault. On the basis of this and other relations, these authors have concluded that much of the folding and low-angle faulting in the vicinity of the Grant Range is of late Tertiary age.

The Blue Eagle fault generally forms a brecciated zone as much as 200 feet (61 m) thick. Just south of Ragged Ridge, a much thicker chaotic zone containing large tectonic blocks of Eureka Quartzite and Ely Springs Dolomite is developed between Ordovician to Devonian dolomite below the fault surface and the Upper Devonian limestone above. Locally, small-scale folds near the fault are overturned eastward, indicating the probable direction of tectonic transport (Kirkpatrick, 1960a, p. 67). Although stratigraphic separation is varied, the fault generally is nearly parallel to adjacent upper plate strata but truncates bedding of lower plate rocks. Through much of its exposed length, the Blue Eagle fault underlies gently dipping Guilmette Limestone. Between Blue Eagle Mountain and Heath Canyon, attenuation of the section is decreased so that the Guilmette is faulted on Simonson Dolomite with little deletion of normal stratigraphy. East and southeast of Blue Eagle Mountain, the upper plate is cut by several high-angle faults that juxtapose Upper Devonian strata against rocks as young as Miocene. Chainman Shale and various Tertiary ash-flow tuff units are emplaced on Simonson Dolomite by the Blue Eagle fault southeast of Heath Canyon. In the Horse Spring Hills, we interpret the fault to lie at the base of a thrust sheet containing overturned Ordovician to Devonian strata. The Blue Eagle fault may also underlie and form the lower limit of fault blocks of Ely Limestone and Tertiary ash-flow tuff along the west edge of White River Valley.

We have inferred the existence of a structurally higher low-angle fault in the north-central Grant Range. The fault has been placed at the base of the Chainman Shale, because that unit is abnormally thin in this area as compared to nearby ranges; however, the fault surface may actually lie within the Chainman Shale. A similar fault has been mapped in the Horse Range at the same stratigraphic position (Moores and others, 1968). The inferred fault apparently is offset by the high-angle faults that bound the blocks above the Blue Eagle fault and presumably would be older than the latest movement on the Blue Eagle fault.

The structural terrane beneath the Blue Eagle fault is characterized by low-angle faults with younger-on-older relations that have displaced broadly folded lower Paleozoic strata. Two such faults have been mapped by Moores and others (1968) southwest of Ragged Ridge. The structurally lower fault (which may correspond to the Cave Canyon thrust of Kirkpatrick, 1960a, p. 60) has placed complexly deformed west-dipping masses of Laketown, Sevy, and Simonson Dolomites on a broad north-trending anticline of Eureka Quartzite and Ely Springs Dolomite. A higher fault occurs beneath Simonson and Guilmette strata, which also are anticlinally folded. The sheet containing this anticline is truncated by the Blue Eagle fault.

Southwest of Blue Eagle Mountain, three additional major low-angle faults are recognized by Hyde and Huttrer (1970). The previously described Grant Canyon fault is exposed in a window at the head of Grant Canyon, where slightly deformed Middle Cambrian beds are faulted on strongly metamorphosed and folded Lower Cambrian strata. The Heath Canyon fault, which places Pogonip beds on Middle and Upper Cambrian, is structurally above the Grant Canyon fault (Hyde and Huttrer, 1970, p. 515). A higher fault with greater stratigraphic separation, the Beaty Canyon fault, crops out between Beaty and Grant Canyons; the lower plate of this structure consists chiefly of the Pogonip Group, whereas Ordovician to Devonian dolomite forms its upper plate. Between Heath Canyon and the Horse Spring Hills, the latter strata are folded into a large north-south anticline. The Beaty Canyon fault appears to truncate the Heath Canyon structure south of Heath Canyon.

Our mapping and interpretation of the structure between Heath and Grant Canyons differs considerably from that of Hyde and Huttrer. We believe that the Heath Canyon fault is terminated by the Beaty Canyon fault at Heath Canyon. South of this canyon, blocks of Cambrian to Devonian strata separated by steep faults have been placed on more deformed Cambrian beds by the higher fault. The high-angle faults in the upper plate appear to truncate at the surface of the Beaty Canyon fault.

Horse Camp Basin

Horse Camp basin is an area of low hills and ridges that separates the main Grant Range from the White Pine and Horse Ranges. It is composed of upper Paleozoic strata, middle Tertiary volcanic rocks, and upper

Tertiary sedimentary rocks that, together, have been deformed into a broad east-plunging syncline. During Miocene and Pliocene time, the basin was a localized depositional site within which accumulated about 10,000 feet (3050 m) of clastic detritus (the Horse Camp Formation of Moores, 1968). Stratigraphically higher units of the Horse Camp Formation unconformably overlie north-trending folds in Upper Devonian to Mississippian strata, Oligocene to Miocene volcanic rocks, and lower beds in the Horse Camp Formation. Higher units in the Horse Camp contain monolithologic breccias and gravity-slide masses of Paleozoic and lower Tertiary strata. Presence of such material within and on the upper Horse Camp section is considered to be supporting evidence for low-angle faulting in the northern Grant Range during late Tertiary time (Moores, 1968, p. 96; Moores and others, 1968, p. 1719, 1720).

The Horse Camp basin is delineated from the main Grant Range at the south end of Ragged Ridge by an east-striking high-angle fault having a stratigraphic separation of 15,000–25,000 feet (4575–7625 m). Moores and others (1968, p. 1716) speculate that this fault curves northward beneath the upper strata of the Horse Camp Formation and bounds the basin on the east in bowl-like fashion. An inferred western extension of the Currant Summit fault (see the section of this bulletin on White Pine Range) is considered to form the northern boundary of the basin.

HORSE RANGE

The Horse Range merges with, but is east of, the White Pine and Grant Ranges. It includes three main topographic elements: a western ridge that trends southward from U.S. Highway 6 to Stone Cabin; a paralleling longer eastern ridge that extends to Wells Station Summit on the south; and a detached group of hills south of the latter ridge and projecting into White River Valley. Crestline elevations are between 7000 and 8000 feet (2135 and 2440 m).

The western ridge, terminated on the north by the east-trending Currant Summit fault (see the section of this bulletin on White Pine Range), is underlain by an east-dipping homocline of Cambrian and Ordovician strata. A normal fault and an elongate graben of Tertiary volcanic rocks form the eastern margin of the block. The ridge is inferred to be bounded on the west by a concealed high-angle fault that separates it from the Tertiary Horse Camp depositional basin (see the section of this bulletin on Grant Range). Several sheets composed of attenuated and brecciated parts of the Cambrian to Mississippian succession, in approximate stratigraphic order and separated by low-angle fault surfaces, mantle the southern part of the ridge. Although Moores and others (1968, pl. 1) indicated that these low-angle faults have overridden their Miocene Horse Camp Formation, mapping by ourselves and by R. K. Hose and M. C. Blake, Jr. (oral commun., 1969) suggests that these faults actually are lapped by the Tertiary sediments.

The eastern ridge of the Horse Range is composed of a north-striking Paleozoic section cut by west-trending high-angle faults of small displacement. This section is separated from east-dipping upper Tertiary strata flanking the northern Grant Range by a normal fault at least 18 miles (29 km) long and with a stratigraphic separation of about 19,000 feet (5800 m) (Scott, 1965, p. 44). The Paleozoic rocks along the west side of the ridge generally are overturned toward the east; however, east of a medially situated west-dipping reverse fault, the strata dip moderately eastward in normal succession. Moores and others (1968, p. 1723) consider this large fold to have formed, like the one in the White Pine Range, during about the middle to late Miocene (20?–10 m.y. ago) after major volcanism and during a period of nondeposition in the Horse Camp basin to the west. Farther east, a bedding-plane fault at the top of the Joana Limestone can be traced southward along the west side of White River valley; this fault, which tectonically thins the Chainman Shale and locally emplaces Ely Limestone on Joana, may correlate with similar faults in the Grant Range to the southwest and farther south in the Horse Range. The northeasternmost part of the ridge is underlain by gently folded Devonian and Mississippian strata; near Currant Summit these are faulted against Tertiary volcanic rocks.

The hills in the southern Horse Range are separated from the eastern ridge by a narrow east-northeast-trending graben of Tertiary volcanic rocks. Immediately south of Wells Station Summit, the Paleozoic rocks are folded into a broad north-trending anticline modified by minor high-angle faults. East of the summit a low-angle fault separates Devonian rocks from Mississippian and Pennsylvanian strata. A complexly faulted block of gently dipping lower Paleozoic rocks farther east has been elevated by a high-angle fault having nearly 8000 feet (2440 m) of stratigraphic separation.

PANCAKE RANGE

The Pancake Range, nearly 100 miles (161 km) long and from 5 to 18 miles (8 to 29 km) wide, extends from north of U.S. Highway 50 in White Pine County to Hot Creek near Nevada Highway 25; about three-fourths of the range is within Nye County. The highest points are Moody Peak (8883 ft or 2709 m) in the north and Portuguese Mountain (9240 ft or 2818 m) in the central part. Summit elevations are about 7000 feet (2135 m) in the low, fishhook-shaped hills that compose the southern part of the range.

The range comprises several northward-elongate structural blocks, which are generally delineated on the east and west by a discontinuous series of en echelon normal faults. The structure of the southern half of the range differs from the rest, however, in being underlain by nested or coalescing Tertiary calderas or parts of calderas with their attendant structures (Ekren, Quinlivan, Snyder, and Kleinhampl, 1974, especially figs. 2, 3). These have been modified by basin-and-range faults. Most of the covering rocks have been stripped off another major Tertiary (Oligocene) constructional volcanic upland (volcano) at Moody Peak, which owes at least part of its present elevation to basin-and-range faults.

Two thrust faults that involve autochthonous pre-Tertiary strata are exposed beneath Oligocene latite lavas and rhyolitic welded tuffs in the northern part of the range. The structurally lower thrust is exposed several miles east of Moody Peak in a north-trending belt near the core of the range and in scattered hills off the east front of the range. The fault has emplaced Devonian and Mississippian rocks on broadly folded Mississippian shale and sandstone (Chainman Shale and Diamond Peak Formation); locally, lacustrine deposits of Cretaceous or earliest Tertiary age appear to be involved in the thrusting. Upper Paleozoic strata of the lower plate, including rocks clearly as young as Permian and possibly as young as Cretaceous, as far south as Portuguese Mountain compose a large syncline overturned toward the east-northeast. A structurally higher thrust north of Moody Peak separates intensely folded Cambrian and Ordovician strata above from less deformed Devonian rocks below and, in places, has overridden Newark Canyon(?) conglomerate. The overturned syncline and both thrusts are unconformably lapped by a cobble and boulder conglomerate lithologically similar to the basal member of the Paleocene to Eocene Sheep Pass Formation. Thus, a Late Cretaceous or earliest Tertiary age assignment seems appropriate for the major deformation in the Pancake Range.

The structure of Portuguese Mountain is complex and poorly understood. Thrust relations between the Devils Gate Limestone and Chainman Shale are exposed locally along the southeast part of the mountain, with the Devils Gate in the upper plate. The attitude of the major fault on the north side is not known with certainty, but it is probably a high-angle fault along which the south block is downthrown. Thus, the low-angle fault that emplaces Devonian over Mississippian on the southeast side of Portuguese Mountain might not crop out on the north side. Portuguese Mountain, however, probably represents an upper plate that could be a segment of the structurally lower thrust exposed in the northern part of the range. This thrust is exposed again beneath a small klippe about 2 miles (3 km) south of Portuguese Mountain.

An appendage of the Pancake Range, which includes the Duckwater Hills, extends northeast from Portuguese Mountain. Structurally, these hills are a series of diversely tilted fault blocks of Devonian and Mississippian strata succeeded by Tertiary welded tuff and flows of varied composition.

Between Portuguese Mountain and Black Rock Summit, lower and middle Paleozoic strata compose a narrow horst bounded on the east and south by Tertiary welded tuff and on the west by Tertiary rhyolite and welded tuff that lie within a caldron complex (Ekren, Quinlivan, Snyder, and Kleinhampl, 1974, especially fig. 2; and Quinlivan and others, 1974). The western fault of the horst marks the approximate perimeter of the caldron complex (Quinlivan and others, 1974). Rocks within the horst generally dip gently toward the east and are cut by cross faults of varied displacement. The little-faulted part of the horst north of Wood Canyon is probably mostly in the lower plate of the structurally lowest thrust described previously, whereas that part of the horst cut by a complex mosaic of faults south of Wood Canyon might be in the upper plate of this thrust.

A structurally highest set of low-angle faults involving Tertiary rocks are exposed in small areas about 1–2 miles (2–3 km) southwest of Portuguese Mountain and just north of Black Rock Summit. At the former locality, allochthonous(?) Tertiary volcanic rocks (Quinlivan and others, 1974) have been emplaced on lower to middle Paleozoic strata and Oligocene volcanic rocks. This allochthon and the imbricate plates of middle Paleozoic carbonate strata overlying Oligocene welded tuff at Black Rock Summit may represent slide masses related to caldron subsidence in the Tertiary rather than to the Laramide period of deformation represented by the structurally lower thrusts.

The southern part of the Pancake Range represents part of the caldron complex mentioned above, the most recent caldera of which is the approximately 25 m.y.-old Lunar Lake caldera (Ekren, Quinlivan, Snyder, and Kleinhampl, 1974). The partly superposed complex of Tertiary constructional (eruptive) and collapse features have been modified by basin-and-range faulting. An incompletely enclosed, crudely circular 11–13 miles (18–21 km) topographic basin, whose floor lies 500–1000 feet (153–305 m) above the levels of the adjacent Hot Creek and Railroad Valleys, defines the present outline of the Lunar Lake caldera. Part of the depression, however, may have originated by basin-and-range faulting, and the actual caldera rim is exposed only on the east in The Wall. Welded tuff of Oligocene and Miocene age and Miocene rhyolite form the border of the depression and are subhorizontal or dip slightly toward the center of the depression. Quaternary basaltic composite cones, cinder cones, scoria mounds, and several maars are aligned along northeast-trending fissures that probably are controlled by faults at depth. Eruptions from these fissures form a series of young basalt flows that now at least partly fill the depression and are in part concealed by alluvium. Some of the tuffs are also believed to have erupted from the fissures during the Miocene prior to basalt eruption (Ekren, Quinlivan, Snyder, and Kleinhampl, 1974, p. 600).

REVEILLE RANGE

About half of the Reveille Range, a 28-mile (45-km) extension of the Pancake Range, is included within northern Nye County. The brief summary below of the structure of the range is elaborated upon in the description of the Reveille mining district. Tertiary and Quaternary volcanic rocks make up most of the range. Paleozoic rocks are exposed only in the central part, near the mining camps of New Reveille and Old Reveille.

Predominantly Ordovician to Devonian strata of the carbonate assemblage form a west-dipping homocline that is bounded on the west by a long north-striking normal fault and is cut by several transverse high- and low-angle faults. One of the latter is exposed about 1/2 mile (0.8 km) west of Gila Mine in a structural window where strata of the middle Paleozoic carbonate assemblage are emplaced over clastic beds inferred to be most likely late

Paleozoic by Ekren, Rogers, and Dixon (1973). The downdropped block off the northwest edge of the homocline was mapped as Pilot Shale, Joana Limestone, and Diamond Peak(?) Formation (Ekren, Rogers, and Dixon, 1973), but we believe that the Joana and higher strata, mapped as Eleana Formation (pl. A1), are imbricated with or faulted against an allochthonous Devonian(?) facies that is similar to and probably part of the Cockalorum Wash Formation allochthon in the Hot Creek Range. If our interpretation is correct, the small outcrop of allochthon is significant, because it would represent the easternmost remnant of a major thrust sheet that advanced from the west.

Tertiary andesite and welded tuff are faulted against and overlap the Paleozoic section. The oldest volcanic rock in the range is a large block of Oligocene welded ash-flow tuff downfaulted into the homocline of Paleozoic strata. However, the major Tertiary structures, mapped and described by Ekren, Rogers, and Dixon (1973; see also Ekren, Quinlivan, Snyder, and Kleinhampl, 1974), are a series of curvilinear strike-slip faults, most of which trend north to northwest and exhibit left-lateral slip. These faults are said to be part of a major shear zone whose last major movement preceded intrusion of dikes about 19 m.y. ago and followed venting of the 24–27-m.y.-old Monotony Tuff. The caldera that formed as a result of the eruption of the Monotony, and which is partly exposed along the eastern flank of the range, was disrupted by the shears. Low-angle faults associated with the shearing have disrupted parts of the Tertiary section. Quaternary basalt flows mantle the range on the west and east flanks. A frontal fault cuts Pleistocene and Holocene valley-fill deposits adjacent to Railroad Valley, suggesting that the Reveille Range has been tilted toward the west relatively recently.

ANTELOPE, HOT CREEK, PARK, AND KAWICH RANGES

The Antelope, Hot Creek, Park, and Kawich Ranges form an essentially continuous north-trending belt, 5–15 miles (8–24 km) wide, which has crestline elevations between 8000 and 9000 feet (2440 and 2745 m). The highest points are Ninemile Peak (10,104 ft or 3082 m) within the Antelope Range and Morey Peak (10,246 ft or 3125 m) in the central Hot Creek Range.

The Antelope Range within the county is underlain chiefly by lower Tertiary dacitic flows, one source of which is probably centered at Ninemile Peak, and by subhorizontal to gently dipping Oligocene and Miocene welded ash-flow tuff. These rocks are broken by a system of normal faults, most of which strike north and demarcate a horst that extends southward from near Ninemile Peak. Carbonate-assemblage Ordovician to Devonian sedimentary rocks are exposed locally beneath the volcanic rocks; they are relatively undeformed except west of Indian Springs Ranch, where Eureka Quartzite and Hanson Creek Dolomite compose a narrow north-trending anticline. Also, a low-angle fault separates overlying Eureka Quartzite from Pogonip Group in a small window just west of Ninemile Peak. This may be a relatively minor bedding-plane-type fault or could be a more significant thrust fault that has its counterpart to the east in the Fish Creek Range, described below.

A few miles east of the Antelope Range is a north-northeast-trending chain of low hills that is an extension of the Fish Creek Range of Eureka County. Here, intensely folded siliceous clastic strata and limestone of a facies distinct from that of the carbonate assemblage crop out. These rocks are assigned to the Cockalorum Wash Formation of middle Paleozoic age and occur discontinuously through a narrow belt as far south as Warm Springs. They could represent an allochthon that was thrust from the west. Nonmarine Upper Cretaceous or Paleocene sedimentary rocks lap the allochthonous Devonian strata and, in turn, are overridden by thrust masses composed of the Nevada and Devils Gate Formations and undifferentiated late Paleozoic strata (sedimentary strata in Hot Creek, Park, and Reveille Ranges, pl. A1; possibly Carbon Ridge Formation). Tertiary intermediate lavas and tuffaceous sedimentary beds and Quaternary or Tertiary basaltic rocks overlie and are faulted against the older rocks.

The Park Range just south of the above-described hills has exposed at its north tip a continuation of the pre-Tertiary geology just described, and farther south the geology is similar to that of the nearby Antelope and northern Hot Creek Ranges. The Park Range is a northeast-trending, internally moderately faulted, east-dipping homoclinal block faulted up along its west edge. The block is dropped down against a similar but smaller homoclinal block on the east (Andesite Ridge). This ridge passes imperceptibly southward into a group of hills with complex stratigraphy and structure, known on the north as the Squaw Hills and on the south as the Heart Hills.

The group of hills of which the Squaw Hills are a part is bounded on the southwest by Hot Creek Valley and on the east by Big Sand Spring Valley. Physiographically and geologically the hills are more a part of the Hot Creek Range than the Pancake Range. Small areas of Paleozoic rocks that crop out several miles east and southeast of Pritchards Station, including faulted blocks of Ordovician to Mississippian strata, are the oldest rocks exposed in the hills. Mississippian shale and sandstone are broadly folded, and, along with some of the other larger Paleozoic masses, as at Red Ring Mountain, the Mississippian rocks are probably autochthonous. Smaller patches of Silurian to Mississippian beds probably are exotic Tertiary slide blocks whose internal stratigraphy is not differentiated on the geologic map from that of other slide blocks composed of Tertiary bedded tuffs, welded ash-flow tuffs, tuffaceous sedimentary strata, and lavas (see the section of this bulletin on Cenozoic Erathem—West-central Region—Landslide Deposits and Breccias; also, see exotic slide blocks, pl. A1). The slide masses overlie Paleozoic strata and Oligocene volcanic and sedimentary rocks. Localization of the slide masses, some of which are arranged in imbricate fashion, was probably due to the instability along the edge of the evolving Oligocene Williams Ridge and Hot Creek Valley caldron complex described by Dixon and others (1972) and Ekren, Hinrichs, Quin-

livan, and Hoover (1973) and Ekren, Quinlivan, Snyder, and Kleinhampl (1974). Ekren, Hinrichs, Quinlivan, and Hoover (1973) mapped a northwest-trending 5-mile (8-km)-long breccia unit (brecciated and faulted tuffs, pl. A1) that nearly bisects the group of hills and also lies along a segment of the inferred margin of the Hot Creek Valley caldron, to which the breccia probably owes its origin. Some slide masses may have evolved during Tertiary thin-skin tectonic deformation in association with postulated left-lateral shearing along an inferred major east-trending fault zone (Dixon and others, 1972; see also Pritchards Station lineament, *in* Ekren and others, 1976). The effects of the forces of caldron subsidence, lateral shearing and attendant phenomena, and basin-and-range faulting, which may all be partly interrelated, in many places are not readily separable. For example, the Red Ring Mountain, where mid-Paleozoic strata are overlain by exotic Tertiary masses and sheets, appears to be a small horst. But the horst might owe its origin partly to all three mechanisms. Other structural features in the hills are equally puzzling and complex, such as the small mass of welded tuff shown as a klippe in the Heart Hills.

The Hot Creek Range is a west-tilted block, composed chiefly of Tertiary volcanic rocks, that has been elevated by normal faults on the east to expose a discontinuous fringe of Paleozoic rocks. These rocks are exposed chiefly in two areas separated by a large Oligocene caldera filled with tuffs and tuffaceous sediments.

North and northwest of Morey Peak, a locally folded section of autochonous Ordovician to Carboniferous rocks is cut by northeast- to east-striking normal faults. A major normal fault has downdropped Nevada Formation against Pogonip Group on the west side of the range. Major movement on the fault may have preceded venting of Tertiary welded tuff because displacement seems to be much less where the fault cuts the Tertiary section to the north. However, this seemingly large pre-Tertiary displacement may be illusory because the downdropped Devonian might represent part of the same klippe exposed just east of the fault, where the lower plate is composed of Ordovician and Silurian rocks. A series of imbricate thrust sheets emplaces strata as old as Ordovician and as young as Mississippian Joana Limestone (limestone lenses of Mississippian age, pl. A1) on strata as young as Carboniferous in the area north and northwest of Morey Peak. One series of klippen emplaces an allochthonous Devonian facies (Cockalorum Wash Formation, pl. A1) on Silurian and Devonian carbonate rocks in and near North Sixmile Canyon; these klippen are remnants of a major thrust that presumably moved from the west. Subsidiary thrusts in the autochthon, which bring Devonian and Mississippian carbonate rocks over Mississippian shale, crop out in the area west of Moores Station. A single small outcrop of gently south-dipping cobble and boulder conglomerate provisionally assigned to Cretaceous or Tertiary sedimentary rocks (sedimentary rocks, pl. A1) may offer a clue to as yet undecipherable structural events in the area.

The postulated left-lateral shear zone along an inferred major east-trending fault zone (Dixon and others, 1972) at the north end of the Squaw Hills is believed by Ekren, Bath, Dixon, Healey, and Quinlivan (1974) to be part of a lineament at least 40 miles (64 km) long originally termed the "Tulle Creek–Pritchards Station lineament" and later referred to as the "Pritchards Station lineament" (Ekren, Bucknam, Carr, Dixon, and Quinlivan, 1976). These workers postulated that where the lineament crosses the Hot Creek Range, left-lateral strike-slip movement passed into a thrust fault emplacing Tertiary volcanic rocks over Paleozoic and Tertiary rocks. This shearing, with the subsequent formation of a north-striking graben over Little Fish Lake Valley to the west, is said to postdate the 23-m.y.-old (early Miocene) Bates Mountain Tuff and predate sediments bearing late Miocene or early Pliocene vertebrates.

Morey Peak and the surrounding highlands, almost as far south as Hot Creek Canyon, are underlain by a complex of volcanic rocks that are associated with what has been termed the "Williams Ridge and Hot Creek Valley caldron complex" (Ekren, Hinrichs, Quinlivan, and Hoover, 1973). The Morey Peak massif is the resurged part of the Williams Ridge caldera, which, in its entirety, is irregularly scalloped in plan (a minimum of about 32 mi or 52 km across; fig. A32) and is inferred to extend east-northeast across Hot Creek and Big Sand Springs Valleys, through the Squaw and Heart Hills, and south to include the southern Pancake Range. The caldron complex contains an unusually thick sequence of Tertiary tuff, tuffaceous sedimentary strata, and minor rhyolite as compared to areas immediately north or south. Rocks exposed within the caldron complex are broken by an irregular, dense network of normal faults of small displacement. Major faults bound the complex and the resurged Morey Peak massif. The boundary faults, which presumably are vertical or steeply dipping into the caldron complex, may have displacements as great as 10,000 feet (3050 m) and separate the caldera fill from adjacent terranes of Paleozoic and Tertiary rock. The caldron complex appears to be lapped on the west by tuffs correlated with the early Miocene Shingle Pass Tuff and stratigraphically adjacent rocks (pl. A1). Subsequent normal faulting of the basin-and-range type has modified the Morey Peak caldera.

The Paleozoic rocks between Hot Creek Canyon and Rawhide Mountain compose a large north-trending anticline, the axis of which generally lies east of the range front but is exposed near Tybo Canyon. A northwest-plunging syncline is developed in lower Paleozoic rocks southwest of Rawhide Mountain. These folds are unconformably overlain by Tertiary sedimentary and volcanic rocks and have been broken by numerous high-angle faults. The older set of faults, such as the reverse fault in Tybo Canyon (2G fault) which is intruded by quartz latite porphyry (Ferguson, 1933), strike west or northwest. Quinlivan and Rogers (1970) consider the 2G reverse fault and its offset westward extensions, the Dimick and Gilmore faults, to be main segments of a major left-lateral strike-slip fault system that arcs southeastward to near Echo Canyon, between the Pancake and Reveille Ranges. At the fault system's extremities in the Reveille and Hot Creek Ranges, offsets on volcanic rocks at least as young as about 20 m.y. and including the late Oligocene Monotony Tuff have been attributed

to movement along this fault system. North and northeast strikes characterize the younger normal faults that displace Paleozoic and Tertiary rocks and, along the range front, Quaternary deposits.

Strata of the inferred allochthonous Devonian facies (Cockalorum Wash Formation) crop out extensively near Warm Springs. These highly folded and sheared rocks are presumed to be thrust on Mississippian shale (Eleana Formation), although relations are obscured by younger normal faults and intervening Tertiary volcanic rocks. Thrust slices of Early Mississippian limestone (limestone lenses of Mississippian age, pl. A1) are imbricated with the allochthonous Devonian strata.

Brecciated masse of autochthonous lower Paleozoic rocks, which probably are gravity slides generated by Tertiary uplift of the range, are mapped as klippen in the southern Hot Creek Range. Several are on high ridges near Tybo, and others of larger extent have overridden Dunderberg Shale south of Hot Creek Canyon along the east side of the range. One mass in Hot Creek Canyon rests on Tertiary welded tuff along a low-angle fault contact that may have been affected by basin-and-range normal faults. More extensive landslide deposits (pl. A1) of similar origin but perhaps partly younger and involving Tertiary rocks are exposed in the western part of the range near Hot Creek Canyon.

The Kawich Range, a topographic and structural continuation of the southern Hot Creek Range, extends for more than 60 miles (97 km). Tertiary volcanic rocks compose almost all exposures in the northern Kawich Range. Crystal-rich welded tuff, the dominant rock type there, has been intruded by a large irregular body of quartz latite porphyry south of the Bellehellen Ranch (pl. A1; Cornwall, 1972). The intrusive body may represent the resurged core of a caldera that is inferred to coincide areally with the position of at least the northern part of the range (Ekren and others, 1976). The portion of the range that is in the area of study consists of a west-tilted block bounded on the east by a concealed normal fault and locally on the west by normal faults, some of which may have disrupted Quaternary alluvium. The mines and prospects of the northern Kawich Range form a well-defined northwest-trending belt that crosses the range north of its highest part (pl. A2). The belt probably defines a major structural feature, such as a caldron margin or moat, or possibly a major northwest-striking left-lateral shear zone paralleling the one postulated between the Hot Creek Range (Tybo area) and the Reveille Range.

MONITOR RANGE

The Monitor Range is about 100 miles (161 km) long and from 6 to 16 miles (10 to 26 km) wide. Summit elevations for most of its length are between 9000 and 10,000 feet (2475 and 3050 m); the highest point (10,886 ft or 3320 m) is an unnamed peak west of Clear Creek. The range joins the Antelope and Hot Creek Ranges at the north and south ends of Little Fish Lake Valley and is connected with the Toquima Range on the west by a narrow bedrock divide between Ralston and Monitor Valleys.

Tertiary volcanic rocks compose more than 90% of the exposed bedrock. Outcrops of Paleozoic rock generally occur only adjacent to Antelope and Little Fish Lake Valleys. The Monitor Range is a westward-tilted fault block that has been elevated by normal faults along the east front. Late Quaternary displacements are evident along several of these faults.

Lower Paleozoic carbonate-assemblage rocks near Antelope Valley have been folded along north-trending axes and subsequently disrupted by normal faults, many of which seem to predate the Tertiary volcanism. A major thrust fault farther south in the range has placed an allochthonous upper Paleozoic sequence over these carbonate-assemblage strata and over a parautochthon containing middle Paleozoic strata.

The allochthon consists of shale, mudstone, chert, and a little phosphatic cherty grit of presumed late Paleozoic age, which are assigned to the Pablo(?) and Diablo(?) Formations, undifferentiated. These rocks are lithically similar to, and may correlate with, the Pumpernickel and Havallah Formations. The thrust is best exposed between Sawmill and Danville Canyons, and the southernmost remnant is preserved in a downdropped block in Green Monster Canyon. Progressively younger strata of the allochthon rest on carbonate-assemblage rocks south of Clear Creek. Large eastward movements along this fault seem mandatory in view of the great differences in lithology of the upper plate rocks as compared to correlative upper Paleozoic strata in the ranges to the east. Therefore, the fault is postulated to be the easternmost remnant of the early Mesozoic Golconda thrust.

Allochthonous rocks resembling the Pablo(?) of the Golconda plate have also been mapped near Dobbin Summit and in a window through Tertiary tuffs at Horse Heaven Mountain. However, the latter outcrop has been assigned to the Vinini Formation and is considered without corroborating evidence to be part of the older Roberts Mountains thrust plate.

The parautochthon near Clear Creek Canyon consists of Devonian and Mississippian limestone and limestone breccias (limestone and shale, undifferentiated, pl. A1); some of the limestone contains Kinderhookian conodonts and is correlative with the Joana Limestone. Flat-lying conglomerate and sandstone locally unconformably(?) overlying the parautochthon have been assigned to the Eleana Formation of the overlap assemblage, but nowhere lap the thrust, whose age has not been determined. Part of the parautochthon, however, is interpreted (Ekren, Bath, Dixon, Healey, and Quinlivan, 1974, fig. 2) to have been involved in Tertiary low-angle faulting about 2.5 miles (4 km) up Clear Creek Canyon. This faulting may be related to structural evolution in the Tertiary along the Pritchards Station lineament, described with the structure of the Hot Creek Range. The involvement of the parautochthon with Tertiary structure does not preclude a pre-Tertiary initial origin for the parautochthon.

South of McCann Canyon, the range widens abruptly and consists of a thick section of Tertiary tuff overlain and intruded by rhyolite. Existence of at least one large and one small caldera in the southern Monitor Range

(fig. A32) is suggested by the great thickness of tuff and by complexities of faulting and intrusion. Also, large blocks of lower Paleozoic strata and Cretaceous(?) granitic rocks engulfed by tuffaceous rocks west and south of Big Ten Peak could be landslide masses derived from a caldera wall. Similar, partly coalescing calderas that could be partially concealed beneath Quaternary alluvium may be present in the vicinity but remain unidentified.

The southern part of the range is cut both by north-striking basin-and-range normal faults and by northwest-striking normal faults that delineate a large graben within which are exposed gently tilted middle Miocene tuff of Saulsbury Wash and rhyolite of less definitive but Tertiary age. The tuff unconformably overlies other ash-flow tuffs in a volcanic complex to the south, in the Ellendale and Hannapah mining districts. Intensely folded Cambrian and Ordovician rocks locally overthrust by the Roberts Mountains Formation are exposed near the southern extremity of the volcanic complex at Ellendale.

The northwest-striking normal faults mentioned above may be the latest manifestations of a northwest-trending lineament, here termed the "Kawich-Toiyabe lineament," that passes across the range between Antelope Spring on the northwest to near Five Mile Spring on the southeast. The lineament may mark a zone of left-lateral shearing that was active in the Tertiary (possibly prior to the late Miocene) and affected the topographic and geologic discontinuity in the northern Kawich Range, at the south end of the Monitor Range, and between the San Antonio and Toquima and Toiyabe Ranges. Such a lineament, with its corollary left-lateral strike-slip faults, essentially parallels a similar zone between the north end of the Reveille Range and Tybo in the Hot Creek Range; this zone is postulated and partly documented by Ekren and others (see especially Ekren, Quinlivan, Snyder, and Kleinhampl, 1974; and Ekren, Bucknam, Carr, Dixon, and Quinlivan, 1976) and is illustrated in figure A32. The east-trending Warm Springs lineament of Ekren and others (1976) also crosses the southern Monitor Range and intersects the Kawich-Toiyabe lineament near Five Mile Spring.

TOQUIMA RANGE

The Toquima Range, 8–14 miles (13–23 km) wide, extends for nearly 70 miles (113 km) southward from Hickison Summit in Lander County to a broad divide at the northern end of the San Antonio Mountains. Wildcat Peak (10,507 ft or 3205 m) and Mount Jefferson (11,949 ft or 3644 m) are the highest points in the range.

The range has been elevated along its eastern flank by normal faults that bound the range between Ikes Canyon and Belmont. Paleozoic strata and Jurassic and Cretaceous plutonic rocks are extensively exposed. A thick sequence of ash-flow tuffs and minor tuffaceous sedimentary strata that possibly represent caldera fill composes the central part of the range at Mount Jefferson and separates the two main areas of exposure of pre-Tertiary rocks. Basically, within the area of study, the range is segmented north to south into six relatively discrete geologic and topographic blocks. The White Rock Mountain block lies on the north and is succeeded southward by the Northumberland block, which is one of the largest areas of pre-Tertiary outcrops in the range; the Mount Jefferson block of Tertiary volcanic rocks is next and is followed by the Belmont-Round Mountain block of Cretaceous plutons, the Bald Mountain Tertiary block, and, on the south, the Manhattan block of chiefly Paleozoic rocks.

In the White Rock Mountain and Northumberland blocks, the Paleozoic rocks consist of a series of imbricate thrust sheets containing contrasting lithologies of approximately equivalent ages (Kay and Crawford, 1964). These thrusts are best exposed on the east side of the range between Ikes and Red Rock Canyons, where they are displaced by northwest-striking normal faults of Tertiary age. The structurally highest thrust, which may be equivalent to the Roberts Mountains thrust of north-central Nevada, has emplaced an intricately folded allochthonous assemblage of Ordovician chert and intermediate volcanic rocks on carbonate and transitional assemblage Cambrian to Devonian strata; the latter crop out as windows between Mill and Ikes Canyon and between Northumberland and Water Canyons. Pennsylvanian strata (Wildcat Peak Formation, pl. A1) lap across the allochthon and, in places, are overridden by it, implying that at least part of the thrusting was post-Carboniferous. Kay and Crawford recognized four other thrusts in the autochthonous or parautochthonous rocks; these faults separate sequences of slightly different facies, which generally are homoclinal but locally are recumbently folded, overturned toward the east. A large fold north of Mill Canyon trends northeasterly, whereas one south of Water Canyon trends northwesterly, suggesting varied directions of tectonic transport for the different thrust slices (Kay and Crawford, 1964, p. 448). A large granitic pluton on the west side of the range (older plutonic rocks, pl. A1) intrudes allochthonous rocks along the Lander County line. A much smaller dioritic body of Jurassic age cuts autochthonous rocks in Northumberland Canyon in the heart of the Northumberland mining district.

An antiform or elliptical dome cored by Cretaceous plutons between Belmont and Round Mountain is defined by the attitudes of flanking lower Paleozoic strata, which although discordant in detail, are grossly concordant with the margins of the plutons (Kleinhampl, 1967).

In the Manhattan block, where Ferguson (1924) studied the geology of the Manhattan mining district in detail, lower Paleozoic rocks are complexly deformed and locally isoclinally folded on both a large and small scale. The main block of the Paleozoic strata may be best described as a faulted anticlinorium, in which fold axes trend northwesterly and many of the folds are overturned toward the northeast. The main faults also strike northwesterly and are offset along conjugate faults. A 6-mile (9-km)-long west-northwest-striking core block of the anticlinorium consists of tightly folded and partly overturned Cambrian Gold Hill Formation that extends through Manhattan. Imbricate low-angle faults define

the core block of Cambrian rocks so that the Cambrian is thrust on folded Ordovician to the north and is itself largely overridden by folded Ordovician beds. In the extreme southwestern part of the range, surrounding Willow Spring, there is a 4-square-mile (10.4 km^2) block whose structural trend lies athwart that of the main trend at Manhattan. Rocks exposed in the block include, from east to west, steeply west-dipping lower Paleozoic beds, greenstone porphyry and associated serpentinite, and Candelaria Formation. Permian Diablo(?) Formation appears to be co-deformed with isoclinally folded lower Paleozoic strata and preserved in the cores of several of the smaller folds in the structural block. Nearer Manhattan in the main structural block, several even smaller outcrops of Permian Diablo(?) Formation, considered by us to be exotic slide masses in the Tertiary section, were described by Ferguson (1924, p. 25–26 and pl. 1) as lying unconformably on the lower Paleozoic strata.

The Tertiary rocks in the range are relatively undeformed except for displacement by high-angle faults of late Tertiary age and for structures associated with caldron collapse (Northumberland caldera of McKee [1974] near West Northumberland Canyon) and, possibly, resurgence in a caldron. The Bald Mountain block is a 6-mile (9.7-km)-wide patch of Tertiary rocks separating the Paleozoic section at Manhattan from the plutons at Belmont and Round Mountain and is believed to be a major west-northwest-trending graben or, according to D. R. Shawe (oral commun., Oct. 1979), a caldera. Evidence for the caldron is described in the section on calderas. Whatever the feature, it is aligned approximately parallel with the northwest-trending Kawich-Toiyabe lineament (described with the structure of the Monitor Range) and forms part of the east-trending Pancake Range lineament (Ekren and others, 1976). The core of the Tertiary grabenlike feature, represented by Bald Mountain, has been injected by irregularly shaped dikes and elevated by a series of northwest-striking normal faults. The Mount Jefferson block is considered to be largely underlain by a Tertiary volcanic center, termed the "Mount Jefferson caldera." The great elevation of the vent rocks in the block may be a result of resurgence or arching within the central collapse zone, modified by basin-and-range faulting that gently tilted the resurged caldera westward. The Mount Jefferson caldera has a simple form compared to other calderas in the region.

TOIYABE RANGE

The southern two-thirds of the Toiyabe Range, one of the highest and most prominent ranges in the Basin and Range province, lies within Nye County. The range is more than 100 miles (161 km) long and between 7 and 10 miles (11 and 16 km) wide, except south of North Twin River where it is more than 15 miles (24 km) in width. At its south end, the Toiyabe Range merges with the Shoshone Mountains on the west. The highest point, Toiyabe Dome, has an altitude of 11,788 feet (3595 m), and most of the crest of the range exceeds 10,000 feet (3050 m). The range is elevated and tilted westward by frontal faults of large throw, which cut Quaternary sediments along the west side of Big Smoky Valley. A series of en echelon normal faults of lesser throw, with the west (valley) side down, locally enhance the western boundary of the range. These are part of a group of parallel high-angle faults, displayed as scarps in Quaternary sediments in Reese River Valley, that probably outline a graben in the buried bedrock. This range and the Shoshone Range differ in topographic form from the Toquima Range by extending as essentially unbroken linear mountain chains throughout their lengths. Major differences in geology from north to south in the ranges have generally not led to severe topographic segmentation as in the Toquima Range.

Lower Paleozoic rocks (autochthonous Cambrian and Ordovician quartzite, slate, and limestone), unconformably succeeded by Permian sedimentary strata and inferred late Paleozoic(?) sedimentary and metavolcanic strata (pl. A1) and intruded by several large Cretaceous and Tertiary granitic plutons and dikes, are exposed continuously along the east flank of the range as far south as Peavine Canyon. The relatively gentle western slope of the range and the crest south of North Twin River is underlain by Tertiary ash-flow tuffs that dip gently toward the west but otherwise are little deformed. A 13-mile (21-km)-diameter, nearly circular caldron underlies the highest part of the range between North Twin River on the north and Broad Creek on the south (Speed and McKee, 1976). Farther south, Tertiary silicic ash-flow tuffs and intrusive bodies and associated sedimentary strata and breccia form a structurally complex volcanic center. The inferred Peavine caldera (fig. A32) is part of the center and underlies the southernmost part of the range.

The pre-Tertiary rocks between the Lander County line and San Juan and McLeod Creeks compose a northwest-dipping homocline, intruded by granite, and truncated on the east by a thrust. Means (1962) had demonstrated that the rocks are complexly folded on a small scale and that two major phases of deformation occurred. The first deformation, tentatively assigned to the mid-Paleozoic Antler orogeny, produced a large north-trending syncline overturned toward the east. The second deformation, ascribed to Mesozoic (possibly Sonoman) events, is evidenced by small-scale folds whose axes trend northwesterly; it was accompanied by metamorphism and the pervasive development of cleavage. Discordant plutons were subsequently emplaced. A northeast-striking normal fault, downthrown on the west with dip slip of between 3500 and 4900 feet (1068 and 1494 m) (Means, 1962, p. 96), displaces pre-Tertiary rocks near the crest of the range.

Paleozoic strata between McLead and Broad Creeks generally dip steeply toward the west, and large-scale isoclinal folds were noted by R. C. Speed (oral commun., 1974) in the Paleozoic section at Ophir Canyon. Farther south in the range, from about Jett Canyon to Boyd Canyon, strata dip southwestward and are strongly folded on a small scale. Fold axes which generally trend west-northwest, parallel to and coextensive with those in the Toquima Range to the east, probably record Mesozoic orogenic events. Several thrust faults of

relatively small displacement crop out south of Jett Canyon; some place older beds on younger, whereas others place younger beds on older. A relatively large fold exposed in Wall Canyon is overturned toward the northeast and suggests tectonic transport in that direction.

High-angle faults of probable Mesozoic or Tertiary age disrupt the Paleozoic strata and, in places, are intruded by granitic rocks, one mass of which was radiometrically dated at about 29 m.y. (Speed and McKee, 1976) at Broad Canyon. This mass forms a dikelike body and occupies a fault surface that separated Ordovician rocks from the Tertiary Darrough Felsite. Reverse faults, which are vertical or dip very steeply, are exposed north of North Twin River and in the valley of South Twin River. The northern segments locally emplace late Paleozoic rocks on early Paleozoic and may represent a folded part of the Golconda thrust. Dip-slip Tertiary movement may have affected this thrust. The steepened thrust faults abut an east-striking fault in North Twin River Canyon on which, according to Ferguson and Cathcart (1954), strike-slip movement may have occurred. This fault has been intruded locally by granitic dikes that are presumably correlative with the approximately 29-m.y.-old body in Broad Canyon farther south. The Broad Canyon body intrudes a northeast-striking fault that crosses from Broad to Pablo Canyons and likewise could have undergone horizontal displacement. The fault separates relatively undeformed rocks on the north from intensely deformed rocks on the south. R. C. Speed (written commun., 1975) considered the hypothetical strike-slip faults to coincide with and possibly represent caldron-bounding faults of a caldera from which the Tertiary Darrough Felsite was erupted (fig. A32). Strike-slip movement may thus not characterize these faults at all.

The inferred Peavine caldera, part of a complex Tertiary volcanic center, impinges on the southeastern part of the Toiyabe Range, where segments of the marginal caldron faults may be recognizable. One segment, coincident with Wood Canyon, separates complexly faulted and intruded tuffaceous rocks of the vent complex on the west from early to middle Tertiary rocks, including chiefly the Darrough Felsite on the east. An east-striking segment, just west of the head of Boyd Canyon, separates mostly Permian rocks on the north from the inferred caldron. The structural blocks of Permian rocks may represent either the northern caldron wall or a resurged block near the wall. Another possible segment of the caldron wall and marginal fault may be exposed about 8 miles (12.3 km) southwest of the mouth of Peavine Canyon, just south of Mud Spring (Bank Spring). There, the Tertiary volcanic complex abuts Paleozoic and Mesozoic strata along a contact that might represent the caldron margin but that coincides with the east-striking Pancake Range lineament (Ekren and others, 1976). This Tertiary volcanic complex in the southernmost part of the Toiyabe Range is lapped on the west by the early Miocene Toiyabe Quartz Latite and a subjacent andesite flow. The lapping rocks are relatively undeformed except for a gentle warp into a broad north-plunging syncline whose axis is approximately coincident with Indian Valley, and along which lies a small Quaternary basaltic volcano at Black Mountain.

Northeast-dipping Permian(?) volcanic and clastic rocks are unconformably succeeded by west-dipping Dunlap formation at the southern tip of the range. Limestone assigned to the Luning Formation locally has been thrust onto the Dunlap (Ferguson and Cathcart, 1954).

SHOSHONE MOUNTAINS

The Shoshone Mountains trend about north in Nye County and are from 5 to 8 miles (8 to 13 km) in width. The highest point is Shoshone Peak South, 10,063 feet (3069 m). Summit elevations south of Ione Canyon are between 8000 and 9000 feet (2440 and 2745 m).

The range, underlain chiefly by Tertiary volcanic rocks, is a horst bounded on the east and west by en echelon normal faults. South of Ione, late Quaternary deposits on the east side of Ione Valley are cut by several faults subsidiary to the main frontal fault.

The pre-Tertiary rocks, with the exception of Permian volcanic rocks near the Lander County line and small windows of Luning formation scattered elsewhere in the range, are restricted to a narrow belt that extends southward from Ione for about 12 miles (19 km) along the west side. Between Ione and Grantsville Canyons, Permian to Triassic strata form an east- to southeast-dipping homocline, intruded by Cretaceous(?) granitic rocks, which has been cut by normal faults, both subparallel and transverse to the range front. Silberling (1959) interpreted the structure to be the eastern upright limb of a large-scale overturned anticline that plunges southeastward.

South of Grantsville Canyon, Triassic and Jurassic strata are cut by two thrust faults of relatively small displacement. The Gabbs and Sunrise Formations have overridden Dunlap Formation along the lower fault and, in turn, are overthrust by the Luning Formation. Strata above and below these thrusts are tightly folded along northwest-trending axes. Overturning of some folds toward the southwest suggests that there was a relative southwestward movement of the upper plates (Silberling, 1959, p. 33). This movement is opposite that documented at Manhattan, where, however, there is a similar northwest trend to the major structures that carry into the Toiyabe Range near Wall Canyon.

Nearly all of the high-angle faults that displace the pre-Tertiary rocks are lapped by the Tertiary volcanic sequence. An important exception is a north-striking, steeply east-dipping normal fault, named the Mercury Mine fault by Silberling (1959), that can be traced southward from the drainage of Ione Canyon. This fault separates Jurassic(?) quartzite and Triassic(?) beds on the west from Tertiary rocks on the east and is one of the controlling factors in the localization of quicksilver mineralization in the Ione area.

Sheared basal volcanic rocks of the Tertiary section about 6.5 miles (11 km) south of Grantsville Canyon (Vitaliano and Vitaliano, 1972) may be related to a regionally extensive subhorizontal detachment between

the pre-Tertiary and Tertiary rocks mapped farther west in Mineral County in the Gillis and Gabbs Valley Ranges by F. J. Kleinhampl, R. W. Kopf, and M. L. Silberman (*in* Stewart and Carlson, 1974; Hardyman and others, 1975). The subhorizontal detachment in Mineral County was considered by Kleinhampl, M. L. Silberman, and R. W. Kopf to be genetically associated with major Tertiary strike-slip faults. The detachment was observed to have the form of a fault zone in which Tertiary ash-flow tuff above Mesozoic "basement" rock is intensely sheared and brecciated. The fault zone is also locally bleached. The physical disturbance extends upwards with diminishing intensity into undisturbed Tertiary rocks. Fault gouge is present locally but is thin and generally confined to the basal part of the zone. It is more common for the sheared part of the Tertiary rock to be shattered and to have retained some semblance of its overall original lithic coherence, particularly upward in the sheared zone. In Wildhorse Canyon, Gillis Range, high-angle faults limited to the upper plate form blocks containing strata that commonly dip westward. Also, secondary low-angle faults in the upper plate extend downward to merge with and disappear into the master detachment fault. The entire zone in Mineral County ranges in thickness from several feet to several hundred feet and commonly is at least 100 feet (31 m) thick. Similar features may be present in the southern Shoshone Range. There, the sheared rock, not examined by us, is generally restricted to zones of rhyolite within the basal Cenozoic Mission Spring Formation of Vitaliano and Vitaliano (1972), which unit was deformed and eroded prior to succeeding deposition (Vitaliano and Vitaliano, 1972).

The geology of the Shoshone Range north of about Idlewild Creek to the county line, described in some detail with the Jackson (Gold Park) mining district, was mapped by Bonham (1970), who showed that this part of the range was a mildly faulted horst, like much of the range farther south. Dip-slip movement on the main horst-bounding faults amounted to at least 1400 feet (427 m) to perhaps more than 6000 feet (1830 m). Steep normal faults with dip-slip movement and as much as several hundred feet of throw break some parts of the horst into a mild mosaic of blocks. The strike of these faults generally ranges from east to northeast and locally northwest. Normal faulting that began in the late Oligocene culminated in the main uplift of the range in the late Pliocene and early Pleistocene (Bonham, 1970). Quaternary sediments bounding the range also exhibit fault scarps. Subhorizontal Tertiary volcanic rocks compose most of the horst, and a gently west-tilted block of incompletely exposed Tertiary volcanic rocks bound the horst on the west. The area just west of South Shoshone Peak and the westernmost horst-bounding fault is underlain by relatively thick trachyandesitic to basaltic flows that might define a vent.

SAN ANTONIO MOUNTAINS

The San Antonio Mountains, most of which lie within northern Nye County, are about 30 miles (48 km) in length and as much as 13 miles (21 km) wide. Summit elevations at the north end of the range are greater than 8000 feet (2440 m) but diminish southward to between 6000 and 7000 feet (1830 and 2135 m).

Slightly to moderately deformed Fraction Tuff and younger tuffaceous sediments and subhorizontal dacite porphyry and basalt flows are exposed over most of the range. These rocks are broken by north-striking normal faults downdropped on the west; one of the latter, part of the trace that cuts Quaternary sediments, bounds the San Antonio Mountains on the west.

Deformed and altered Tertiary (Oligocene and Miocene) volcanic rocks crop out beneath the Fraction Tuff near Tonopah and locally along the west side of the range. Nolan (1935b), in a study of the underground workings of the Tonopah district, concluded that these older rocks generally dip toward the west and are cut by three groups of faults: north-south faults of low easterly dip that are restricted to the eastern part of the district; curved, convex-upward faults that dip eastward; and steeper northeast- and northwest-striking normal faults. The complex pattern of faulting may have resulted from intrusion of an igneous cupola immediately beneath the district, evidence for which consists of an alteration halo centered over the cupola in the rocks underlying the district and a corroborating mineral zonation.

Pre-Tertiary rocks are exposed in three areas: in the first, northwest of Liberty Springs, intensely folded and thrust-faulted Mississippian strata are emplaced over and against the Permian Pablo(?) Formation, which consists of volcanic and volcaniclastic rocks. The latter rocks compose a west-trending syncline according to Ferguson and Muller (1949, p. 51). A Late Cretaceous alaskitic pluton in this area intrudes mice schist and limestone at the Hall molybdenum property. In the second area, southwest of Lime Mountain, Mississippian rocks have overridden highly deformed undated strata assigned to the lower Paleozoic (shale and limestone, pl. A1) along a low-angle fault. The Paleozoic rocks are intruded by a Mesozoic(?) granitic pluton farther south. A third small area west of Nevada Highway 8A near Ralston Valley is underlain by highly deformed Ordovician chert and slate.

The main uplift of the range occurred no earlier than the middle Miocene, and movement on high-angle normal faults has continued since at least that time. Just west of the Liberty springs, Tertiary welded tuff sheared along a low-angle fault overlies steeply dipping volcaniclastic strata assigned to the Tonopah Formation. Erosional remnants of other breccia masses that are faulted onto or unconformably overlying older Tertiary rocks also crop out near Maggie Blues (site) on the east side of the range. The exact age and origin of the low-angle fault is not known, but it must postdate the Tonopah Formation. Several origins for similar Tertiary structures described elsewhere in this bulletin include landsliding into calderas and detachment of sections in fault blocks formed between major strike-slip faults. The Siebert Tuff (part of sedimentary strata and interbedded tuffs, pl. A1) south of the crescent dunes has been deformed into open folds whose exact origin is also unclear.

The immediate area of the Tonopah mining district is considered to coincide with a complex Tertiary volcanic center that has been the site of numerous intrusions of rhyolitic to trachyandesitic composition during development of the center. Basalt appears to have erupted last, and Red Mountain north of Tonopah is a basaltic volcano. Another moderately large Tertiary complex at the extreme north end of the range (San Antone district) may also represent a volcanic center characterized by numerous intrusions.

ROYSTON HILLS

The Royston Hills form a crescent-shaped low range, concave toward the southwest, that merges with the Cedar Mountains just west of the county line. The hills, more than 25 miles (40 km) long and from 1 to 5 miles (2 to 8 km) wide, have a maximum relief of about 1000 feet (305 m) above adjacent valleys.

Tertiary volcanic rocks compose about half the exposed bedrock. Subhorizontal Miocene and Pliocene younger(?) mafic rocks (a subunit of dacitic to basaltic rocks, pl. A1) form a caprock on very slightly tilted tuffaceous sedimentary strata and other dacitic to basaltic rocks which, in turn, overlie slightly tilted welded ash-flow tuff and tuffaceous sedimentary rocks (silicic volcanic rocks, pl. A1). The caprock flows locally lie directly on pre-Tertiary metavolcanic and volcaniclastic rocks and chert (Pablo Formation, pl. A1).

The latter pre-Tertiary rocks, which generally strike west, crop out in the southern part of the Royston Hills. Farther north, the Luning Formation is folded into a broad, west-plunging syncline with a steep southern flank and locally is involved in minor thrusting; the axis of the fold, if projected westward, would coincide with that of a large syncline mapped by Ferguson and Muller (1949) in the Cedar Mountains. Small dioritic bodies have intruded and locally metamorphosed the Luning Formation.

PARADISE RANGE

The Paradise Range in the extreme northwestern part of Nye County is a north-trending range merging northward into the Desatoya Mountains several miles north of the county line and separated from the Cedar Mountains on the south by low hills and a broad dissected valley. The crest of the main 24-mile (38-km)-long segment in Nye County lies generally above 7000 feet (2135 m), and the highest peaks, Paradise and Sherman Peaks, nearly 8700 feet (2657 m) in elevation, are in the south and central parts, respectively. Relief is greatest on the west next to Gabbs and Lodi Valleys, the floors of which lie just below 5000 feet (1525 m) and nearly everywhere are separated from the mountainous terrain by basin-and-range normal faults. The west edge of Ione Valley on the east is marked generally by the 6600-or 6800-foot (2013- or 2075-m) contour and is not everywhere a fault.

The extreme southern, eastern, and northern parts of the Paradise Range are underlain by Tertiary intermediate lavas and rhyolitic welded tuffs that presumably once extended across the site of the range, but were later elevated and eroded to expose folded and thrust-faulted Permian(?) and Mesozoic rocks consisting of greenstone, volcaniclastic rocks, carbonate strata, and minor clastic rocks including shale, siltstone, conglomerate, arkose, and quartzite. Plutonic rocks cut the Permian(?) and Mesozoic section and range in composition from granite to gabbro; granodiorite predominates. Dikes of varied compositions and uncertain age, probably late Mesozoic or early Tertiary, cut the plutons as well as the other pre-Tertiary rocks. Many of the dikes compose a 5-mile (8-km)-long swarm that extends southeastward across the range from near Gabbs.

Several major north-northeast- to north- northwest-striking normal faults define the Paradise Range and break it into northward-elongate blocks. The faults are parallel to en echelon, and the blocks west of the faults are downthrown. The eastern homoclinal block dips eastward and is itself partly cut by a similar fault of lesser throw whose trace passes near Brunton Pass and Antelope Spring. Deformed pre-Tertiary rocks are exposed along the west base of the homocline beneath tilted but otherwise relatively undeformed Tertiary welded tuff. The fault defining the west side of the block extends from the south near Pactolus to cross the range just west of Paradise Peak and splays northward into two branches near the head of McGery Canyon. Tilt of the main western block, here termed the "Gabbs block," is obscured by north-northwest-trending folds in the pre-Tertiary strata. A general westward to southwestward dip might be construed, however, from the average west dip of the Paradise thrust as indicated by Vitaliano and Callaghan (1963, cross sections) and the present restriction of Tertiary rocks to the southwestern part of the range.

The compositions of the Permian(?) Pablo and Triassic Excelsior Formations record the earliest tectonic events of the area and are described in the stratigraphy section of the report. These strata compose part of a suite of rocks that appear to have evolved in an area west of the Paleozoic and early Mesozoic continental margin and perhaps in an emerging island-arc setting, where influxes of continent-derived sediments sporadically inundated the largely subsea volcanic terrain. The age of rocks is only inferred (see Excelsior and Pablo Formations, Mesozoic stratigraphy), and R. C. Speed (written and oral commun., 1970-74; 1977a) considers them to be in part possibly Jurassic and autochthonous. In any event, they are in the upper plate of a thrust (South thrust of Vitaliano and Callaghan, 1963) that has overridden the Paradise thrust of Vitaliano and Callaghan (1963). The Paradise thrust emplaced Late Triassic beds (Luning Formation) over strata as young as the Lower and Middle Jurassic Dunlap Formation and may correlate with the Cinnabar Canyon thrust of the Pilot Mountains (Ferguson and Muller, 1949, p. 35; also see Luning thrust in Speed, 1977b); whereas the South thrust may be an extension of the thrust faults farther west defined as the East Ridge thrust of the Pilot Mountains and the New York Canyon thrust of the Gabbs Valley Range (Ferguson and Muller, 1949, p. 26–29 and 35–37). Both the Paradise and South thrusts

probably formed during the Late Jurassic Nevadan orogeny, presumably along with the large north-northwest-striking open and isoclinal folds in the lower plate of the Paradise thrust and, perhaps, with many of the folds in the upper plate. Evidence for earlier major orogenic events, like the Early Triassic Sonoma orogeny and the pre-Sonoman Antler event were not distinguished in the area. Cretaceous(?) to Eocene plutonism marked the end of discernible major thrust faulting; however, Kral (1951, p. 96–97 and 111) and Humphrey and Wyatt (1958, p. 40, 43) stated that low-angle faulting followed emplacement of granitic rocks near Ellsworth as well as in the Lodi Hills on the west. This faulting may be relatively minor and possibly related to doming and (or) major strike-slip faulting in the Tertiary which has been described nearby in Soda Spring Valley (Ferguson and Muller, 1949; Nielsen, 1964, and Shawe, 1965).

The obvious major normal faults cut the Tertiary volcanic rocks. Movement on some of the major faults outlining the range has affected Holocene sediments; scarps exist in Quaternary alluvium at many places along the west side of the range and in one place off the southeastern margin of the range.

LODI HILLS

The isolated 24-square-mile (62 km^2) circular mountainous area known as the Lodi Hills, lying about 7 miles (11 km) north of Gabbs, exhibits structures and a stratigraphic section that are chiefly extensions of those mapped nearby in the Paradise Range. (For details, see the section of this bulletin on Lodi District). The deformed Upper Triassic Luning Formation is cut by several northeast- to northwest-striking steep faults. Siliceous clastic strata, carbonate beds, and greenstone(?), provisionally assigned to the Middle Triassic(?) Excelsior Formation by us and to the Jurassic by R. C. Speed (see the section of this bulletin on Geology and Structure of the Ranges—Paradise Range), are thrust over Excelsior containing a plutonic(?) phase and also over the Luning in the northwest part of the Lodi Hills. The Luning is shown as thrust over the 49-m.y.-old Illinois granitic pluton on the basis of data supplied by others. This thrust may represent a relatively minor displacement (see the section of this bulletin on Geology and Structure of the Ranges—Paradise Range).

The form of the Lodi Hills is apparently not directly controlled by bounding basin-and-range normal faults, although one such fault defines the north edge of the mountain, and Tertiary volcanic rocks north of the fault are downthrown. This fault or an extension of it may be partly concealed beneath alluvium along the north edge of the Quartz Mountain district and could be an effective northern limit to the known mineralized zone of the southern block. Magnetic data indicate that the concealed part of the dioritic pluton at the south end of the mountain is of great extent southwest of the outcrop (Davis and others, 1977) and belies the presence of a buried northwest-striking fault bounding the Lodi Hills on the west.

MONTE CRISTO MOUNTAINS

The Monte Cristo Mountains lie athwart the extreme west end of northern Nye County and extend north and southwest for several miles into the adjacent counties. The range consists of a generally north-trending mountain block about 17 miles (27 km) long and 3 miles (5 km) wide, the central 8 miles (13 km) and highest part (6635 ft or 2024 m) of which is in Nye County. The range tends to merge on the north outside the county with several ranges and groups of hills that have variable trends. On the south, the range arcs to the southwest through a 7-mile (11-km)-long segment of appreciably lower elevation before abruptly terminating just outside the county.

The range within the county is underlain on the east by Tertiary rocks faulted against and partly lapping westward onto Mesozoic(?) rocks that form the core and western part of the mountains. The fault between Tertiary and Mesozoic rocks is inferred to be a western-bounding caldron-margin fault (Ekren and Byers, 1978), and if so, the same Tertiary section may not be present in the downdropped block just west of the range. The Mesozoic(?) rocks consist of a dioritic pluton (granodiorite, Ekren and Byers, 1978) that has intruded deformed Triassic Excelsior Formation or equivalent strata. The Tertiary rocks east of the fault include silicic volcanic rocks (pl. A1) composed chiefly of rhyolitic ash-flow tuff and lava and intrusive bodies of intermediate composition (dacitic to basaltic rocks, pl. A1). A small Tertiary rhyolite body (silicic volcanic rocks, rhyolitic to trachyandesitic domes, plugs, and breccias, pl. A1) 2.3 miles (3.7 km) southeast of the main peak in the range and some of the bodies of intermediate composition may be confined to the inferred caldron margin (Ekren and Byers, 1977; 1978).

The general impression is given of an eastward tilt (caldronward) to the units composing the range. Several prominent normal faults with a strong north-trending component cut the Mesozoic and Tertiary rocks, and several well-exposed, range-bounding splayed faults mark a zone along the west side of the range and partly cut unconsolidated Quaternary valley fill deposits (chiefly fanglomerate) as well as bedrock. One fault partly bounding the west edge of the range cuts southeastward into the range and appears to cross the pluton; it may continue concealed beneath Quaternary alluvium to a termination against a hypothesized concealed major northeast-striking range-bounding and (or) caldron-bounding fault. A low, nearly featureless, gently east-tilted block of Tertiary tuffaceous fluviolacustrine beds just east of the Monte Cristo Mountains is of comparable size to the mountain block and is in part separated from it by the hypothesized major fault mentioned above. The trace of this fault is largely concealed beneath ubiquitous Holocene(?) eolian and alluvial deposits. A south-trending strand of the fault locally exhibits scarps preserved from the 1954 earthquake according to Ekren and Byers (1978). These workers indicated left-lateral movement on the strand and the main fault, as well as major downthrow on the west that tilt the Monte Cristo block and the inferred caldron-bounding fault eastward.

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Comment

This volume (Bulletin 99A) and map (pl. A1) concludes the general geologic description of northern Nye County. The Nevada Bureau of Mines and Geology published Bulletin 99B, a companion volume by the same authors, in 1984. That volume describes the mineral resources of northern Nye County. The two reports complement one another, and when used together should prove invaluable to further geologic studies of the region and to the discovery of additional mineral deposits.

Nevada Bureau of Mines and Geology

Bulletin 99A

Addendum to References

(cut on dotted line and attach to page 172)

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Comment

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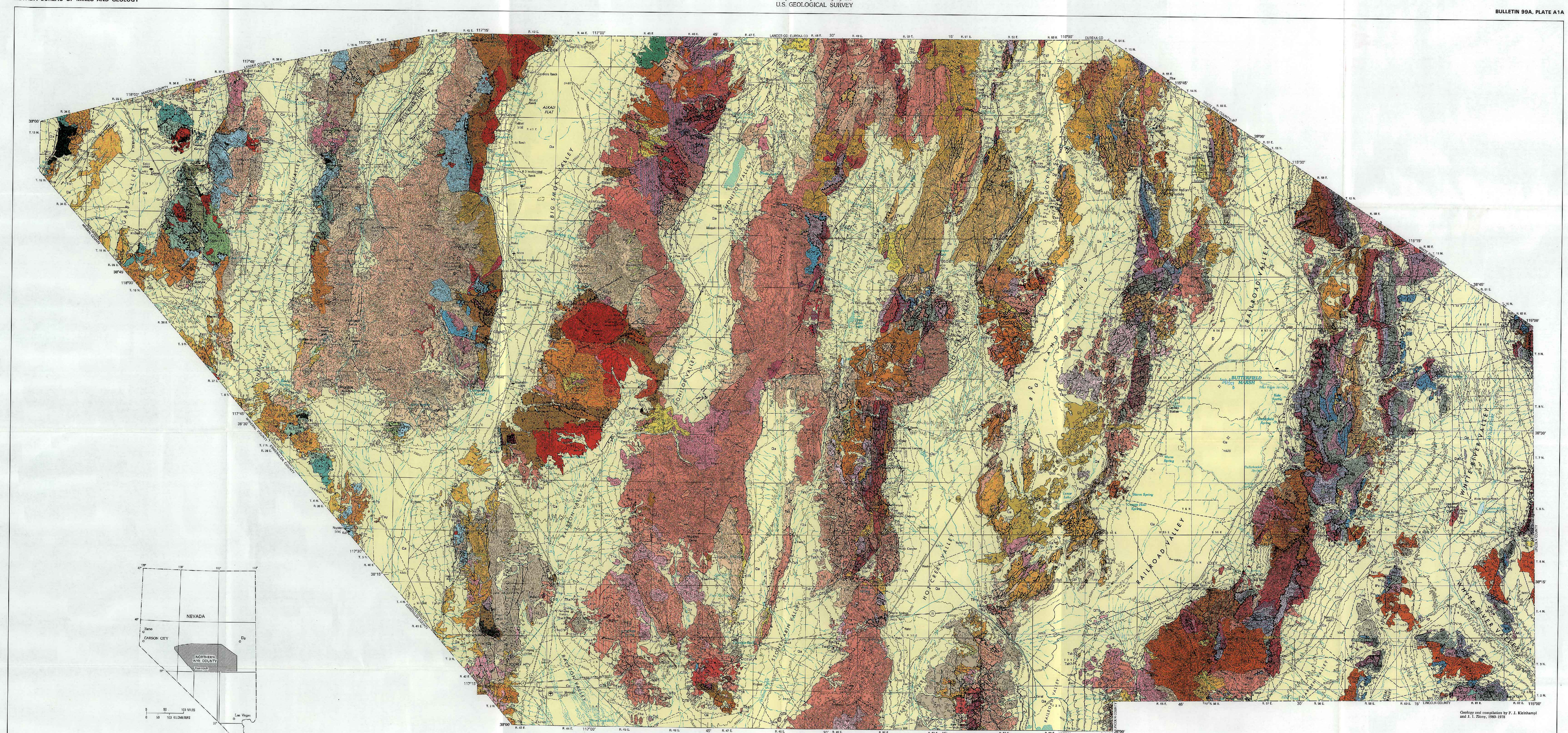
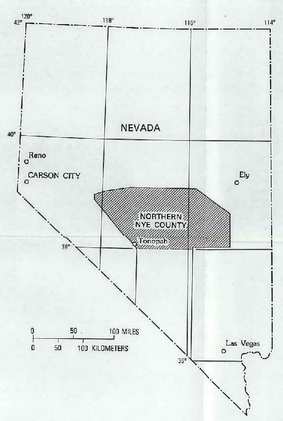
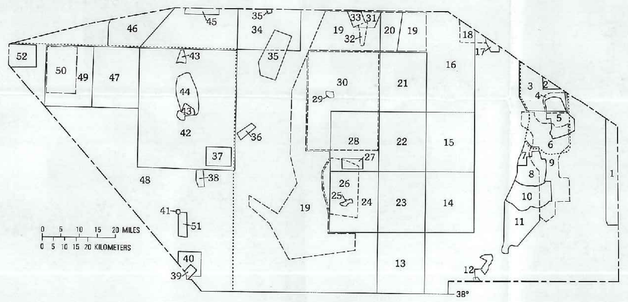
Prepared cooperatively by the
U.S. GEOLOGICAL SURVEY





INDEX MAP OF NEVADA SHOWING LOCATION OF NORTHERN NYE COUNTY



INDEX MAP OF NORTHERN NYE COUNTY, NEVADA, SHOWING SOURCES OF GEOLOGIC MAP DATA[1]

(Numbers correspond to those found on index map. Complete references listed in references cited.)

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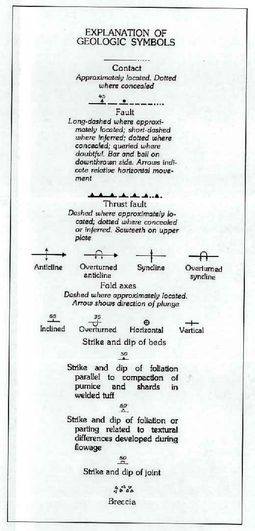
[1]In most cases, maps of others have been generalized or modified.



GEOLOGIC MAP OF NORTHERN NYE COUNTY, NEVADA

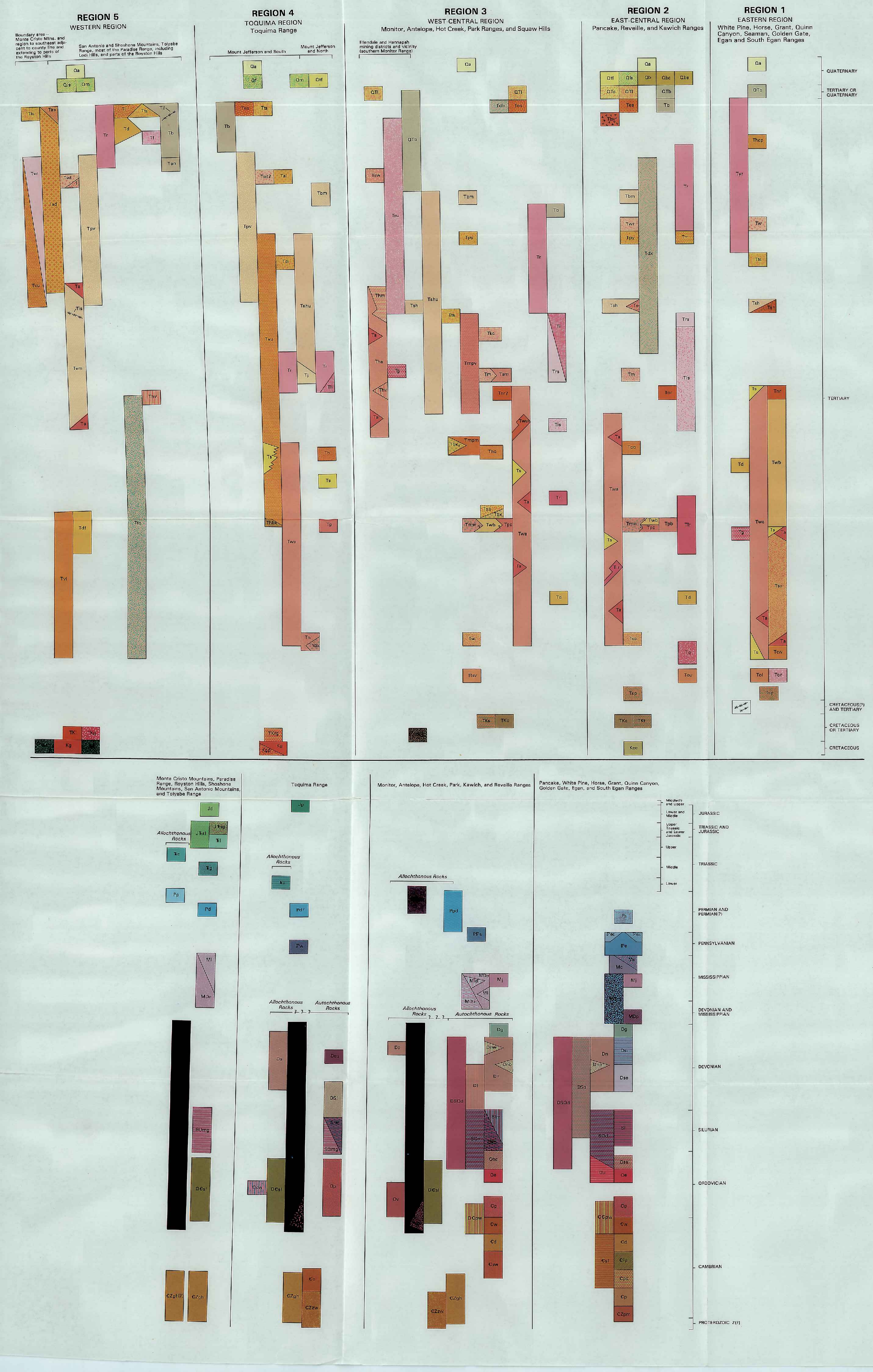
by Frank J. Kleinhampl and Joseph I. Ziony

Explanation to geological units on plate A1B

NEVADA BUREAU OF MINES AND GEOLOGY

Prepared cooperatively by the U.S. GEOLOGICAL SURVEY

BULLETIN 99A, PLATE A1B



Th TUFF OF HOODOO CANYON—Crystal-rich ash-flow tuff about 31 m.y. old; includes minor overlying tuffaceous sedimentary rocks, in vicinity of White Rock Mountain

Ts TUFFACEOUS SEDIMENTARY ROCKS—Lacustrine mudstone, shale, siltstone, and some coarser clastic strata that are in part fluviatile. Limestone not seen

Tp PANCAKE SUMMIT TUFF AND OVERLYING TUFF—Crystal-rich rhyolite ash-flow tuffs. Includes tuff of Stoneberger Canyon of McKee (1972; 1976). Radiometric age about 31 to 32 m.y.

REGION 3 (West-Central Region)

MONITOR, ANTELOPE, HOT CREEK, PARK RANGES, AND SQUAW HILLS

Ellendale and Hannapah mining districts and vicinity (southern Monitor Range)

QTl LANDSLIDE DEPOSITS—May or may not have originated like exotic slide blocks, (unit Tes) elsewhere

QTb BASALTIC AND ANDESITIC ROCKS—The uppermost of a thick series of flows was dated at 18.9 ± 1.5 m.y. at Thunder Mountain (northeast part of Tonopah 15-minute quadrangle) by Armstrong and others (1972) but could be younger (see text). Another unit was dated at 10.2 ± 0.9 m.y. in Moores Station quadrangle, Pancake Range

Tru RHYOLITES, UNDIFFERENTIATED—Dome and plugs of rhyolite of uncertain age relations with rocks in vicinity of Ellendale and Hannapah mining districts. May be of more than one age, with possible range of about 16 to 26 m.y.

Tsw TUFF OF SAULSBURY WASH—Rhyolitic welded ash-flow tuff. Radiometric age 21.6 ± 0.6 m.y. Lies with slight angular discordance across a surface of low to moderate relief cut into underlying volcanic rocks. May include tuff of Clipper Gap of Gromme, McKee, and Blake (1972) in northernmost exposures near Antelope Spring

Tq QUARTZ DIORITE—In southern Monitor Range only—age about 26 m.y.

The, Thm, Thv, Ta VOLCANIC ROCKS OF HANNAPAH AND ELLENDALE MINING DISTRICTS—The, rhyolitic to quartz latitic welded ash-flow tuffs, vent tuffs, air-fall tuffs, pumice flows, and intercalated sedimentary rocks, undifferentiated. Some rocks shown as unit. The may be correlative with thick undifferentiated ash-flow tuffs (Twa) of the Hunts and McCann Canyons area, northern Monitor Range. Thm, tuffs of McKinney Tanks; air-fall tuffs and incipiently welded tuffs and sedimentary rocks; tuffaceous and lacustrine beds intercalated with fluviatile strata. Not mapped separately everywhere from unit The. Tuffaceous rocks common, but limestone not seen and may be absent. Thv, tuffs of Hannapah and probable vent rocks; chiefly welded, rhyolitic to quartz latitic; some agglutinates. Relatively discrete compared to the other volcanic rocks of Hannapah and Ellendale mining districts and vicinity. Not mapped separately everywhere. Ta, andesitic to dacitic rocks in flows, dikes, and small irregular bodies. Commonly propylitized. Age uncertain; in part may be as young as the basaltic and andesitic rocks that form the capping unit in the area (see unit QTb, above), but generally believed to be older. Includes small bodies of dacite and (or) latite near Thunder Mountain

MONITOR, ANTELOPE, HOT CREEK, PARK RANGES, AND SQUAW HILLS

QTl LANDSLIDE DEPOSITS—May or may not have originated like exotic slide blocks, unit Tes, below

Tdb DEBRIS BEDS—Tuffaceous debris (near Tybo) of Quinlivan and Rogers (1974)

Tes EXOTIC SLIDE BLOCKS—Generally monolithologic and believed to have originated as blocks either slumping into collapse zones (moats) from rims that bound calderas or shearing out along transcurrent faults. The blocks, therefore, are related to differing ages of development of Tertiary volcanic terrain and are as diverse in time of emplacement as they are in lithology. Generally only the largest blocks are shown

Tbm BATES MOUNTAIN TUFF—Rhyolitic ash-flow tuff; radiometric age 22.8 ± 0.9 m.y. Mapped with unit Tshu in the Monitor Range

Tpy YOUNG TUFFS OF THE PANCAKE CALDERA COMPLEX—Silicic to intermediate ash-flow tuffs recognized chiefly in the Hot Creek Range. Includes, from youngest to oldest, informally named granite-weathering tuff, clinkstone-weathering tuff, tuff of Black Beauty Mesa, tuff of Buckwheat Rim, tuff of Buckskin Point, and tuff of Lunar Cuesta. Last-named unit has mean age of 24.6 ± 0.75 m.y.

Tr RHYOLITE—In domes, plugs, and flows. Associated locally with pumiceous material; mostly phenocryst-poor and lithified. Mapped only near Dianas Punch Bowl Spring, Monitor Valley, and near Hunts Canyon, Monitor Range. Probably correlative with many of the nearby rhyolites in the southern Monitor Range that are mapped with the rhyolites, undifferentiated (Tru)

Tb MAFIC ROCKS—Lavas; mapped only in Morey Peak quadrangle just southwest of Fish Lake, Hot Creek Range

Tsh, Tshu, Tts SHINGLE PASS TUFF AND STRATIGRAPHICALLY ADJACENT ROCKS—Tsh, Shingle Pass Tuff; crystal-poor rhyolitic ash-flow tuffs about 25.1 ± 1.0 m.y. old. Tshu, ash-flow tuffs, undifferentiated. Age range about 23 to 29 m.y. In Morey Peak quadrangle, Hot Creek Range, includes from top to bottom, the tuff of Lunar Cuesta, Shingle Pass Tuff, and the young tuffs of Moores Station area, Needles Range(?) Formation (of minor extent), unnamed ash-flow tuffs, and local bedded tuff and sedimentary strata. In the central part of the Monitor Range locally includes the Bates Mountain Tuff and the tuff of Clipper Gap of Gromme, McKee, and Blake (1972). Tts, tuffaceous sedimentary rocks; mapped only in Tybo quadrangle, Hot Creek Range

Tkc TUFF OF KILN CANYON—Chiefly rhyolitic to quartz latitic ash-flow tuff. Age 25.1 ± 1.0 m.y. (biotite); 24.1 ± 0.9 m.y. (sanidine)

Tm, Tam MONOTONY TUFF AND LAVA—Tm, Monotony Tuff; rhyolitic and quartz latitic ash-flow tuff (26.5–27.0 ± 0.8 m.y.). Tam, andesitic lavas and breccias underlying and locally overlying Monotony Tuff. Includes tuff and sedimentary strata

Tmpy YOUNG TUFFS OF MOORES STATION AREA—Includes tuff of Orange Lichen Creek, tuff of Pott Hole Valley, and, at base, tuff of Crested Wheat Ridge (28.6 m.y. old). Chiefly rhyolitic welded tuffs

Tmpm, Tbx MIDDLE TUFFS OF MOORES STATION AREA—Tmpm, rhyolitic to quartz latitic ash-flow tuffs and tuffaceous sedimentary rocks and breccias. Includes tuffaceous rocks of Slanted Butte, tuffs of Moores Station Buttes (30.7 m.y.), tuff of the Needles (30.3 m.y.), tuff and debris beds and other underlying tuffs and minor sedimentary rocks. Tbx, brecciated and faulted tuffs of Chaos Creek and tuff of Williams Ridge and Morey Peak

Tnr? NEEDLES RANGE(?) FORMATION—Dacitic welded ash-flow tuff mapped only in one small outcrop in Pritchards Station quadrangle

Ti, Trs INTRUSIVE ROCKS, UNDIFFERENTIATED, AND RHYOLITE OF BIG SAND SPRINGS VALLEY—Ti, primarily rhyolite but also rhyodacitic and andesitic dikes and irregular small bodies. Trs, rhyolite of Big Sand Springs Valley, 25.8 ± 1.3 m.y. old, and other rhyolites; mapped only in southeast part of Moores Station quadrangle and in Hot Creek Range west of Tybo. Includes bodies that intrude rocks as young as tuff of Kiln Canyon, Hot Creek Range, Tybo quadrangle

Tis INTERMEDIATE TO SILICIC LAVAS AND INTRUSIVE BODIES—Primarily rhyodacitic to andesitic rocks in dikes, sills, and flows; especially near U.S. Highway 6 in vicinity of Hot Creek and Kawich Ranges. Ages uncertain

Thc TUFF OF HOT CREEK CANYON—Rhyolitic to quartz latitic welded tuff. 30.0 ± 0.9 m.y. old

Tgg, Tbx GILMORE GULCH FORMATION AND RELATED ROCKS—Tgg, Gilmore Gulch Formation. Chiefly clastic sedimentary strata, with some limestone and locally underlying megabreccia and a little welded tuff. Overlies tuff of Williams Ridge and Morey Peak in the Tybo quadrangle, Hot Creek Range. Tbx, megabreccia and welded tuff as much as 1000 ft thick (separated locally from unit Tgg)

Tmw, Twb, Tpc ASH-FLOW TUFFS—Tmw, tuff of Williams Ridge and Morey Peak, rhyolitic to rhyodacitic composition, chiefly welded ash-flow tuff 30.5 ± 32.7 m.y. old. Twb, Windous Butte Formation; rhyolitic to quartz latitic welded tuff, mean age 30.7 m.y. Brecciated locally. Tpc, Pancake Summit Tuff and tuff of Cottonwood Canyon. Rhyolitic to quartz latitic ash-flow tuffs chiefly in Pritchards Station quadrangle. Mean age of tuff of Pancake Summit is 32 m.y. and age range of tuff of Cottonwood Canyon is 30.1–30.3 m.y. Units may intertongue

Tri SILICIC ROCKS—Chiefly as dikes in Moores Station quadrangle, Hot Creek Range, and larger irregular bodies elsewhere

Td ROCKS OF INTERMEDIATE COMPOSITION—Chiefly latitic lavas and some welded vitric tuffs; especially extensive and thick in Pritchards Station quadrangle, Hot Creek Range, and very thin in adjacent Moores Station quadrangle. Correlative with unit Td of Pancake Range

Tsc STONE CABIN FORMATION—Rhyolitic welded ash-flow tuff, especially extensive in Pritchards Station quadrangle, but not present in Moores Station quadrangle to south

Twa, Ta, Ts, Twal VOLCANIC ROCKS—Twa, ash-flow tuffs and minor intermediate lavas, undifferentiated. May include several hundred feet of intermediate lavas in Monitor Range west of Antelope and Dry Valleys. Section thousands of feet thick in Monitor Range where correlatives are uncertain or unknown except for one unit whose age is given below. In Hot Creek Range includes rocks as young as tuff of Sixmile Canyon and other units, like tuff of Red Rock Canyon, tuffs of Chaos Creek, and the old tuffs of the Pancake caldera complex (about 30 m.y. old; see elsewhere for description), tuff of Twin Peaks (Tybo quadrangle only), and tuff of Black Rock Summit. May locally include tuffs as old as the tuff of Williams Ridge and Morey Peak (30.5–32.7 m.y.) and the Stone Cabin Formation (mean age 34.1 m.y.). Radiometric age ranges from about 30 to about 35.3 m.y. except in Monitor Range where the youngest known age is about 26.4 m.y. (rocks capping crest south of Clear Creek Canyon). Ta, andesitic rocks; chiefly flows. Ts, tuffaceous sedimentary rocks. Twal, rhyolitic to rhyodacitic intrusive bodies believed by H. E. Cook (written commun., 1966, p. 44–47) to be genetically related to and possibly feeders for, nearby ash-flow tuffs in Hot Creek Range

Ttsv TUFFACEOUS ROCKS, SEDIMENTARY STRATA, AND RHYOLITIC BODIES, UNDIFFERENTIATED—Includes bedded tuff, tuffaceous sedimentary strata, and some lacustrine limestone; rhyolitic bodies predominate near Dobbin Summit, Monitor Range. Near Pritchards Station, rhyolite is 37.2 ± 1.3 m.y. old, and except for some volcanic rocks in the Toiyabe Range, is the oldest dated Tertiary volcanic rock of northern Nye County. Tuffaceous sandstone, siltstone, lacustrine limestone, and bedded tuff are common in the hills east of Pritchards Station

DIORITIC ROCKS—Fine- to medium-grained biotite diorite near Stargo Spring, Dobbin Summit area, Monitor Range, and biotite hornblende porphyry in the Ellendale mining district, southern Monitor Range. Locally altered and mineralized

TKs, TKc SEDIMENTARY ROCKS—TKs, fine to coarse clastic rocks; locally includes limestone. TKc, conglomerate

REGION 2 (East-Central Region)

PANCAKE, REVEILLE, AND KAWICH RANGES

Qtf TUFA DEPOSITS—Chiefly calcareous material, in aprons and around orifices of springs

Qls YOUNGER LANDSLIDE DEPOSITS

Qb, Qbc, Qba BASALTIC ROCKS—Qb, basalt in flows. Qbc, basaltic scoria in cones and in mounds. Qba, basaltic ash and scoria, undifferentiated

QTc VOLCANOGENIC CLASTIC ROCKS—Chiefly conglomerate and sandstone. Mapped in Moody Peak quadrangle, Pancake Range

QTl LANDSLIDE DEPOSITS

QTb BASALT, ANDESITE, AND LATITE—May prove to be part of much older rocks of intermediate composition, unit Td

Tes EXOTIC SLIDE BLOCKS—Each is generally monolithologic; believed to have originated as blocks either slumping into collapse zones (moats) from rims that bound calderas or shearing out along transcurrent faults. The blocks, therefore, are related to differing ages of development of Tertiary volcanic terrain and are as diverse in time of emplacement as they are in lithology. Generally only the largest blocks are shown

Tb BASALT—Olivine bearing in Reveille Range, where unit is 5.7 ± 0.2 m.y. old

Tbx BRECCIA—Mapped near junction of Eureka, Nye and White Pine Counties

Tbm BATES MOUNTAIN TUFF—Rhyolitic ash-flow tuff, mapped west of Duckwater in Pancake Range

Twr WELDED TUFFS AND MISCELLANEOUS ROCKS OF THE REVEILLE RANGE—Welded ash-flow tuffs, air-fall tuffs, and tuffaceous sedimentary strata; about 21–25 m.y. old. Includes tuff of White Blotch Spring at base, a rhyolitic ash-flow tuff. May be partial age equivalent of young tuffs of the Pancake caldera complex, unit Tpy, described below

Tpy YOUNG TUFFS OF THE PANCAKE CALDERA COMPLEX—Silicic to intermediate ash-flow tuffs, chiefly in Reveille Range and southern Pancake Range (south of U.S. Highway 6). Includes from youngest to oldest, informally named granite-weathering tuff, clinkstone-weathering tuff, tuff of Black Beauty Mesa, tuff of Buckwheat Rim, tuff of Buckskin Point, and tuff of Lunar Cuesta. Radiometric ages range from about 23 to 25 m.y.

Tr SILICIC TO INTERMEDIATE LAVAS AND INTRUSIVE BODIES—Mapped in the Reveille and Lunar Crater quadrangles. Includes quartz latite dikes 18.7 ± 0.8 m.y. old in the Reveille Range and quartz latite and andesite lavas and breccias about 22–24 m.y. old in the Lunar Crater quadrangle

Trr ROCKS OF THE REVEILLE RANGE—Silicic tuffs and intrusive bodies and sedimentary strata, all about 24 to 25 m.y. old, such as informally named rhyolite and tuff of Streuben Knob and tuff of northern Reveille Range

Tsh, Te SHINGLE PASS TUFF AND TUFF OF BALD MOUNTAIN—Tsh, Shingle Pass Tuff; crystal-poor rhyolitic welded ash-flow tuffs. Includes tuff of Arrowhead, in the Reveille Range, and Bates Mountain Tuff, locally west of Duckwater in the Pancake Range. Te, tuff of Bald Mountain. Resembles Shingle Pass Tuff, but correlated with a unit of the Bald Mountain caldera in the Groom Range, Lincoln County. Mapped only in Reveille quadrangle

Tdx DEBRIS—A melange possibly formed between 18.5 and 26 m.y. ago, and containing volcanic rocks older than unit Trr. Mapped in southernmost Pancake Range and Reveille Range

Trs RHYOLITE OF BIG SAND SPRINGS VALLEY—Chiefly in Portuguese Mountain quadrangle, Pancake Range; age 25.8 ± 1.3 m.y.

Tm MONOTONY TUFF—Rhyolitic and quartz latitic ash-flow tuff; includes undifferentiated tuff and breccia in the Portuguese Mountain quadrangle. Radiometric age 26.5–27.0 ± 0.8 m.y.

Tnr NEEDLES RANGE FORMATION—Dacitic ash-flow tuff; mapped only in northwest part of Sand Springs 15-minute quadrangle, Pancake Range

Tis INTERMEDIATE TO SILICIC LAVAS AND INTRUSIVE BODIES—Includes rhyodacite of Bellehelen Lakes of Gardner and others (1980), a large 26.4 ± 1.3-m.y.-old dome and associated flows of porphyritic rhyodacite in Kawich Range

Tpo OLD TUFFS OF THE PANCAKE CALDERA COMPLEX—Silicic ash-flow tuffs; chiefly in southern Pancake Range. Includes, from youngest to oldest, informally named tuff of Palisade Mesa (29.9 m.y) and tuff of Halligan Mesa (30.3 m.y.). May locally include tuff of Black Rock Summit

Tmw, Twb, Tpc, Tpb SILICIC ASH-FLOW TUFFS—Tmw, tuff of Williams Ridge and Morey Peak, rhyolitic to rhyodacitic in composition; age range 30.5 to 32.7 m.y. Also includes tuff of Pritchards Station in Portuguese Mountain quadrangle, Pancake Range. Twb, Windous Butte Formation; rhyolitic welded ash-flow tuff; mean age 30.7 m.y. Tpc, Pancake Summit Tuff and tuff of Cottonwood Canyon. Rhyolitic to quartz latitic ash-flow tuffs; chiefly in vicinity of Moody Peak quadrangle, Pancake Range. Mean age of Pancake Summit Tuff is 32 m.y. Tpb, Pancake Summit Tuff and Windous Butte Formation, undivided; so mapped in Moody Peak quadrangle, Pancake Range

Tlr RHYOLITE LAVA—Mapped mainly near Portuguese Mountain

Twa, Ta, Tlr, Ts VOLCANIC ROCKS—Twa, chiefly crystal-rich rhyolitic welded ash-flow tuffs. Includes tuff of Big Round Valley and tuff of Black Rock Summit in Pancake Range, and unnamed ash-flow tuffs and tuffaceous rocks, chiefly in Kawich Range. Some Twa is in the upper plate of a low-angle fault at Portuguese Mountain. Ta, andesitic rocks; chiefly lavas and minor intrusive bodies. Tlr, chiefly silicic lava flows and small intrusive bodies. Ts, bedded tuff, tuffaceous sedimentary strata, and breccia; underlies tuff of Pritchard Station in Portuguese Mountain

Tsc STONE CABIN FORMATION—Rhyolitic welded ash-flow tuff. Mean age 34.1 m.y.

Td ROCKS OF INTERMEDIATE COMPOSITION—Includes dacitic and quartz latitic lavas and feeders; chiefly in Moody Peak quadrangle and Duckwater areas of the Pancake Range. Also includes quartz latite lava in Portuguese Mountain quadrangle, Pancake Range

Tq RHYOLITIC LAVA OF PORTUGUESE MOUNTAIN—Quartz-crystal-rich rhyolitic lava, lithic tuff, and breccia, and phenocryst-poor rhyolitic lava and rhyodacitic lava in vicinity of Portuguese Mountain, Pancake Range. Includes dikes locally

Tov OLDER VOLCANIC ROCKS—Chiefly lavas and intrusive bodies of silicic to intermediate composition and some ash-flow tuffs, mainly in Portuguese Mountain quadrangle, Pancake Range. Consists of tuffs and tuffaceous sedimentary strata in the Duckwater Hills. Mapped as unit Ttsv in region to the west

Tsp SHEEP PASS FORMATION

TKc, TKt SEDIMENTARY ROCKS AND TUFFS—TKc, conglomerate and (or) breccia. TKt, volcanogenic sedimentary rocks and tuffs; locally includes lacustrine limestone

Knc NEWARK CANYON FORMATION—Sandstone, shale, and conglomerate and minor mudstone. Chiefly red brown, some gray beds. One dinosaur bone of nondefinitive type found (Dixon, oral commun., 1970)

REGION 1 (Eastern Region)

WHITE PINE, HORSE, GRANT, QUINN CANYON, SEAMAN, GOLDEN GATE, EGAN, AND SOUTH EGAN RANGES

QTb BASALT, ANDESITE, AND LATITE

Thcp HORSE CAMP FORMATION OF MOORES (1964)—An assemblage of sedimentary rocks, tuffs, and slide blocks, including conglomerate, silty and sandy volcaniclastic strata, breccia, tuffs, and limestone and zeolite beds. Major monolithologic breccia and landslide masses within the Horse Camp are mapped as the contained major Paleozoic or Tertiary map unit in blocks surrounded by low-angle faults

Tvr RHYOLITIC TO LATITIC FLOWS AND PLUGS

Tw RHYOLITIC WELDED ASH-FLOW TUFFS—Age in part 22.6 ± 0.7 m.y. Mapped in vicinity of Quinn Canyon

Tts SEDIMENTARY ROCKS AND TUFFS—White tuffaceous lacustrine deposits, rhyolitic air-fall and ash-flow tuffs. Mapped in vicinity of Quinn Canyon

Tsh, Tsn SHINGLE PASS AND NEEDLES RANGE FORMATIONS—Tsh, Shingle Pass Tuff. Crystal-deficient rhyolitic welded ash-flow tuffs. Radiometric age 23.8 to 25.1 ± 1.0 m.y. Tsn, Shingle Pass(?) and Needles Range Formations, undivided, and other ash-flow tuffs. Mapped only south and southeast of Grant Range

Td RHYODACITIC TO QUARTZ LATITIC PORPHYRY IN STOCKS, PLUGS, AND DIKES—Age unknown but the range >25 m.y. to about 32 m.y. seems probable for many bodies, with a range from about 29 to 32 m.y. most likely

Tg GRANITIC ROCKS—Chiefly quartz monzonite. Radiometric age of stock at Troy Canyon in Grant Range is 23 m.y.; stock at Willow Creek in Quinn Canyon Range, 26.8 ± 0.5 m.y.; in White Pine County, 31 m.y. and 36 m.y. for the Silver Spring and Railroad stocks, respectively (Schilling, 1965, and given as 32.9 and 32.6 m.y., respectively, in Moores, Scott, and Lumsden, 1968)

Twa, Tnr, Twb, Tsc, Tcw, Ts, Ta VOLCANIC ROCKS—Twa, chiefly crystal-rich welded ash-flow tuffs of rhyolitic to quartz latitic composition. Tnr, Needles Range(?) Formation. Radiometric age 27.2 to 29.7 m.y. Twb, Windous Butte Formation. Radiometric age 30.7 m.y. Tsc, Stone Cabin Formation; age 34.1 m.y. Tcw, Calloway Well Formation of Scott (1965a); age is 33.2 ± 0.7 m.y. Ts, sedimentary rocks, in part volcanogenic in origin. Includes Currant Tuff near Currant and air-fall and ash-flow tuffs older than about 22 m.y. west of Quinn Canyon. Ta, andesite in flows

Tol, Tor OLDER VOLCANIC ROCKS—Tol, latite. Tor, rhyolite and dacite. Radiometric age of rhyolite east of Currant about 35 m.y.

Tsp SHEEP PASS FORMATION—Conglomerate overlain by lacustrine limestone and shale

GRANITIC AND RHYOLITIC TO BASALTIC DIKES AND SILLS

Dg DEVILS GATE LIMESTONE IN PANCAKE RANGE; ELSEWHERE GUILMETTE FORMATION—Chiefly limestone

Dn, Dno NEVADA FORMATION—Dn, chiefly dolomite. Dno, Oxyoke Canyon Sandstone Member

Dsi SIMONSON DOLOMITE

Dse SEVY DOLOMITE

EXPLANATION TO ACCOMPANY GEOLOGIC MAP, NORTHERN NYE COUNTY, NEVADA

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