EIS001443

BOARD OF SUPERVISORS

COUNTY OF INYO

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January 24, 2000

Wendy R. Dixon
Yucca Mountain Site Characterization Office
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
P.O. Box 30307, Mail Stop 010
North Las Vegas, Nevada
89036-0307

RE: Inyo County's Comments on the *Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada.*

Dear Ms. Dixon,

Inyo County, as a designated Affected Unit of Local Government under the Nuclear Waste Policy Act, is charged with oversight of Federal activities relating to the proposed Yucca Mountain Nuclear Waste Repository. In accordance with our responsibilities regarding the proposed repository, we have reviewed the Draft Environmental Impact Statement (DEIS) issued by the Department of Energy (DOE) for the proposed Yucca Mountain Repository. Inyo County's comments on the DEIS, as adopted by the Inyo County Board of Supervisors on January 24, 2000, are attached along with two County-sponsored hydrologic reports which, as specified in the text of our comments, are incorporated by reference into our response to the DEIS.

1 Inyo County has serious concerns over the completeness and utility of the DEIS. We find DOE's evaluation of the transportation component of the proposal overly generalized and fundamentally inadequate to the task of providing the public and decision makers with sufficient information to comprehend the implications of repository development on national and local transportation risks, emergency response infrastructure, and overall project costs. The DEIS fails to address transportation routing in sufficient detail to allow local and regional agencies to objectively analyze the project's affects on their constituents' health and economic welfare.

2 The DEIS's discussion of the range of possible repository designs and the behavior of affected geologic and hydrologic systems leads us to the conclusion that the proposal constitutes a critical departure from DOE's original intent to design and construct a facility which would permanently
3... isolate radioactive materials from humans. 3 The DEIS lacks mitigation measures adequate to address

3 cont. the contamination of the regional aquifer and associated demise of the economy of the Amargosa Valley, the communities of Death Valley Junction, Shoshone and Tecopa, and the destruction of surface and groundwater sources crucial to Death Valley National Park.

4 Our evaluation of the project and DOE's mandate under the Nuclear Waste Policy Act reveal that DOE has failed to effectively and objectively exercise it's authority and obligation under the National Environmental Policy Act (NEPA) to develop and analyze realistic project alternatives on a level equal to that provided for the proposed repository. Treatment of cumulative impacts and indirect effects under NEPA are also seriously compromised.

5 As you will see from our comments, the deficiencies of the DEIS are fundamental and widespread. We request that the Department of Energy, in consultation with all affected agencies, amend the DEIS to address these concerns and recirculate the document for public review.

If you have any questions about this submittal or require additional information, please feel free to contact Andrew Remus, Project Coordinator, Inyo County Yucca Mountain Repository Assessment Office at (760) 878-0447.

Sincerely,

Michael Dorame, Chair
Inyo County Board of Supervisors

cc: Senator Dianne Feinstein
Senator Barbara Boxer
Governor Gray Davis
Congressman Jerry Lewis

INYO COUNTY, CALIFORNIA

COMMENTS ON

The Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada

Adopted January 24, 2000
Inyo County Board of Supervisors
Inyo County, California

The County of Inyo, State of California, is an Affected Unit of Local Government under the Nuclear Waste Policy Act of 1982, as amended. Inyo County has prepared its response to the U.S. Department of Energy's (DOE's) *Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (DEIS). This response expands upon and supplements the comments made by Inyo County officials at the November 4, 1999 U.S. Department of Energy hearing on the Yucca Mountain Draft Environmental Impact Statement (held in Lone Pine, California).

The County has identified a number of issues regarding the Draft Environmental Impact Statement which should be addressed by the Department of Energy in the course of developing the Final Environmental Impact Statement. These issues are discussed below, organized by general topic area. Directly following each subsection - where appropriate - is a recommendation specifying the concerns that need to be addressed by DOE.

Compliance With the National Environmental Policy Act

Treatment of Project Alternatives

6... Inyo County recognizes that the proposed Yucca Mountain Nuclear Waste Repository is provided significant exceptions to normal NEPA requirements via the Nuclear Waste Policy Act of 1982, as amended. Specifically, DOE is exempt from considering the need for a repository, the timing of availability of the repository, alternatives to geologic disposal, or alternatives to the Yucca Mountain site. The Department of Energy, in developing its NEPA evaluation for the proposed repository is, however, obligated to evaluate reasonable alternatives outside the scope of what Congress has approved or funded because the findings of the Environmental Impact Statement may serve as the basis for modifying the Congressional mandate. This is part of the Congress-informing function of NEPA necessary to placing the proposal in a proper context for purposes of decision-making.

The NEPA exemptions provided by Congress have been interpreted by DOE to limit analysis of project alternatives to a discussion of a range of repository designs, generic

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6 cont. treatment of varying combinations of rail and truck transport, and inclusion of two variations of a "No-Action Alternative". The No-Action Alternatives are stated to be (in the DEIS itself) untenable and included simply for comparison with the proposed action. DOE recognizes that neither of the no-action alternatives is likely to be implemented should the repository not be built. The development of improbable and/or unreasonable alternatives runs counter to DOE's obligation under NEPA to rigorously explore and objectively evaluate all reasonable alternatives, even when such alternatives are outside the jurisdiction of the Department of Energy (40 CFR 1502.14 (a), (c)).

The inclusion of two project alternatives - in the form of variations of a "No Action Alternative" serves as recognition, by DOE, of its obligation to analyze alternatives to construction of the repository, but the analysis of these alternatives is not on a par with that of the proposed repository itself. In fact, the DEIS does not even begin to develop and evaluate project alternatives at a level of detail equivalent to that provided for the proposed action. Such treatment of project alternatives cripples decision-makers in any attempt to discern how development of the repository compares, in the terms of cost, time, resource commitment and risk, to technologically feasible alternatives to Yucca Mountain. Per Council on Environmental Quality (CEQ) Regulations, an EIS *should present the environmental impacts of the proposal and alternatives in comparative form...sharply defining issues and providing a clear basis for choice among options by decisionmakers and the public* (40 CFR 1502.14).

7 Lacking the detailed alternative project descriptions, environmental risk, and fiscal impact analysis necessary to develop and compare alternatives to the proposal, the DEIS fails to meet that section of NEPA which requires the study, development and description of *appropriate alternatives to recommended courses of action in any proposal which involves unresolved conflicts concerning alternative uses of available resources* (42 USC Section 4332 (E)).

The statement of underlying need determines the range of alternatives in the DEIS (40 CFR Section 1502.13). An action is proposed to meet the underlying need. Alternatives that do not meet the underlying need have no place in the DEIS. The "no-action" alternatives "...mean the proposed activity would not take place, and the resulting environmental effects from taking no action would be compared with the effects of permitting the proposed activity or an alternate activity to go forward" (CEQ, Forty Questions, 51 Federal Regulation 15618).

8 Ultimately, the unresolved conflict is whether the deep geologic repository called for in the Nuclear Waste Policy Act can and will be developed, or will be displaced by some other method of solving the problem of storage of spent nuclear fuel. This lack of meaningful, well-developed alternatives supportive of rational decision-making violates the spirit and intent of NEPA. It is well within DOE's purview to provide Congress with analysis of a range of feasible alternatives which achieve both the purposes of NEPA and the intent of the Nuclear Waste Policy Act. Absent a balanced and comprehensive approach to complying with NEPA, the DEIS leaves decision-makers without the information necessary to weigh options and alternatives for disposal of spent nuclear fuel and high-level radioactive waste.

9 **Specific Recommendation: DOE should eliminate the current project alternatives described in the DEIS and develop a range of reasonable project alternatives, providing analysis of each at a level of detail matching that provided for the proposed repository. Alternatives should include: 1) a no-action alternative that assumes permanent on-site storage of existing and future stocks of spent fuel and high-level waste; 2) an alternative which redirects DOE resources towards waste-volume reduction and consolidation of spent nuclear fuel and high-level waste at *existing* DOE storage facilities; and 3) any other alternative which can be implemented using available knowledge and technology which meets the need for storage of spent nuclear fuel and high-level waste expressed in the Nuclear Waste Policy Act. Alternatives must be screened to ensure they meet the underlying need.**

Indirect Effects

10 CEQ regulations concerning treatment of direct and indirect project effects require *that indirect effects, which are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable* be analyzed by the EIS (40 CFR 1508.8). The DEIS fails to address a number of impacts which DOE may view as indirect effects of the project. These impacts are discussed in detail in later sections of this commentary. By way of example, the most obvious effect of the project - which DOE apparently considers indirect and unworthy of analysis at this time - is the extensive transportation campaign necessary to move nuclear waste to Yucca Mountain. Operation of the proposed repository unquestionably includes the creation of new risks accruing to transportation of spent nuclear fuel and high-level radioactive waste to the repository site from locations all across the United States. The transportation campaign required to move waste into Yucca Mountain is later in time, generally further removed in distance and unquestionably foreseeable, yet the DEIS does not attempt to quantify the impact of the transportation campaign or develop the range of transportation alternatives necessary to compare risks to human populations and infrastructure. Even if the Department of Energy considers the transportation impacts associated with development and operation of the repository *indirect effects* of the project, the DEIS must include meaningful analysis of indirect effects of the project if the DEIS is to be considered a credible attempt to comply with NEPA. The NEPA exemptions provided DOE by the Nuclear Waste Policy Act do not include exemption from addressing such effects.

Consideration of Cumulative Impacts

11... The DEIS treats both geohydrologic and transportation impacts of the proposed repository as "stand alone" issues without recognition of the fact that the repository would operate in an environment already heavily impacted by past and ongoing nuclear waste activities. Territory adjacent to the Yucca Mountain site is heavily contaminated by radioactive materials as a result of decades of Atomic Energy Commission (AEC)/Department of Energy nuclear testing, while many of the roadways and rail corridors expected to be used for transport of spent nuclear fuel and high-level nuclear waste are already in service for the transport of low level and defense wastes to the Nevada Test Site and the Waste Isolation Pilot Plant in New Mexico. Operation of the Yucca Mountain repository would be one in a series of similar, linked actions undertaken by a single agency: the Department of Energy. The additional risks which Yucca

11 cont. Mountain would place on groundwater resources, human populations and national and regional transportation resources must be analyzed and weighted within the context of past, present and foreseeable non-Yucca Mountain-related AEC/DOE actions in order to meet the intent of NEPA and allow decisionmakers and the public to place the proposed action in the proper context. The NEPA exemptions provided DOE by the Nuclear Waste Policy Act do not include exemption from addressing cumulative impacts.

12 **Specific Recommendation: The DEIS should be amended to include description of the environmental context within which repository operations and transportation of nuclear waste will take place. Specifically, the DEIS needs to map and quantify the current level of environmental contamination in the region, and current and projected non-Yucca Mountain nuclear and hazardous waste shipment activity. This information needs to be compiled in a manner such that the incremental increase in risk posed by the repository and the total risk to humans and natural resources posed by the sum of DOE activities is clearly discernable.**

Transportation

Deferral of Waste Routing Designations

13 The DEIS does not identify specific primary, secondary or emergency transportation routes for nuclear waste traveling through California, although the means for identifying appropriate routes are readily available. Specific routing decisions, in terms of the use of rail or trucks, designation of primary and alternate routes through Nevada and California, and analysis of the impacts of making the road, rail and emergency response improvements necessary to safely accommodate the waste transportation campaign are all deferred to the indefinite future.

Highway routes can be identified by applying national highway routing regulations to these shipments, and rail routes can be identified by examining available rail lines and their classification. The DEIS could have analyzed impacts specific to national transportation after first identifying the routes based on available information. Instead, DOE performed a limited generic transportation analysis that avoided analysis of specific conditions, impacts, and hazards along the routes and the controversy associated with such determinations.

Specific Recommendation: DOE needs to apply current spent nuclear fuel and high-level nuclear waste transportation restrictions and requirements to the current national transportation system to determine which transportation corridors could be used for Yucca Mountain waste. An inventory of populations, emergency response capabilities, geographic and infrastructural limitations etc. must be developed preparatory to completion of a national-scale comprehensive risk analysis for eligible roadways and rail. The risk analysis methodology should be subject to public review as part of the revised DEIS and should provide a range of transportation-risk options and associated fiscal impact estimations.

California State Route 127

14 Given that Low Level Nuclear Waste is currently being transported on State Route 127 through Inyo and San Bernardino counties and shipments from DOE's Fernald, Ohio uranium plant cleanup operation are scheduled to begin using SR127 in 2000 to move waste packages to the Nevada Test Site, a precedent is now being set for expanded use of the route for high-level waste and spent fuel. The DEIS, however, does not acknowledge or project the role California corridors will play in moving high-level waste and spent fuel to Yucca Mountain.

State Route 127 is not an engineered route, to the extent that most of SR127 originated as a wagon trail that was paved over a period of time. Our recent survey of the route from its junction in the south with Interstate 15 at Baker to its junction with Nevada Route 95 in the north revealed numerous unbanked, unsigned high-speed turns, blind rises where visibility is nil, sustained grades in excess of modern standards and dozens of washes crossing both over and under the pavement. The road does not include turnouts or wide shoulders. State Route 127 variously parallels, crosses and recrosses the Amargosa River, a shallow desert river of considerable drainage which originates near Yucca Mountain and terminates in Death Valley. The Amargosa is typical of arid region streams, being dry most of the year, yet subject to rapid flooding and pronounced erosion and sedimentation. The route passes through four towns, two of which include sharp 90-degree turns in the middle of the town. There are few alternate routes useful to diverting commercial and passenger traffic around accident or clean-up sites.

In response to questions raised at the November 4, 1999 Yucca Mountain DEIS Hearing in Lone Pine, California, DOE staff clearly stated that the State of California would have to authorize the Department of Energy to use State Route 127 for transport of Yucca Mountain waste. This statement embodies a significant departure from DOE's practice in transporting low level nuclear waste on this route (which does not require State approval). The DEIS should explain what Yucca Mountain Repository-specific procedures are proposed to be put in place which would give States veto power over the use of their routes, and map the routes affecting by these same provisions.

Specific Recommendation: The DEIS needs to identify all California roadways and rail corridors eligible for use as primary, secondary or emergency routes for transport of waste to Yucca Mountain. Procedures for selecting routes and the role of state and local agencies in route selection and transport notification should be explained. Unless California State Route 127 is to be definitively excluded from carrying Yucca Mountain shipments, the DEIS should discuss the role State Route 127 could play in the Yucca Mountain transportation campaign.

Risk Analysis

15... Route choice will affect the safety, cost and timing of transport operations. DOE needs to engage in a comprehensive study of this issue in order to develop a scientifically defensible, least-risk-based determination of routes. Private carriers should not be burdened with the responsibility to evaluate and choose routes. The preferred corridors should be mapped by DOE and the required roadway and emergency response

15 cont. improvements identified. Narrowing the number of potential routes via risk analysis allows evaluation of road, emergency response improvements, identification of impacted jurisdictions, quantification of costs and start up and maintenance requirements. Without such information, it is impossible to objectively choose among transportation options, for which the levels of risk and cost no doubt would vary greatly.

16 DOE's risk analysis for the proposal relied upon the RADTRAN4 computer program to calculate radiological impacts to populations along transportation routes under both normal and accident conditions. The DEIS does not discuss the specific origins of this model, its assumptions, or if and how the model remains applicable to conditions on undeveloped routes where transport vehicles operate slowly on narrow roadways passing through populated areas where there is limited clearance between businesses or residences and the radioactive cargo.

17 **Specific Recommendation: The DEIS should include results of a comprehensive national-scale risk analyses to determine least-risk based solutions to the question of which roadway and rail corridors to use to increase the predictability of waste transportation operations. The risk analysis should provide the quantitative information necessary to confirm or deny the value of each reasonable potential transportation scenario. Impacted populations and resources should to be clearly identified in the DEIS. DOE should use the results of this analysis to systematically dictate routes to private carriers. The value of the Chalk Mountain Route for achieving major reductions in risk to civilian populations should be quantified and discussed. The specific assumptions used by the RADTRAN4 model should be discussed by the DEIS.**

Emergency Response & Section 180(c) Considerations

18 Communities along State Route 127 constitute the most isolated populations in Inyo County. Assistance with roadway incidents must come from the Inyo County Sheriff Unit at Shoshone, Park Service Rangers dispatched out of Cow Creek near Furnace Creek, or California Highway Patrol also coming out of Death Valley or out of Pahrump, Nevada. Most of the route lies one to three hours from any public assistance. To deal with major roadway incidents, County Sheriff units are sent from Lone Pine, which is three hours away from the closest segment of SR127.

Currently, the State Route 127 towns of Tecopa, Shoshone, and Death Valley Junction are served by a single Volunteer Fire Protection District that is without adequate funding. In case of a serious toxic or radiological release in Inyo County, specialist response teams must be brought in from either San Bernardino or Bakersfield, a process which takes a minimum of three to four hours, assuming that the response team is not occupied elsewhere. The closest medical facility of any note is in Pahrump, which is a minimum of thirty minutes from the closest segments of the road and several hours away from the furthest. The closest fully equipped hospital is in Las Vegas, which is at least two hours away from the closest sections of SR127.

19... State Route 127 serves much of the tourist traffic flowing into Death Valley National Park from Las Vegas and Southern California, with recent estimates showing park usage on the order of 1.4 million visitors/year. Considerable increases in traffic volume are

19 cont. expected to accompany the growth of California and of both Pahrump and Las Vegas, Nevada (the Nation's fastest-growing medium-size and large cities, respectively). Also, there are approximately 1000 acres of land in the vicinity of the town of Death Valley Junction (intersection of SR127 and SR190) that may be released to the Timbisha-Shoshone tribe for their use. If developed to mixed residential and commercial uses, this territory could host an unknown number of additional residents and contribute significantly to traffic on Route 127. Per information received from Caltrans, the route is not scheduled for major improvements through 2015.

20 The Nuclear Waste Policy Act, Section 180(c) calls for Federal action to provide improvements in emergency response training and capability along routes designated for the transport of high-level nuclear waste and spent fuel. The virtual absence of emergency response capability on Route 127 and the isolated character and the current configuration of this roadway promise to make compliance with this part of the Act an involved and expensive exercise on the part of the Federal Government. The DEIS makes no attempt to configure or estimate the required dedications of Federal resources necessary to meets its obligations under Section 180(c).

Other necessary improvements prerequisite to regular use of SR 127 include complete reconstruction of some sections of the roadway and the construction, equipping and staffing of emergency response stations. The County and the State will be saddled with significant new costs to safeguard its residents. The EIS fails to address, in any manner, the significant fiscal and possibly significant environmental impacts of meeting these obligations. These impacts are inseparable from the issue of the repository itself and need to be quantified by the EIS.

21 **Specific Recommendation: Based on the results of the previously mentioned transportation risk analysis, DOE must identify roadway and emergency response improvements necessary to safeguard residents and resources in the vicinity of California State Route 127, consistent with implementation of Section 180(c) of the Nuclear Waste Policy Act. The costs of these improvements and their maintenance for the duration of the Yucca Mountain repository transportation campaign should be estimated as part of the *fiscal impact analysis* necessary to compare and eventually designate waste transport corridors for the project.**

Rail Transportation

22 Due to the lack of information in the DEIS on the relative risks posed by the possible range of rail-truck transportation scenarios, it is impossible at this time to determine whether a rail or truck-focused transportation campaign will best serve the need to mitigate the risks associated with the proposed repository. Inyo County does, however, have a preference for development and use of the Chalk Mountain Route for waste shipments originating east of California. Dedication of this route to nuclear waste transport would make extensive use of secure Federal lands directly north of the repository site and could significantly reduce the number of shipments on southern routes (Interstate 15, Interstate 40, Nevada Routes 95 and 160 and California State Route 127)

Transportation-Specific NEPA Evaluation

23 The transportation campaign is an integral part of the Yucca Mountain project. It is inseparable from the operation of the proposed repository. Consideration, in detail, of transportation impacts cannot reasonably be deferred to future analysis any more than other off-site impacts. Without detailed information on likely primary and secondary routes in California and the staging of shipments, it is impossible for Inyo County to evaluate the impacts of the shipping campaign on our area. While it is DOE's contention that the DEIS is sufficient to serve as the "umbrella" environmental impact document for future Federal transportation decisions, the DEIS fails to include the data, mapping and analysis sufficient to compare routes and support even general route designations. Absent transportation specific impact analysis in the DEIS, it is impossible to determine the suitability of a repository at Yucca Mountain.

Groundwater

Inyo County Hydrologic Studies

24... The DEIS recognizes uncertainties about groundwater flow boundaries among sub-basins within the Death Valley groundwater basin. Contamination of the deep regional aquifer, which appears to underlie both Yucca Mountain and the Tecopa-Shoshone-Death Valley Junction area, poses the most significant long-term threat to the citizens and economy of Inyo County. Inyo County, in conjunction with Nye and Esmeralda Counties (Nevada) and the USGS, have engaged in groundwater research which points to a direct connection between water in the deep 'Lower Carbonate Aquifer' beneath Yucca Mountain and surface discharges (springs) in Death Valley National Park *("An Evaluation of the Hydrology at Yucca Mountain: The Lower Carbonate Aquifer and Amargosa River"*, Inyo & Esmeralda Counties, 1996, and *"Death Valley Springs Geochemical Investigation"*, Inyo County, 1998, provided as Attachments A & B). These studies were funded with DOE grant money and done to a high standard of scientific accuracy, being subject to Federal (USGS) quality assurance and quality control measures.

The 1996 study of the Lower Carbonate Aquifer suggests a significant degree of hydrologic connectivity between the Lower Carbonate Aquifer lying beneath the proposed repository and surface manifestations of the same formation within Death Valley National Park. The study also indicated that populations in Amargosa Valley (including the California towns of Death Valley Junction, Shoshone, and Tecopa) utilize groundwater that may be hydrologically contiguous to a southward extension of the Lower Carbonate Aquifer.

The 1998 investigation of the geochemistry of spring waters in the mountains east of Death Valley (some of which are developed to serve domestic and commercial uses in Death Valley) gave indications that these spring waters may be dominated by input from the Lower Carbonate Aquifer, perhaps via relatively fast pathways through fractures in the formation. It should be noted that these same springs also sustain populations of a number of threatened and endangered species.

24 cont. The Draft Environmental Impact Statement does not address our findings, either to acknowledge or deny the implications of these studies with regard to potential pathways for contaminants to reach human populations or a National Park. Our studies, which have been available to DOE for some time, are absent from the estimated 50,000 pages of technical background material which went into development of the DEIS. We are formally including, by reference, these studies into our comments on the DEIS.

The County considers this a critical oversight on the part of DOE, which should be rectified by serious consideration of our scientific work and placement of our findings in the proper context.

The entire range of available scientific studies on groundwater flow in the Amargosa Valley, including applicable groundwater dating methodologies and flow velocity measurements, should be discussed. Competing models and methods and their results should be compared by the DEIS to provide a clear view of the current state of knowledge on the region's hydrology. The discussion of subsurface transport mechanisms of radionuclides needs further development, comparing the potential roles of colloidal, suspended particulate, and solution transport of contaminants under a range of assumptions about climate and subsurface conditions.

Specific Recommendation: DOE should review the above-cited research products for merit, incorporating the information into the hydrology database compiled for purposes of evaluating potential impacts to regional aquifers. If our reports have been submitted using a format or methodology not acceptable to DOE, Inyo County should be informed immediately to allow the County to redirect our research and reporting efforts. The DEIS should utilize the entire range of available hydrologic models and methods to bound projections of groundwater flow, contaminant transport concentrations, and velocity in the region potentially impacted by release of radioactive contaminants from the repository.

Repository Design & Performance

<u>*Selection of a Repository Design*</u>

25 It is recognized that the repository design is still evolving outside of the EIS process and that the specific design of the repository is not yet known. In order for the EIS to be useful to the Nuclear Regulatory Commission in its consideration of DOE's license application for construction of the repository, the specific impacts of the chosen specific design will need to be determined, to the extent possible, and incorporated into the Final EIS.

Assuming that the impacts of the design chosen for the repository remain within the bounds of those environmental impacts considered in the DEIS (i.e. the EIS remains valid for the chosen design), the Final EIS should include a detailed description of the selected repository design and an analysis of its potential impacts, including a comparison with reasonable alternatives that were considered and discussion of any impact mitigation measures which were incorporated into the design subsequent to distribution of the DEIS.

Groundwater Impacts

26 After release of the DEIS, DOE - in response to a Nuclear Waste Technical Review Board critique of the original proposal for a "hot" (high thermal loading) repository - opted for a "cool" design. The choice of a low thermal loading design appears, to the best of our knowledge, to be based on DOE's finding that the cooler design is easier to model, not because there is evidence that this is an otherwise superior alternative.

The change of repository design from a "hot" repository to a "cool" repository has major and insufficiently researched implications for groundwater flow and groundwater chemistry. A hot repository has the potential to intercept and boil off groundwater infiltrating through the tuffaceous material above the emplacement blocks, thereby heading off the input of contaminated liquids into the saturated zone. A hot repository also, however, may accelerate waste package disintegration and increase the density and size of local rock fractures, accelerating contamination of the saturated zone. There is insufficient information on the behavior of the hydrology and geology of Yucca Mountain to develop a balanced design that minimizes or avoids contact between water and waste materials. This being the case, the current state of knowledge and information available to preparers of the DEIS is inadequate to development of a NEPA document sufficient to support a decision on repository design.

27 It is DOE's contention that the DEIS is sufficiently broad in its treatment of repository design variations to cover the switch to a cooler repository, however, recent technical discussions on repository performance conducted by the Advisory Committee on Nuclear Waste and the Nuclear Waste Technical Review Board reflect considerable uncertainty in our understanding of how the repository will behave under the cooler design. We do not believe that the current state of knowledge on repository performance lends itself to a determination that the DEIS is adequate to support a decision on which design should be adopted.

Specific Recommendation: Given the inadequate state of knowledge on the viability of the various design variations described in the DEIS, the current DEIS cannot be used as the basis for choosing the specific design to be submitted to the NRC for licensing. Choice of repository design must be deferred until sufficient research has been completed to allow for an informed choice. The selection process should be subject to separate NEPA treatment at the appropriate time.

Mitigation of Groundwater Impacts

28 All of the design alternatives considered in the EIS lead, ultimately, to a repository that is expected to leak (albeit at different rates depending on the particular choice of tunnel configuration, waste packaging, assumptions regarding geology, climate, and the response of the waste packages to the repository environment). Given the scale and complexities of the aquifers subject to potential contamination by the project, mitigation of impacts to these resources will range somewhere between extremely expensive to completely impossible. The DEIS should explain DOE's stance on providing mitigation, and either consider the adoption of feasible mitigation measures or state that such impacts cannot or will not be mitigated by the Federal government.

Waste Package Design

29 It is recognized that the Nuclear Regulatory Commission has recently initiated a new program of cask testing which proposes to subject transportation cask prototypes to an expanded range of physical tests. Since the nature and, of course, results of these tests are at present unknown and cask options cannot be evaluated via the NEPA process at this time, the current Yucca Mountain DEIS cannot be used as a base document from which to tier off a NEPA evaluation of possible cask designs. Further discussion of cask designs at this time is therefore unwarranted.

Monitoring and Retrieveability

30 DOE's proposal calls for backfilling of the emplacement drifts and closure of the repository between 50 and 300 years after disposal operations begin. Backfilling and closing the repository prohibits monitoring of the waste packages for structural integrity and increases the difficulty and cost of retrieving the waste should a radioactive release occur or new findings and technologies emerge which provide for safer forms of storage or reuse of the nuclear material.

Contrary to the expectation incorporated into DEIS that significant radioactive releases from the repository are inevitable, DOE must adopt as its goal complete and permanent isolation of radioactive material from humans. In our estimation, the only way to both meet this goal and to mitigate the many uncertainties associated with repository performance is to have a permanently open and thoroughly monitored facility. DOE should not attempt to anticipate a closure date for the repository and should quantify, to the extent possible, the fiscal impact of funding a closely monitored facility capable of retrieving and replacing failed waste packages.

The project should provide, as a mitigation and risk-reduction measure, for on-site third party monitoring of the repository both during and after the emplacement phase. It is recommended that either the National Science Foundation or Nuclear Regulatory Commission be specified as the third party and provided the necessary funding via the Nuclear Waste Policy Act.

Economic Development Considerations

31... Groundwater modeling used as the basis for the DEIS does not take into account the potential for accelerated transport of radionuclides due to projected increases in regional groundwater extractions. Growth in Pahrump, the Amargosa Valley, and possible development of pending regional groundwater claims by the City of Las Vegas may lead to significant changes in the direction and volume of groundwater flow from Yucca Mountain. It is well within the ability and purview of DOE to attempt a reasonable projection of the effects of urban development on the regional groundwater system and to incorporate these expectations into the groundwater models utilized in development of the DEIS.

31 cont. **Specific Recommendation: Groundwater modeling conducted in support of the repository site evaluation process should be reworked to incorporate reasonable projections of future regional groundwater usage. The likely effects of regional groundwater development on contaminant plume paths, velocity, and radionuclide concentrations should be projected and mapped.**

Socioeconomic Impacts

32 Socioeconomic impact analysis in the DEIS is limited to regional impacts on employment, housing and other standard economic indicators. There is no analysis of potential socioeconomic disturbances due to repository operation and transportation under both normal and accident conditions. Conversely, the DEIS lacks discussion of the impact of socioeconomic changes on the operation of the repository. Growth rates and development expectations along transportation corridors, and the implications of same for the evolution of new transportation risks during the 30-year span of repository operations are not considered.

33 The knowledge that nuclear waste transportation or accidents are associated with particular locations/roadways can have adverse economic impacts to those locations due to accumulating stigma. Inyo County, with its tourism-based economy revolving around the use of Death Valley National Park, is particularly vulnerable to the economic impacts of stigma. The same holds true for risks associated with possible contamination of the regional aquifer serving commercial uses in Death Valley. In light of the economic benefits received by the County and the State of California from Death Valley National Park (which on average receives 1.4 million visitors per year), the security and public perception of State Route 127 is of utmost importance. The EIS should consider the potential socioeconomic impacts of stigma associated with the proposed action and evaluate potential mitigation options.

34 The project could also affect property values in the southeastern portion of the County, an area that is likely to experience considerable growth during the 30-year time-span for which the repository would accept waste. The DEIS, if it is to truly function as a tool for analyzing the impact of the repository, must attempt to project the economic consequences of the designation of specific waste hauling routes and of repository contamination of the regional groundwater system on local economies.

Conclusory Remarks

35... The DEIS admits to significant uncertainties in 1) the final repository design; 2) the expected performance of both natural and man-made barriers to radionuclide release; 3) the response of the natural environment (transport mechanisms) to inputs of radioactive materials; and 4) the health impacts of the expected radiological contamination of the regional aquifer. The DEIS fails to address in a meaningful way issues of transportation or socioeconomic impacts and does not provide well-developed alternatives for consideration by the public or decision makers. None of the design options result in a repository that isolates radionuclides from the accessible environment. Cumulatively, the current level of uncertainty associated with the project and the lack of

35 cont. scientific information necessary to reduce some of the major uncertainties makes it difficult to imagine that the document will be found adequate for use by the Nuclear Regulatory Commission in its consideration of DOE's application for a license to construct a repository.

36 The absence of meaningful treatment of the environmental impacts of the transportation component of the project is a major flaw in the Draft Environmental Impact Statement which will eventually require that DOE develop a second Environmental Impact Statement specific to transportation issues. This being the case, Inyo County objects to the use of the current DEIS as the basis for future decision-making on waste transport and requests that DOE amend the Environmental Impact Statement to address the full range of impacts accruing to construction and operation of the repository.

37 The DEIS as a whole is narrowly scoped, to the degree that comprehensive analysis of the impact of the proposal is impossible. Taking into account those NEPA exemptions granted by Congressional action, the development of project alternatives in the DEIS remains unnecessarily restricted, obstructing attempts to weigh the costs and benefits of the proposed repository. It is unclear whether a Supplemental EIS or a new EIS is needed. Typically, a Supplement needs to be prepared if new information or circumstances become apparent. In the case of Yucca Mountain, the information DOE would require to correctly draft an EIS is either: 1) already available or readily developed (e.g. data prerequisite to rail and road corridor risk analysis); or 2) unlikely to be available in the near future (such as statistically significant data on waste package, emplacement drift or aquifer behavior). The revised DEIS needs to differentiate clearly between the known and the unknowable for the benefit of both reviewers and future decision-makers.

EIS001443

The HYDRODYNAMICS Group
studies in mass and energy tranport in the earth

Death Valley Springs Geochemical Investigation

Yucca Mountain Nuclear Respository, Inyo County Oversight-1998

Submitted to:

Inyo County Planning Department:
Yucca Mountain Repository Oversight Program

March, 1999

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DEATH VALLEY SPRINGS GEOCHMICAL INVESTIGATION

YUCCA MOUNTAIN NUCLEAR WASTE REPOSITORY, INYO COUNTY OVERSIGHT-1998

EXECUTIVE SUMMARY

Yucca Mountain, Nevada is under study as the site of the only proposed high-level nuclear waste repository in the United States. The repository concept uses the philosophy of multiple barriers, both engineered and natural, each of which impedes the movement of radionuclides into the accessible environment. The proposed repository would be in the unsaturated zone in Tertiary tuffaceous rocks. The principal transporting mechanism for radionuclides is moving ground water. Underlying the repository is an extensive Lower Carbonate Aquifer known to be highly permeable. Inyo County, as an affected unit of local government under the Nuclear Waste Policy Act, as amended, is concerned with the connections between the Lower Carbonate Aquifer underlying Yucca Mountain and the carbonate sources of waters in Inyo County, especially the Death Valley region. This report is a summary of the investigations conducted by Inyo County's consultants, the Hydrodynamics Group, during calendar year 1998.

This report presents the results of The Hydrodynamics Group's 1998 collection of water samples from 23 springs and 2 creeks in Death Valley. The overall goal of this study was the evaluation of far-field issues related to potential transport, by ground water, of radionuclides into Inyo County, including Death Valley, and the evaluation of a connection between the Lower Carbonate Aquifer and the biosphere. Death Valley is believed to be a discharge point for regional ground water aquifers below Yucca Mountain. The objective of this geochemical study of spring waters was to help further characterize the ground water in the Death Valley mountain blocks, and to determine the source of these waters.

Prior research was reviewed to determine areas where sampling was needed. Less than 10 percent of known springs in Death Valley National Park have been sampled and analyzed. The sampling of springs for isotopic analysis by the USGS has been limited to the large Funeral Mountain springs discharging along the Furnace Creek Fault and along the alluvial fans on the east flank of the Panamint Mountain range. The USGS had also sampled a select number of springs in the Black Mountain range for isotopic analysis. Following this review the selected water sources were sampled. The samples were collected, preserved, and shipped for analysis to the USGS's Denver laboratory, Huffman Laboratories, and Beta Analytical Laboratory by The Hydrodynamics Group's personnel. The evaluation of the geochemical composition of the springs of the Death Valley National Park and the Yucca Mountain study area established the chemical composition of the spring waters. The

comparison of the regional geochemical composition, concentration of isotopes, and the regional geological conditions allowed an evaluation of the source of the spring waters relative to the Lower Carbonate Aquifer.

The results of this study suggest the need to further characterize the springs and hydrogeology of the Death Valley area, and to better understand the hydraulic connection between the Funeral Mountain springs and the Lower Carbonate Aquifer beneath Yucca Mountain and the Amargosa Valley. It is recommended that additional springs be sampled and analyzed for major anion and cations, and stable isotope concentrations. The report further recommends the drilling of two exploratory wells east of the Funeral Mountains to further evaluate the possible hydraulic connection between the springs in the Furnace Creek area and the Lower Carbonate Aquifer.

1.0 INTRODUCTION

Yucca Mountain is the site of the only proposed high-level nuclear waste repository in the United States. The repository concept uses the philosophy of multiple barriers, both engineered and natural, each of which impedes the movement of radionulcides into the accessible environment. The proposed repository would be in the unsaturated zone above the water table in Tertiary tuffaceous rocks. The principal transporting mechanism for radionuclides is moving ground water. Underlying the repository at approximately 2-km (6,000 feet) is an extensive Lower Carbonate Aquifer known to be highly permeable.

Inyo County has participated in oversight activities for the Yucca Mountain Nuclear Waste Repository since 1987. The purpose of Inyo County's oversight activities is to ensure that repository siting and subsequent repository activities do not adversely impact the public health, safety, or welfare of County residents or the environment, including Death Valley National Park. The Hydrodynamics Group, Inyo County's hydrogeology consultants, determined that a linkage between the alluvial and carbonate aquifers at Yucca Mountain and Death Valley in Inyo County may be possible. Winograde (1975) suggested that the springs on the east side of Death Valley may be points of discharge from the Lower Carbonate Aquifer.

This investigation of Death Valley springs was performed in support of Inyo County's Yucca Mountain Oversight Program. Inyo County's Yucca Mountain Oversight Program identified a number of spring sources in the Death Valley Mountain ranges. This report presents the results of The Hydrodynamics Group's 1998 collection of water samples from 23 springs and 2 creeks in Death Valley. Samples were analyzed for concentrations of major cations and anions, and isotopic ratios of strontium, uranium, and oxygen. The results of the analysis were compared to the chemical analyses of other available carbonate aquifer and spring samples in the Yucca Mountain project area.

1.1 Statement of the Problem

The linkages between the alluvial and carbonate aquifers, the recharge and discharge points, and ground water travel time are key to Inyo County's hydrological concerns about the proposed Yucca Mountain Nuclear Waste Repository. Death Valley is the terminus for surface water drainage from Yucca Mountain and Amargosa Valley. It is also believed that ground water from the Lower Carbonate Aquifer discharges into Death Valley via springs. The relationship between waters in Death Valley and the ground water flowing under Yucca Mountain has yet to be determined.

Specifically, The Hydrodynamics Group's hydraulic model (Bredehoeft, et. al., 1996) of the Amargosa River system indicates a negative water balance. Measured stream flows exceed what would be expected for published evapotranspiration (ET) rates and precipitation. This suggests a significant contribution to Amargosa river flows from a larger ground water system (Bredehoeft, et. al., 1996). Winograd (1975) and other researchers suggest that ground water in the Yucca Mountain area is hydraulically connected to the Lower Carbonate Aquifer. Discharge from the major springs in Death Valley may be fault-controlled and hydraulically connected to the Lower Carbonate Aquifer.

The U.S. Geological Survey's (USGS) numerical ground water model of the Yucca Mountain area (D'Agnesses, et. al., 1997) is based on limited data on the hydrology of the Death Valley system. Major data gaps exist in:

1. ET values for Death Valley,
2. inflow into Death Valley from the Amargosa River,
3. infiltration into the Death Valley mountain ranges,
4. the source of spring waters in Death Valley,
5. water level data,
6. hydraulic parameters, and
7. hydraulic boundary conditions in Death Valley.

These major data gaps need to be filled for the USGS numerical ground water model of the Yucca Mountain area to be used effectively as a tool to evaluate the potential for the transport of radionuclides from Yucca Mountain.

The drilling of wells in Death Valley is environmentally unacceptable. The chemical analysis of spring and creek waters in Death Valley provides an environmentally acceptable means of evaluating the source of these waters. Ground water can absorb and precipitate chemicals from rock materials along its flow path. The dissolved chemicals in the waters can also react to produce compounds or ratios of selected chemicals that suggest either a source for the water or a travel path for the water. A limitation on use of chemical analysis for water source analysis is that the interpretation of results does not provide a definitive answer. This is partially due to the possible mixing of waters from more than one source. Thus, the interpretation of chemical composition of waters for purposes of source analysis can be problematic.

1.2 Goal and Objective

The overall goal of this study was the evaluation of far-field issues related to potential transport, by ground water, of radionuclides into Inyo County, including Death Valley, and the evaluation of a connection between the Lower Carbonate Aquifer and the biosphere. Death Valley is believed to be a discharge point for regional ground water aquifers below Yucca Mountain.

The objective of this geochemical study of spring waters was to help further characterize the ground water in the Death Valley mountain blocks, and to determine the source of these waters.

2.0 Hydrogeology of the Death Valley Drainage Basin

The hydrogeology of the Death Valley Drainage Basin is important to the understanding of the movement of ground water from Yucca Mountain and the spring discharge in Death Valley National Park (DVNP). Please note that while reference will be made to Death Valley Natiional Monument (DVNM), the springs sampled for this study are within the original boundaries of the DVNM. The National Monument was changed to a National Park by the California Desert Protection Act of 1992, with the addition of 1.3 million acres to the lands formerly designated as a National Monument. The boundary of the Park,, while approximately fixed in 1994, are not yet generally available in map form. The geology of the Death Valley Drainage Basin (DVDB) and the hydrostratigraphy of Death Valley are described below. This provides a framework for the characterization of springs in Death Valley.

2.1 Geologic Framework of the Death Valley Drainage Basin

The geology and hydrogeology of the DVDB, which includes DVNP, has been described in countless books, publications, and articles. Among these are Charles Hunt's book entitled *Death Valley: Geology, Ecology, Archaeology*, 1975; and Harris & Tuttle's book entitled *Geology of National Parks*, Fifth Edition, 1997. More recently, Harrill (1995), Faunt (1997), and D'Agnese, et. al., (1997) published articles on the geology and hydrogeology of the DVDB. The USGS publications were specific to issues concerning the modeling of ground water within the Yucca Mountain nuclear waste repository study area. An overview of the geology and hydrogeology of the DVDB and DVNP, as presented by these and other authors is provided below.

Death Valley is located in the southwest corner of the Great Basin physiographic province and in the southwest portion of the DVDB (Plate 1). The Great Basin and DVDB are within the northern part of the Basin and Range physiographic province. Numerous northwest-trending mountain ranges and intervening broad and flat valleys, or basins, characterize the Basin and Range province. The ranges are spaced about 20-30 km (12 to 18 miles) apart.

The DVDB covers an area of about 40,100 km^2 (15,800 $mi.^2$). Surface and ground water drainage in the Basin is, in general, towards Death Valley. The DVDB includes the northwest trending basins and ranges of the Panamint Valley, Panamint Range, Death Valley, Grapevine-Funeral-Black Mountain Ranges, Amargosa Valley, and Yucca-Spector-Spring Mountain Range (Plate 2). The mountain ranges cover about 25 percent of DVDB, and can be greater then 80 km (50 miles) in length, and 8 to 24 km (5 to 15 miles) wide (Herrill, 1995). The altitude of these ranges varies between 304 to 2,743 meters (1,000 to 9,000 feet) above valley floors. The intervening basin can extend over 120 km (75 miles) in length, and can range in width from 3 to 40 km (2 to 25 miles). The valley floors are relatively flat with altitudes ranging from 5,000 feet in the northern half of the DVDB to over –60 meters (-200 feet) in Death Valley.

The Death Valley portion of the Great Basin has a long geological history. Mifflin (1988) states that:

> *The Great Basin region displays the record of a long and active history of intermittent marine sedimentation and large-scale compressive deformation, island-arc plutonism and volcanism, bimodal basaltic and silicic volcanism, extensional tectonics, and terrestrial sedimentation.* Mifflin further states: *Rock types, ages, and deformational structures range through much of the known spectrum, and in many areas impressive diversities exist in juxtaposed rock types.*

This results in geology that is highly variable and complex. Although it is possible to readily map the surface geology of the area, our knowledge of the subsurface geology beneath the alluvial basin is based upon a limited number of boreholes. The areal distribution of major geological rock types in the DVDB is shown on Plate 3. Faunt (1997) states the DVDB consists of:

> *Precambrian- and Cambrian-age clastic and crystalline rocks: Paleozoic-age clastic and carbonate rocks; clastic and intrusive rocks of Mesozoic age; varied fluvaial, paludal, pond, and playa sedimentary rocks of Pliocene age; volcanic rocks and alluvium of Tertiary age; and alluvium, colluvium, and eolian deposits of Quaternary age.*

A generalized geologic column of major geological rock types is provided in Table 1. Fiero (1986) illustrated the geological history of the Great Basin, which includes the DVNP, in his book entitled *Geology of the Great Basin, 1986*. A summary of the principal geologic events in DVNP as discussed in Fiero's book is listed in Table 1. It is evident that a variety of sedimentary and igneous intrusive and extrusive rocks have been subjected to both compressional and extensional deformation (Harrell, 1995). Compressional and extensional deformation activities are evident in the complex patterns of high and low angle faults, which have been mapped by Faunt (D'Agnesse, et al, 1997) (Plate 4). Currently Death Valley is experiencing extensional deformation and tilting to the east resulting in the continued dropping of Death Valley.

2.2 Hydrogeology Framework of DVDB

Pal Consultants' report entitled *A Conceptual Model of the Death Valley Ground-Water Flow System, Nevada, California, 1995,* (Harrell, 1995) provides an extensive presentation on the numerous published studies that developed conceptual models of the hydrogeology framework of Death Valley. Central to the recently developed hydrogeology framework models of the DVDB is the integration of hydrostratigraphic units and structural elements.

In an idealized basin and range setting, ground water generally moves downward from mountainous recharge regions, then laterally toward discharge areas, and then upward into the discharge areas (Faunt, 1997). Faunt (1997) states that:

> *The mountain ranges consist primarily of uplifted, faulted, and exhumed rocks of metamorphic and sedimentary origin. Locally, the rocks have been intruded or overlain by both volcanic and intrusive rocks of many different ages and compositions. The way in which these rocks were deposited, lithified, deformed, fractured, and weathered ultimately controls the way in which ground water enters, flows through, and exits the hydrogeologic system.*

Death Valley is the terminal discharge point for 27 hydrographic areas, with a surface area of about 40,922 km^2 (15,800 $mi.^2$), (Plate 5) (Harrel, 1995). Faunt (1997) defined the hydrogeologic framework of these hydrographic areas by use of hydrostratigraphic map units (Plate 6). The hydrostratigraphic map of DVDB covers an area of approximately 100,000-km^2 (38,610 $mi.^2$). The hydrostratigraphic map consists of ten units (Faunt, 1997). Units were first delineated by grouping geological units by similar rock types, and second by similar hydrologic properties. A description of these hydrostratigraphic units is provided in USGS Water-Resource Investigation Report 95-4132 (Faunt, 1997).

The movement of surface and ground water through this hydrogeology framework has been studied using the USGS's numerical ground water model of the Yucca Mountain area (D'Agneses, et. al., 1997). D'Agneses (1997) used the hydrotratigraphy described above for his analysis.

3.0 Springs of Death Valley

The National Park Service (NPS) has identified 289 springs and seeps within the boundaries of DVNP. These springs and seeps were identified and cataloged by NSP Rangers starting in the late 1940's. Information collected on these springs and seeps is filed in four binders at the Environmental Services building in DVNP. A summary of information collected on these springs and seeps is provided in Appendix A. The locations of these springs are shown on Plate 7. The locations of these springs and seeps are accurate to the nearest 1/4 section.

The springs in DVNP can be grouped into the following four types:

Type 1	Springs along Steeply Dipping Faults
Type 2	Mountain Springs
Type 3	Springs at Impermeable Structural Barriers
Type 4	Springs at the Edge of Alluvial Fans

3.1 Springs Along Steeply Dipping Faults

The springs with the greatest discharge are located along the steeply dipping Furnace Creek fault system between the Funeral and Black Mountain ranges (Plate 8). The major springs are named Nevares, Texas, and Travertine. These springs have an estimated total discharge of 158 liters per second (L/sec) (2,500 gallons per minute (gpm)), and are a water supply to the community of Furnace Creek. The springs discharge from the Paleozoic-age carbonates at the base of the Funeral Mountain range near the trace of the Furnace Creek fault. The spring orifices are marked by prominent white travertine mounds down-gradient. The source of water to these springs is of interest because they discharge from Paleozoic-age carbonate of the same age as the Lower Carbonate Aquifers at Yucca Mountain.

3.2 Mountain Springs

Mountain springs and seeps represent the greatest number of springs. Over 200 are listed in Appendix A. Most of these springs have small volumes of discharge. These springs are located at the higher altitudes in the Grapevine, Black Mountain, and Panamint Mountain ranges (Plate 7). A number of these springs are located at or near low-angle faults. The springs, for the most part, are located along intermittent creeks. Springs were observed to discharge from minor fractures in bedrock outcrops and from shallow soils. Springs can be located by the growth of willows at the spring orifice. Thus, the number of springs named "Willow" in DVNP. At a number of these springs the discharge is completely absorbed by associated vegetation. We observed spring discharge rates from negligible to 1.26 L/sec (20 gpm) with the average about 0.32 L/sec (5 gpm). Springs flows typically disappear less than 4.6 meters (15 feet) down-gradient of the spring.

3.3 Springs at Impermeable Structural Barriers

There are a limited number of springs emerging at impermeable structural barriers in and near the Salt Pan areas. The most noted of these springs is McLean that helps maintain flow of Salt Creek through the Salt Creek Hills (Plate 3). Two other examples of this spring type are Salt Creek spring and the small springs above the Park Service area at Nevares spring (Plate 7). The location of these springs near salt creek, and their close proximity to springs up-gradient suggest the source of water to these springs is the ponding of shallow ground water at relatively impermeable, structural barriers. Discharge from these springs is on the order of 0.63 L/sec (10 gpm), and typically has a high dissolved mineral content.

3.4 Springs at the Edge of Alluvial Fans

Springs at the edge of the alluvial fans along the salt pan at the base of the Panamint Mountain range represent the second most prolific springs in DVNP. The best known of these springs are Tule, Shorty Wells, Eagle Borax, and Bennett Well (Plate 8). The water table below the coarse alluvial fan materials is estimated to have a slope of 7.6 to 15.2 meters per km (25 to 50 feet per mile). The water table is estimated to be several hundred feet below ground surface near the base of the mountain range, and at the land surface near the toe of the alluvial fan. Ground water discharges at the foot of alluvial fans at the Salt Pan. These springs commonly have associated willow and salt grass by open discharge channels. A distinct spring orifice is not evident at these springs. Total discharge from these springs is on the order of 95 L/sec (1,500 gpm) (Appendix B). Discharges from these springs typically have a high dissolved mineral content.

4.0 SPRING WATER SAMPLING PROGRAM

Less than 10 percent of known springs in DVNP have been sampled and analyzed. The sampling of springs for isotopic analysis by the USGS has been limited to the large discharge springs along the Furnace Creek Fault and along the alluvial fans on the east flank of the Panamint Mountain range.

The USGS also sampled a select number of springs in the Black Mountain range for isotopic analysis. The results of chemical analysis of spring samples collected by the USGS in DVNP are provided in Appendix B.

The chemical composition of the higher altitude, Type 2, springs, and the Type 3 springs in DVNP is essentially unknown. Thus, our spring sampling program focused on the Type 2 and 3 springs; as these may provide insight into the source of ground water in DVNP. Our goal was to sample 25 additional springs in DVNP for chemical analysis. We initially identified 30 springs from the National Park Service's inventory of springs in DVNP, with the understanding that some of these springs may not be flowing. Criteria for selecting these springs included whether the spring had been sampled before, geographic location, type of spring source rock, reported discharge volumes, and access. Of the 30 selected springs, only 23 were flowing and/or accessible.

Water samples from 23 springs and 2 creeks in DVNP were collected, preserved, and shipped for analysis to the USGS's Denver laboratory, Huffman Laboratories, and Beta Analytical Laboratory by The Hydrodynamics Group's personnel (Table 2). A description of our sample collection and analysis procedures and the results of our study are provided below.

4.1 Sample Collection and Analysis Procedures

Water samples were collected, preserved, and shipped in accordance with U.S. Geological Survey Yucca Mountain Program ground water sampling protocols under the direction of Zell Petermen (Senior Geologist, U.S. Geological Survey, Yucca Mountain Project Branch). Each spring source was sampled once in this study. A summary of the analysis performed and information collected on each spring source is provided in Table 3.

4.2 Data Collected and Results of Analysis

The results of the analyses by the USGS, Huffman Laboratory, and Beta Analytical are provided in Tables 4 and 5. A summary of collected field data is provided in Table 6.

5.0 ANALYSIS OF GEOCHEMICAL SPRING DATA

Springs have proven useful in the characterization of flow systems because they are integrated samples of a ground-water flow system reflected in a single point of discharge. The geochemical composition and physical characteristics of spring waters can be representative of an entire ground water flow system, and therefore very conducive to regional ground water studies. The geochemical composition of springs can provides clues to the source, travel path, mixing of waters, and other processes within the ground water system.

Our evaluation of the geochemical composition of the springs of DVNP and the Yucca Mountain study area first established the chemical composition of the spring waters, which is provided in this section of the report. Secondly, we compared the regional geochemical composition, concentrations of isotopes, and the regional geological conditions to evaluate the source of the spring waters relative to the Lower Carbonate Aquifers below Yucca Mountain.

5.1 Chemical Composition of Springs (Piper Analysis)

Piper diagrams are an acceptable method to portray the chemical composition of spring waters. A trilinear "Piper" diagram (Piper, 1953) is a technique for displaying water chemistry data. The method graphically shows the relative concentrations of major cations (Ca^{+2}, Mg^{+2}, and K^{+}) and anions (CO_3^-, HCO_3^-, and SO_4^-). Spring water of similar compositions will plot at or near the same position on a Piper diagram; this suggests a common source.

Piper diagram plots were prepared for springs sampled by mountain blocks (Plates 9, 10, 11, 12, 13, and 14). The index to the spring data points on Plate 9 is provided in Table 7 (Appendix B). Spring data points for chemical analysis provided by the USGS are designated by "spring name-USGS" (Appendix B).

The Piper diagrams of the DVNP springs indicate a very close match of chemical compositions for springs within a give mountain block (Plate 9). A description of the chemical composition of spring waters by mountain block is provided below.

The Piper diagram plot of the Grapevine springs indicates that all but two of the springs are located near the top of the recharge system (Plate 10). The very high HCO_3^- concentrations and very low concentrations of Na^+, Cl^-, SO_4^-, and Mg^{+2} indicate a very young ground water source. The springs sampled are at higher elevations near the winter snowfields, and are discharging from rhyolitic bedrock. Discharge rates ranged from a trace to over 20 gpm, and springs are located near intermittent creeks. The Stainger and Daylight springs differ from the other Grapevine springs in that they are localized intermittent seeps that pond water at the surface where it evaporates. Daylight spring was dry during our visit in May of 1998.

The Piper diagrams of the Funeral Mountain springs have very similar chemical compositions (Plate 11). These spring waters have high concentrations of Na^+, K^+, and Mg^{+2}, and intermediate concentrations of HCO_3^-, SO_4^- and Cl^-. This indicate water discharging from these springs has followed long travel paths. The source rock for these springs is carbonate. These springs are known for their association with travertine deposits at the spring orifices. The significance of these springs will be discussed in Section 6.0 and 7.0 of this report.

The Black Mountain springs can be described as a mixed bag of sources, based on the wide range of chemical compositions on the Piper diagrams (Plate 12). The Ibex, Lemonade and Salisburg springs have similar chemical compositions, but are not geographically near each other. The high concentration of NaCl and moderate concentration of HCO_3^- in these three spring waters indicates a small localized ground water flow path. Water discharging from these three springs was observed to pond, and eventually evaporates. The Willow spring is unique in that it plots near the center of the piper diagram (Plate 12). Willow spring is the discharge point for Gold Valley. Gold Valley is a higher altitude colluvial filled valley. The valley is composed of a wide range of metamorphic and igneous rocks. The chemical composition and location of Willow spring in Gold Valley suggest the source of water is discharge from the colluvial materials and basement rock.

The Piper diagram for the Panamint Mountain range springs reflect a range of composition that are indicative of their source rocks (Plate 13). The chemical composition of these springs shows very high concentrations of Ca^{+2}, and very low concentrations of NaCl and Mg^{+2}. The wide ranges of HCO_3^- and SO_4^- are indicators of the maturity of the water. A mature water will have a higher concentration of SO_4^- and a lower concentration of HCO_3^-. The opposite is true for intermediate-mature water. The more mature waters are from springs discharging from carbonate rocks, like Dripping spring. The C^{14} determined age of Dripping spring is about 7,000 years. The relatively higher concentrations of $CaSO_4$ in this water indicate a source of gypsum and/or other hydrothermally deposited minerals. There are a number of higher altitude small mining operations, near the Lime Kiln spring that are associated with hydrothermal deposits.

The Piper diagrams for the Death Valley Salt Pan springs are totally dominated by evaporation processes, with concentrations of NaCl exceeding that of sea water in some springs (Plate 14). These waters have essentially no concentrations of Ca^{+2}, Mg^{+2}, and HCO_3^-. The concentrations of SO_4^- are low to moderate suggesting these waters had sulfates in them prior to evaporation. The composition of the Eagle Borax Spring is similar to Panamint Mountain springs, which suggest this is a fault controlled spring source.

5.2 Stable Isotopes of Deuterium and Oxygen-18

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The stable isotopes of deuterium and oxygen-18 are useful in the interpretation of a spring source; these isotopes provide a signature of the recharge source, a means to evaluate the evaporation history of the water, and a means to evaluate certain rock-water reactions. The analysis of these isotopes can allow a constrained interpretation of ground water flow path. The isotope data is especially useful (when combined with other parameters), such as general water chemistry, type of spring source rock, and discharge rates.

Deuterium and oxygen-18 values are plotted on Plate 15. The Modern Water Line (MWL) is shown as a guide to average composition trends (Craig, 1961). Frequently, waters of the Great Basin plot slightly to the right of the MWL. This is because of evaporation during liquid precipitation in the generally dry atmosphere.

A considerable portion of the precipitation in the higher mountains is snow. Water samples from this water source plot on or just above the MWL, which is evident in the deuterium and oxygen-18 values for the Grapevine and some of the Panamint springs. For example, Johnnie Shoshone spring, a higher altitude spring in the Panamint Mountain range, plots to the left of the MWL. The spring has a relatively small catchment area, with recharge from a large number of winter snowstorm events. The higher altitude Panamint Mountain range's Hummingbird and Thorndike springs plot nearly on the MWL. The Wildrose spring differs from this pattern by plotting to the right of the MWL. Wildrose spring is located in the same drainage basin as these three springs, but at a lower elevation (approximately 1,250 m (4,101 feet) elevation). Discharge from Wildrose spring appears to be from a much larger drainage area. The Lime Kiln, and Upper Emigrant springs also represent discharge from relatively large drainage basins in the Panamint Mountain ranges, and plot just right of the MWL.

A number of moderate elevation springs 1,000 to 3,000 m (3,281 to 9,843 feet) in elevation show a strong shift to the right of the MWL; this reflects the influence of evaporation. Ibex and Salsberry springs in the Black Mountain range have small spring catchments that experience evaporation. The Navel Springs in the Funeral Mountain range also shows an evaporation effect, and influence from localized recharge. The Navel springs have a significantly heavier isotopic signature than the Texas, Travertine, and Nevares springs in the Funeral Mountain range. The Texas, Travertine, and Navares springs plot very close to the MWL. It is believed Texas, Travertine, and Nevares springs represent an older interbasin carbonate rock flow system. These springs also reflect more pluvial Pleistocene climate age waters, thus the lower isotopic values.

The Salt Pan springs show the greatest shift to the right from the MWL. All of the Salt Pan springs (McLean, Buried Wagon, Saratoga, Owls Hole, and Salt Creek) have gross water chemistries indicating dissolution of evaporates, primarily halite (NaCl) and some sodium sulfate minerals.

5.3 Uranium $^{234}U/^{238}U$ Isotopes

The uranium content in groundwater and ratio between the uranium isotopes of $^{234}U/^{238}U$ may provide insight into the source of the water (Ludwig et., al., 1993). Paces, et al. (1998) states:

> *Uranium-234 is an intermediate decay product of ^{238}U, which, if undisturbed, reaches a state of secular equilibrium, activity (decays per unit time) of the daughter is equal to that of the parent such that the $^{234}U/^{238}U$ activity ratio = 1.0 in solid materials older than several million years. In contrast, oxygenated ground waters in southern Nevada have $^{234}U/^{238}U$ ratios that are nearly always greater than those in surface runoff ($^{234}U/^{238}U$ activity ratios commonly between 1.5 and 2.0; J.B. Paces et al., USGS, written comm., 1996) or soil-zone materials (initial $^{234}U/^{238}U$ ratios of 1.3 to 2.0). Therefore, elevated $^{234}U/^{238}U$ signatures are obtained by incorporating ^{234}U preferentially to ^{238}U along flow paths due to processes related to the effects of radioactive decay in the adjacent wall rock. The dominant mechanisms are preferentially leaching of ^{234}U from radiation-damaged lattice sites (Szilard-Chalmers effect), radiation-induced oxidation of ^{234}U leading to a more soluble uranyl ion, and alpha-recoil of ^{234}Th off of crystal surfaces. The amount of ^{234}U excess relative to ^{238}U is limited by rates of ^{234}U decay, water rock ratios, flow-path length, and the amount of bulk-rock dissolution from the aquifer. These factors typically result in $^{234}U/^{238}U$ activity ratios between about 2 and 4 in most southern Nevada ground water.*

DVNP springs are relatively rich in uranium. Two potential sources of uranium are hydrothermal mineralization, (Panamint mountain range springs) and uranium concentrated by evaporation (Salt Pan springs).

The springs with the highest concentration of uranium are the salt pans springs of Buried Wagon, McLean, Salt Creek, Owls Hole, and Saratoga, which range between 16.22 and 25.22 parts per billion (ppb) uranium (Table 5). These springs have $^{234}U/^{238}U$ activity ratios that range between 1.25 and 1.73. The concentration of uranium in the Panamint springs of Johnnie Shoshone, Upper Emigrant, and Anvil range between 8.502 to 21.244 ppb. These springs have $^{234}U/^{238}U$ activity ratios that range between 1.25 and 2.83.

Paces, et., al. (1998) plotted uranium concentrations versus $^{234}U/^{238}U$ activity ratios for well and spring waters in the DVDB (Plate 16). Plate 16 also includes a plot of uranium concentrations versus $^{234}U/^{238}U$ activity ratios for Death Valley spring. Paces, et., al. (1998) states: *that ground water associated with carbonate, alluvial, and Precambrian-rock aquifers from Oasis Valley, Amargosa Valley, Spring Mountains and easternmost NTS (Nevada Test Site) have $^{234}U/^{238}U$ activity ratios of about 1.5 to 4*. Paces, et., al. (1998) further indicates waters from volcanic-rock aquifers beneath Yucca Mountain and western Yucca Flat commonly have values greater than 4, with anomalously high values of over 7 in shallow (saturated zone) wells. The $^{234}U/^{238}U$ activity ratio for Lower Carbonate Aquifer waters from UE-25p1 was 2.32. Paces, et., al. (1998) further indicates waters with the most elevated $^{234}U/^{238}U$ activity ratios (about 6) appear to be restricted to uranium concentrations less than about 3 ppb. The uranium concentrations and $^{234}U/^{238}U$ activity ratios for the Death Valley springs are consistent with Paces' observations for other well and spring waters in the DVDB.

5.4 Strontium Isotopic Ratios Analysis

The strontium isotope ^{87}Sr is a daughter of rubidium-87. Strontium chemically behaves similar to calcium and magnesium, but is not as abundant. Concentrations of ^{87}Sr and ^{86}Sr will vary for different rock types. For example, ^{87}Sr is found in greatest abundance in granitic and syenitic igneous rocks. Evaporates and marine sedimentary rocks contain abundant strontium, but normally have a lower concentration of ^{87}Sr. Igneous and volcanic rock have intermediate concentrations of ^{87}Sr. Because of this variation in concentrations of strontium isotopes by rock type, isotopic ratios of $^{87}Sr/^{86}Sr$ in ground water, expressed in per milliliters of ^{86}Sr in seawater, can provide a means of evaluating the source of the water.

The concentration of strontium and relative abundance of ^{87}Sr in the Death Valley spring waters are consistent with the general interpretations of water source areas previously discussed. For example, higher concentrations of strontium isotopes in Panamint Mountain springs are consistent for granite pluton rock type. The Tertiary pyroclastic volcanic rocks of the Grapevine Mountain springs have relatively low concentration of strontium isotopes. The relative high concentration of strontium isotope, and intermediate concentration of ^{87}Sr in the Death Valley salt pan spring water are indicative of evaporate deposits. The Willow spring in the Black Mountain range has a low concentration of strontium, and intermediate concentrations of ^{87}Sr. The low concentration of strontium is typical for a metamorphic rock type, but the intermediate concentration of ^{87}Sr suggests an eolian source from the alluvial basin sediments. The concentration of ^{87}Sr from 11.1 to 13.9 per milliliter in the Furnace Creek area springs (Travertine, Texas, and Nevares) are in the same ranges as the Big Bore and Last Chance springs, located just south of the Ash Meadows springs.

6.0 INTERPRETATION OF REGIONAL FLOW

In discussing the regional flow of the area there are several areas worthy of special discussion—the Furnace Creek area, Yucca Mountain and the Nevada Test Site (NTS), Ash Meadows, the Amargosa Valley, and finally the mountains in the vicinity of Death Valley.

6.1 Regional Hydrogeology

The Ash Meadows springs represent a window in the middle of the larger lower carbonate flow system. Up-gradient from the Ash Meadow area the carbonate aquifer is confined. The limited available hydraulic head information suggests that the potential for flow may be upward from the lower carbonate aquifer into the overlying alluvial fill of the Amargosa Desert basin. There may be a small amount of upward leakage. The exploratory holes being drilled by Nye County in early 1999 should provide more data on the hydraulic head in the area of the Amargosa Desert to the south of Yucca Mountain.

At the west margin of the area the lower carbonate aquifer is exposed in the Funeral Mountains; however, there is no hydraulic head information in this area. Within Funeral Mountains there are numerous faults. The fine-grained basin fill of the Amagora Desert terminates against the Funeral Mountains; this truncates the fine-grained basin-fill deposits and thus eliminates the obvious confining layer for the lower carbonate aquifer.

The Furnace Creek Fault Zone trends NW on the Death Valley side of the Funeral Mountains. It forms a barrier for further westerly flow in the lower carbonate aquifer. The fault provides localized conduits for upward flow through the Pleistocene and Pliocene sediments; this flow forms the Furnace Creek springs.

In the zone where the majority of springs occur, a splay of the major fault zone—the Greenwater Valley Fault, meets the Furnace Creek Fault Zone. The two faults form a graben 0.64 km (0.4 mile) wide. Within the graben are highly deformed and faulted Pliocene fine-grained sediments that are overlain by less deformed Pleistocene alluvial fan deposits. The alluvial fan deposits are also faulted. It is along these faults, within the fine-grained sediments, where the larger springs occur.

The Furnace Creek Fault Zone shows evidence for repeated lateral and vertical movements. It is a regional, deep-seated, transverse fault zone that has both segments with major vertical movement, and other segments with lateral movements. It forms the east flank of Death Valley along the Funeral Mountains; further to the north it bounds the eastside of the White Mountains.

One primary splay of the Furnace Creek Fault Zone extends southward to the west of the Resting Spring Range, down the Amargosa Valley to the Tecopa area. This Furnace Creek Fault is also the regional structural feature that terminates the lower carbonate aquifer in the Tecopa area. It controls the discharge from the carbonate aquifer both in Death Valley and to the south in the Shoshone and Tecopa areas.

There is evidence of a long history of flow in the lower carbonate aquifer. Paleo-Spring features occur in the Tecopa area, along Furnace Creek, and eastward in the Ash Meadows area. In the Death Valley area the paleo-springs occur where the Furnace Creek Fault Zone and associated faults establish the westerly limit of the lower carbonate aquifer. Along Furnace Creek travertine filled veins and travertine spring deposits occur within the Pleistocene alluvial fan deposits. These paleo-spring features appear to represent a period of significantly greater flow within the carbonate system. Winograd and Doty (1980) have recognized similar paleo-springs, of uncertain age, high above Furnace Creek at altitudes much greater than the current base level.

To the south in Tecopa Valley, along the bajada flanking the Resting Spring Range, travertine spring deposits occur associated with pluvial lake, beach deposits. These springs were also controlled by north-south faults associated with the Furnance Creek Fault Zone. Morrison (1999) dated the beach deposits in the Tecopa area at approximately 200,000 years before present. The deposits formed from thermal springs during the highest stand of Lake Tecopa. Later the lake basin was breached, and the Amargosa River drained to Death Valley.

These paleo-spring features are significant in that they suggest:

1) periods of higher hydraulic head in the past—perhaps as old as the late Pleistocene, ~200,000 years ago;
2) such paleo-spring features are recognized only in areas where major faults form deep- seated barriers to interbasin regional flow; the faults cause discharge from the carbonate rock system.

Most of the paleohydrologic features in this area of the carbonate rock province are not as well dated: however, the Tecopa area features are dated at 200,000 years in age. These old features suggest that tectonic movements in the area have not changed the flow system markedly from that which existed during the Pleistocene pluvial period. The spring areas of the past have been maintained in the same areas. The thermal character of the paleo-spring features suggests deep circulation within a confined system.

6.2 Furnace Creek Springs

The Furnace Creek spring area has large and small springs, and seeps; they combine to produce a discharge that is greater than 6,615 m^3 per year (5000 acre-feet per year) (Hunt et. al., 1966). These springs are interpreted as discharge from the regional carbonate aquifer. The discharge is too large to come from a drainage basin in the adjacent Funeral Mountains—a basin approximately 1,036 km^2 (400 square miles).

The source of these springs is an important consideration for the disposal of nuclear wastes at Yucca Mountain. If the major flow to the Furnace Creek spring is from Ash Meadows and to the east, then the risk of radionuclide transport from Yucca Mountain is reduced. If, on the other hand, the major flow path is from Yucca Mountain and NTS, then the risk is greater. It is this question that is the focus of our work.

6.3 Yucca Mountain Recharge

The UE 25-P1 drill-hole at Yucca Mountain was a 1,798 meter (5,900 foot) deep exploratory hole that penetrated 487 meters (1,600 feet) of Paleozoic carbonate rocks underlying the volcanic tuffs. It is the only drill hole at Yucca Mountain to have penetrated the lower carbonate aquifer. The borehole encountered carbonate rock beneath a fault zone believed to have significant displacement.

The hydraulic head measured in the carbonate rock is approximately 18 meters (60 feet) higher than that measured in the overlying volcanic tuff sequence. This indicates that any flow, or leakage, is upward from the carbonate aquifer into the Tertiary volcanic rocks in that area.

The major ion chemistry of the carbonate aquifer water is that of a regional aquifer. The major ion chemistry is similar to that of Texas and Travertine springs in Death Valley, and different than that of the Ash Meadows springs. The Ash Meadows springs are more dilute in the major ions; this may suggest that there is an important different source of recharge for Ash Meadows. Most researchers now agree that much of the water in the springs of Ash meadows is from the Spring Mountains.

The deuterium in the UE 25-P1 carbonate water is -107 units, too light for either Ash Meadows or the Furnace Creek area waters. This indicates that carbonate water from Yucca Mountain must be mixed with water containing heavier deuterium to reach the deuterium values observed in Furnace Creek spring waters.

In conclusion, it is likely that UE 25-P1 carbonate rock water is old, and that it represents a slower zone of flow within the carbonate rock flow system.

6.4 Recharge From Amargosa Desert Basin Fill

The data for wells in the Amargosa Desert is limited. There are 26 wells with gross water chemistries; 20 of these have stable isotope analyses. The average deuterium content is -102 units, and average oxygen-18 content is -13 units. The deuterium ranged from -98 to -105 units, and oxygen-18 from -12.6 to -13.8 units. Both the deuterium and oxygen-18 values are slightly heavier than the Furnace Creek spring waters, but individual analyses overlap the Furnace Creek data.

Claassen (1985) suggested that the Amargosa Desert basin-fill waters came from several sources: 1) carbonate aquifer water, 2) water recharged from surface flows in the Amargosa River and Forty Mile Wash, and 3) water from the volcanic aquifers to the north in the area of NTS. Claassen (1985) recognized the possibility of upward leakage of ground water along the same fault that localizes the Ash Meadow springs. Water from wells in the Amargosa Desert has deuterium and oxygen-18 contents that are similar to the Ash Meadow springs.

6.5 Ash Meadows Springs

The discharge of the Ash Meadows springs is estimated to be approximately 20.96×10^6 m^3 per year (17,000 acre-feet per year). Hunt et al. (1966) hypothesized that ground water is recharged in the Spring Mountains. It then flows westward to the Ash Meadows area then on to Death Valley. The Ash Meadows springs are approximately halfway along the postulated flow path.

Winograd and Thordarson (1975) mapped the regional head in the lower carbonate aquifer. Their map suggests ground-water flow form the northeast side of the Spring Mountains, around the northwest extension of the range, to the Ash Meadows springs. This interpretation differs from that of the Hunt et al. (1966); Hunt et al. suggested a flow path directly west from Pahrump Valley to Ash Meadows.

The major flow path for ground water now appears to be from the north side of the Spring Mountains. This northern flow supplies the bulk of the water to the Ash meadow springs. With this interpretation, it is the combination of ground water from NTS mixed with a larger percent of Spring Mountain derived ground water that supplies the Ash Meadow springs.

One can compare the isotopic data for the Ash Meadows spring water with that from the Furnace Creek springs. One interpretation is that the Furnace Creek regional springs are the result of flow that bypasses the Ash Meadow springs; the Death Valley springs in this interpretation are the down-gradient extension of the Ash Meadows regional flow system. The deuterium/oxygen-18 isotopic composition of the water suggests that there is no significant source of recharge between Ash Meadows and the Furnace Creek area. There is about 48 km (30 miles) of travel distance between Ash Meadows and Death Valley.

Local and small-local "carbonate" flow systems occur in both the Spring Mountain and Pahrump Valley. These local and small-local flow systems have water with almost no Na+K of $Cl+SO_4$. Water from the Ash Meadows Spring has a major ion content that is typical for a regional carbonate system. However, the water from Ash Meadows has only approximately 50% of the Na+K and $Cl+SO_4$ that is present in the Furnace Creek springs.

The major ions of Na+K, $Cl+SO_4$ increase significantly between Ash Meadows and Furnace Creek, while the stable isotopes are unaffected. One explanation for the increase in major ions is dissolution from the carbonate rock of minerals, principally gypsum, that increases the Na+K, and $Cl+SO_4$ content of the water; Mifflin favors this explanation. Winograd, on the other hand, argues there is little, or no gypsum in the carbonate rocks in this area. He suggests there must be a contribution of other water high in $Cl+SO_4$ along the flow path to the Furnace Creek springs.

The limited hydraulic head data in the area suggests regional flow is from from Pahute Mesa to Yucca Flat then southwest to Oasis Valley. To the south the flow is toward the Amargosa Desert, and continuing to the Ash Meadows springs. There is a significant range in the deuterium values from these areas; the variation is 8 to 10 deuterium units. The variation suggests different ages for the waters.

An explanation for the variation in deuterium isotopes is that there is a significant component of old pluvial climate derived recharge in some, if not most, the deeper flow systems both in the larger basin-fill aquifers as well as parts of the regional carbonate flow system. Flow within parts of these systems may be sufficiently slow to still contain water that is more than 12,000 years old.

A mix of deuterium data from young and old water may be misleading in identifying recharge areas for the regional carbonate aquifer. The isotope analyses for the Ash Meadows spring waters may pose such difficulties. The contribution from the Spring Mountain and the Sheep Range contribution may be significantly underestimated. The data suggests that the combined recharge in northeastern portion of Las Vegas Valley had an average deuterium content of -103 units—representing recharge that occurred during an earlier pluvial climate. The data from the local-small springs in the surrounding mountain ranges indicates that the current recharge has a deuterium content no lighter than -96 units. There may be a difference in the deuterium content of -7 units between recharge in an earlier pluvial climate recharge and recharge today.

Thomas et al. (1996) suggested that 40% of Pahranagat Valley water, with an average deuterium content of –109 units, mixes with 60% of Spring Mountain water, with an average deuterium content of -99 units, to yield the observed deuterium content of the Ash Meadow spring water, -103 units. Mifflin suggested that if the average deuterium content of the Spring Mountain recharge is -97 units then a 50/50 mix results. This demonstrates how sensitive the calculations of recharge area are to small changes in isotopic composition. There is no independent evidence for recharge coming from Pahranagat Valley.

The stable isotope data is insufficient to be used exclusively to identify the areas of recharge regional flow systems within the carbonate rocks. In some areas where the water may be quite old the interpretation is made more difficult by the potential shift in deuterium/oxygen-18 composition between the present climate and an older pluvial climate. Mifflin suggests that the regional deuterium data indicate a variation between the current recharge and older pluvial climate recharge of 6 to 7 deuterium units.

6.6 Springs in the Vicinity of Death Valley

We collected samples of water from 23 springs in the vicinity of Death Valley, as previously discussed. Most of these were in the mountain ranges that surround the valley. When we plotted the chemistry of the water on Piper diagrams the water from the various mountain ranges grouped nicely; the major ion water chemistry has a distinct signal for each mountain range. This reflects the fact that the major ion water chemistry takes on a distinct character from the local geology.

6.7 Local Recharge in the Funeral Mountains

It is probable that some recharge to the lower carbonate aquifer occurs through the carbonate rocks of the Funeral Mountains. This is even more probable because of the carbonate rocks are highly fractured and faulted in the Funeral Mountains. There are no high-altitude springs in the Funeral Mountains that can be used to directly characterize the stable isotopic signatures of local recharge.

At first glance, Navel spring appears that it may represent local recharge. However, Navel spring waters have stable isotope signatures that indicate low altitude recharge and some evaporation; these waters are too heavy to be representative of local recharge in the Funeral Mountains.

The major spring waters—Texas, Travertine, Nevares—are clearly too light in stable isotopes to be derived entirely from local recharge.

The total amount of local recharge in the Funeral Mountains is estimated to be approximately four times larger than the recharge in Gold Valley in the Black Mountains. Gold Valley is similar in elevation; water from Gold Valley is expected to have a stable isotopic signature similar to the recharge area in the Funeral Mountains. Willow spring in Gold Valley has an average discharge between 2.5 to 3.15 L/sec. (40 and 50 gpm). This is about 6% of the discharge of the Furnace Creek springs. Willow Spring water has a deuterium content of –92 units, and an oxygen-18 content of -11.4 units.

Assuming that the local recharge in the Funeral Mountains is similar in isotopic composition to Willow spring water, it requires only 6% Funeral Mountain local recharge water mixed with Ash Meadow spring water to yield water that is the same isotopic composition as water in the Furnace Creek springs.

7.0 HYDROGEOCHEMICAL INTERPRETATIONS

The large springs at the base of the Funeral Mountains in Death Valley are an enigma. The discharge is too large—6.125 x 10^6 m^3 (5000 acre-feet/year)—to be recharge from the associated, nearby drainage basins in the Funeral Mountains. The suggestion is that these springs are supported by inter-basin ground-water flow in the lower carbonate aquifer.

A number of investigators have hypothesized the source of these springs. Most of these ideas have been based upon the similarity of the spring water chemistry to other ground water in the region. The various investigators have used both the major ion and the isotope chemistry of the water. The question arises, after collecting and analyzing waters from another set of springs during this investigation—most of them in the vicinity of Death Valley, whether we can further constrain the source of the water for the springs of Furnace Creek.

There are several interpretations for the source of these springs. Hunt et al. (1966) suggested the source was in the Springs Mountains (south of Las Vegas) about 80 km (50 miles) to the east. In Hunt et al. (1960) the interpretation is that ground water would flow through the lower carbonate aquifer along a path through Pahrump Valley to Ash Meadows and then to Death Valley.

Winograd and Thordarson (1975) observed that ground water from the springs in the Ash Meadows Area, and in the alluvial fill along the Amargosa River is similar in gross chemistry to the water of the Furnace Creek springs. (Winograd and Thordarson (1975) published a U.S. Geological Survey Professional Paper on the geochemistry of ground water in the area of the Nevada Test Site (NTS). This publication was a long time in process. Winograd and Thordarson worked at NTS for almost a decade in the 1960s; their ideas were widely discussed long before the their Professional Paper was published.) They suggested that at least some of the recharge for both the springs at Ash Meadows and in the Furnace Creek area in Death Valley came from the north in the vicinity of NTS.

Mifflin (1968) studied the hydrochemical facies of carbonate rock flow systems in Nevada. He compared the water chemistries of all large discharge springs (greater than 9.5 L/sec. (150 gallons per minute)) within the region in which the "bedrock" is dominated by carbonate rock—his so-called "carbonate rock province". Mifflin found that as the length of a ground-water flow path increased in the carbonate rock, the "conservative" major ions of Na+K and $Cl+SO_4$ continued to increase in concentration. On the other hand, the Ca+Mg and HCO_3+CO_3 content of the water generally remained at, or close to, saturation with respect to the carbonate rocks of the aquifer. Mifflin used other supporting data, such as presence or absence of atomic bomb-derived tritium, geographic and terrain information, water budgets, and a few carbon-14 analyses that indicate apparent age of the water, to support his hypothesis. He argued that the weight of the evidence supported the idea that the length of ground-water flow path determined the widely varying concentrations of the major ion chemistry of the water. The length of the flow path is a surrogate measure for the residence time of water in the aquifer.

Mifflin (1968) went on to suggest that the flow systems as interpreted from the spring water chemistries could be subdivided into three flow systems: 1) small-local, 2) local, and 3) regional. The division between the water chemistry of "local" and "regional" springs was established by comparing the chemistry of known regional (interbasin) springs (established by evidence other than chemistry) with the chemistry of known local springs. The chemistry of local and regional springs differs by approximately one equivalent per million (epm) for Na+K and $Cl+SO_4$.

Claassen (1985), based upon a study of hydrochemistry, suggested Amargosa Basin fill waters may be derived, at least in small part, from the volcanic terrain in the Yucca Mountain area.

Johnson (1980) studied the temporal relationships of water chemistry, discharge, and tritium content of a group of "small-local" and "local" springs along the East Side of the Ruby Mountains. Johnson's (1980) investigation reinforces Mifflin's idea of shallow flow systems for the "small-local" springs and deeper, larger flow systems for the "local" springs.

The major ion ground-water chemistry in both carbonate rock and basin-fill, regional flow systems may be quite similar. The stable isotopes of deuterium and oxygen-18 have been used to identify areas of recharge. Winograd and Friedman (1972) were the first to use the stable isotope deuterium as a tracer; they showed that deuterium varied in concentration in recharge areas within Mifflin's carbonate rock province.

Winograd and Friedman demonstrated that stable isotopes in water were a potentially powerful technique that could be used to interpret source areas for the large regional flow systems. Kirk and Campana (1980), Claassen, (1985,1986), Lyles and Hess (1988), Novak (1988), Hershey and Mizell (1995), Thomas et al. (1996), and Pohlmann et al. (1998) revisited the general spring hydrogeochemistry within Mifflin's carbonate rock province. They considered the stable isotopes of deuterium and oxygen-18, as well as other isotopes, and trace constituents in the spring waters.

In this investigation we sampled and analyzed the water chemistry of an additional set of springs in the immediate vicinity of Death Valley. One of the objectives was to help further characterize the ground water in the Death Valley mountain blocks, and to determine the source of these waters. Specially, we are interested in how much of the water in the Furnace Creek springs (Lower Carbonate Aquifer springs) comes from a local source, and how much comes from the Amargosa Valley and Yucca Mountain areas.. We hoped to constrain the local recharge by looking again at the hydrochemistry of the water.

In using the geochemistry of the spring water for interpreting sources and flow paths there are three, more or less, independent data sets. The first is the major ion composition of the water. The second is the stable isotope composition of the water—most of this data is for deuterium/oxygen-18. The third is the age dating of the water using tritium, or carbon-14 age of the water.

7.1 Major Ion Chemistry

Winograd and Thordarson (1975) used the major ion chemistry of the ground water in the lower carbonate aquifer to suggest the source of recharge. For the carbonate springs in Death Valley they suggested three potential recharge areas: 1) the Nevada Test Site area, 2) the Amargosa Desert, and 3) the area to the east in the Spring Mountains that supplies much of the Ash Meadow springs.

Winograd and Thordarson (1975) based their interpretation on the major ion chemistry of waters from these areas. The major ion constituent chemistry of water from well 16/48-17a1 in basin-fill alluvium, on the west side of the Amargosa Desert, is very similar to water from Navares, Texas, and Travertine springs in the Furnace Creek. The major ion chemistry of water from the Ash Meadows regional springs, that also discharge from the lower carbonate aquifer, are similar; however the Ash Meadow water has less Na+K and $Cl+SO_4$. The chemistry of the Pahrump Valley—Spring Mountain waters are significantly different; they have almost no Na+K and $Cl+SO_4$.

7.2 Isotopes—Deuterium/Oxygen-18

Craig (1961) defined a relationship between deuterium and oxygen-18 that he defined as the ***meteoric water line (MWL).*** Craig suggested that precipitation from all over the world should fall along the MWL. It is this hypothesis of Craig's that forms the basis for much of the use of deuterium and oxygen-18 as tracers in water. Plate 15, adapted from Thomas et al. (1996), shows the relationship between deuterium and oxygen-18 for ground water from our area of interest.

The data from southern Nevada and southwestern California are shifted slightly to the right from Craig's (1961) global MWL. Water that has undergone evaporation becomes heavier in oxygen-18 with respect to deuterium because of fractionation caused by evaporation. This suggests that water that plots to the right of the MWL has undergone evaporation; the further the data plots further to the right of the MWL, the more evaporation is indicated.

Precipitation in the arid region that occurs in liquid form evaporates slightly during fall through the atmosphere. This explains the shift to the right in the majority of the data from this area of southern Nevada and southwestern California. Precipitation that occurs as snow or ice does not evaporate and fractionate; we expect these waters to plot closer to the MWL. Water that is strongly shifted to the right of the MWL indicates that these waters have undergone significant evaporation.

Both deuterium and oxygen-18 in precipitation are influenced by a number of factors related to moisture sources, to storm path histories, and air temperature. Deuterium and oxygen-18 concentrations in ground water in recharge areas, as represented by small-local springs and shallow wells in mountainous areas, are an integrated sample of summer and winter precipitation. Geography, especially altitude of the recharge area, is important in determining the deuterium and oxygen-18 content of recharging ground water. A further complication that may enter into interpretations is the age of the ground water.

A large, and independently derived body of evidence indicates cooler to significantly colder pluvial climates existed in the region in the not too distant past. The cooler climate should have produced precipitation that is lighter in deuterium and oxygen-18 than water recharged during the current, and warmer, interglacial climate of the region. There are two conditions for the recharge in the large regional flow systems:

1. all the recharge in these large systems is younger than the last major pluvial climate in the region—approximately 12,000 years ago, or
2. some of the water is older than 12,000 years and is pluvial.

If some of the water is older than 12,000 years, the interpretation of recharge areas based upon the deuterium/oxygen-18 isotopic composition is more complex.

Thomas et al. (1996) concluded that deuterium in water, from a set of samples from recharge areas in the Spring Mountains and the Sheep Range, did not show a trend towards lighter values with greater apparent age. He inferred the age of the water from the carbon-14 content of the water (the percent modern carbon); his ages are only relative. All the water analyzed by Thomas et al. appears to be associated with the modern MWL.

Mifflin reviewed for this study the currently available deuterium data within the region that we and other researchers collected—displayed in Plate 15, (Thomas et al., 1996). Mifflin suggested, based upon his review of the data for the region, that some of the water in the deeper parts of the flow system appears to be lighter in deuterium. Mifflin commented that the water used by Thomas et al. (1996) in their analysis is from the mountain ranges in areas where one would expect the water to be younger than 12,000 years.

Mifflin went on to suggest that deuterium is generally lighter (higher values) in the known regional carbonate springs than in the potential recharge areas as outlined by Thomas et al. (1996). Values from the basins many be more negative than -100 units (more negative values are lighter). Mifflin argues that the general relationship of light deuterium values in the basins with heavier values in the mountains indicates that we are dealing with of two different ages of water—an old, lighter water, and a more recent heavier water. Undoubtedly, any shift in the MWL occurs gradually as climate changes, and there is a continuum from light to heavier—it is not purely bimodal.

These interpretations assume that the precision of the deuterium determinations is within 1 or 2 tritium units. Tritium is hard to analyze; such precision is hard to achieve, especially when more than one laboratory does the analyses. Therefore, spring sampled for this study were not analyzed for tritium.

Regardless of the problems that attend interpretation of stable isotopic data, once the water is in the confined portions of regional carbonate aquifer flow systems the isotopic composition of the water remains unchanged, especially deuterium. The isotopic composition remains constant over considerable distances and time. The composition changes as waters from differing sources mix.

7.3 Carbon-14

The carbon-14 ages are problematic in the Lower Carbonate Aquifer because of the potential for carbon exchange with the rock. A number of investigators have attempted to correct the carbon-14 ages using various techniques. None of these attempts is very convincing. Older carbon-14 dates are only suggestive; the carbon-14 dates cannot be used quantitatively in the Lower Carbonate Aquifer. Therefore, the results of our carbon-14 analyses was not used for comparative analysis with Lower Carbonate Aquifer carbon-14 data from other sources.

8.0 CONCLUSIONS

The water sampled and analyzed from small-local springs in mountain ranges in the vicinity of Death Valley have a major ion signature that groups the waters nicely by mountain range.

By comparing the deuterium content of the large regional springs in the Furnace Creek area with the deuterium content of the small-local springs in the Death Valley area we can constrain the amount of local recharge to the carbonate aquifer in the Funeral Mountains. The amount of local recharge is less than 10% of the regional spring discharge in the Furnace Creek area. This is further evidence that the major springs in the Furnace Creek area discharge from the regional carbonate aquifer.

The question of the ultimate source of recharge for the Death Valley carbonate springs remains unanswered. The three possibilities outlined originally by Winograd and Thordarson (1975) remain possibilities. The water can come from recharge in 1) the area of NTS and Yucca Mountain; or 2) the Amargosa Basin fill deposits, or 3) the area to the east that includes the Ash Meadow springs, or some combination of all three. We now know that the local recharge is quite small.

The deuterium/oxygen-18 data suggest that some water in the Lower Carbonate Aquifer may have come from recharge that is older than 12,000 years, from a time when the climate was cooler and wetter. This cooler and wetter climate had isotopes of deuterium and oxygen-18 that were lighter; they represent a shifted MWL during the cooler, wetter climate.

9.0 RECOMMENDATIONS

The results of this study suggest the need to further characterize the springs and hydrogeology of the Death Valley area, and to better understand the hydraulic connection between the Funeral Mountain springs and the Lower Carbonate Aquifer beneath Yucca Mountain and the Amargosa Valley. It is recommended that additional springs be sampled and analyzed for major anion and cations, and stable isotope concentrations. We further recommend the drilling of two exploratory wells east of the Funeral Mountains to further evaluate the possible hydraulic connection between the springs in Furnace Creek area and the Lower Carbonate Aquifer

The Death Valley springs in the Furnace Creek area, upper Funeral Mountain range, Grapevine Springs area near Scotty's Castle, and the Cottonwood Mountains have not been fully characterized in terms of discharge rates and water chemistry. Further characterization will help to determine the source of spring waters in the northern portions of the Death Valley area, and from the carbonate springs in the Furnace Creek area. It will also improve our understanding of the hydrogeology of the Death Valley area in terms of recharge and water balance. We recommended selected springs be characterized and sampled according to the sampling protocols developed for this study.

Our understanding of the hydraulic connection between the Funeral Mountain springs and the Lower Carbonate Aquifer would be improved with 1) the drilling of two exploratory monitoring wells, and 2) chemical analysis of water from the Ash Meadows springs and wells in the Amargosa Valley. We recommend the drilling and construction of two approximately 460 meters (1,500 feet) deep monitoring wells on the east side of the Funeral Mountain range. One of the wells should be along an extension of the Furnace Creek fault in the Amargosa Valley. The wells should be designed to allow geological logging of drill cutting, water sampling from selected aquifers for chemical analysis, and water level measures in the Lower Carbonate Aquifer. Water samples should be collected from these two wells and from selected springs and wells in the Amargosa Valley, according to the protocols developed for this study.

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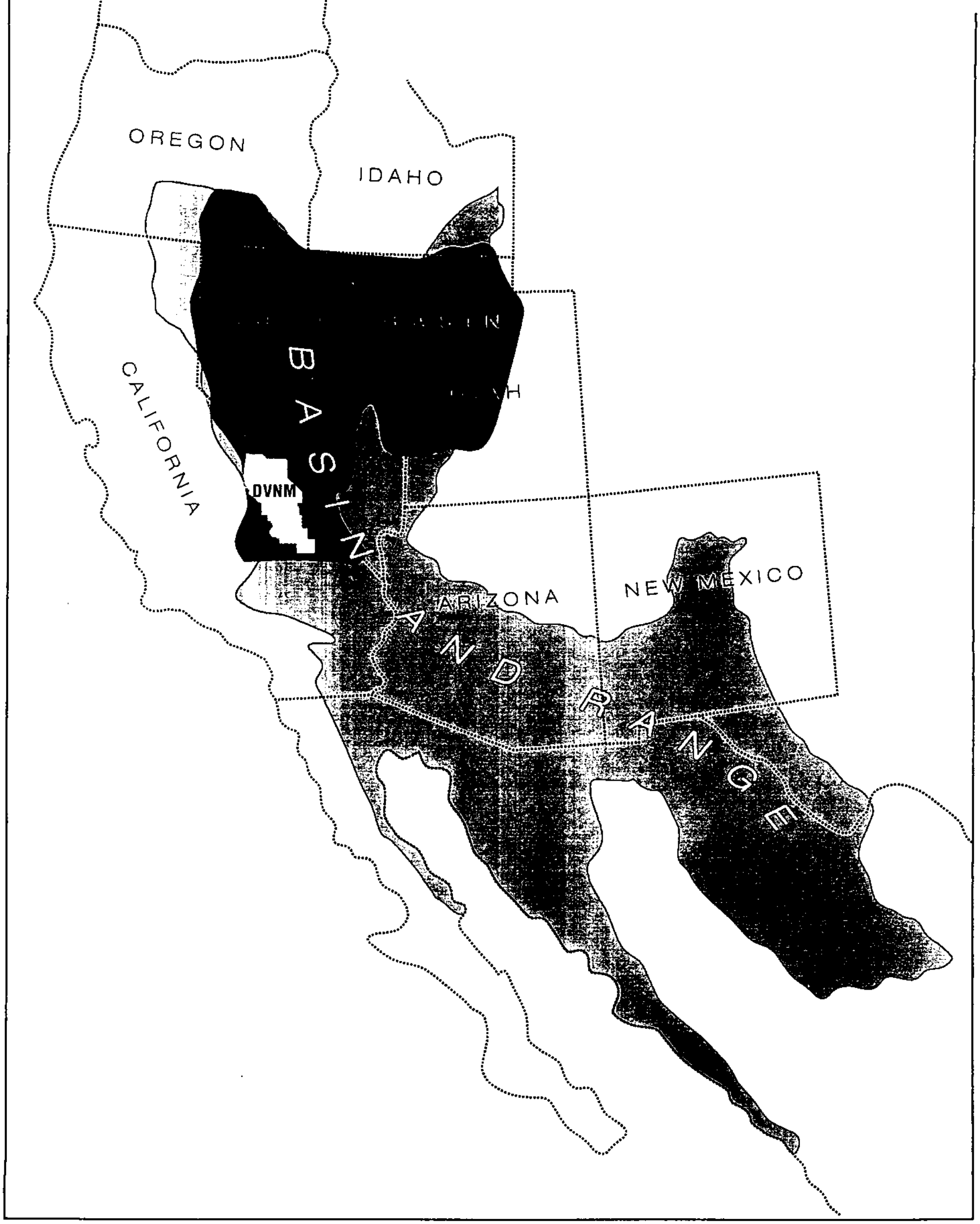

PLATE 1 – Boundaries of Basin & Range and Great Basin Provinces
(apapted from Fiero. 1986)

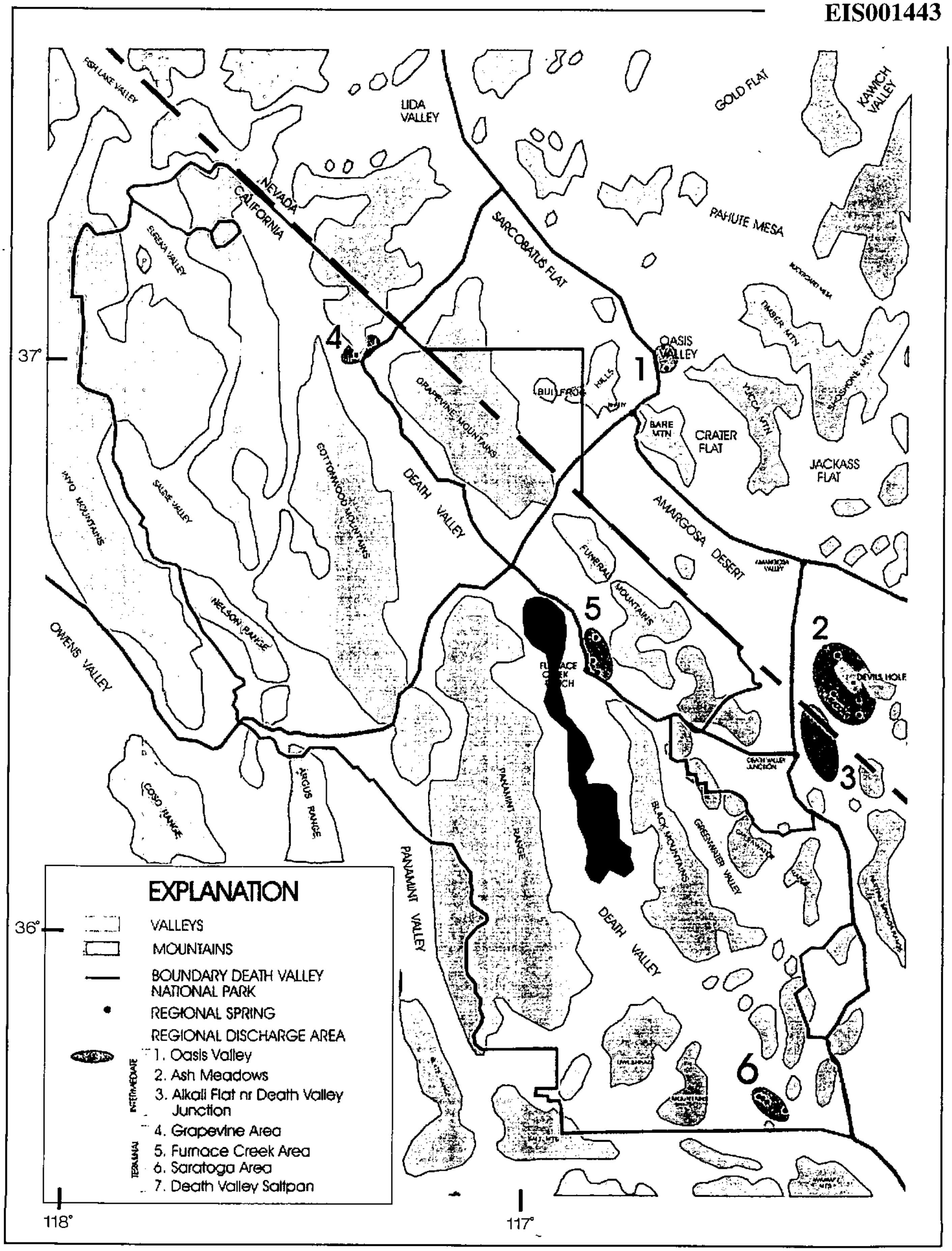

PLATE 2 – Selected Features of Death Valley National Park and adjacent areas

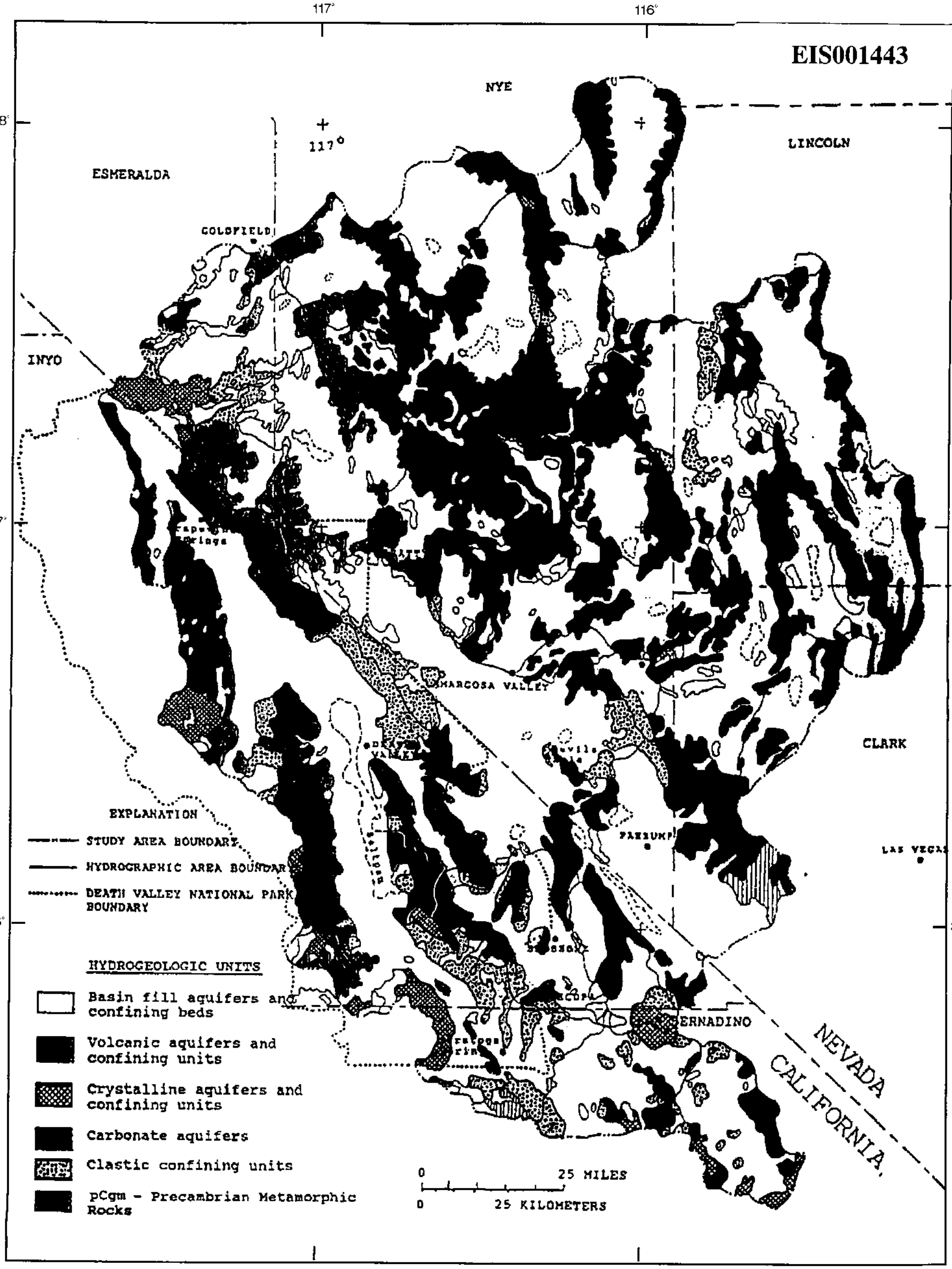

PLATE 3 – Generalized Geological Map of Death Valley Drainage Basin Area

(apapted from Pal Consultants, 1995)

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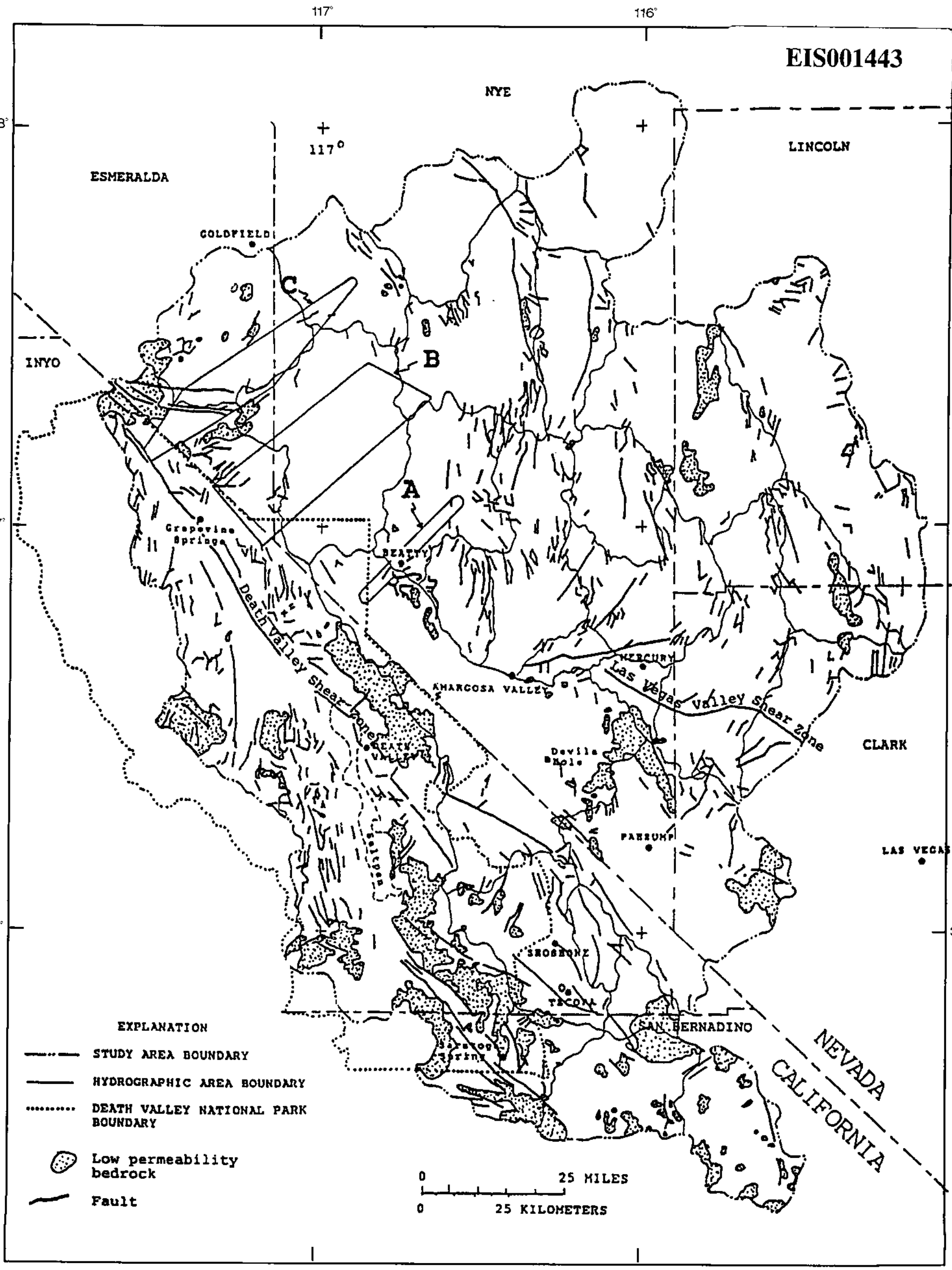

PLATE 4 – Major Fault and Structural Features Map of the Death Valley Drainage Basin Area
(apapted from Harrill, 1995)

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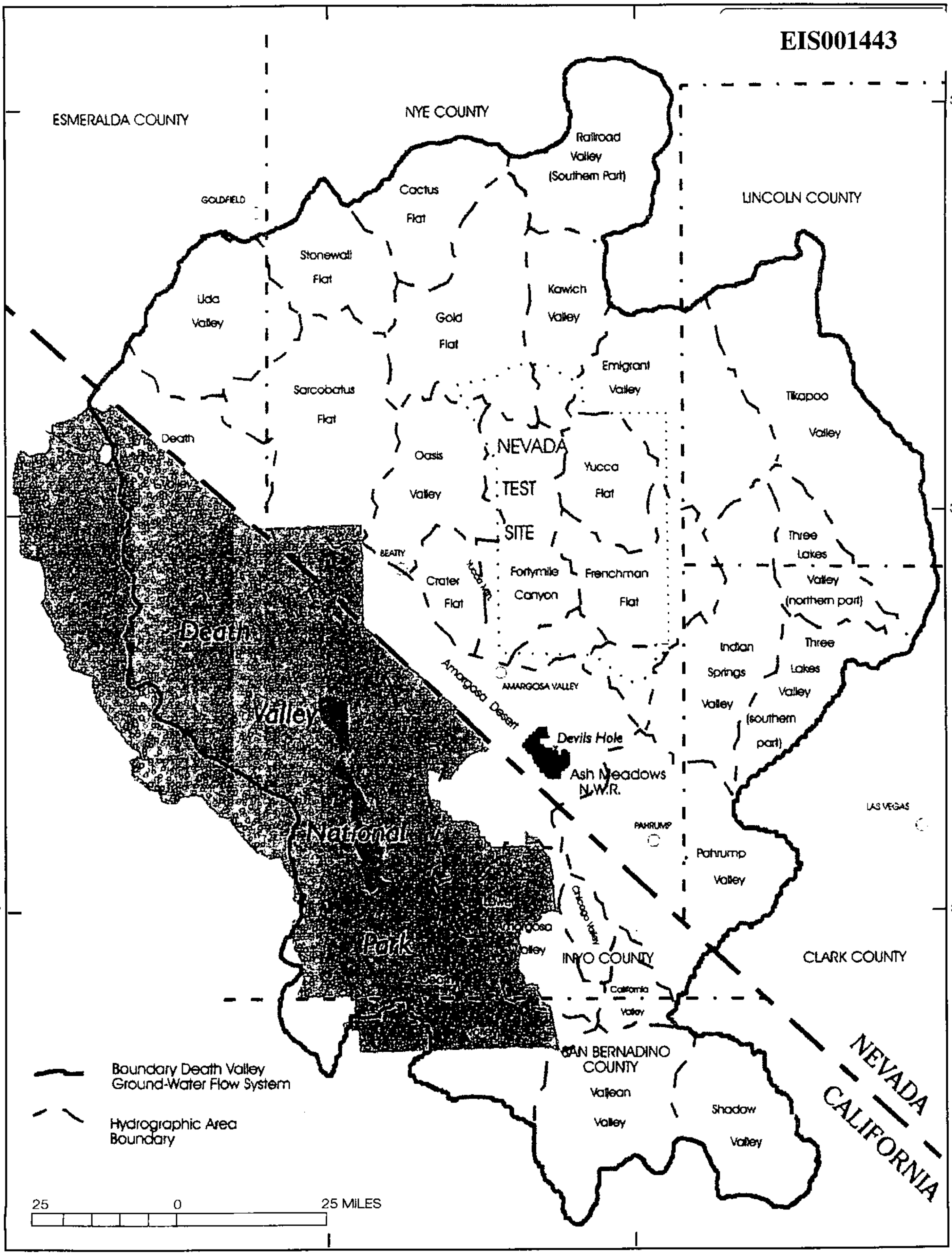

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PLATE 5 – Sub-Drainage Basin Boundaries in Death Valley Drainage Basin

(apapted from Bedinger & Harrill, 1998)

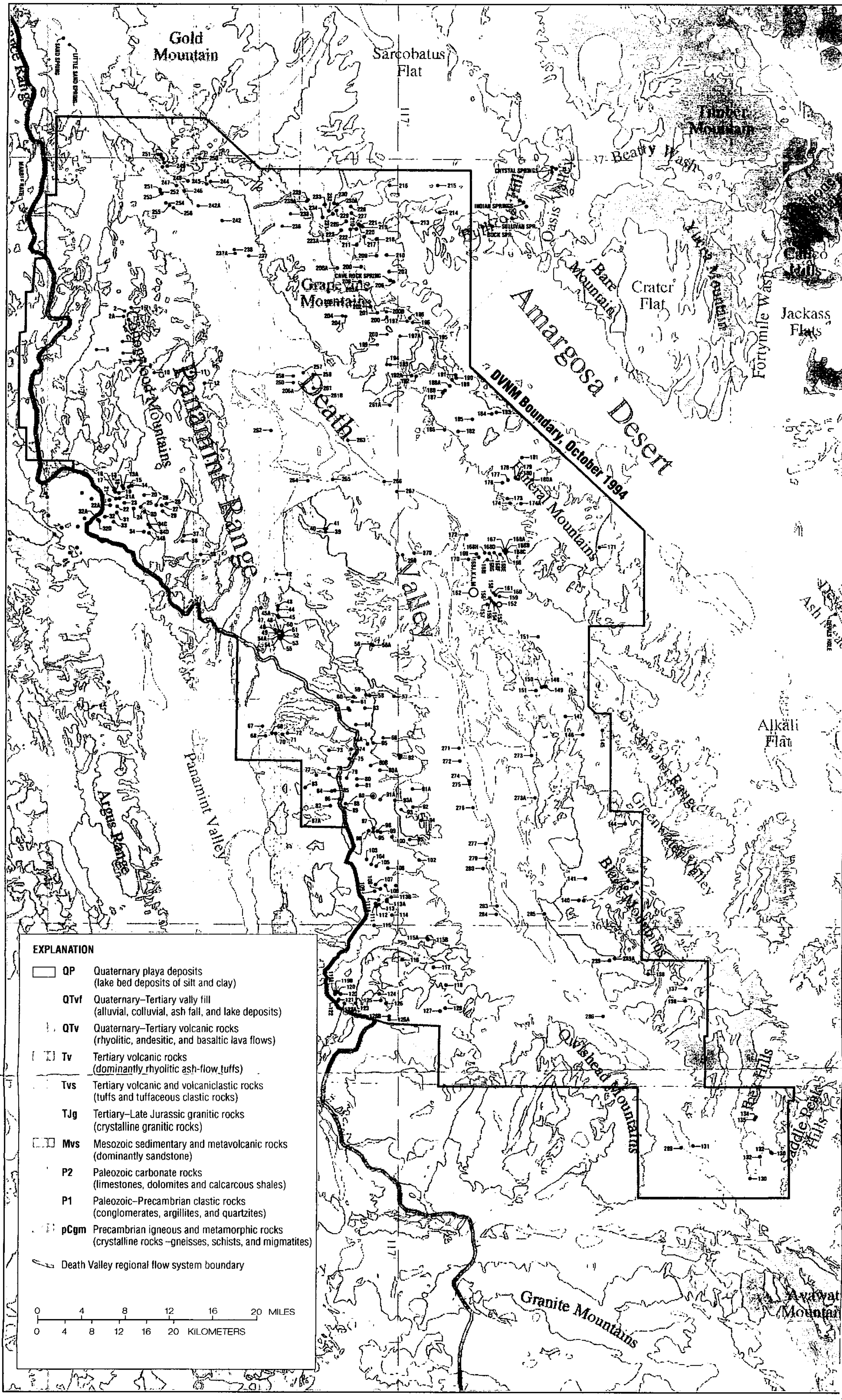

PLATE 6 – Hydrographic Units Map of Death Valley Area Showing Spring Locations
(adapted from Faunt, 1997)

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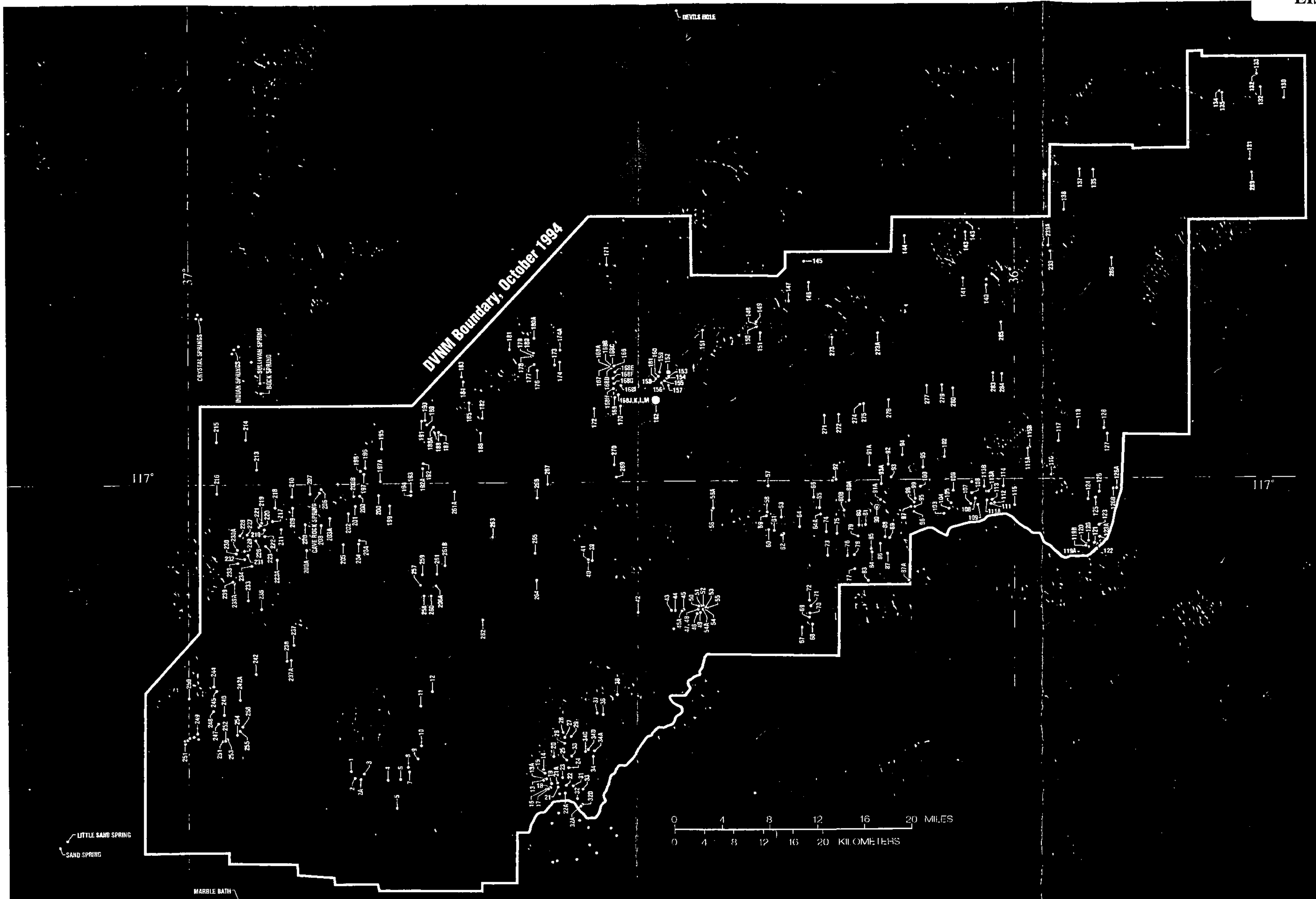

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PLATE 7 – Locations of Springs in Death Valley, Shown on Satallite Image

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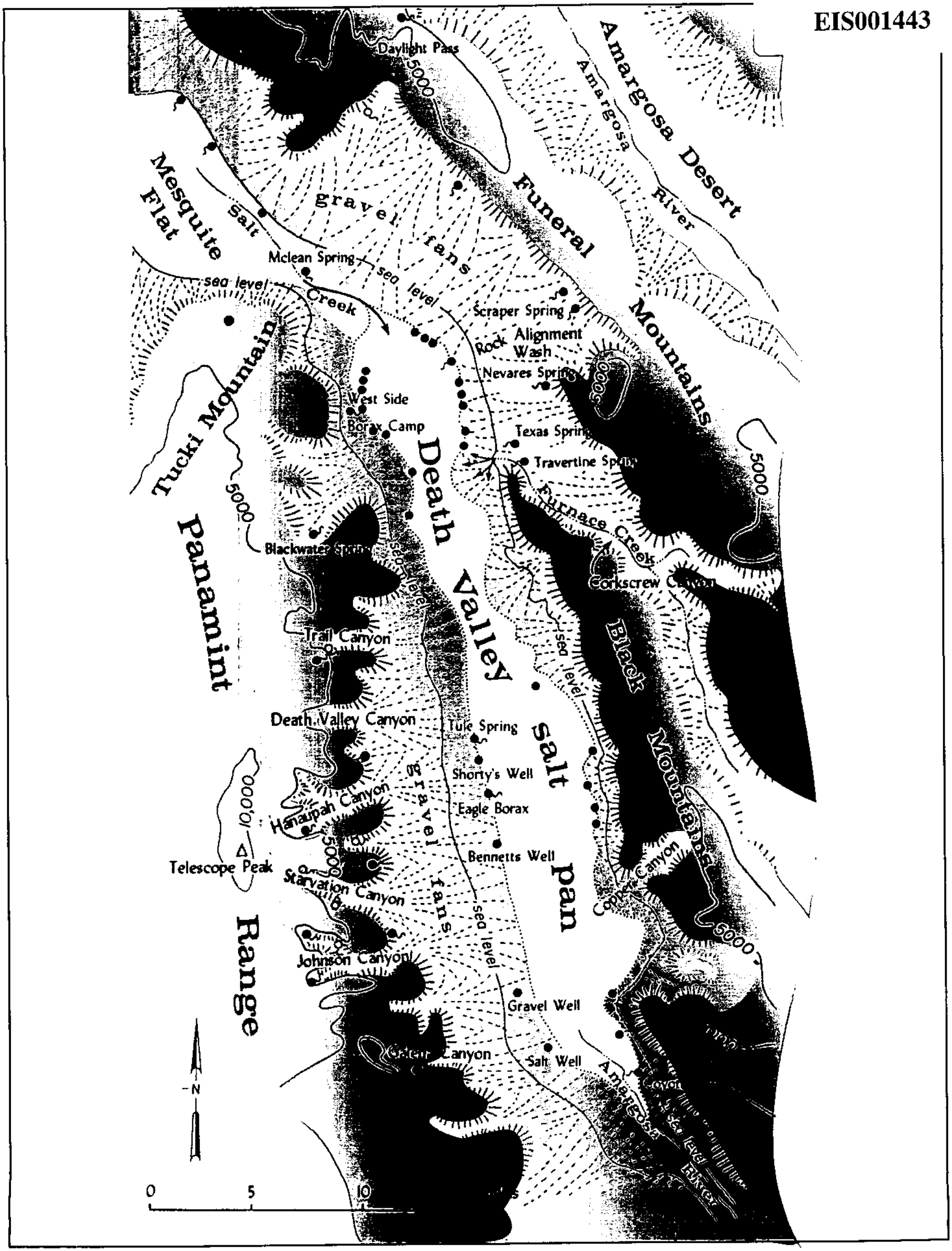

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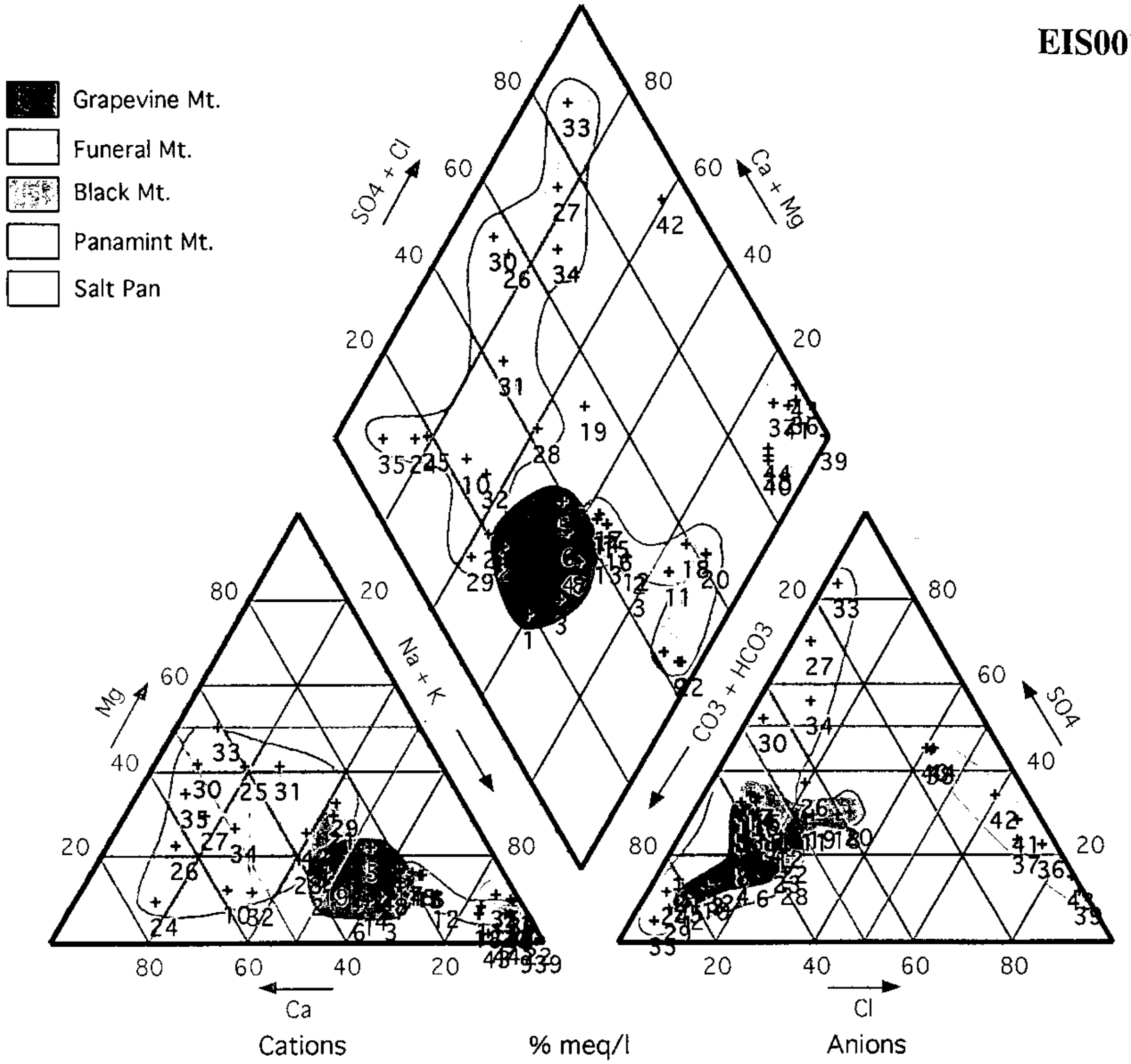
PLATE 8 – Map of Major Springs and Seeps Around the Salt Pan of Death Valley National Monument

(apapted from Hunt, 1975)



No.	TDS	Sample	No.	TDS	Sample
1	228	G: Strozzi Ranch Spring	19	567	B: Willow Spring
2	203	G: Cordwood Spring	20	1816	B: Ibex Spring
3	295	G: Little Willow Spring	21	817	B: Virgin Spring
4	198	G: Knoll Spring	22	595	B: Lemonade Spring-USGS
5	716	G: Klare Spring-USGS	23	480	B: Salisburg Spring
6	309	G: Woodcamp Spring	24	183	P: Thorndike Spring
7	895	G: Grapevine Ranch #1-USGS	25	540	P: Johnnie Shoesone Spring
8	945	G: Grapevine Ranch #6-USGS	26	409	P: Hummingbird Spring
9	585	G: Stainger Spring-USGS	27	889	P: Wildrose Spring
10	187	G: Daylight Spring-USGS	28	570	P: Suprize Canyon Creek
11	684	F: Navel Spring	29	658	P: Burns #1 Spring
12	985	F: Upper Navel Spring	30	578	P: Lime Kiln Spring
13	761	F: Travertine Spring-USGS	31	1047	P: Upper Emigrant Spring
14	809	F: Nevares Spring-USGS	32	383	P: Anvil Spring
15	735	F: Travertine Spring-USGS	33	1116	P: Dripping Spring
16	773	F: Texas Spring-USGS	34	474	P: Warm Spring
17	780	F: Nevares Spring-USGS	35	294	P: Jaybird Spring-USGS

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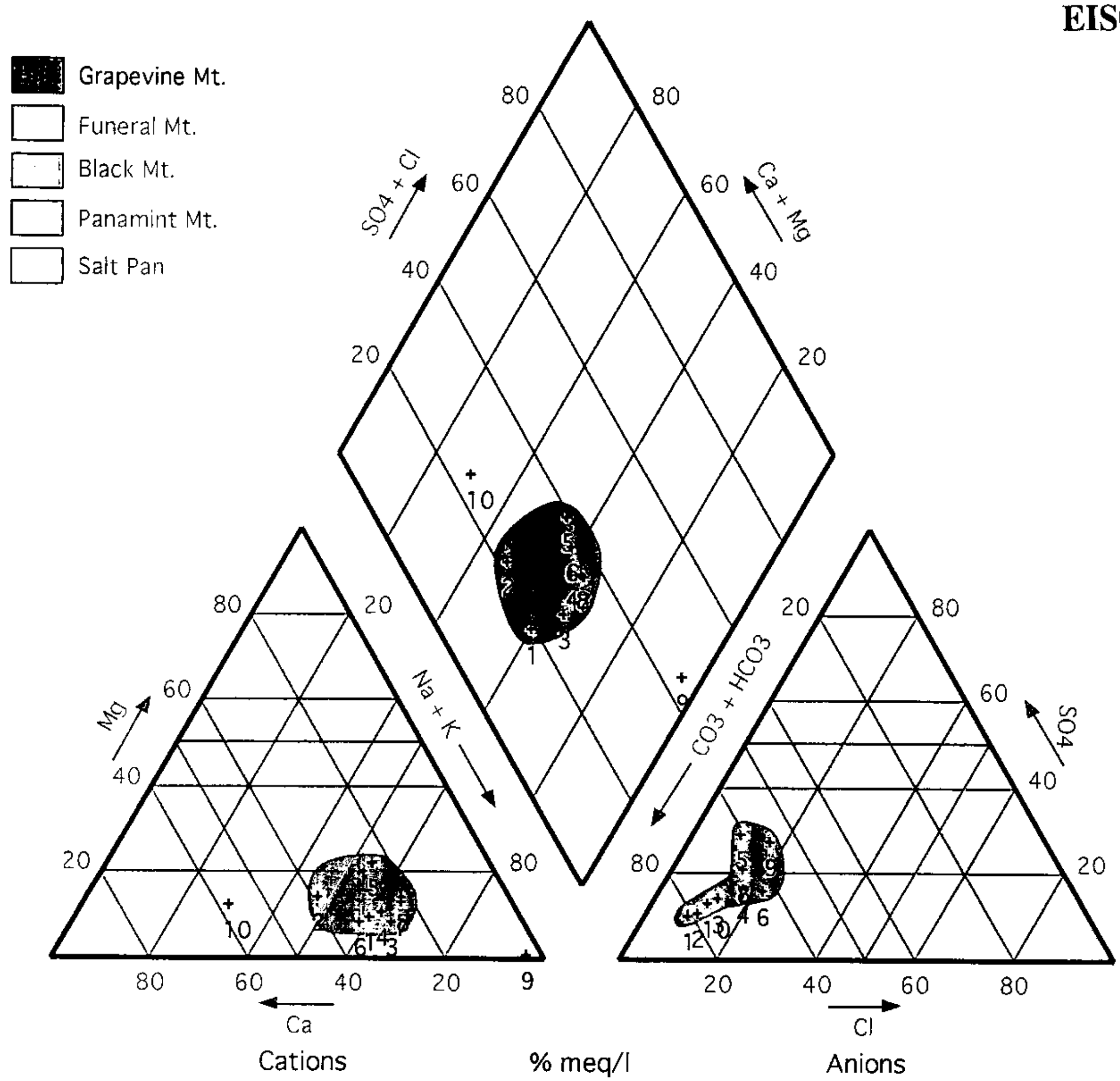
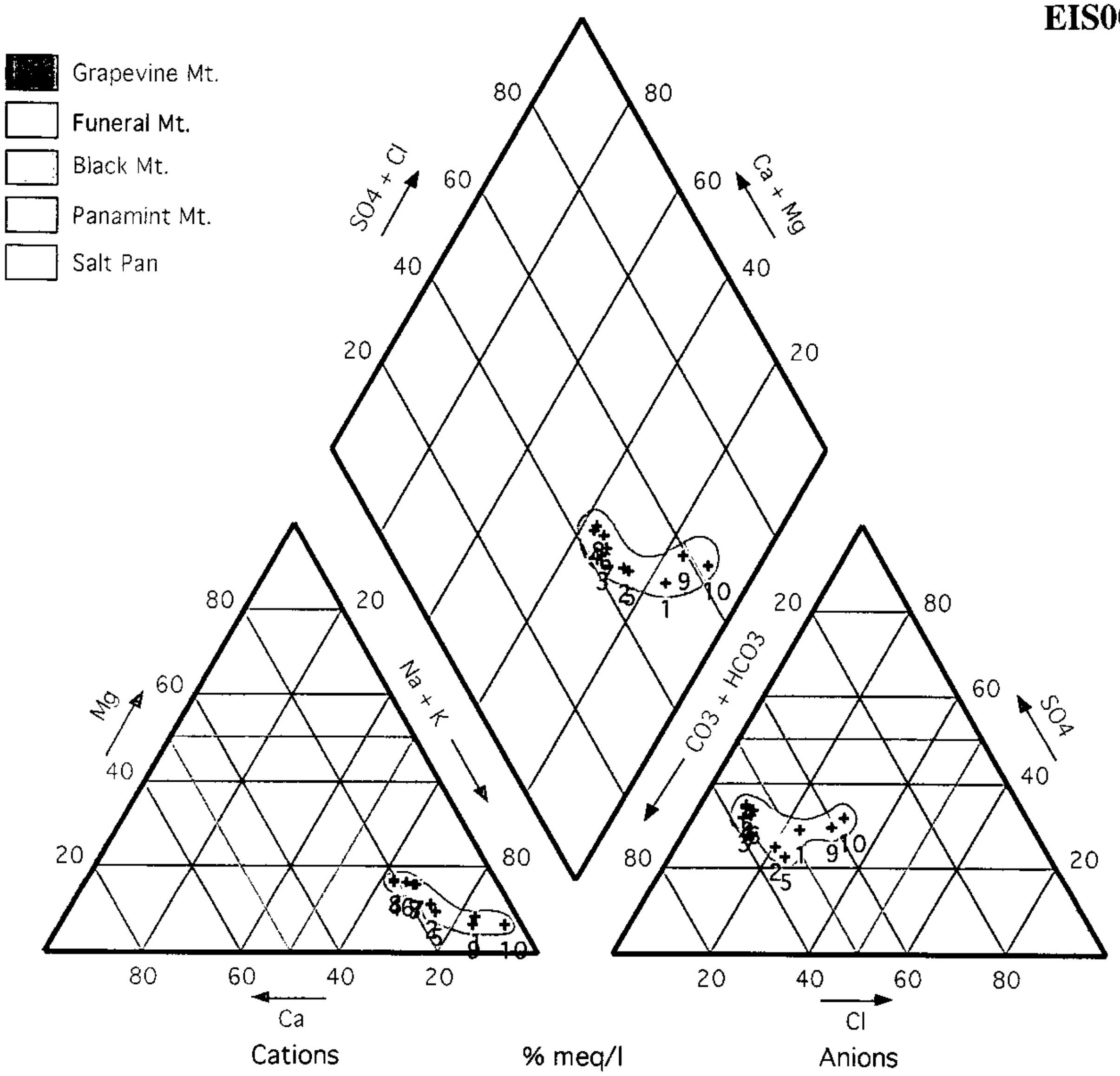


No.	TDS	Sample
1	226	Strozzi Ranch Spring
2	205	Cordwood Spring
3	295	Little Willow Spring
4	196	Knoll Spring
5	716	Klare Spring-USGS
6	309	Woodcamp Spring
7	895	Grapevine Ranch #1 -USGS
8	945	Grapevine Ranch-#3-USGS
9	585	Staininger Spring-USGS
10	187	Daylight Spring-USGS

PLATE 10 – Piper Diagram of Death Valley National Monument Grapevine Mt. Range Springs



No.	TDS	Sample
1	684	Navel Spring
2	985	Upper Navel Spring
3	768	Travertine Spring-USGS
4	809	Nevares Spring-USGS
5	685	Navel Spring-USGS
6	735	Travertine Spring-USGS
7	773	Texas Spring-USGS
8	780	Nevares Spring-USGS
9	3741	Keane Wonder Spring-USGS
10	3429	Keane Wonder Mine-USGS

PLATE 11 – Piper Diagram of Death Valley National Monument Funeral Mt. Range Springs

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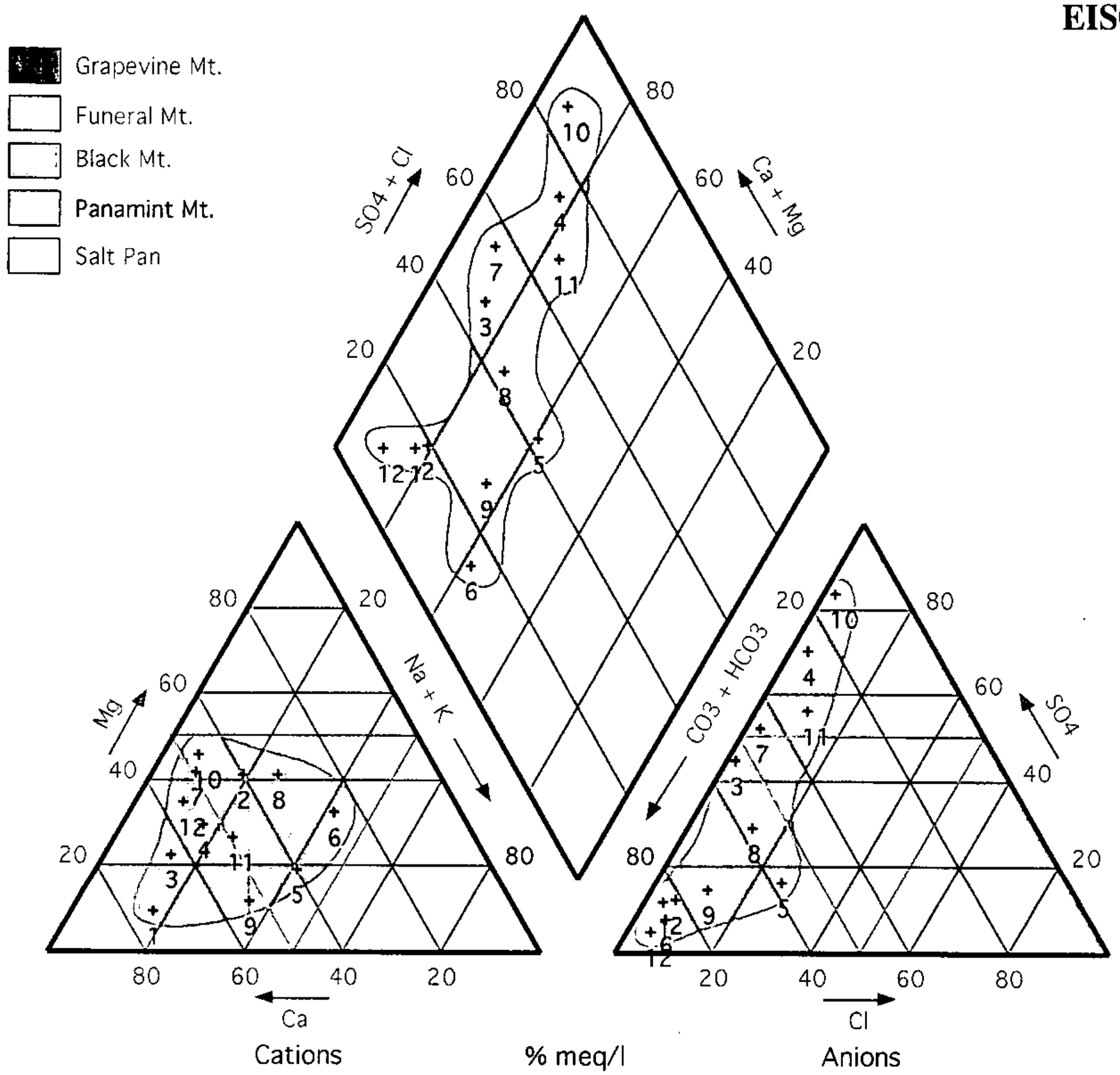
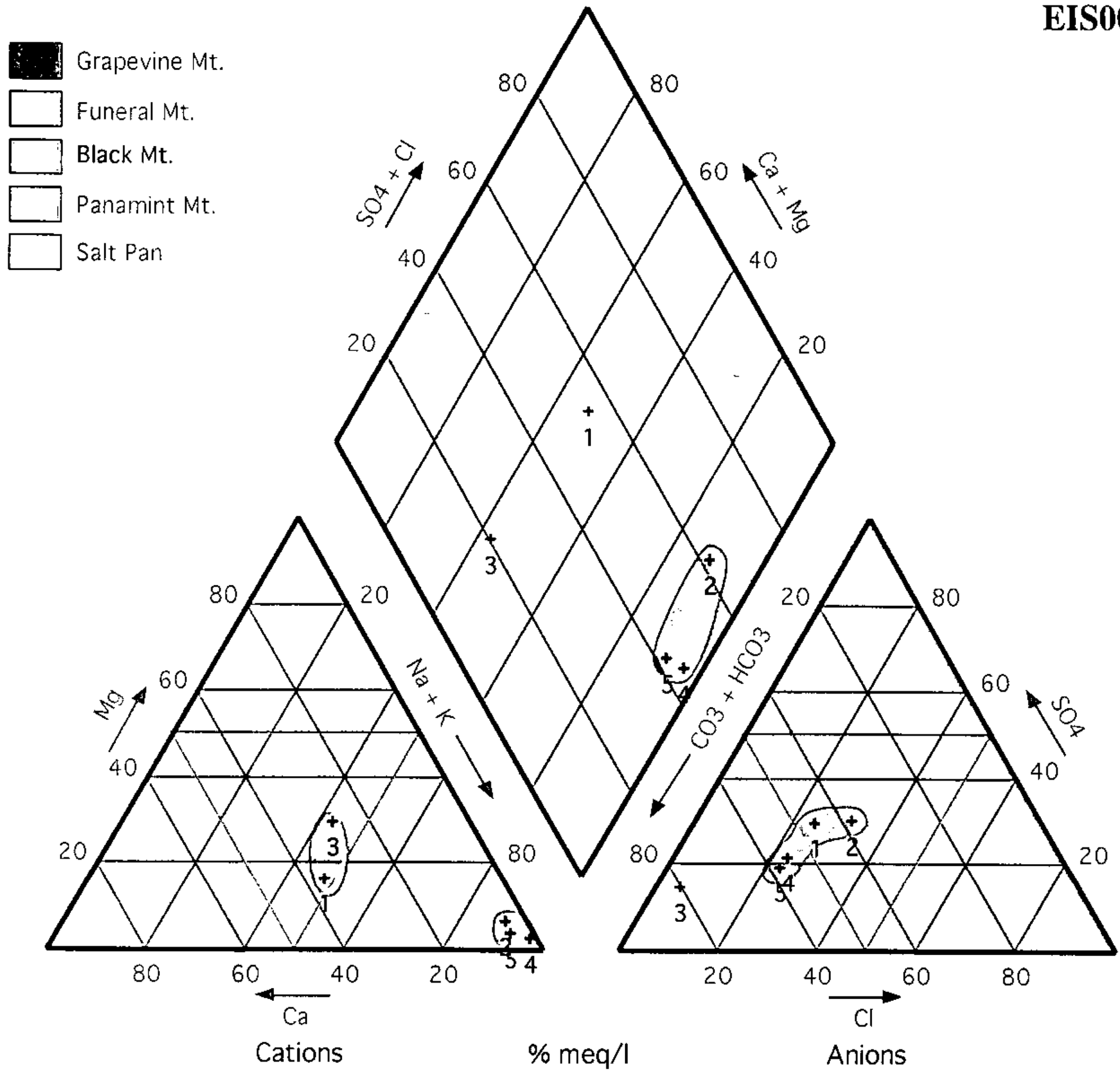
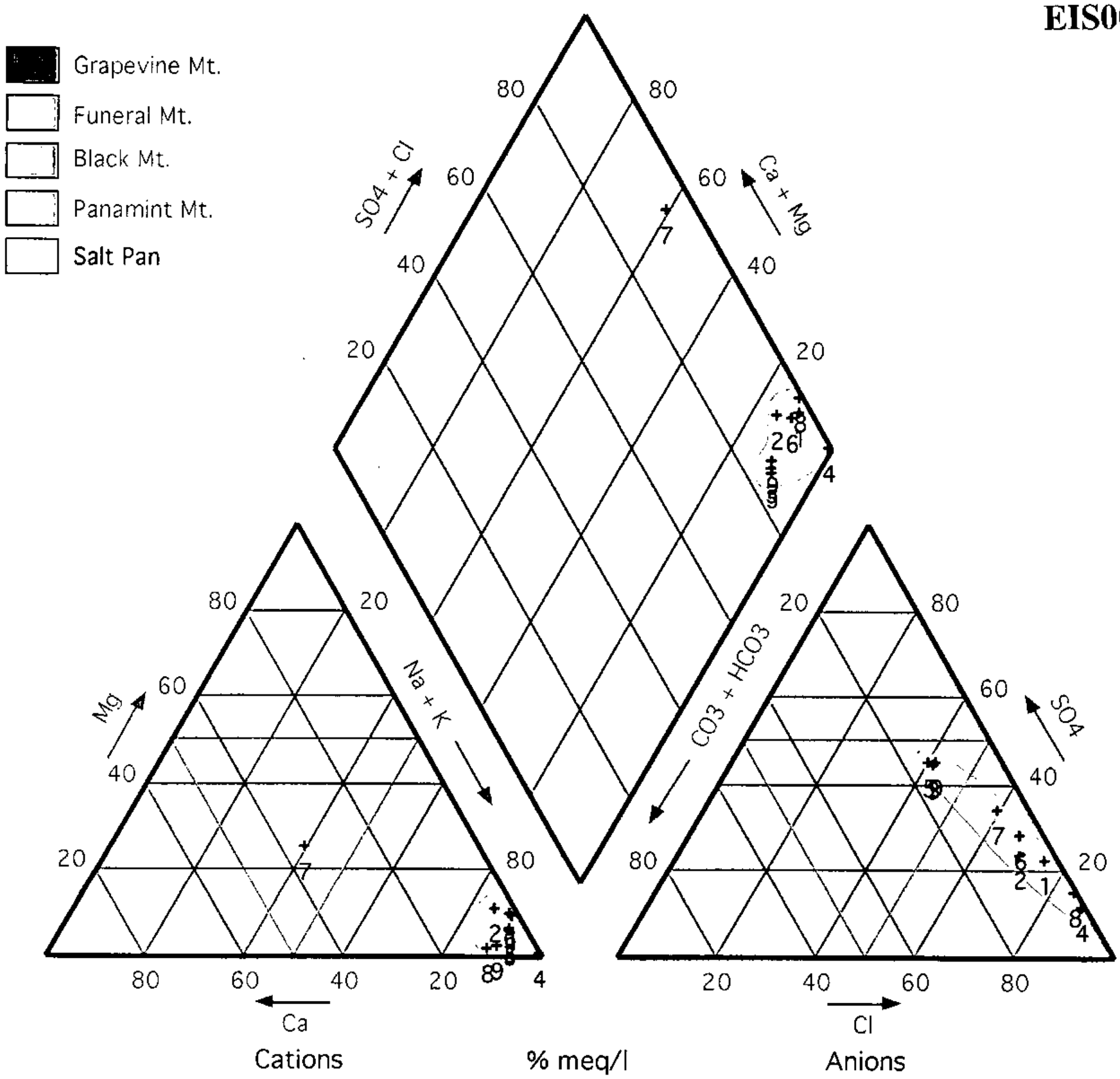


No.	TDS	Sample
1	184	Thorndike Spring
2	541	Johnnie Shoshone Sp.
3	370	Hummingbird Spring
4	889	Wildrose Spring
5	570	Suprize Canyon Creek
6	658	Burns #1 Spring
7	578	Lime Kiln Spring
8	1047	Upper Emigrant Spring
9	383	Anvil Spring
10	1144	Dripping Spring
11	474	Warm Spring
12	294	Jaybird Spring-USGS



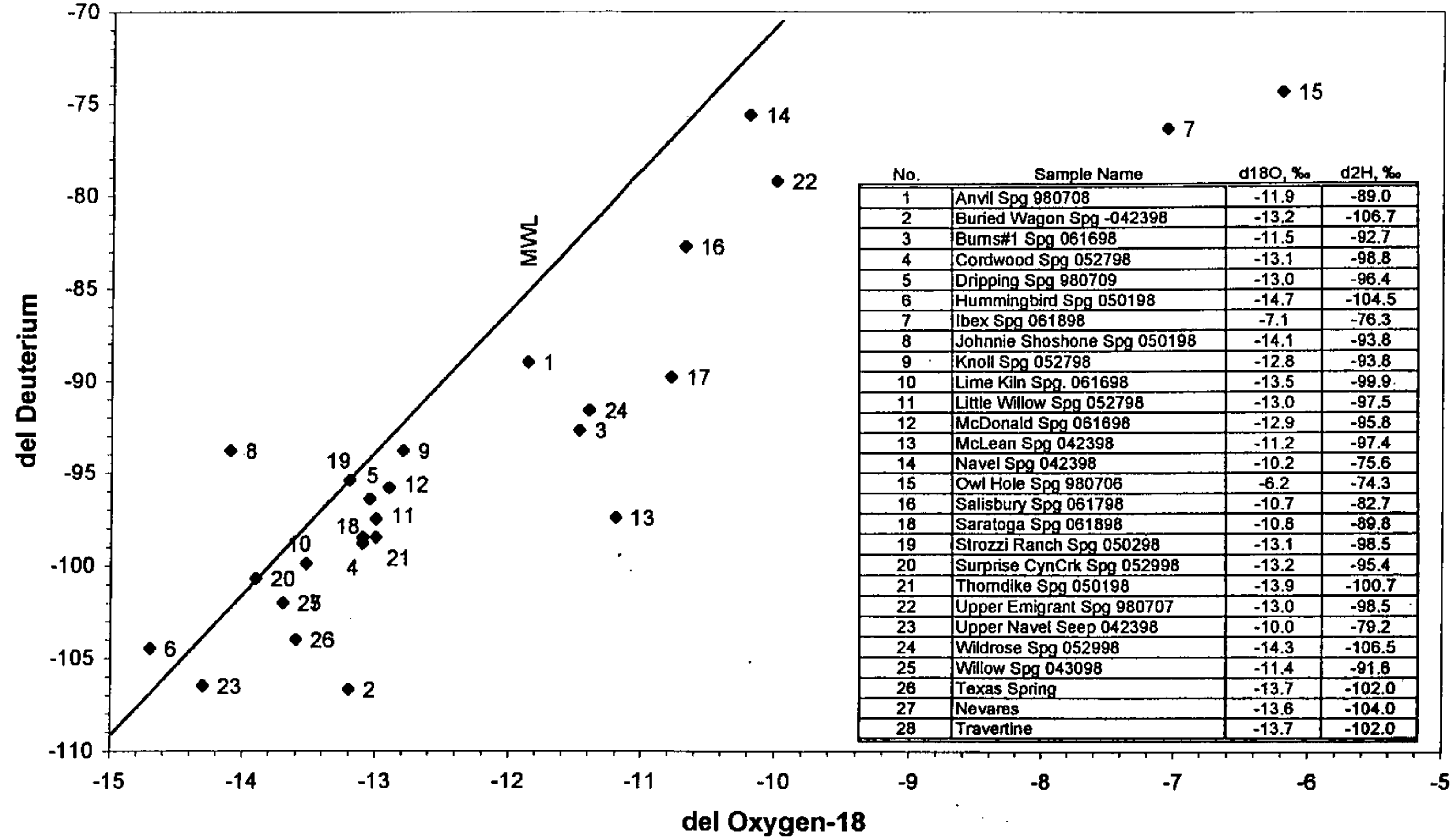
No.	TDS	Sample
1	567	Willow Spring
2	1816	Ibex Spring
3	817	Virgin Spring-USGS
4	595	Lemonade Spring-USGS
5	480	Salisbury Spring

PLATE 13 – Piper Diagram of Death Valley National Monument Black Mt. Range Springs



No.	TDS	Sample
1	29603	Buried Wagon
2	8149	McLean Spring
3	3229	Saratogo Spring
4	348996	Salt Creek
5	3187	Saratogao Spring-USGS
6	17523	Salt Creek-USGS
7	5188	Eagle Borax Spring-USGS
8	23586	Badwater Spring-USGS
9	7948	Owl Hole Spring

Plate 15. Deuterium and Oxygen-18 Graph of Death Valley Springs



No.	Sample Name	d18O, ‰	d2H, ‰
1	Anvil Spg 980708	-11.9	-89.0
2	Buried Wagon Spg -042398	-13.2	-106.7
3	Burns#1 Spg 061698	-11.5	-92.7
4	Cordwood Spg 052798	-13.1	-98.8
5	Dripping Spg 980709	-13.0	-96.4
6	Hummingbird Spg 050198	-14.7	-104.5
7	Ibex Spg 061898	-7.1	-76.3
8	Johnnie Shoshone Spg 050198	-14.1	-93.8
9	Knoll Spg 052798	-12.8	-93.8
10	Lime Kiln Spg. 061698	-13.5	-99.9
11	Little Willow Spg 052798	-13.0	-97.5
12	McDonald Spg 061698	-12.9	-95.8
13	McLean Spg 042398	-11.2	-97.4
14	Navel Spg 042398	-10.2	-75.6
15	Owl Hole Spg 980706	-6.2	-74.3
16	Salisbury Spg 061798	-10.7	-82.7
18	Saratoga Spg 061898	-10.8	-89.8
19	Strozzi Ranch Spg 050298	-13.1	-98.5
20	Surprise CynCrk Spg 052998	-13.2	-95.4
21	Thorndike Spg 050198	-13.9	-100.7
22	Upper Emigrant Spg 980707	-13.0	-98.5
23	Upper Navel Seep 042398	-10.0	-79.2
24	Wildrose Spg 052998	-14.3	-106.5
25	Willow Spg 043098	-11.4	-91.6
26	Texas Spring	-13.7	-102.0
27	Nevares	-13.6	-104.0
28	Travertine	-13.7	-102.0

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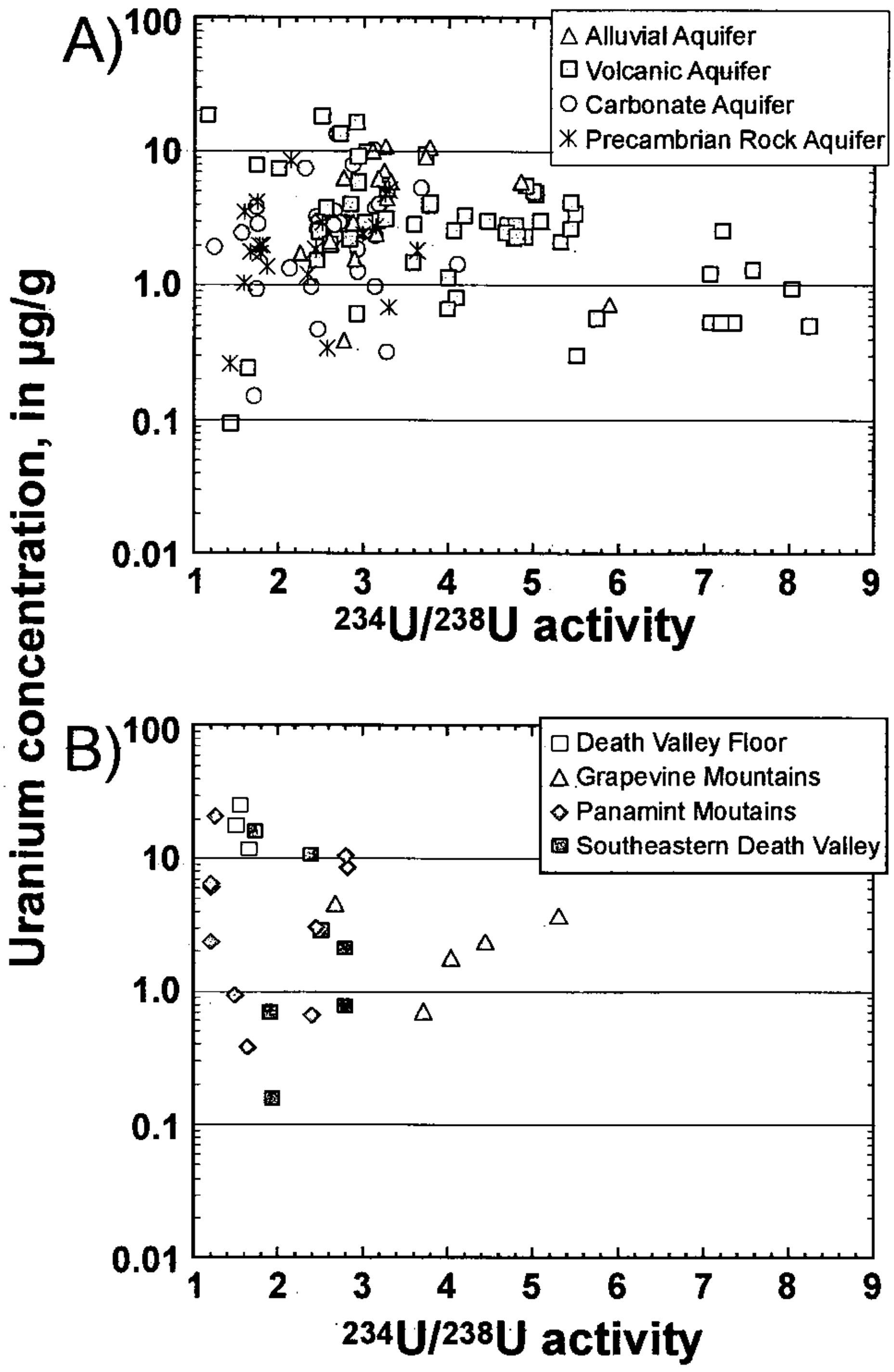

Figure : Plots of uranium concentrations versus $^{234}U/^{238}U$ activity ratios for saturated-zone waters. A) Regional ground water in the Yucca Mountain vicinity (from Paces and other, 1998). B) Death Valley springs. Southeastern Death Valley category includes Navel Spring and Upper Navel Seep, Willow Spring, Salisbury Spring, Ibex Spring, Saratoga Spring, and Owl Hole Spring.

Plate 16. Uranium Concentrations Versus $^{234}U/^{238}U$ Activity Ratios.

Table 1. Geologic Column and Summary of Principal Geologic Events in DVNP (Adapted from Harris, et. al., 1997)

Time Units			Rock Units		
Era	Period	Epoch	Group	Formation	Principal Geologic Events
Cenozoic	Quaternary	Holocene	Alluvial fans, stream and playa deposits, dunes		Continued deposition in modern Death Valley
	Tertiary	Miocene	Numerous sedimentary, volcanic and plutonic units		Opening of modern Death Valley Continued development of the present ranges & basins Onset of major extension
				Several formations	Deposition on relatively subdued terrian
		Oligocene		Titus Canyon	
			Major Unconformity		
Mesozoic	Cretaceous/ Jurassic		Granitic plutons		Thrust faulting and intrusion of plutons related to Sierra Nevada batholith
	Triassic			Butte Valley	Shallow marine deposition
				Unconformity	
Paleozoic	Pennsylvanian			Resting Spring Shale	Development of a long-continuing carbonate bank on a passive continental margin; numerous intervals of emergence, interrupted by deposition of a blanket of sandstone in Middle Ordovician time.
	Mississippian			Tin Mountain Limestone Lost Burro	
	Devonian/ Silurian			Hidden Valley Dolomite	
	Ordovician			Ely Springs Dolomite Eureka Quartzite	
			Pogonip		
	Cambrian			Nopah Bonanza King	
				Carrara Zobriskie Quartzite Wood Canyon	Deposition of a wedge of siliciclastic sediments during and immediately following the rifting along a new continental margin.
Prototerozic				Stirling Quartzite Johnnie Ibex Noonday Dolomite	Shallow to deep maring deposition along an incipient continental margin.
				Unconformity	
			Pahrump	Kingston Peak	Glacio-marine deposition
				Beck Spring	Shallow marine deposition
				Crystal Spring	Rapid uplift and erosion
			Unconformity		
			Crystalline basement		Regional metamorphism

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Table 2. List of Springs and Creeks Sampled in DVNM

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No.	NPS No.	Sample Name	UTM - X (m) Easting	UTM - Y (m) Northing	Mountain Range	Elevation (Feet)
1	223	Cordwood Spg 052798	493024.0	4087677.0	Grapevine	6380
2	221	Knoll Spg 052798	494311.0	4088262.0	Grapevine	6260
3	219	Little Willow Spg 052798	493841.0	4087646.0	Grapevine	6144
4	209	McDonald Spg 061698	498441.0	4084069.0	Grapevine	5590
5	NA	Strozzi Ranch Spg 050298	490402.6	4088049.6	Grapevine	6240
6	148	Navel Spg 042398	525503.0	4026081.3	Funeral	2100
7	149	Upper Navel Seep 042398	525637.7	4026026.2	Funeral	2160
8	NA	Saisberry Spg 061798	552496.0	3976264.0	Black	3293
9	140	Willow Spg 043098	528048.0	3989246.0	Black	2680
10	134	Ibex Spg 061898	553254.0	3958614.0	Black	1100
11	123	Anvil Spg 980708	492357.0	3975186.0	Panamint	4253
12	53	Burns#1 Spg 061698	483135.8	4027730.1	Panamint	5239
13	63	Dripping Spg 980709	496409.5	4019395.5	Panamint	3799
14	76	Hummingbird Spg 050198	490288.3	4008308.5	Panamint	7200
15	74	Johnnie Shoshone Spg 050198	493610.9	4011201.6	Panamint	7200
16	NA	Lime Kiln Spg. 061698	485700.0	3996422.0	Panamint	4058
17	248	Surprise CynCrk Spg 052998	484500.0	3996239.0	Panamint	2733
18	75	Thorndike Spg 050198	493285.3	4009722.9	Panamint	7860
19	45	Upper Emigrant Spg 980707	482544.0	4030966.0	Panamint	4127
20	72	Wildrose Spg 052998	482584.0	4013281.0	Panamint	3930
21	UN	Owl Hole Spg 980706	531915.0	3943786.0	Salt Pan	1902
22	266	McLean Spg 042398	498315.6	4050575.9	Salt Pan	-130
23	267	Salt Creek-980709	512139.0	4021930.0	Salt Pan	-140
24	NA	Buried Wagon Spg -042398	498166.5	4050816.3	Salt Pan	-130
25	130	Saratoga Spg 061898	552284.0	3948472.0	Salt Pan	209

Table 3. Summary of Analysis Performed and Information Collected for Springs Sampled

Analysis:	USGS	• Strontium isotopes
		• Uranium $^{234}U/^{238}U$ isotopes
		• Oxygen/Deuterium
	Huffman	• Major anions and cations
	Beta Analytical	• Carbon ^{14}C
Protocols:	Yucca Mountain protocols using USGS	
	Field data:	• Global Positioning System (GPS) location
		• Data and time of sample collection
		• Temperature, pH, conductivity, TDS, dissolved oxygen, turbidity
		• Spring flow rate estimate
		• Site photos and videos
		• Site geology map & site plan
		• Field Activities Log
		• Field calibration records
Sample Bottles:		• USGS & Huffman Laboratory provide bottles
		• Sampling equipment (0.2u vacuum filters).
		• One archival sample from each spring
		• USGS provides sample numbers

Table 4. Chemical Analysis of Springs and Creeks Sampled In DVNM

Huffman sample #		152798-01	152798-02	152798-03	152798-04	156498-01	156498-02	156498-03	156498-04	156498-05
Client sample tag #	SPC-	00516972	00516971	00516969	00516970	00516973	00516974	00516975	00516976	00516977
Client sample code		Navel Spring	Upper Navel	Buried Wagon	McLean Spring	Willow Spring	Thorndike Spring	Johnnie Shoshone Spring	Hummingbird Spring	Strozzi Ranch Spring
				(names switched - corrected)						
ANALYTE	units									
pH	units	8.60	8.28	8.19	8.03	7.51	7.74	7.54	7.76	7.35
Spec Conductance	uS/cm	857	1170	36900	11400	697	207	579	438	232
DSRD (180)	mg/l	582	815	31000	8265	502	145	372	317	226
Alkalinity as CaCO3	mg/l	204	346	627	470	176	95	288	131	101
Bicarbonate as HCO3	mg/l	228	422	765	574	214	116	352	159	123
Carbonate as CO3	mg/l	17	<1	<1	<1	<1	<1	<1	<1	<1
Hardness as CaCO3	mg/l	73	172	2680	989	195	91	287	205	52
Bromide	mg/l	0.3	0.3	94	40	0.9	<0.1	1.5	<0.1	1.2
Chloride	mg/l	75	93	12700	3160	68	3.2	17	4.2	8.2
Nitrate as NO3	mg/l	31	22	<1	<1	1.7	<0.1	0.7	<0.1	1
O-phosphate as PO4	mg/l	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Sulfate as SO4	mg/l	125	154	5110	1470	111	13	41	107	12
Ca	mg/l	15	41	135	97	54	32	55	61	16
K	mg/l	7.8	14	717	186	6.6	1.1	1.6	2.3	10
Mg	mg/l	8.9	17	558	175	15	2.5	34	13	2.9
Na	mg/l	168	209	9590	2440	79	7.7	29	14	30
Ag	mg/l	<0.01	<0.01	<1	<1	<0.01	<0.01	<0.01	<0.01	<0.01
As	mg/l	0.195	0.162	0.216	0.089	0.004	<0.001	0.001	<0.001	0.003
Ba	mg/l	0.036	0.093	<0.01	0.030	0.070	0.010	0.124	0.001	<0.001
Be	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cd	mg/l	<0.002	<0.002	<0.01	<0.01	<0.002	<0.002	<0.002	<0.002	<0.002
Cr	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu	mg/l	<0.005	<0.005	<0.01	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005
Fe	mg/l	0.03	0.07	0.03	0.06	0.19	<0.02	0.02	<0.02	<0.02
Hg	mg/l	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Mn	mg/l	<0.002	<0.002	0.04	<0.01	0.220	<0.002	0.179	0.061	<0.002
Ni	mg/l	<0.003	<0.003	<0.01	<0.01	<0.003	<0.003	<0.003	<0.003	<0.003
Pb	mg/l	<0.002	<0.002	<0.05	<0.05	<0.002	<0.002	<0.002	<0.002	<0.002
Sb	mg/l	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Se	mg/l	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Si	mg/l	8.5	12	26	45	16	6.8	8.7	8.8	24
Tl	mg/l	<0.002	<0.002	<0.1	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002
Zn	mg/l	<0.01	<0.01	<1	<1	<0.01	<0.01	<0.01	<0.01	<0.01

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Table 4. Chemical Analysis of Springs and Creeks Sampled In DVNM

Huffman sample #		166798-01	166798-02	166798-03	166798-04	166798-05	173998-01	173998-02	173998-03	173998-04
Client sample tag #	SPC-	00516978	00516979	00516980	00516981	00516982	00516983	00516984	00516985	00516986
Client sample code		Cordwood Spring	Little Willow Spring	Knoll Spring	Wildrose Spring	Sunrise Canyon Creek Springs	McDonald Spring	Burns #1 Spring	Lime Kiln Spring	Salisberry Spring
ANALYTE	units									
pH	units	7.18	7.89	7.73	7.56	8.31	7.61	7.65	7.85	8.10
Spec Conductance	uS/cm	254	327	221	1031	695	759	744	736	608
DSRD (180)	mg/l	200	253	191	837	528	507	458	512	463
Alkalinity as CaCO3	mg/l	100	125	71	164	163	218	353	177	164
Bicarbonate as HCO3	mg/l	122	153	87	200	190	264	431	216	200
Carbonate as CO3	mg/l	<1	<1	<1	<1	4	<1	<1	<1	<1
Hardness as CaCO3	mg/l	73	63	49	512	382	239	257	372	26
Bromide	mg/l	<0.1	0.2	<0.1	0.2	0.1	0.8	0.6	<0.1	2.3
Chloride	mg/l	10	16	13	19	10	70	20	10	47
Nitrate as NO3	mg/l	1	0.2	1.6	<0.1	0.1	0.5	3.2	1.1	1.5
O-phosphate as PO4	mg/l	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Sulfate as SO4	mg/l	13	23	17	431	231	59	30	200	52
Ca	mg/l	21	19	14	131	78	62	43	80	6.2
K	mg/l	6.9	7	9.3	7.1	5.3	2.3	1.9	5.0	5.4
Mg	mg/l	4.5	3.5	3.2	44	40	18	33	41	3
Na	mg/l	25	48	30	43	13	71	80	14	138
Ag	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
As	mg/l	0.002	0.002	0.003	0.007	0.003	0.006	0.003	0.002	0.006
Ba	mg/l	<0.001	<0.001	0.002	0.022	0.036	0.067	0.055	0.040	0.009
Be	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cd	mg/l	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cr	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Fe	mg/l	<0.02	<0.02	0.10	<0.02	<0.02	<0.02	<0.02	<0.02	0.05
Hg	mg/l	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Mn	mg/l	<0.002	<0.002	<0.002	<0.002	<0.002	0.175	0.030	0.007	0.004
Ni	mg/l	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Pb	mg/l	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Sb	mg/l	<0.001	<0.001	<0.001	0.002	0.001	<0.001	<0.001	0.001	0.001
Se	mg/l	<0.001	<0.001	<0.001	0.001	0.001	<0.001	0.001	<0.001	<0.001
Si	mg/l	24	24	22	13	9.4	22	15	9.5	26
Tl	mg/l	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Zn	mg/l	<0.01	<0.01	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	0.02

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Table 4. Chemical Analysis of Springs and Creeks Sampled In DVNM

Huffman sample #		173998-05	173998-06	183198-01	183198-02	183198-03	183198-04	183198-05
Client sample tag #	SPC-	00516987	00516988	00516989	00516990	00516991	00516992	00516993
Client sample code		Saratoga Spring	Ibex Spring	Owl Hole Spring	Upper Emigrant Spring	Anvil Spring	Dripping Spring	Salt Creek
ANALYTE	units							
pH	units	8.16	8.42	7.75	7.61	7.67	8.14	7.68
Spec Conductance	uS/cm	4780	2560	10570	1285	481	1453	176400
DSRD (180)	mg/l	3071	1616	7862	900	344	1233	290100
Alkalinity as CaCO3	mg/l	339	443	812	428	173	122	1365
Bicarbonate as HCO3	mg/l	414	540	991	522	211	149	1665
Carbonate as CO3	mg/l	<1	27	<1	<1	<1	<1	<1
Hardness as CaCO3	mg/l	245	147	662	568	157	857	1996
Bromide	mg/l	2.6	1.6	5.5	0.5	<0.1	0.3	250.0
Chloride	mg/l	695	290	1810	73	20	18	191000
Nitrate as NO3	mg/l	4.6	0.2	<0.1	0.2	14	0.2	<10
O-phosphate as PO4	mg/l	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<30
Sulfate as SO4	mg/l	1017	374	2670	210	33	710	34900
Ca	mg/l	34	22	177	86	48	144	78
K	mg/l	32	13	21	2.9	2.9	7.7	8470
Mg	mg/l	36	20	33	64	6.3	85	280
Na	mg/l	977	511	2260	75	35	23	112600
Ag	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
As	mg/l	0.015	0.045	0.288	0.002	<0.001	<0.001	0.353
Ba	mg/l	0.021	0.040	0.027	0.028	0.032	0.029	<0.10
Be	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cd	mg/l	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cr	mg/l	0.03	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.05
Fe	mg/l	<0.02	0.07	0.08	<0.02	<0.02	<0.02	<0.2
Hg	mg/l	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Mn	mg/l	<0.002	0.017	0.302	0.009	<0.002	0.019	0.439
Ni	mg/l	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.03
Pb	mg/l	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.02
Sb	mg/l	<0.001	0.008	<0.001	<0.001	<0.001	<0.001	0.003
Se	mg/l	0.002	<0.001	0.001	<0.001	0.001	<0.001	0.011
Si	mg/l	18	18	15	13	12	6.3	1.3
Tl	mg/l	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.02
Zn	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 5. Isotopic Composition of DVNM Sampled Springs and Creeks

No.	Sample Name	δ18O, ™	δ2H, ™	Conc. Sr, ppm	δ87Σρ	Conc. U (ppb)	Measured 234U/238U activity		Beta Analytical Data		UTM - X (m) Easting	UTM - Y (m) Northing
									Age	C13/C12		
1	Anvil Spg 980708	-11.87	-89.0	0.1811	16.15	21.244	1.254	(0.007)	2,710+-40BP	(7.2/mil)	492357.0	3975186.0
2	Buried Wagon Spg -042398	-13.2	-106.7	23.9990	6.42	11.667	1.660	(0.022)			498166.5	4050816.3
3	Burns#1 Spg 061698	-11.47	-92.7	0.8944	4.50	3.061	2.441	(0.020)			483135.8	4027730.1
4	Cordwood Spg 052798	-13.10	-98.8	0.0236	2.09	2.377	4.439	(0.023)			493024.0	4087677.0
5	Dripping Spg 980709	-13.05	-96.4	1.0364	26.68	0.936	1.490	(0.010)	6,430+-40BP	(0.7/mil)	496409.5	4019395.5
6	Hummingbird Spg 050198	-14.70	-104.5	0.3010	28.00	0.380	1.626	(0.027)			490288.3	4008308.5
7	Ibex Spg 061898	-7.06	-76.3	0.7146	16.96	0.759	2.796	(0.021)	3,880+-50BP	(3.5/mil)	553254.0	3958614.0
8	Johnnie Shoshone Spg 050198	-14.10	-93.8	0.3365, 0.3291	21.50, 21.60	8.502	2.832	(0.017)			493610.9	4011201.6
9	Knoll Spg 052798	-12.8	-93.8	0.0232	1.17	0.718	3.702	(0.032)			494311.0	4088262.0
10	Lime Kiln Spg. 061698	-13.52	-99.9	0.4559	33.91	6.021	1.212	(0.006)			485700.0	3996422.0
11	Little Willow Spg 052798	-13.0	-97.5	0.0262	1.92	4.620	2.666	(0.014)			493841.0	4087646.0
12	McDonald Spg 061698	-12.90	-95.8	0.6199	-0.23	3.747	5.308	(0.028)			498441.0	4084069.0
13	McLean Spg 042398	-11, -11.2	-97.4	26.1898	6.52	25.222	1.546	(0.020)	1,540+-40BP	(6.9/mi)	498315.6	4050575.9
14	Navel Spg 042398	-10.0, -10.2	-75.6	0.5164	5.96	2.038	2.786	(0.018)			525503.0	4026081.3
15	Owl Hole Spg 980706	-6.20	-74.3	8.2533	6.03	10.412	2.384	(0.013)	104.8+-0.5% PMC	(11.0/mil)	531915.0	3943786.0
16	Salisbury Spg 061798	-10.68	-82.7	0.0428	1.62	0.152	1.931	(0.016)	103.5+-0.6% PMC	(15.9/mil)	552496.0	3976264.0
17	Salt Creek-980709	-0.3*	-51.8, -55.7*	3.6847	7.81	17.569	1.505	(0.046)			512139.0	4021930.0
18	Saratoga Spg 061898	-10.78	-89.8	3.0642	10.23	16.229	1.732	(0.009)			552284.0	3948472.0
19	Strozzi Ranch Spg 050298	-13.10	-98.5	0.0177	1.65	1.779	4.026	(0.029)			490402.6	4088049.6
20	Surprise CynCrk Spg 052998	-13.20	-95.4	0.4540	34.03	6.591	1.200	(0.007)			484500.0	3996239.0
21	Thorndike Spg 050198	-13.90	-100.7	0.1297	17.30	0.668	2.397	(0.028)			493285.3	4009722.9
22	Upper Emigrant Spg 980707	-13.0	-98.5	1.1121	17.36	10.396	2.806	(0.016)			482544.0	4030966.0
23	Upper Navel Seep 042398	-9.9, -10.0	-79.2	0.7697	5.85	2.807	2.519	(0.062)			525637.7	4026026.2
24	Wildrose Spg 052998	-14.30	-106.5	1.2358	10.64	2.405	1.207	(0.007)			482584.0	4013281.0
25	Willow Spg 043098	-11.40	-91.6	0.5992	4.39	0.685	1.922	(0.011)	1,850+_50BP	(10.4/mil)	528048.0	3989246.0

δ18O ανδ δ2H φορμ θ.Φ. Ωηελαν, ΥΣΓΣ, Δενϖερ; Σρ ανδ δ87Σρ φορμ Ζ.Ε. Πετερμαν, ΥΣΓΣ, Δενϖερ; Υ ανδ 234Υ/238Υ φορμ θ.Β. Παχεσ, ΥΣΓΣ, Δενϖερ.

* High salinity affects both the precision and accuracy of stable isotope determinations.

Table 6. Field Data Collected for Springs and Creeks Sampled in DVNM

No.	NPS No.	Sample Name	UTM - X (m) Easting	UTM - Y (m) Northing	Mountain Range	Elevation (Feet)	Discharge (gpm)	Temperature (Degree F)	pH	Conductivity (uohm)	TDS (mg/L)	Turbitity (ntu)	Dissolved O (%)
1	223	Cordwood Spg 052798	493024.0	4087677.0	Grapevine	6380	20-30	49.5	7.54	197.2	155	0.45	4.8
2	221	Knoll Spg 052798	494311.0	4088262.0	Grapevine	6260	<1	50	7.5	188	125	401	2.2
3	219	Little Willow Spg 052798	493841.0	4087646.0	Grapevine	6144	20-30+	47.3	8.21	351	210	0.38	4.3
4	209	McDonald Spg 061698	498441.0	4084069.0	Grapevine	5590	<1	68	7.8	780	425	15.4	4.8
5	NA	Strozzi Ranch Spg 050298	490402.6	4088049.6	Grapevine	6240	40+	49.5	7.3	317	145	1.5	3.6
6	148	Navel Spg 042398	525503.0	4026081.3	Funeral	2100	0.88	82	8.59	830	600	0.27	1.9
7	149	Upper Navel Seep 042398	525637.7	4026026.2	Funeral	2160	0.12	70	7.86	1204	750	1.53	1.7
8	NA	Salsberry Spg 061798	552496.0	3976264.0	Black	3293	0.25	66.5	7.7	506	430	0.53	4.7
9	140	Willow Spg 043098	528048.0	3989246.0	Black	2680	50+	60	7.72	637	450	0.74	2
10	134	Ibex Spg 061898	553254.0	3958614.0	Black	1100	15	71	8.2	>2500	1075	4.7	4.5
11	123	Anvil Spg 980708	492357.0	3975186.0	Panamint	4253	1.15	65.5	8.07	422	211	0.8	2.9
12	53	Burns#1 Spg 061698	483135.8	4027730.1	Panamint	5239	2-5	59.5	7.93	760	487	3.85	3.5
13	63	Dripping Spg 980709	496409.5	40139395.5	Panamint	3799	0.01	66	7.87	1229	615	4.5	1.5
14	76	Hummingbird Spg 050198	490288.3	4008308.5	Panamint	7200	0.41	48.5	7.76	440	275	17.2	0.8
15	74	Johnnie Shoshone Spg 050198	493610.9	4011201.6	Panamint	7200	0.01	48.5	7.55	643	350	316	0.8
16	NA	Lime Kiln Spg. 061698	485700.0	3996422.0	Panamint	4058	30+	62	8.22	829	510	0.21	0.5
17	248	Surprise CynCrk Spg 052998	484500.0	3996239.0	Panamint	2733	est. 1200	55	8.52	658	450	0.38	0.5
18	75	Thorndike Spg 050198	493285.3	4009722.9	Panamint	7860	30-50	39.5	7.62	329	135	0.19	4.8
19	45	Upper Emigrant Spg 980707	482544.0	4030966.0	Panamint	4127	0.25	72	7.87	1290	900	0.18	3.8
20	72	Wildrose Spg 052998	482584.0	4013281.0	Panamint	3930	30-40	61.5	7.65	180	65	0.23	4.8
21	UN	Owl Hole Spg 980706	531915.0	3943786.0	Salt Pan	1902	<10	69.5	7.5	>10,000	>2500	6.16	2.1
22	266	McLean Spg 042398	498315.6	4050575.9	Salt Pan	-130	100	60	8.12	11,000+	>10,000	0.77	3.5
23	267	Salt Creek-980709	512139.0	4021930.0	Salt Pan	-140	No Flow	90	7.48	Off Scale	Off Scale	3.2	0.2
24	NA	Buried Wagon Spg -042398	498166.5	4050816.3	Salt Pan	-130	8	62	7.91	>20,000	20,000+	1.86	2.2
25	130	Saratoga Spg 061898	552284.0	3948472.0	Salt Pan	209	est. 1200	81	8.5	4720	>2000	0.53	4.7

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APPENDIX A

National Park Services
Listing of Springs in
Death Valley National Monument

EIS001443

		2/10/99		NATIONAL PARK SERVICE WATER SOURCES-DEATH VALLEY NATIONAL MONUMENT							Page 1
	SPRING WATER SOURCE			LOCATION			USGS 15 MIN.		FLOW	OBSERVE	FLOW
NO.	(Unless noted by *)	AREA	S.	T.	R.	MER.	QUADRANGLE	ELEVA.	GPM	DATE	OTHER
1	Bighorn	SW1/4NW1/4	5	13S	42E	MDM	Tin Mtn.	6240	0.10	Aug-78	
1A	Yashiro	NE1/4SW1/4	6	13S	42E	MDM	Tin Mtn.	6920		Apr-77	Seep
2	Sheep	NW1/4SE1/4	6	13S	42E	MDM	Tin Mtn.	6840	0.10	Aug-77	
2A	Sheepwater	NE1/4NW1/4	7	13S	42E	MDM	Tin Mtn.	7200		Aug-77	Seep
3	Pinyon	NE1/4SE1/4	7	13S	42E	MDM	Tin Mtn.	7200	0.20	Dec-79	
4	Burro	SE1/4NW1/4	19	13S	41E	MDM	Tin Mtn.	7360	0.10	Nov-79	
5	Quartz	NW1/4SW1/4	26	13S	42E	MDM	Tin Mtn.	5200	0.20	Mar-80	
6	Rest	SE1/4NW1/4	30	13S	42E	MDM	Tin Mtn.	6700		Nov-79	Seep
7	Rye Grass	NW1/4NW1/4	32	13S	42E	MDM	Tin Mtn.	6320	0.15	Jan-79	
8	Wagon	NE1/4NW1/4	32	13S	42E	MDM	Tin Mtn.	6080		Mar-80	Seep
8A	Red Rock	SE1/4NW1/4	29	13S	42E	MDM	Tin Mtn.	6400		Mar-80	Dry
9	Leaning Rock*	SW1/4SW1/4	33	14S	42E	MDM	Tin Mtn.	5500		Aug-77	Pothole
10	Falcon Sheep	SE1/4NW1/4	3	14S	43E	MDM	Marble Can.	4320		Aug-59	Seep
11	Unnamed*	NE1/4NE1/4	6	14S	43E	MDM	Marble Can.	2280			Tank
12	Unnamed*	SE1/4NW1/4	9	15S	42E	MDM	Marble Can.	1000			Tank
13	Goldbelt	NW1/4SE1/4	30	15S	42E	MDM	Marble Can.	5000		Jan-78	Pool
13A	Burro Slide	NW1/4SE1/4	31	15S	42E	MDM	Marble Can.	4900	0.20	Dec-77	
14	Single tree	NEI/4SW1/4	29	15S	42E	MDM	Marble Can.	4600		Sep-77	Dry
15	Frypan	SW1/4SW1/4	29	15S	42E	MDM	Marble Can.	4700		Jan-78	Dry
15A	White Crown	NE1/4NE1/4	31	15S	42E	MDM	Marble Can.	5000	0.50	Dec-77	
16	Horsetail	SW1/4NE1/4	36	15S	41E	MDM	Marble Can.	5600		Apr-69	Dry
17	Goldbelt Grade	NW1/4SE1/4	36	15S	41E	MDM	Marble Can.	5600	0.25	Oct-81	
18	Thickets	NE1/4SE1/4	36	15S	41E	MDM	Marble Can.	5700		Aug-76	Dry
19	Coyote Hole	SW1/4NW1/4	31	15S	42E	MDM	Marble Can.	5500		Aug-76	Seep
20	Bull	NW1/4SE1/4	33	15S	42E	MDM	Marble Can.	4100	15.00	Mar-78	
20A	Pussywillow	SE1/4NW1/4	34	15S	42E	MDM	Marble Can.	3750	0.50	Jan-78	
20B	Marble Potholes*	MANY	27	15S	42E	MDM	Marble Can.	4000		Jan-78	Pothole
21	Lamb	NE1/4NE1/4	1	16S	42E	MDM	Marble Can.	5800		Aug-76	Dry
21A	Paintbrush	SE1/4SW1/4	31	16S	42E	MDM	Marble Can.	5700		Aug-78	Seep
22	Early Bird	NE1/4SW1/4	1	16S	42E	MDM	Marble Can.	6400		Apr-75	Seep
22A	Dirty Fingers	NE1/4SW1/4	1	16S	41E	MDM	Marble Can.	6520	0.15	Aug-76	
23	Unnamed	SE1/4NE1/4	6	16S	42E	MDM	Marble Can.	6400	2.00	Aug-76	
24	Badman	SW1/4SE1/4	5	16S	42E	MDM	Marble Can.	5400		Apr-75	Seep
25	Flycatcher	NE1/4SW1/4	4	16S	42E	MDM	Marble Can.	500	0.25	Feb-78	
26	Horshoe	SW1/4NE1/4	3	16S	42E	MDM	Marble Can.	4000	13.00	Jan-78	
27	Deadhorse	SE1/4NW1/4	2	16S	42E	MDM	Marble Can.	3760		Jan-76	Dry
28	Longhorn	SW1/4NE1/4	2	16S	42E	MDM	Marble Can.	3400	20.00	Mar-78	
29	Lightning	NE1/4NW1/4	11	16S	42E	MDM	Marble Can.	4200	1.00	Mar-78	
30	Panther	NW1/4NE1/4	9	16S	42E	MDM	Marble Can.	5000	4.00	Aug-76	
31	Bottle	NW1/4NW1/4	7	16S	42E	MDM	Marble Can.	6400	2.00	Mar-71	
32	Hunter	NE1/4SE1/4	11	16S	41E	MDM	Marble Can.	6680	1.00	Apr-75	
32A	Huntercabin	SE1/4SW1/4	11	16S	41E	MDM	Marble Can.	6800	0.05	Jul-81	
32B	Hunter Corral	NE1/4NW1/4	14	16S	41E	MDM	Marble Can.	6720	0.60	Jul-81	
33	Sister	NE1/4NE1/4	13	16S	41E	MDM	Marble Can.	6700		Jul-59	
34	Poorman	SW1/4SE1/4	16	16S	42E	MDM	Marble Can.	4840	1.50	Apr-78	
34A	Open	NW1/4NW1/4	22	16	42E	MDM	Marble Can.	4330	1.00	Aug-76	
34B	Tiny Tank*	SW1/4NW1/4	15	16S	42E	MDM	Marble Can.	4400	0.01	Apr-77	
34C	Rising Sun	NW1/4NW1/4	15	16S	42E	MDM	Marble Can.	4700	0.40	Apr-78	
35	Cottonwood	NW1/4SE1/4	.26	16S	42E	MDM	Marble Can.	3600		Apr-77	Abundant
36	Sidewinder	NW1/4SW1/4	19	16S	43E	MDM	Marble Can.	3200	0.50	Apr-77	

NO.	SPRING WATER SOURCE (Unless noted by *)	AREA	LOCATION S.	T.	R.	MER.	USGS 15 MIN. QUADRANGLE	ELEVA.	FLOW GPM	OBSERVE DATE	FLOW OTHER
37	Lower Cottonwood	NE1/4NW1/4	19	16S	43E	MDM	Marble Can.	3000	20.00	Feb-76	
38	Arrow	SW1/4SW1/4	28	16S	43E	MDM	Marble Can.	3800		Jun-59	Seep
39	West Twin	NW1/4NW1/4	30	16S	45E	MDM	Stovepipe	4320		Mar-70	Seep
40	Tucki (twin)	NW1/4NW1/4	30	16S	45E	MDM	Stovepipe	3980	0.50	Jun-57	
41	Gypsum	NE1/4NW1/4	30	16S	45E	MDM	Stovepipe	3800	1.00	Jun-57	
42	Telephone	SW1/4SE1/4	3	17S	44E	MDM	Emigrant	2900		Jul-75	Dry
43	Jayhawker	SW1/4SW1/4	21	17S	44E	MDM	Emigrant	4160		Mar-76	Pool
43A	Pioneer	SW1/4SE1/4	22	17S	44E	MDM	Emigrant	3760		Jul-83	Tied to Emigrant pipe
44	Emigrant (lower)	NW1/4NE1/4	27	17S	44E	MDM	Emigrant	3840	2.40	Aug-59	
45	Upper Emigrant (middle)	NW1/4SE1/4	27	17S	44E	MDM	Emigrant	4080		Sep-68	Seep
45A	Tree	NW1/4SE1/4	27	17S	44E	MDM	Emigrant	4160		Aug-59	Dry
46	Green	SE1/4SW1/4	34	17S	44E	MDM	Emigrant	5200	0.20	Sep-81	
47	Canyon	NE1/4NE1/4	3	18S	44E	MDM	Emigrant	4800	1.00	Sep-81	
48	Emigrant Burro	NE1/4NE1/4	3	18S	44E	MDM	Emigrant	4880		Sep-81	Seep
49	Malapai	NW1/4NE1/4	3	18S	44E	MDM	Emigrant	5040		Sep-81	Seep
50	Ed	NW1/4NW1/4	2	18S	44E	MDM	Emigrant	5120		Aug-59	
51	Wee	SW1/4NW1/4	2	18S	44E	MDM	Emigrant	5200		May-59	
52	Covered	SW1/4NW1/4	2	18S	44E	MDM	Emigrant	5120		May-59	Dry
53	Burns	NW1/4SW1/4	2	18S	44E	MDM	Emigrant	5280	0.25	Jan-75	
54	Emigrant Willow	NE1/4SE1/4	3	18S	44E	MDM	Emigrant	5360		Aug-73	Dry
54A	Centennial	SE1/4NE1/4	3	18S	44E	MDM	Emigrant	5080	2.00	Apr-76	
55	Chukar	SW1/4SW1/4	2	18S	44E	MDM	Emigrant	5280		Feb-75	Dry
56	Black Water	NE1/4NW1/4	7	18S	46E	MDM	Emigrant	3200	1.00	Feb-77	
56A	Wetfork	SE1/4NW1/4	7	18S	46E	MDM	Emigrant	2960		Feb-77	Seep
56B	South Fork Spgs. (2)	NW1/4SW1/4	8	18S	46E	MDM	Emigrant	2800		Aug-81	Seep
57	Wheel	SW1/4SW1/4	33	18S	46E	MDM	Emigrant	2240		May-60	Seasonal
58	Highgrade	SW1/4SW1/4	31	18S	46E	MDM	Emigrant	3600		Aug-78	Pool
59	Singlejack	SE1/4SE1/4	36	18S	45E	MDM	Emigrant	3600		Aug-78	Dry
60	High Noon	NW1/4NE1/4	2	19S	45E	MDM	Emigrant	4700	4.00	Apr-78	
61	Tarantula	SW1/4NE1/4	2	19S	45E	MDM	Emigrant	4800		Dec-75	Seep
62	Blue Cliff	NE1/4NW1/4	11	19S	45E	MDM	Emigrant	5360	3.00	Aug-78	
62A	Apron	NW1/4NE1/4	11	19S	45E	MDM	Emigrant	5400	1.00	Apr-78	
63	Dripping	NE1/4NE1/4	12	19S	45E	MDM	Emigrant	4320	1.10	Aug-78	
64	Morning Glory	SE1/4SE1/4	14	19S	45E	MDM	Emigrant	6800	1.50	Aug-65	
64A	Uppermost	NW1/4SW1/4	30	19S	46E	MDM	Emigrant	5760	0.50	Mar-70	
65	Pistol	SE1/4NW1/4	30	19S	46E	MDM	Emigrant	5040		Mar-70	Dry
66	Shotgun	SE1/4SW1/4	20	19S	46E	MDM	Emigrant	4000	20.00	Apr-70	
66A	Second	SW1/4NE1/4	30	19S	46E	MDM	Emigrant		2.00	Mar-70	
66B	Unnamed					MDM	Emigrant			Mar-70	Dry
67	Mud	NE1/4NW1/4	21	19S	44E	MDM	Emigrant	4080		Dec-82	Seep
68	Wildrose Station	SW1/4SE1/4	21	19S	44E	MDM	Emigrant	3600	8.00	May-73	
69	Roadside	NE1/4SW1/4	22	19S	44E	MDM	Emigrant	4000	0.70	Aug-69	
70	Poplar	NW1/4SE1/4	22	19S	44E	MDM	Emigrant	4100	0.25	Aug-59	
71	Antimony	SW1/4SW1/4	23	19S	44E	MDM	Emigrant	4520		Aug-59	Dry
72	Wildrose Rgr. Stn. Sys.*	NW1/4SE1/4	23	19S	44E	MDM	Emigrant	4300	10.00	Jul-75	
72A	Wildrose Stock Tank	NW1/4SE1/4	23	19S	44E	MDM	Emigrant	4350		Jul-83	Seep
73	Wildhorse	NE1/4NW1/4	33	19S	45E	MDM	Telescope	6720		Jul-69	Seep
74	Johnnie Shoshone	SW1/4SE1/4	26	19S	45E	MDM	Telescope	7200		Jul-59	Seep
75	Thorndike	SW1/4SW1/4	35	19S	45E	MDM	Telescope	7620		Jul-59	Seasonal
76	Hummingbird.	NE1/4SW1/4	4	20S	45E	MDM	Telescope	7200	0.25	Aug-81	

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	SPRING WATER SOURCE		LOCATION				USGS 15 MIN.		FLOW	OBSERVE	FLOW
NO.	(Unless noted by *)	AREA	S.	T.	R.	MER.	QUADRANGLE	ELEVA.	GPM	DATE	OTHER
77	Redtail	SE1/4NW1/4	8	20S	45E	MDM	Telescope	6640		Dec-57	DRY
78	Tuber (cold)	SW1/4NE1/4	9	20S	45E	MDM	Telescope	7650	50.00	Jun-81	
79	Mahogany	NW1/4SE1/4	11	20S	45E	MDM	Telescope	7600	50.00	Jul-47	
80	Flicker	NW1/4SE1/4	12	20S	45E	MDM	Telescope	6800		Jul-47	
80A	Naghipah	SE1/4SW1/4	5	20S	46E	MDM	Telescope	4160	2.00	Jan-72	
80B	Noggin	SE1/4NW1/4	6	20S	46E	MDM	Telescope	5120	1.50	Jan-72	
81	Lark	NW1/4SW1/4	13	20S	45E	MDM	Telescope	5560		Jul-47	
82	Spur					MDM	Bennetts Well	3000	1.00	Apr-59	
83	Yellowjacket	SE1/4NW1/4	18	20S	45E	MDM	Telescope	5280	50.00	Aug-59	
84	Birch	SE1/4SE1/4	18	20S	45E	MDM	Telescope	7520	150.00	Jun-81	
85	Jail	NW1/4SW1/4	15	20S	45E	MDM	Telescope	8000	15.00	Jun-81	
86	Eagle	NW1/4SE1/4	22	20S	45E	MDM	Telescope	9360		Dec-72	DRY
87	Upper Hall Cyn. Pipeln *	NW1/4NE1/4	28	20S	45E	MDM	Telescope	8400		Mar-59	
87A	Late	SE1/4SW1/4	31	20S	45E	MDM	Telescope	7000		Sep-59	SEEP
88	Telescope	SW1/4SW1/4	23	20S	45E	MDM	Telescope	9000	6.00	May-84	
89	Dixon	SW1/4NW1/4	26	20S	45E	MDM	Telescope	9800	2.00	Sep-81	
90	Main Hanaupah (4)	All	19	20S	46E	MDM	Telescope	4000	250.00	Jul-76	
91	South Hanaupah (2)	SE1/4NW1/4	20	20S	46E	MDM	Telescope	3800		Dec-78	SEASONAL
91	South Hanaupah (cont)	NE1/4SW1/4	20	20S	46E	MDM	Telescope	4000		Dec-78	SEASONAL
91A	Benny	NE1/4SE1/4	14	20S	46E	MDM	Bennetts Well	3720		Mar-71	SEEP
92	Prospector	NE1/4NE1/4	26	20S	46E	MDM	Bennetts Well	1800		Apr-59	DRY
92A	Arsenic			20S	46E	MDM	Bennetts Well			Aug-59	
93	Panamint Burro	SE1/4NE1/4	27	20S	46E	MDM	Bennetts Well	2360	3.00	Mar-70	
94	Whisper	SW1/4NE1/4	36	20S	46E	MDM	Bennetts Well	1340		Apr-59	DRY
95	Quartzite	NW1/4NE1/4	12	21S	46E	MDM	Bennetts Well	2600	1.00	Mar-70	
96	Primrose	SE1/4NW1/4	5	21S	46E	MDM	Telescope	4720		Mar-80	
97	Roadrunner	SW1/4NW1/4	5	21S	46E	MDM	Telescope	4460	100.00	Mar-80	
98	Snake (2)	SE1/4NE1/4	5	21S	46E	MDM	Telescope	4240	25.00	Mar-80	
98	Snake (cont.)	SW1/4NW1/4	4	21S	46E	MDM	Telescope	4240		Mar-80	
99	Windy	NE1/4SW1/4	4	21S	46E	MDM	Telescope	3950		Mar-80	SEEP
100	Widow	SE1/4SW1/4	3	21S	46E	MDM	Telescope	3360	10.00	Mar-80	
101	Ghost	NE1/4NE1/4	15	21S	46E	MDM	Bennetts Well	3200	4.00	Mar-80	
102	White Tanks	SE1/4SW1/4	18	21S	47E	MDM	Bennetts Well	1720	1.00	Mar-80	
103	Towhee	NW1/4NW1/4	20	21S	46E	MDM	Telescope	5440	15.00	Jun-81	
104	Hungry Bill's	SE1/4NW1/4	20	21S	46E	MDM	Telescope	5000	20.00	Jun-81	
105	Mint	NE1/4SW1/4	20	21S	46E	MDM	Telescope	4800	20.00	Jun-81	
106	Wilson	SW1/4SW1/4	22	21S	46E	MDM	Telescope	4000	6.00	Jun-81	
107	Dog	SE1/4NE1/4	32	21S	46E	MDM	Telescope	5040	15.00	Mar-80	
108	Feather	NE1/4NE1/4	33	21S	46E	MDM	Telescope	4200	5.00	Mar-80	
108A	Greenleaf					MDM		4800	3.00	Mar-80	
109	Cloud	SE1/4SE1/4	32	21S	46E	MDM	Telescope	5440	0.10	Mar-80	
110	Winter	NE1/4NW1/4	35	21S	46E	MDM	Bennetts Well	3800		Mar-80	SEEP
111	Jigger	SW1/4SW1/4	4	22S	46E	MDM	Telescope	5600		Mar-80	SEEP
111A	Sidehill	NW1/4SW1/4	4	22S	46E	MDM	Telescope	5200	0.25	Mar-80	
112	Lizard	NW1/4NW1/4	9	22S	46E	MDM	Telescope	5400		Sep-81	SEEP
113	Liar	SE1/4SW1/4	4	22S	46E	MDM	Telescope	5100	2.00	Sep-81	
113A	Edge	NW1/4SW1/4	3	22S	46E	MDM	Telescope	4800		Mar-80	DRY
113B	Six Spring Canyon	SE1/4NW1/4	3	22S	46E	MDM	Telescope	4160		Mar-80	SEEP
114	Drum	NE1/4SE1/4	10	22S	46E	MDM	Bennetts Well	4260		Sep-81	SEEP
115	Arrastre	SE1/4SE1/4	17	22S	46E	MDM	Telescope	5560		Sep-81	SEEP

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	SPRING WATER SOURCE			LOCATION			USGS 15 MIN.		FLOW	OBSERVE	FLOW
NO.	(Unless noted by *)	AREA	S.	T.	R.	MER.	QUADRANGLE	ELEVA.	GPM	DATE	OTHER
115A	Upper Talc Mine	NE1/4SW1/4	19	22S	47E	MDM	Bennetts Well	3080	2.00		
115B	Lower Talc Mine	SW1/4SE1/4	19	22S	47E	MDM	Bennetts Well	3000	0.25	Oct-77	
116	Grubstake	SE1/4NW1/4	35	22S	46E	MDM	Wingate Wash	3540		Feb-82	Seep
117	Warm	NW1/4NW1/4	6	23S	47E	MDM	Wingate Wash	2480	50.00	Dec-77	
118	Anvil Mesquite	NE1/4NW1/4	7	21N	1E	SBM	Wingate Wash	1800		May-82	Dry
119	Mill	SE1/4SW1/4	14	23S	45E	MDM	Manly Peak	4560		Jan-81	Dry
119A	Quail	NW1/4NW1/4	23	23S	45E	MDM	Manly Peak	4640	2.00	Nov-84	
119B	Hatchet	NW1/4NW1/4	23	23S	45E	MDM	Manly Peak	4730	1.50	Jan-81	
120	Anvil Mesquite	NW1/4NE1/4	23	23S	45E	MDM	Manly Peak	4300	7.00	Nov-84	
121	Greater View	NW1/4SE1/4	23	23S	45E	MDM	Manly Peak	4420	3.00	Nov-84	
122	Jubilee	SE1/4SW1/4	23	23S	45E	MDM	Manly Peak	4500	4.00	Nov-84	
123	Anvil Willow	NW1/4NW1/4	30	23S	46E	MDM	Manly Peak	3600	7.00	Mar-80	
123A	Butte Valley	NW1/4NW1/4	25	23S	45E	MDM	Manly Peak	4080		Mar-80	Seep
124	Halter	NE1//4NW1/4	21	23S	46E	MDM	Manly Peak	3240	1.00	May-81	
125	Little	NE1/4SW1/4	21	23S	46E	MDM	Manly Peak	3360		May-81	Seep
126	Fivenmile	NE1/4NE1/4	28	23S	46E	MDM	Manly Peak	3320		May-81	Seep
126A	Needle	SW1/4NW1/4	34	23S	46E	MDM	Manly Peak	3800		Jan-72	Seep
126B	Nopah	NW1/4NW1/4	34	23S	46E	MDM	Manly Peak	3760		Jan-72	Seep
127	Ram	SW1/4NE1/4	29	23S	47E	MDM	Wingate Wash	2200		Nov-79	Dry
128	Lost	SE1/4NW1/4	19	21S	1E	SBM	Wingate Wash	2200	4.00	Nov-79	
129	unassigned number					MDM					
130	Saratoga	SW1/4NW1/4	2	18N	5E	SBM	Avawatz Pass	200	15.00	Apr-81	
131	Amargosa River	SE1/4NE1/4	23	19N	4E	SBM	Leach Lake	120	20.00	Apr-81	
132	Superior Mine Tks. *	NW1/4NW1/4	25	19N	5E	SBM	Avawatz Pass	800		Nov-78	Dry
133	Superior Mine Tks. *	SE1/4SE1/4	24	19N	5E	SBM	Avawatz Pass	480		Nov-78	Capped
134	Ibex #1	NE1/4NE1/4	2	19N	5E	SBM	Shoshone	1100	1.50	Dec-80	
135	Ibex #2	NE1/4NE1/4	2	19N	5E	SBM	Shoshone	1100		Dec-80	Private Well
136	Bradbury Well*	SE1/4SE1/4	15	21N	4E	SBM	Confld. Hills	1750		Mar-80	Well
137	Rhodes	NE1/4SE1/4	10	21N	4E	SBM	Confld. Hills	1930	1.00	Mar-80	
138	Virgin	SW1/4NE1/4	6	22N	4E	SBM	Confld. Hills	2400		Feb-81	Seep
139	Scotty's	NW1/4NW1/4	34	22N	3E	SBM	Confld. Hills	2040		May-82	Seasonal pools
139A	Timpapah	SW1/4SE1/4	27	22N	3E	SBM	Confld. Hills	2800		Apr-80	Pools
140	Willow	NE1/4SE1/4	31	22.5N	3E	SBM	Confld. Hills	2680	3.00	Nov-84	
141	Sheep Canyon (5 seeps)	NE1/4NE1/4	19	22.5N	3E	SBM	Funeral Peak	1000		Apr-80	Seep
142	Hidden	SW1/4SE1/4	24	22.5N	3E	SBM	Funeral Peak	4800		Jan-80	Seep
142A	Pool Spring	SE1/4SE1/4	24	22.5N	3E	SBM	Funeral Peak	4840		Sep-83	Pool
143	Brown	NE1/4SE1/4	23	22.5N	3E	SBM	Funeral Peak	5200		Jun-69	
144	Greenwater	NE1/4NW1/4	11	23N	3E	SBM	Funeral Peak	5060		Jul-78	Seep
145	Young	SE1/4SW1/4	20	25N	3E	SBM	Funeral Peak	3120		Mar-78	Dry
146	Lemonade (cold)	SE1/4SE1/4	1	25N	2E	SBM	Ryan	3760	0.01	Apr-77	
147	Monumnet Canyon Creek	SE1/4SW1/4	36	26N	2E	SBM	Ryan	2880		Apr-78	Seasonal
148	Navel (main)	SE1/4NW1/4	13	26N	2E	SBM	Ryan	2100		Aug-80	Tanks full
149	Navel (upper seeps)	SE1/4NW1/4	13	26N	2E	SBM	Ryan	2160		Jul-78	Basins full
150	Salty Navel	NW1/4NW1/4	13	26N	2E	SBM	Ryan	1960		Aug-80	Seeps
151	Fossil	NW1/4NW1/4	14	26N	2E	SBM	Ryan	1980		Aug-78	Seeps
151A	Sedge Seeps	NE1/4NW1/4	9	26N	2E	SBM	Furnace Creek	1200		Sep-59	Seeps
152	Travertime	All	23-26	27E	1E	SBM	Furnace Creek	400	950.00	Nov-57	
153	Suap in F.C. Wash*	SW1/4SE1/4	23	27N	1E	SBM	Furnace Creek	220	675.00	Nov-57	
154	Buried tile F. C. Wash	SE1/4SW1/4	23	27N	1E	SBM	Furnace Creek	200	200.00	Oct-57	
155	Furnace Cr. Inn Tunnel	NE1/4SW1/4	23	27N	1E	SBM	Furnace Creek	240	200.00	Nov-57	

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156	NPS Trench (obliterate)	NW1/4SW1/4	23	27N	1E	SBM	Furnace Creek	240		Aug-59	
157	Spider	NW1/4NW1/4	26	27N	1E	SBM	Furnace Creek	80		Jun-78	Seep
158	Furnace Cr. Inn Wells*	SW1/4NW1/4	23	27N	1E	SBM	Furnace Creek	200		Dec-48	Destroyed
159	NPS Well #1*	SW1/4NW1/4	24	27E	1E	SBM	Furnace Creek	480		Jul-59	Capped
160	Texas (9 spgs.)	NW1/4NE1/4	23	27E	1E	SBM	Furnace Creek	400	225.00	Aug-59	
161	27 undevlpd spgs FC area				1E	SBM	Furnace Creek			Aug-59	Seeps
162	F.C. Ranch Ponds	SE1/4SW1/4	16	27N	1E	SBM	Furnace Creek	-180		Aug-59	Private
163	Gnome #1 & #2	NW1/4SE1/4	3	27N	1E	SBM	Furnace Creek	-100	4.00	Dec-78	
164	Cow	NE1/4NE1/4	3	27E	1E	SBM	Chlor. Cliff	240	24.00	Aug-59	
165	Calf	NW1/4NE1/4	3	27N	1E	SBM	Chlor. Cliff	240		Aug-59	Seep
166	Bighorn Seeps (7)	SW1/4NE1/4	36	28N	1E	SBM	Chlor. Cliff	880		Aug-59	Seeps
167	Nevares (5)	SW1/4NE1/4	36	28N	1E	SBM	Chlor. Cliff	900	270.00	Aug-59	
168	Lower Nevares (12)	All	33-36	28N	1E	SBM	Chlor. Cliff	460	22.00	Aug-59	
169	Sewer Lagoon *	NE1/4SE1/4	33	28N	1E	SBM	Chlor. Cliff	-80		Aug-80	Obliterated
170	Saltbush (sewer) *	NW1/4NW1/4	4	27N	1E	SBM	Chlor. Cliff	-280		Feb-78	Obliterated
171	Echo Waterholes	NW1/4SW1/4	33	28N	3E	SBM	Big Dune	5040		Sep-59	Seasonal
172	Buckboard	SW1/4SW1/4	21	28N	1E	SBM	Chlor. Cliff	-26		Aug-68	Seep
173	Charlies Well (oblitratd)	SE1/4NW1/4	17	28N	1E	SBM	Chlor. Cliff	-250		Dec-60	Obliterated
174	Scraper	SE1/4SE1/4	1	28N	1E	SBM	Chlor. Cliff	1280		Mar-78	Seep
174A	USGS Spring		6	28N	2E	SBM	Chlor. Cliff	1760		Sep-83	Seep
175	Table	NW1/4SE1/4	1	28N	1E	SBM	Chlor. Cliff	1200		Mar-78	Seep
176	Moth	NW1/4NW1/4	36	29N	1E	SBM	Chlor. Cliff	1280		Jan-71	Dry
177	Maidenhair	SE1/4SE1/4	25	29N	1E	SBM	Chlor. Cliff	1520		Jan-71	Seep
178	Poison	NE1/4SW1/4	30	29N	1E	SBM	Chlor. Cliff	1920	0.10	Dec-75	
179	Point	SW1/4SE1/4	30	29N	1E	SBM	Chlor. Cliff	2000		Jan-72	Dry
180	Petroglyph	SE1/4SE1/4	30	29N	1E	SBM	Chlor. Cliff	2080		Jan-72	Dry
180A	Indian Pass Pothole.*	SE1/4SE1/4	29	29N	1E	SBM	Chlor. Cliff	2720		Feb-72	Potholes
181	Copper Bell (obliterated)	SW1/4SW1/4	17	29N	1E	SBM	Chlor. Cliff	3200		Nov-59	Obliterated
182	Unnamed Well *	SW1/4NW1/4	5	29N	1E	SBM	Chlor. Cliff	1800		Mar-79	Dry
183	Rice's Well *	NW1/4SE1/4	26	30N	1E	SBM	Chlor. Cliff	4480		Mar-79	Seep
184	Unnamed Well *	SE1/4SW1/4	28	30N	1E	SBM	Chlor. Cliff	5120		Aug-59	Not found
185	Unnamed Well *	SW1/4SE1/4	28	30N	1E	SBM	Chlor. Cliff	4100		Aug-59	Dry
186	Keane Wonder (4 spgs)	S1/2SE1/4	1	15S	46E	MDM	Chlor. Cliff	1200	5.00	Jul-78	
187	Maonarch Creek	NE1/4SE1/4	24	14S	46E	MDM	Chlor. Cliff	3160	10.00	Oct-81	
188	Bed Spring	NW1/4SW1/4	18	30N	1E	SBM	Chlor. Cliff	3040		Mar-79	Seep
188A	Jingle Seep	SE1/4NW1/4	18	30N	1E	SBM	Chlor. Cliff	3780		Mar-78	Seep
190	Pump House Well *	SE1/4SE1/4	7	30N	1E	SBM	Chlor. Cliff	3680		Mar-79	Water in well
189	Hopeful (2 spgs.)	NW1/4SW1/4	8	30N	1E	SBM	Chlor. Cliff	3920		Nov-83	Seeps
191	Keane	SW1/4NW1/4	8	30N	1E	SBM	Chlor. Cliff	3880	1.00	Nov-83	
192	New Hole-In-Rock	SW1/4NW1/4	15	14S	46E	MDM	Chlor. Cliff	2880		May-81	Seep
192A	Old Hole-In-Rock	SW1/4NE1/4	16	14S	46E	MDM	Chlor. Cliff	2960		Jan-78	Seep
193	Fire	SW1/4NE1/4	8	14S	46E	MDM	Bullfrog	3720		Jan-78	Seep
194	Corkscrew	NE1/4NW1/4	8	14S	46E	MDM	Bullfrog	4120		Jan-78	Seep
195	Daylight	NE1/4NE1/4	35	13S	46E	MDM	Bullfrog	4440		Apr-78	Seep
196	Bullfrog	SE1/4SW1/4	22	13S	46E	MDM	Bullfrog	4800		Jul-81	Seep
197	Bindle	NE1/4SE1/4	21	13S	46E	MDM	Bullfrog	5000		Dec-79	Dry
197A	Owl	SE1/4SW1/4	29	13S	46E	MDM	Bullfrog	4500		May-81	Seep
198	Daylight Willow	SW1/4NW1/4	22	13S	46E	MDM	Bullfrog	4740		Nov-83	Seep
199	Lostman	NE1/4SE1/4	36	13S	45E	MDM	Grapevine	3120		Feb-78	Dry
200	Fern	NE1/4SW1/4	30	13S	46E	MDM	Grapevine	4000	1.50	Feb-78	

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200A	Potlikker Seep	SE1/4SW1/4	18	13S	46E	MDM	Grapevine	4400		Nov-83	Seep
200B	Overlook Seep	SW1/4NW1/4	18	13S	46E	MDM	Grapevine	4800		Mar-78	Seasonal
201	Two Barrel	NE1/4SE1/4	13	13S	45E	MDM	Grapevine	5200		Jun-81	Dry
202	Butterfly	NW1/4NW1/4	13	13S	45E	MDM	Grapevine	4580		Oct-77	Dry
202A	Upper Leadfield	NE1/4SW1/4	12	13S	45E	MDM	Grapevine	5000	0.10	Jun-82	
202B	Wired Rock Spring	NE1/4NE1/4	12	13S	45E	MDM	Grapevine	4900		Feb-84	Seep
202C	White Pass Gate Seep	SE1/4NW1/4	18	13S	46E	MDM	Grapevine	5000		Feb-84	Seep
203	Trigger	SW1/4SW1/4	15	13S	45E	MDM	Grapevine	3600		Jan-77	Dry
204	Poacher	SW1/4SE1/4	16	13S	45E	MDM	Grapevine	3440		Jan-77	Dry
205	Klare	NW1/4SE1/4	9	13S	45E	MDM	Grapevine	3120	1.00	Jan-77	
205A	Leadfield	NW1/4SW1/4	2	13S	45E	MDM	Grapevine	4400		Mar-77	Dry
206	Cave Rock #1	NE1/4NE1/4	26	12SN	44EN	MDM	Grapevine	5000	0.05	Dec-80	
207	Cave Rock #2	SE1/4NW1/4	24	12SN	44EN	MDM	Bullfrog	5100		Dec-77	Dry
208	Tincan	SE1/4NE1/4	27	12S	45E	MDM	Grapevine	5200		Oct-75	Dry
208A	Palmer Seep	SW1/4NE1/4	29	12S	45E	MDM	Grapevine	5280		Jun-74	Dry
208B	Epipactis	NE1/4SE1/4	34	12S	45E	MDM	Grapevine	4960	1.80	Jun-74	
208C	Hohum	SW1/4SW1/4	2	12SN	45E	MDM	Grapevine	4000		Nov-79	Seep
209	McDonald #1	SE1/4SW1/4	10	12SN	44EN	MDM	Grapevine	6320		Jul-77	Dry
210	McDonald #@	NE1/4SW1/4	11	12SN	44EN	MDM	Grapevine	5560	1.00	Oct-81	
211	Alakali	NE1/4SW1/4	5	12SN	44EN	MDM	Grapevine	6640		Jun-78	Dry
211A	Boundry	SW1/4SW1/4	6	12SN	44EN	MDM	Grapevine	6400	3.00	Jun-79	
212	Mexican Camp	NE1/4NW1/4	3	12SN	44EN	MDM	Grapevine	5940		Jun-78	Dry
213	Buck	NE1/4NW1/4	5	12SN	45EN	MDM	Bullfrog	4800		Feb-78	Dry
214	Goldbar Well	SW1/4NE1/4	34	11SN	45EN	MDM	Bullfrog	4680		Nov-79	Dry
215	Currie Wells (3)	NE1/4NW1/4	22	11SN	45EN	MDM	Bullfrog	4500	0.33	Oct-80	
216	Wood Camp	NW1/4NE1/4	24	11SN	44EN	MDM	Bullfrog	4900	2.40	Jun-83	
217	Mexican	NW1/4NW1/4	4	12SN	44EN	MDM	Grapevine	4860		Jun-78	Dry
218	Larkspur	SE1/4NW1/4	32	11SN	44EN	MDM	Grapevine	6400	1.00	Mar-80	
219	Little Willow	NW1/4NW1/4	33	11SN	44EN	MDM	Grapevine	6300		Dec-77	Seep
220	Tule George	NE1/4NE1/4	32	11SN	44EN	MDM	Grapevine	6160	1.00	Mar-80	
221	Knoll	SE1/4SE1/4	29	11SN	44EN	MDM	Grapevine	6300		Dec-77	Dry
222	Brier	SE1/4NE1/4	31	11SN	44EN	MDM	Grapevine	6400	0.60	Jul-82	
223	Cordwood	SW1/4NW1/4	31	11SN	44EN	MDM	Grapevine	7100		Aug-77	Dry
223A	Wahguyhe	SE1/4SE1/4	7	12S	46E	MDM	Grapevine	5920		Jun-74	Seep
224	Black Springs #4495									Aug-77	Dry
225	Trail									Aug-77	Dry
226	Black Spot	NW1/4SE1/4	30	11SN	44EN	MDM	Grapevine	6700		Aug-77	Dry
227	Rabbit Brush	SW1/4SW1/4	20	11SN	44EN	MDM	Grapevine	6200	0.50	Jan-79	
228	Cliff	NE1/4NE1/4	19	11SN	44EN	MDM	Grapevine	6200		Jan-79	Seasonal
229	Delf's #2	NW1/4SE1/4	24	11SN	43EN	MDM	Grapevine	6800		Feb-78	Not found
230	Log	SE1/4SW1/4	13	11SN	43EN	MDM	Grapevine	6800	2.00	Dec-77	
230A	C-B Spring	SW1/4SE1/4	13	11SN	43EN	MDM	Grapevine	6800		Feb-78	Dry
231	Delf's #1	SW1/4SW1/4	24	11SN	43EN	MDM	Grapevine	6900		Jul-77	Seep
232	Pine	NE1/4SE1/4	23	11SN	43EN	MDM	Grapevine	6100		Sep-77	Seep
233	Jaybird	NW1/4NE1/4	23	11SN	43EN	MDM	Grapevine	6800	0.80	Jun-74	
234	Doe	SE1/4NW1/4	26	11SN	43EN	MDM	Grapevine	7300	0.03	Dec-80	
235	Shell	SW1/4NW1/4	34	11SN	44EN	MDM	Grapevine	7380		Aug-59	
236	Ramhorn	NW1/4SE1/4	4	11SN	44EN	MDM	Grapevine	4400		Oct-69	Seep
237	Jackknife	NW1/4NE1/4	24	12S	43EN	MDM	Tin Mtn.	2300	1.00	Oct-60	
237A	Trickling Spring	NE1/4SE1/4	23	12S	43EN	MDM	Tin Mtn.	2000	0.20	Aug-77	

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238	Forgotten Creek	SW1/4NE1/4	23	12S	43E	MDM	Tin Mtn	2000		Oct-80	Seeps
239	Nelson	NE1/4SE1/4	16	11S	43EN	MDM	Grapevine	6880	4.00	Jun-78	
239A	Funston	NE1/4SE1/4	16	11S	43EN	MDM	Grapevine	6980		Jun-78	Seasonal
240	Grapevine Willow	NW1/4NW1/4	2	10SN	43EN	MDM	Bonnie Clr.	6500		Jul-69	Seep
240A	Bonnie Claire Seep	NW1/4NE1/4	1	11SN	43EN	MDM	Bonnie Clr.	5600		Dec-71	Dry
241	Shrike	SW1/4SE1/4	4	12S	43E	MDM	Tin Mtn	1900		Jun-80	Dry
242	Obsidian Seeps	NW1/4NW1/4	3	12S	43E	MDM	Tin Mtn	2480		Jun-80	Dry
242A	Bushy Seep	SE1/4SE1/4	30	11S	43E	MDM	Tin Mtn	2240		Jan-84	Dry
243	Beeseep	NE1/4NE1/4	20	11S	43E	MDM	Tin Mtn	3040		Jan-84	Dry
244	Whisker	NW1/4SW1/4	16	11S	43E	MDM	Tin Mtn	2960		Jan-84	Dry
245	Mortar	SE1/4SE1/4	17	11S	43E	MDM	Tin Mtn	3140	0.50	Jan-84	
246	Ranger	NW1/4SE1/4	24	11S	42E	MDM	Tin Mtn	2400	0.50	Jan-78	
247	Traderat	NW1/4NW1/4	24	11S	42E	MDM	Tin Mtn	2240	1.70	Jan-78	
248	Surprise	SW1/4NW1/4	18	11S	43E	MDM	Ubehebe Cr.	2840	2.00	Feb-78	
248A	Gargoyle	NE1/4SW1/4	7	11S	43E	MDM	Ubehebe Cr.	2920	0.20	Jan-80	
249	Mound	SW1/4SW1/4	2	11S	42E	MDM	Ubehebe Cr.	2680	5.00	Feb-78	
250	Scotty's Castle	SW1/4NW1/4	5	11S	43E	MDM	Ubehebe Cr.	3250		Aug-59	Abundant
250A	Grapevine Ranch	All	8	11S	42E	MDM	Ubehebe Cr.	2780	200.00	Aug-79	
2251	Lantern	SW1/4NE1/4	22	11S	42E	MDM	Tin Mtn	2000		Jan-80	Seep
252	Wheelbarrow	NW1/4SE1/4	22	11S	42E	MDM	Tin Mtn	2000		Jan-78	
253	Horsefly	NW1/4SE1/4	22	11S	42E	MDM	Tin Mtn	2000		Jan-78	Seep
242	Blackjack	NW1/4SE1/4	26	11S	42E	MDM	Tin Mtn	1880		Oct-77	Seeps
255	Hobo	SE1/4SW1/4	26	11S	42E	MDM	Tin Mtn	1800		Oct-77	Seep
256	Mesquite	SE1/4SW1/4	26	11S	42E	MDM	Tin Mtn	1780	16.00	Nov-77	
257	Surveyor's Well*	SW1/4SW1/4	12	14S	44E	MDM	Stovepipe	60		Nov-77	Pool
258	Unnamed Well *	NE1/4NW1/4	14	14S	44E	MDM	Stovepipe	50		Jan-79	Seep
259	Midway Well *	NW1/4NW1/4	18	14S	45E	MDM	Stovepipe	70		Dec-78	Capped
260	Ruiz Well *	SW1/4SW1/4	14	14S	44E	MDM	Stovepipe	40		Jan-78	Dry
260A	Tiger Beetle Creek	Many	14-24	14S	44E	MDM	Stovepipe	20		Apr-78	Seasonal
261	Triangle	SW1/4NW1/4	19	14S	45E	MDM	Stovepipe	40		May-84	Dry
261A	Bebbia Potholes	Many	30-31	14S	46E	MDM	Stovepipe	1600		Dec-77	Dry
261B	Palm	NE1/4NE1/4	30	14S	45E	MDM	Stovepipe	80		May-84	Seep
262	Indian Map Well*	SE1/4NW1/4	9	15S	44E	MDM	Stovepipe	70		Sep-59	Obliterated
263	Stovepipe Well *	NW1/4NW1/4	15	15S	45E	MDM	Stovepipe	-50		Aug-59	Capped
264	Stovepipe Well* (hotel)	Pvt. Prop.				MDM	Stovepipe	0		Aug-59	Brackish
264A	NPS R.O. Well	SW1/4SE1/4	36	15S	44E	MDM	Stovepipe	90		Dec-78	
265	Dune Salt Well *	NE1/4SE1/4	32	15S	45E	MDM	Stovepipe	-40			
266	Mc Lean	SE1/4SW1/4	31	15S	46E	MDM	Stovepipe	-130			
267	Salt Creek-stream *	Many	many	15S	46E	MDM	Stovepipe	-140		Mar-81	Varies
268	Salt Well * (obliterated)					MDM	Chlor. Cliff			Sep-59	Obliterated
269	Salt	SW1/4SE1/4	28	16.5S	46E	MDM	Chlor. Cliff	-240			
270	Sulfur	SE1/4NE1/4	27	16.5S	46E	MDM	Chlor. Cliff	-260			
271	Tule	SW1/4NW1/4	28	25N	1E	SBM	Bennetts Well	-260			
271A	Badwater Potholes *	NW1/4NW1/4	21	26N	2E	SBM	Furnace Creek	0		Jun-80	Potholes
272	Shorty's Well*	NW1/4SW1/4	33	25N	1E	SBM	Bennetts Well	-210		May-83	Water 5' down
273	Badwater	SW1/4NE1/4	33	26N	2E	SBM	Bennetts Well	-280		Aug-59	Pond
273A	Tinaja Baja*	SE1/4SE1/4	18	24N	2E	SBM	Bennetts Well	-200		Jan-79	Pothole
274	Eagle Borax	SW1/4NW1/4	10	24N	1E	SBM	Bennetts Well	-260		Feb-65	Large pond
275	Sowbelly Well*	NE1/4SE1/4	9	24N	1E	SBM	Bennetts Well	-260			
276	Bennetts Well*	NE1/4SW1/4	22	24N	1E	SBM	Bennetts Well	-250			

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277	Salisbury Well *		11	23N	1E	SBM	Bennetts Well	-250		Sep-59	Dry
278	Dry Well *		2	23N	1E	SBM	Bennetts Well	-25		Sep-59	Dry
279	Mesquite Well *	NE1/4NW1/4	14	23N	1E	SBM	Bennetts Well	-25			Dry
280	Gravel Well *	NW1/4NW1/4	23	23N	1E	SBM	Bennetts Well	-200		Jan-80	Capped
281	Mesquite Well *	NW1/4SE1/4	35	23N	1E	SBM	Bennetts Well	-246			
282	Mesquite Well *	NE1/4NW1/4	14	23N	1E	SBM	Bennetts Well	-25			Dry
283	Hawk	SW1/4NW1/4	1	23N	1E	SBM	Bennetts Well	-250		Jun-82	Pool
284	Salt Well *	NW1/4NW1/4	12	23N	1E	SBM	Bennetts Well	-220		Mar-80	Water 6' down
285	Coyote Wells *	NW1/4NW1/4	10	22N	2E	SBM	Bennetts Well	-240		Jun-82	Dry
285A	Bicentennial	SE1/4SE1/4	15	22N	2E	SBM	Funeral Peak	-220		Jun-82	Seep
286	Ashford Well *	NW1/4NE1/4	28	21N	3E	SBM	Confid. Hills	0		Dec-78	Dry
287	Confidence Mill Well *	SW1/4NW1/4	9	20N	4E	SBM	Confid. Hills	-20			
288	Confidence										
289	Blister Well*	SE1/4NE1/4	22	19N	4E	SBM	Leach Lake	153		Dec-78	Dry

APPENDIX B

Chemical Analysis Data
Provided by USGS
And
Piper Diagram Cation and Anion
Spring Data Point Values

File: Death Valley-Composite

G: Strozzi Ranch	Mg/l
Mg	2.900
Ca	16.000
Na	30.000
K	10.000
CO3	1.000
HCO3	123.000
Cl	8.200
SO4	12.000
Fe	0.020
SiO2	24.000
NO3	1.000

Ion Balance: **1.020**
TDS: **228.1**

G: Cordwood	Mg/l
Mg	4.500
Ca	21.000
Na	25.000
K	6.900
CO3	1.000
HCO3	122.000
Cl	10.000
SO4	13.000
Fe	0.020

Ion Balance: **1.038**
TDS: **203.4**

G: Little Willow	Mg/l
Mg	3.500
Ca	19.000
Na	48.000
K	7.000
CO3	1.000
HCO3	153.000
Cl	16.000
SO4	23.000
Fe	0.020
SiO2	24.000
NO3	0.200

Ion Balance: **1.008**
TDS: **294.7**

G: Knoll	Mg/l
Mg	3.200
Ca	14.000
Na	30.000
K	9.300
CO3	1.000
HCO3	87.000
Cl	13.000
SO4	17.000
Fe	0.100
SiO2	22.000
NO3	1.600

Ion Balance: **1.137**
TDS: **198.2**

G: Klare-USGS	Mg/l
Mg	24.000
Ca	44.000
Na	110.000
K	4.800
CO3	1.000
HCO3	349.000
Cl	33.000
SO4	130.000
Fe	0.020
SiO2	20.000
NO3	0.300

Ion Balance: **0.966**
TDS: **716.1**

G: Woodcamp	Mg/l
Mg	3.300
Ca	23.000
Na	38.000
K	14.000
CO3	1.000
HCO3	122.000
Cl	24.000
SO4	24.000
Fe	0.020
SiO2	57.000
NO3	3.000

Ion Balance: **1.053**
TDS: **309.3**

File: Death Valley-Composite

G:Grapevine-USGS	Mg/l
Mg	18.000
Ca	52.000
Na	160.000
K	15.000
CO3	1.000
HCO3	467.000
Cl	62.000
SO4	120.000

Ion Balance: **0.957**
TDS: **895.0**

G:Grapevine-USGS	Mg/l
Mg	20.000
Ca	51.000
Na	168.000
K	5.700
CO3	1.000
HCO3	477.000
Cl	64.000
SO4	120.000
SiO2	38.000
NO3	0.110

Ion Balance: **0.958**
TDS: **944.8**

G:Stainger-USGS	Mg/l
Mg	0.520
Ca	4.600
Na	150.000
K	5.200
CO3	1.000
HCO3	233.000
Cl	42.000
SO4	89.000
SiO2	59.000
NO3	0.860

Ion Balance: **1.004**
TDS: **585.2**

G:Daylight-USGS	Mg/l
Mg	3.700
Ca	29.000
Na	16.000
K	1.800
CO3	1.000
HCO3	110.000
Cl	10.000
SO4	15.000

Ion Balance: **1.026**
TDS: **186.5**

F: Navel	Mg/l
Mg	8.900
Ca	15.000
Na	168.000
K	7.800
CO3	17.000
HCO3	228.000
Cl	75.000
SO4	125.000
Fe	0.030
SiO2	8.500
NO3	31.000

Ion Balance: **0.944**
TDS: **684.2**

F: Upper Navel	Mg/l
Mg	17.000
Ca	41.000
Na	209.000
K	14.000
CO3	1.000
HCO3	422.000
Cl	93.000
SO4	154.000
Fe	0.070
SiO2	12.000
NO3	22.000

Ion Balance: **0.982**
TDS: **985.1**

File: Death Valley-Composite

F:Travertine-USGS Mg/l

Mg	18.000
Ca	33.000
Na	140.000
K	12.000
CO3	1.000
HCO3	343.000
Cl	30.000
SO4	150.000
Fe	3.000
Cu	1.000
SiO2	30.000
NO3	0.130

Ion Balance: **1.004**
TDS: **761.1**

F:Nevares-USGS Mg/l

Mg	20.000
Ca	42.000
Na	140.000
K	11.000
CO3	1.000
HCO3	353.000
Cl	37.000
SO4	170.000
Fe	4.000
Cu	1.000
Mn	4.000
SiO2	26.000
NO3	0.050

Ion Balance: **1.003**
TDS: **809.0**

F:Travertine-USGS Mg/l

Mg	19.000
Ca	36.000
Na	140.000
K	10.000
CO3	0.000
HCO3	330.000
Cl	40.000
SO4	160.000

Ion Balance: **0.984**
TDS: **735.0**

F: Texas-USGS Mg/l

Mg	20.000
Ca	35.000
Na	155.000
K	12.000
CO3	0.000
HCO3	348.000
Cl	43.000
SO4	160.000

Ion Balance: **1.019**
TDS: **773.0**

F:Nevares-USGS Mg/l

Mg	21.000
Ca	43.000
Na	145.000
K	11.000
CO3	0.000
HCO3	350.000
Cl	36.000
SO4	174.000

Ion Balance: **1.008**
TDS: **780.0**

F:K. Wonder-USGS Mg/l

Mg	38.000
Ca	100.000
Na	970.000
K	43.000
CO3	0.000
HCO3	1300.000
Cl	550.000
SO4	740.000

Ion Balance: **0.984**
TDS: **3741.0**

B: Willow Mg/l

Mg	15.000
Ca	54.000
Na	79.000
K	6.600
CO3	1.000
HCO3	214.000
Cl	68.000
SO4	111.000
Fe	0.190
Mn	0.220
SiO2	16.000
NO3	1.700

Ion Balance: **0.968**
TDS: **566.7**

File: Death Valley-Composite

B: Ibex

B: Ibex	Mg/l
Mg	20.000
Ca	22.000
Na	511.000
K	13.000
CO3	27.000
HCO3	540.000
Cl	290.000
SO4	374.000
Fe	0.020
Mn	0.300
SiO2	18.000
NO3	0.200

Ion Balance: **0.984**
TDS: **1815.5**

B: Virgin

B: Virgin	Mg/l
Mg	35.000
Ca	54.000
Na	92.000
K	6.100
CO3	1.000
HCO3	488.000
Cl	19.000
SO4	71.000
Fe	3.000
Cu	2.000
Mn	5.000
SiO2	30.000
NO3	11.000

Ion Balance: **0.986**
TDS: **817.1**

B: Lemonade-USGS

B: Lemonade-USGS	Mg/l
Mg	2.100
Ca	2.200
Na	180.000
K	7.400
CO3	0.000
HCO3	260.000
Cl	64.000
SO4	79.000

Ion Balance: **1.077**
TDS: **594.7**

B: Salisburg

B: Salisburg	Mg/l
Mg	3.000
Ca	6.200
Na	138.000
K	5.400
CO3	1.000
HCO3	200.000
Cl	47.000
SO4	52.000
Fe	0.050
SiO2	26.000
NO3	1.500

Ion Balance: **1.166**
TDS: **480.1**

P: Thorndike

P: Thorndike	Mg/l
Mg	2.500
Ca	32.000
Na	7.700
K	1.100
CO3	1.000
HCO3	116.000
Cl	3.300
SO4	13.000
Fe	0.020
SiO2	6.800

Ion Balance: **0.943**
TDS: **183.4**

P: Johnnie S.

P: Johnnie S.	Mg/l
Mg	34.000
Ca	55.000
Na	29.000
K	1.000
CO3	1.000
HCO3	352.000
Cl	17.000
SO4	41.000
Fe	0.020
Mn	0.180
SiO2	8.700
NO3	1.000

Ion Balance: **0.956**
TDS: **539.9**

File: Death Valley-Composite

P: Hummingbird

P: Hummingbird	Mg/l
Mg	13.000
Ca	61.000
Na	14.000
K	2.800
CO3	1.000
HCO3	159.000
Cl	42.000
SO4	107.000
Fe	0.020
Mn	0.060
SiO2	8.800

Ion Balance: **0.793**
TDS: **408.7**

P: Wildrose

P: Wildrose	Mg/l
Mg	44.000
Ca	131.000
Na	43.000
K	7.100
CO3	1.000
HCO3	200.000
Cl	19.000
SO4	431.000
Fe	0.020
SiO2	13.000
NO3	0.100

Ion Balance: **0.952**
TDS: **889.2**

P: Suprize Canyon

P: Suprize Canyon	Mg/l
Mg	18.000
Ca	62.000
Na	71.000
K	2.300
CO3	1.000
HCO3	264.000
Cl	70.000
SO4	59.000
Fe	0.020
Mn	0.300
SiO2	22.000
NO3	0.500

Ion Balance: **1.021**
TDS: **570.1**

P: Burns #1

P: Burns #1	Mg/l
Mg	33.000
Ca	43.000
Na	80.000
K	1.000
CO3	1.000
HCO3	431.000
Cl	20.000
SO4	30.000
Fe	0.020
Al	0.300
SiO2	15.000
NO3	3.200

Ion Balance: **1.008**
TDS: **657.5**

P: Lime Kiln

P: Lime Kiln	Mg/l
Mg	41.000
Ca	80.000
Na	14.000
K	5.000
CO3	1.000
HCO3	216.000
Cl	10.000
SO4	200.000
Fe	0.020
Mn	0.100
SiO2	9.500
NO3	1.100

Ion Balance: **1.009**
TDS: **577.7**

P: Upper Emigrant

P: Upper Emigrant	Mg/l
Mg	64.000
Ca	86.000
Na	75.000
K	2.900
CO3	1.000
HCO3	522.000
Cl	73.000
SO4	210.000
Fe	0.020
Mn	0.100
SiO2	13.000
NO3	0.200

Ion Balance: **0.859**
TDS: **1047.2**

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File: Death Valley-Composite

P: Anvil	Mg/l
Mg	6.300
Ca	48.000
Na	35.000
K	2.900
CO3	1.000
HCO3	211.000
Cl	20.000
SO4	33.000
Fe	0.020
SiO2	12.000
NO3	14.000

Ion Balance: **0.908**
TDS: **383.2**

P: Dripping	Mg/l
Mg	85.000
Ca	114.000
Na	23.000
K	7.700
CO3	1.000
HCO3	149.000
Cl	18.000
SO4	710.000
Fe	0.020
Mn	0.020
SiO2	6.300
NO3	2.000

Ion Balance: **0.780**
TDS: **1116.0**

P: Warm	Mg/l
Mg	20.000
Ca	61.000
Na	32.000
K	3.500
CO3	1.000
HCO3	125.000
Cl	25.000
SO4	170.000
Fe	3.000
Cu	1.000
Mn	1.000
SiO2	31.000
NO3	0.740

Ion Balance: **1.001**
TDS: **474.2**

P: Jaybird-USGS	Mg/l
Mg	16.000
Ca	42.000
Na	8.300
K	1.300
CO3	0.000
HCO3	211.000
Cl	6.800
SO4	8.800

Ion Balance: **0.993**
TDS: **294.2**

SP: Buried Wagon	Mg/l
Mg	558.000
Ca	135.000
Na	9590.000
K	717.000
CO3	1.000
HCO3	765.000
Cl	12700.000
SO4	5110.000
Fe	0.030
Mn	0.040
SiO2	26.000
NO3	1.000

Ion Balance: **1.023**
TDS: **29603.1**

SP: McLean	Mg/l
Mg	175.000
Ca	97.000
Na	2440.000
K	186.000
CO3	1.000
HCO3	574.000
Cl	3160.000
SO4	1470.000
Fe	0.060
SiO2	45.000
NO3	1.000

Ion Balance: **1.007**
TDS: **8149.1**

File: Death Valley-Composite

SP: Saratoga

	Mg/l
Mg	36.000
Ca	34.000
Na	977.000
K	32.000
CO3	1.000
HCO3	414.000
Cl	695.000
SO4	1017.000
Fe	0.020
SiO2	18.000
NO3	4.600

Ion Balance: **1.006**
TDS: **3228.6**

SP: Salt Creek

	Mg/l
Mg	280.000
Ca	78.000
Na	112600.000
K	8470.000
CO3	1.000
HCO3	1665.000
Cl	191000.000
SO4	34900.000
Fe	0.200
Cu	0.050
Mn	0.440
SiO2	1.300
NO3	6.000

Ion Balance: **0.837**
TDS: **349002.0**

SP: Saratoga-USGS

	Mg/l
Mg	34.000
Ca	32.000
Na	960.000
K	33.000
CO3	1.000
HCO3	427.000
Cl	660.000
SO4	1000.000
SiO2	39.000
NO3	1.300

Ion Balance: **1.011**
TDS: **3187.3**

SP: Salt Creek-USGS

	Mg/l
Mg	410.000
Ca	120.000
Na	6800.000
K	480.000
CO3	1.000
HCO3	653.000
Cl	5700.000
SO4	3300.000

Ion Balance: **1.448**
TDS: **17464.0**

SP:Eagle Borax-USGS

	Mg/l
Mg	270.000
Ca	610.000
Na	760.000
K	28.000
CO3	0.000
HCO3	320.000
Cl	1800.000
SO4	1400.000

Ion Balance: **1.015**
TDS: **5188.0**

SP: Badwater-USGS

	Mg/l
Mg	95.000
Ca	833.000
Na	8050.000
K	334.000
CO3	0.000
HCO3	114.000
Cl	11400.000
SO4	2760.000

Ion Balance: **1.071**
TDS: **23586.0**

SP: Owl Hole

	Mg/l
Mg	33.000
Ca	177.000
Na	2260.000
K	21.000
CO3	1.000
HCO3	991.000
Cl	1810.000
SO4	2640.000
Fe	0.020
Mn	0.100
SiO2	15.000
NO3	0.100

Ion Balance: **0.903**
TDS: **7948.2**

File: Death Valley-Composite

EIS001443

The HYDRODYNAMICS Group
studies in mass & energy transport in the earth

AN EVALUATION OF THE HYDROLOGY AT YUCCA MOUNTAIN:

THE LOWER CARBONATE AQUIFER AND AMARGOSA RIVER

Prepared for

INYO COUNTY, CALIFORNIA
&
ESMERALDA COUNTY, NEVADA

February 1, 1996

Prepared by
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EXECUTIVE SUMMARY

Yucca Mountain is the site of the United States' only proposed high-level nuclear repository. The repository was designed using the philosophy of multiple barriers, both engineered and natural, each of which impede the movement of contaminants. The proposed repository would be in the unsaturated zone above the water table in Tertiary tuffaceous rocks. The principal transporting mechanism is moving ground water. Underlying the repository at approximately 2 km (6,000 feet) is an extensive Lower Carbonate Aquifer known to be highly permeable. Should contaminants get to the Lower Carbonate Aquifer they would be moved by ground water back to the biosphere, over some period of time. Several points of potential discharge are the springs on the east side of Death Valley, within Inyo County. Esmeralda County, on the other hand, is up gradient, and has little chance of contamination from Yucca Mountain through the carbonate aquifer. This study was supported by both Esmeralda and Inyo Counties.

We can separate the potential impacts of the repository into 1) near-field and 2) far-field effects. There are a number of near-field effects that are difficult to predict. Among these are:

1) the impact of hot canisters on the redistribution of the moisture in the unsaturated zone;

2) the impact of so-called fast paths of recharge that move water quickly through the fractures in the unsaturated zone; and

3) the logistics of building the repository.

An important objective of our study was the evaluation of far-field issues related to the regional ground-water hydrology for potential migration of radionuclides into Inyo and Esmeralda Counties. Our study indicates that:

1) data from the UE-25p1 exploratory borehole suggests that it is unlikely that radionuclide contaminants will move to the Lower Carbonate Aquifer in the vicinity of Yucca Mountain because the potential for ground water movement is upward out of the carbonates into the tuff;

2) should contaminants get to the Lower Carbonate Aquifer they will be moved by ground water back to the biosphere, over a relatively short period (several thousand years);

3) the ultimate discharge points for the Lower Carbonate Aquifers appears to be the springs on the east side of Death Valley, within Inyo County;

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4) Esmeralda County is up gradient from Yucca Mountain and has little chance of ground water contamination from a Yucca Mountain repository through the carbonate aquifer; and

5) there are geohydrologic data gaps that make predicting the repository performance including the transport of contaminants in the Lower Carbonate Aquifer uncertain.

Our investigation suggested a number of activities that would enhance our understanding of the potential for contaminate transport into and through the Lower Carbonate Aquifer system. The following oversight study activities are recommended.

Amargosa River Basin Hydrology Studies

The HyMet Amargosa River basin rainfall-runoff model suggests there may be a significant transfer of ground-water inflow into the basin through the Lower Carbonate Aquifer in adjacent areas. It is recommended that the HyMet model be used to further evaluate this relationship. The transfer of ground-water inflow into the Amargosa River basin from the Lower Carbonate Aquifer has not been quantified in previous studies. Further analyses of the stream record would help in the evaluation of ground-water transfer to the Amargosa River basin. It is also suggested that the Amargosa River stream gage be reinstalled to assist in this analysis.

Lower Carbonate Aquifer Studies

Other investigations of the Lower Carbonate Aquifer are recommended below:

1) There should be sufficient test drilling in the vicinity of Yucca Mountain to indicate that the high head, observed in UE-25p1, persists everywhere beneath the proposed repository. The experience with the UE-25p1 test hole demonstrates the value of the empirical data gained from drilling and monitoring at Yucca Mountain. Numerical ground-water modeling could be used to suggest drilling locations.

2) It is further suggested that connectivity of the Lower Carbonate Aquifer be evaluated by geochemical analysis of spring water associated with the Death Valley basin to help determine the source of these waters. A spring sampling and analysis program in the Amargosa and Funeral Mountains is warranted.

3) A numerical transport model of the deep Lower Carbonate Aquifer would provide important insights into the potential migration of contaminants from the Yucca Mountain repository. A regional numerical model of the deep aquifer system would provide a means to evaluate:

- the suggested higher head in the Lower Carbonate Aquifer,
- ground water travel times of contaminates,
- aquifer connectivity, and
- the significance of geologic and hydrologic data gaps.

In particular, society cannot guarantee that large climate changes will preserve the upward flow potential between the Lower Carbonate Aquifer and the overlying Tuffs. Aquifer modeling can be used to estimate the impact of climate changes on the flow system. The modeling may provide an indication of how stable the potential for upward flow is. It should provide an estimate of over what area the upward potential currently exists.

4) Were the head in the Lower Carbonate Aquifer to be lowered, one of the natural barriers at the site would be destroyed. We wish to emphasize--as a potential barrier to nuclide transport, it is important that the high head in the Lower Carbonate Aquifer be preserved in the vicinity of the repository. No action should be taken either through construction and filling of the repository, or through development of the Lower Carbonate Aquifer for water supply to reduce the deep carbonate head.

Yucca Mountain Technical Oversight

It is suggest that technical oversight of the nuclear waste program continue. Current nuclear waste policy may change to include a Interim Federal Storage (IFS) facility. The potential for a significant release of radionuclides from an IFS facility near Yucca Mountain is uncertain, and should be reviewed. With regard to Inyo County, the focus of oversight activities should be on studies concerning regional ground water issues, geology and hydrology, and criteria for licensing regarding ground water travel times. Oversight activities should include:

- Attend meetings related to ground water issues at Yucca Mountain,
- Review DOE and research reports on repository performance,
- Technical support to county personnel, and
- Review waste storage policy plans.

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We would also like to acknowledge several researchers and consultants for their assistance in providing data, information on their current research activities, and candid discussion on our work. Specifically, we would like to thank Dr. Isaac Winograd with the U.S. Geological Survey, Dr. Marty Mifflin with Mifflin & Associates, and Dr. Edward Price and Richard Waddell with GeoTrans Consultants, Inc. Their assistance was important to our study efforts.

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1.0 INTRODUCTION

Yucca Mountain is the site of the United States' only proposed high-level nuclear repository. The repository was designed using the philosophy of multiple barriers, both engineered and natural, each of which impede the movement of contaminants. The proposed repository would be in the unsaturated zone above the water table in Tertiary tuffaceous rocks. The principal transporting mechanism is moving ground water. Underlying the repository at approximately 2 km (6,000 feet) is an extensive Lower Carbonate Aquifer known to be highly permeable. Should contaminants get to the Lower Carbonate Aquifer they would be moved by ground water back to the biosphere, over some period of time. Several points of potential discharge are the springs on the east side of Death Valley, within Inyo County. Esmeralda County, on the other hand, is up gradient, and has little chance of contamination from Yucca Mountain through the carbonate aquifer. In this paper we address the likelihood of contaminant movement to the deep Lower Carbonate Aquifer. This study was supported by both Esmeralda and Inyo Counties.

We can separate the potential impacts of the repository into 1) near-field and 2) far-field effects. There are a number of near-field effects that are difficult to predict. Among these are:

1) the impact of hot canisters on the redistribution of the moisture in the unsaturated zone;

2) the impact of so-called fast paths of recharge that move water quickly through the fractures in the unsaturated zone; and

3) the logistics of building the repository.

We do not wish to minimize the problems of the near-field, but both Esmeralda and Inyo Counties are at some distance from the repository site; their concerns are in the far field. Our focus in this report is on the far-field effects. The major pathway of potential transport of radionuclides away from the repository is through moving ground-water. Of most concern, especially to Inyo County, is the deep, highly permeable, Paleozoic Lower Carbonate Aquifer that underlies the repository and is thought to have its ultimate discharge in springs along the east side of Death Valley. Much of the discussion in this report is on the regional aquifers, especially the deep Lower Carbonate Aquifer.

An important objective of our study was the evaluation of far-fieldissues related to the regional ground-water hydrology for potential migration of radionuclides into Inyo and Esmeralda Counties. The deep carbonate aquifer provides the most probable path for the long distance migration of radionuclides from Yucca Mountain into Inyo and/or Esmeralda Counties. Based on these facts, important issues to be addressed in the following report include:

1) Is the present climate stable?

2) Does the deep carbonate aquifer provide a continues pathway from Yucca Mountain to either Inyo and/or Esmeralda Counties?

3) Is there a ground-water driving force to move flow from the repository to Inyo and Esmeralda Counties.

2.0 SURFACE WATER HYDROLOGY AND CLIMATOLOGY

Potential radionuclide transport from the repository into and through the Lower Carbonate Aquifer is a partial function of the surface water hydrology and climatology of the Death Valley Watershed. Inyo County, especially Death Valley, is the lowest topographic point in the area and the ultimate point of discharge for the Amargosa River and the deep carbonate aquifer. Esmeralda County, on the other hand, is topographic higher (and therefore upstream) from the Amargosa Desert area surrounding Yucca Mountain. For this reason, it is unlikely that contaminants will reach Esmeralda County from Yucca Mountain.

We modeled rainfall-runoff of the Amargosa River basin in order to gain an understanding of the physical characteristics that control the movement of water through the watershed. Input data for our runoff simulation includes: 1) the 21-year daily discharge record of the Amargosa River, and 2) daily observations from precipitation and temperature stations in Nevada and California. Figure 2.0 show the drainage divides of the Amargosa River and Salt Creek, the gaging station locations, and the locations of the temperature and precipitation stations used in this analysis.

2.1 Setting

The Amargosa River originates in the mountains of Southwestern Nevada, flows south and west and ends in the sinks and playas of Death Valley in Inyo and San Bernardino Counties, California. The river was gauged for approximately 21 years (1962-83) at Tecopa, CA by the US Geological Survey (gage no. 10251300, elevation, 1310 feet). Gauging was discontinued after the station was destroyed by a flood on August 19, 1983. The drainage area above this gage is 3090 square miles and includes the Yucca Mountain repository site. Two other gauge discharge sites in Inyo County are also available but have not yet been included in the analysis (Salt Creek near Stovepipe Wells, CA 1974-present; Darwin Creek near Darwin, CA, 1963-89). Our effort in this study was to first understand the hydrology of the Amargosa River. The two other sites will be analyzed if further investigations of the Amargosa basin are funded (Figure 2.1 shows the annual runoff of the Amargosa River and Darwin Creek).

2.2 Streamflow Simulation

We adapted the Hymet simulation model for the Amargosa River to produce daily simulations of discharge for the 21 year period of record. The model converts observed daily precipitation and temperature into daily stream discharge at the gaging site. To make this calculation the model includes the hydrologic parameters: soil moisture, evapotranspiration (ET), infiltration, recharge, ground water storage and the outflow of ground water to the surface as springs. The model is calibrated by adjusting these hydrologic parameters plus the outflow of ground water to the surface as springs. Calibration is done by adjusting these hydrologic parameters until an adequate fit of simulated to observed discharge is achieved. Figure 2.2 is a schematic flow diagram of the HyMet model; it illustrates how the model accounts for the movement of water through the system.

We made significant revisions of model algorithms and the computer code for this project because of the unique character of the Amargosa watershed. The main differences between this basin and most others in the world are the extreme desert conditions that manifest itself 1) in low humidity and high rates of evaporation and transpiration, 2) long periods with no streamflow, 3) the sporadic nature of precipitation into the basin, and 4) the apparent inflow of ground water into the basin across drainage divides via deep aquifers.

There are a large number of hydrologic variables that can be calculated with the model. The most important variables are related to evapo-transpiration and the input and outflow of ground water. Simulated rates of evapotranspiration at the Franklin Lake playa had the largest effect on the early ground-water model transmissivity (Czarnecki, 1990). Also important is separating ground water movement into deep and shallow components.

The actual data input to the model are an average of four, equally weighted precipitation records, two maximum and minimum temperature records, and for simulation verification the daily discharge of the gauge at Tecopa. The temperature stations are separated by a 2125 foot (648 meter) elevation difference so that the temperature/elevation distribution is calculated. A listing of these input files are provide in an enclosed computer disk.

We attained a maximum R-squared value of 0.69 between calculated and observed streamflow for the Amargosa River discharge. Although the accuracy for simulating discharge is not as high as that attained by this model for most other catchments, the relatively extreme weather and hydrologic conditions in the Amargosa basin suggests that an R-squared value of nearly 0.7 is reasonable.

2.3 HyMet Model Results

The most important finding in the HyMet model analysis is that the water balance for the Amargosa basin is slightly negative; there is more runoff and evaporation from the basin than precipitation. The water balance for this basin can then be expressed as:

$$R + E > P$$

where:

R = Observed runoff
E = Simulated evaporation
P = Precipitation based on observed precipitation at four stations, Dagget, Death Valley, Inyo, Kern, Trona

The models suggests that ground-water inflow into the basin from the Lower Carbonate Aquifer is equal to approximately 0.5 cm (0.2 inches) of water averaged over the drainage area, or 33,000 acre-feet per year. This suggests there may be a significant transfer of water into the basin from adjacent areas by ground water movement.

The investigation also indicates:

1. Temperatures at most of the forty weather stations examined in this region are increasing. Most of these increases occurred in the past decade and therefore may not indicate an unusual or unprecedented rise in temperature. However, the nearest long-term station reveals a pattern similar to those in the Inyo county region. Sacramento station's record is much longer (117 years) and demonstrates a nearly continuous increase since the turn of the century, (Figure 2.3a).

2. Basin evapo-transpiration is increasing while potential (observed pan evaporation at Death Valley) is decreasing. This contradictory finding is not completely understood. It may possibly be explained by a combination of greater precipitation and higher temperatures: 1) potential ET is reduced because both humidity and precipitation has increased, and 2) actual ET is

humidity and precipitation has increased, and 2) actual ET is increased because more moisture is available for evaporation. These results may be due to a recent change in climate. This way suggest greater water losses in the future by increased evapo-transpiration, see Figures 2.3b and c.

3. High discharge events at the Amargosa gage usually are heavy precipitation during severe thunderstorms over smaller portion of the basin. In other words, total basin precipitation during these storms cannot be consistently predicted from a few weather stations (as is the case for most watersheds). Each storm that produces high runoff may be detected at a only a few precipitation gages. This suggests that even a small change in climate can alter precipitation patterns in this region. The effect on the hydrology may be even more significant (Figure 2.3d) .

4. The Amargosa River discharge increases during periods of cooler weather and no precipitation, suggesting an increase in ground water outflow caused by reduced evapo-transpiration. This implies that vegetation plays a critical role in evapo-transpiration from this basin.

5. Precipitation over the past 45 years has increased at nearly every station in the region, (Figure 2.3.e).

2.4 Climatology

The observed changes in rainfall, temperature, and pan evaporation may be manifestation of large scale changes in global climate. Because of man's impact on the climate, future changes may be impossible to predict.

3.0 GEOLOGY

The Lower Carbonate Aquifer is the most likely potential pathway for transport of contaminants from Yucca Mountain to Inyo County, as previously discussed. The geology of the Lower Carbonate Aquifer at Yucca Mountain forms a framework for understanding potential pathways for radionuclide transport from the repository to the biosphere. The geology was evaluated to determine if the Lower Carbonate Aquifer exists as a continuous media for contaminate transport into either Inyo and/or Esmeralda Counties. The geology of the Lower Carbonate Aquifer was evaluated in terms of its stratigraphy, structure, areal distribution, and thickness.

Our understanding of the geology of the Lower Carbonate Aquifer is limited by available data. There is a lack of deep drilling associated with Yucca mountain. At present, only two exploratory boreholes, UE25p1 and Felderhoff-Federal No. 25-1, have penetrated the Lower Carbonate Aquifer near Yucca Mountain, with hydrologic borehole data limited to UE25p1. Geophysical surveys lines provide limited coverage. An extensive discussion of the regional geology of the Lower Carbonate Aquifer was first presented in Winograd's and Thordarson's 1975 United States Geological Survey (USGS) Professional Paper 712-C. Recently, our understanding of the geology of the Lower Carbonate Aquifer has been enhanced by two regional geologic studies, by GeoTrans/IT Corporations and by the USGS.

The GeoTrans/IT Corporations investigation was supported by the Weapons Program, and the USGS study by the Yucca Mountain Nuclear Waste Program. It seems at first glance that these two modeling efforts are redundant. However, given the importance of understanding the ground-water hydrology of the region this redundancy may be warranted. To date, only a preliminary copy of the GeoTrans/IT model is available for public scrutiny.

A copy of the GeoTrans/IT Preliminary Regional Geological Model was provided for our review. The USGS model is promised for late 1995 or early 1996. Our evaluation of the geology of the Lower Carbonate Aquifer is based on Winograd's and Thordarson's 1975 publication, GeoTrans/IT Preliminary Regional Geological Model, and selected publications. A description of the GeoTrans/IT Preliminary Regional Geological Model is provided below.

3.1 GeoTrans/IT Preliminary Regional Geological Model

The GeoTrans/IT Preliminary Regional Geological Model is a three-dimensional conceptual hydrogeologic model of the Death Valley ground-water flow system. The model was developed to characterize the geologic and hydrologic framework of the Death Valley drainage system in support of ground-water flow and radionuclide transport modeling of the Nevada Test Site. The study area is approximately 28,490 square kilometers (11,000 square miles), which covers a significant portion of Southern Nevada and a portion of Inyo County, California, Figure 3.1. The study area includes the Yucca Mountain Repository site, the Amargosa Valley, and portions of Death Valley.

The model includes digitized structural elevation maps of hydrostratigraphic units of the study area. Interpreting the geology involved a process of combining surface geology, digital topography, geologic cross-sections to develop hydrostratigraphic unit data on a 2 kilometer (6,000 feet) grid spacing. Geologic data was integrated into the analysis using a GIS-based Environmental Resource Management Applications (ERMA) computer system. The three-dimensional geometric projections that show the relationship of the hydrostratigraphic units made using the program Voxel Analyst within ERMA. Each element of the modeling effort was reviewed by a team of geologists, experts in the study area.

The GeoTrans/IT Preliminary Regional Geological Model represents one of the most comprehensive geological interpretation of southern Nevada and portions of Death Valley. The model accounts for exploratory borehole data gaps through the use of geophysical data and use of the Voxel Analyst geological interpretation program.

Our study focused on maps of the surface elevation and depth to the Lower Carbonate Aquifer developed by GeoTrans/IT using their Preliminary Regional Geological Model. GeoTrans/IT prepared geologic cross-sections for our specific interests.

3.2 Stratigraphy

Winograd and Thordarson, 1975, indicate that the Yucca Mountain area is part of the miogeosynclinal belt of the Corilleran geosyncline, which covered the western most portion of North America. The geosyncline was an elongated subsiding trough in which over 11,000 meters (37,000 feet) of marine sediments were deposited. The miogeosynclinal belt occupied the eastern portion of this trough. Deposition in this belt was relatively continuous, and was dominated by Paleozoic-age carbonate and clastic sediments. These sediments have been divided into 16 formations, which include the Lower Carbonate Aquifer hydrogeologic unit, Table 3.2a. No Mesozoic-age rock are found in the area except for a few minor intrusive masses, which indicates a extensive period of uplift and erosion. Tertiary-age rock consist of more than 3,900 meters (13,000 feet) of extrusive volcanics that were erupted from large caldera centers, such as the Timber Mountain Caldera. Recent Quaternary-age sediments consist of alluvium that filled the low-lying areas. The stratigraphy of the Yucca Mountain study area is illustrated in Table 3.2a (Winograd and Thordarson, 1975).

The Precambrian and Paleozoic sediments consist of two major depositional sequences of clastic and carbonate sedimentation. This sequence is defined by hydrostratigraphic units in Table 3.2a as Lower Clastic Aquitard, Lower Carbonate Aquifer, Upper Clastic Aquitard, and Upper Carbonate Aquifer. Winograd and Thordarson, 1975, indicate there are no major unconformities within the Precambrian and Paleozoic sediments. They also indicate that there are several disconformities in these sediments that are not marked by deep subareal erosion of the underlying rocks. GeoTrans/IT's correlation of pre-Tertiary formations are presented in Table 3.2b, and correlation and definition of hydrostratigraphic units are presented in Table 3.2c. In general, the GeoTrans/IT grouping of formations into hydrostratigraphic units closely correlates with the units defined by Winograd and Thordarson (1975), with some simplification. However, GeoTrans/IT's did divide Silurian-age sediments into the Laketown Dolomite, Roberts Mountain Formation and Lone Mountain Dolomite in the Yucca Mountain area, which are designated "undifferentiated" by Winograd and Thordarson, 1975.

The Lower Carbonate Aquifer is composed of marine of limestone, dolomite, calcareous shales, and quartzite over most of the study area. There is a facies change to a clastic rock in the northwest portion of the study area toward the north ends of Esmeralda and Nye Counties. Geologic descriptions of these sediments in drilling rock cores are confined to rock type and secondary permeability features. Vuggy porosity is present locally, but is isolated. A few cavities were encountered in the Lower Carbonate Aquifer, the largest was 0.61 meters (2 feet). Winograd and Thordarson, 1975, observed four types of fractures in Lower Carbonate Aquifer cores:

1. fractures filled with breccia or clayey gouge,
2. fractures with slickensides,
3. fractures sealed with calcite, dolomite, or other minerals, and
4. fractures partly filled with calcite or dolomite.

3.3 Structure

The structural geology of the area is the result of two major periods of deformation. The first major orogeny occurred in the late Mesozoic and early Tertiary. This period of tectonics resulted in uplift, erosion, and subsequent folding, and both strike-slip and thrust faulting of the Precambrian and Paleozoic sediments. During the Tertiary Period extrusive volcanics from major caldera centers covered the area as previously noted. Beginning in the Miocene and continuing into the Quaternary large-scale normal faulting disrupted the Precambrain and Paleozoic sediments, and volcanics breaking the area into basin and ranges. As a result of this geologic history, the structural geology of the Yucca Mountain is complex.

Major structural features of the Amargosa Desert/Death Valley portions of the area are identified in Figure 3.3a. The subsurface relationship of these features to the Lower Carbonate Aquifer is illustrated in the geological cross-sections developed by GeoTrans/IT in Figures 3.3b, c, d and e. (Note that the figure numbers shown on these cross-sections are referenced in GeoTrans/IT Preliminary Regional Geological Model report).

The Amargosa Desert/Death Valley area east of Yucca Mountain is divided into two sub-areas by the Bare Mountain Fault, which is illustrated in Figure 2.3d. West of the Bare Mountain Fault the Lower Clastic Confining Aquifer is structurally high and is exposed at the surface. The Lower Clastic Confining Aquifer forms the floor of the Amargosa alluvial basin, and in some areas is covered by relatively thin Tertiary sediments below the alluvium. East of the Bare Mountain Fault the Lower Carbonate Aquifer is present in the down-dropped side of the fault. At Yucca Mountain the Lower Carbonate Aquifer is overlain by Tertiary volcanics, Figure 3.3b.

The Amargosa Desert/Death Valley area south of Yucca Mountain is characterized by displacement of the Lower Carbonate Aquifer by the Schwaub Peak, Specter Range, and Wheeler Pass Thrust faults. Thrust faulting has resulted in Lower Clastic Confining Aquifer being lifted to a higher structural level above the Lower Carbonate Aquifer, as shown on Figure 3.3c. (Note that the magnitude of displacement of faults shown on Figures 3.3b, c, d and e is exaggerated by the vertical scale of the figures and the 2 kilometer (1.24 mile) grid spacing of the model). The Lower Carbonate Aquifer thins westward through the Funeral Mountains into Death Valley. This thinning is due to both tectonic uplift and erosion during the Tertiary, Figure 3.3e. The Lower Carbonate Aquifer is covered by alluvial fill in the southern portion of the Amargosa Desert, Figures 3.3b and e.

The Lower Carbonate Aquifer is truncated by the Belted Range Thrust just north of Yucca Mountain. The Belted Range Thrust occurs in the same place as the anomalously high water table gradient in the Tuff Aquifer. A description of this high hydraulic gradient is provided in **4.0 GROUND WATER HYDROLOGY** of this report.

3.4 Lower Carbonate Aquifer Areal Distribution and Thickness

The Lower Carbonate Aquifer, in general, underlies the alluvial valley fill and crops out in and along the flanks of Funeral Mountains. The Lower Carbonate Aquifer has an maximum thickness of about 8,000 meters (26,000 feet) (GeoTrans/IT, 1995). The areal distribution of the Lower Carbonate Aquifer is shown in Figure 3.3a and 3.4.

The Lower Carbonate Aquifer has been eroded from the Desert, Halfpint and Papoose Ranges east of the study area. It has also been eroded from western portions of the area in Esmeralda and Nye Counties. The Lower Carbonate Aquifer is not present directly north of Yucca Mountain either because it is eroded away or faulted out by the Belted Thrust fault.

The Lower Carbonate Aquifer is present below Yucca Mountain at a depth of about 1,000 meters (3,000 feet), and extends southward below the Amargosa Desert into Death Valley. The Lower Carbonate Aquifer is also present in the Furnace Creek area into Death Valley. It is thinner in this area than it is at Yucca Mountain. The depth to Lower Carbonate Aquifer map, Figure 3.4, indicates surface exposures of the Lower Carbonate Aquifer at the southern end of the Amargosa Valley and near the Franklin Lake Playa.

3.5 Geological Continuity Of The Lower Carbonate Aquifer

The best interpretation of available geological data indicates that the Lower Carbonate Aquifer is continuous from beneath Yucca Mountain to Death Valley, and is a potential pathway for radionuclide transport to the biosphere in what appears to be the ultimate discharge points for the aquifer in Death Valley. The Lower Carbonate Aquifer has been displaced by faults that may form local barriers to flow. However, the areal extent of fault displacement is limited, and is not believed to constitute a complete barrier to ground water flow.

4.0 GROUND WATER HYDROLOGY

Dissolved radionuclides can be transported to the biosphere by the movement of ground water. Ground water is caused to flow by a downhill gradient in hydraulic head; the velocity of flow is described by Darcy's Law. To determine if there is ground-water movement one must examining the driving force--the gradient in hydraulic head. Under most local conditions flow is in the direction of the gradient in head. The regional ground-water hydrology down gradient from the Yucca Mountain repository was evaluated both in terms of the potential driving forces and connectivity to the biosphere.

Prior to 1960, the paradigm that characterized the ground-water hydrology of the Great Basin was that each mountain range formed a hydrologic divide. With this hypothesis each valley was independent of the next valley and could be treated as a separate ground-water system.

Isaac Winograd, working on the U.S. Geological Survey's (USGS) Nuclear Weapons Testing Program at the Nevada Test Site (NTS) in the early 1960s, recognized that the deep Paleozoic carbonate rocks that underlie the region of southern Nevada form a permeable aquifer that integrates the ground water hydrology of much of the region.

This was a new and different paradigm. It was quickly accepted by a number of other ground-water hydrologists working in the area (Maxey and Mifflin, 1966; Maxey, 1968; Mifflin, 1968). Winograd, and his co-worker at NTS, Bill Thordarson, finally published their ideas in a definitive work on the hydrogeology of the region in a USGS Professional Paper (Winograd and Thordarson, 1975).

As pointed out above, there are a very limited number of holes that penetrate the deep Lower Carbonate Aquifer beneath the valley fill. Much of the physical knowledge of the system is based upon studies of the outcrop areas, most of which are in the mountain ranges. Much of Winograd's and Thordarson's scientific argument for Lower Carbonate Aquifer ground water movement and discharge into springs in the Amargosa Desert and Death Valley was based upon the similarity of the chemistry of the ground-water. The Carbonate chemical signature identified by Winograd and Thordarson (1975) can be interpreted differently, as will be discussed below.

It is important to note that not all the potential sources of Deep Carbonate ground water have been sampled. It is possible to increase the information base, especially in the Funeral Range, through additional data collection to determine if the source of spring water on the east side of Death Valley is the Lower Carbonate Aquifer.

4.1 Yucca Mountain Regional Aquifers

At Yucca Mountain there are two principal aquifers 1) the Tuff Aquifer, and 2) the Lower Carbonate Aquifer, which are described below.

4.1.1 Tuff Aquifer

The Tertiary age tuffaceous rocks that outcrop and overlies the Paleozoic carbonate rocks make up the water table aquifer at Yucca mountain. A number of holes penetrate this aquifer in the vicinity of Yucca Mountain.

Figure 4.1.1 is a schematic stratigraphic column showing the rock units penetrated by the several UE-25 holes. These holes are typical of the Tuff Aquifer. The rocks of the Tuff Aquifer include both welded and unwelded tuffs. The principal permeability in the welded tuffs is fracture permeability. Data from the UE-25p1 hole suggests that the Tuff Aquifer permeability is an order of magnitude less than the underlying Paleozoic Lower Carbonate Aquifer (Craig and Robison, 1984):

Tuff Hydraulic Conductivity	6.1×10^{-8} m/sec (0.2×10^{-6} ft/sec)
Carbonate Hydraulic Conductivity	6.1×10^{-7} m/sec (2.0×10^{-6} ft/sec)

The carbonate, since it has the higher permeability, is considered to be the most probable pathway for contaminant transport to the biosphere. However, as discussed below, the hydraulic head gradient moves water upward out of the Carbonate Aquifer in the vicinity of the repository. This hydraulic condition would block the transport of radionuclide into the Carbonate aquifer. This suggests that migration pathways through the tuffs must be reexamined in terms of:

- the regional extent of the upward hydraulic gradient in the carbonate aquifers, and
- lateral movement through the tuffs back to the biosphere. We did not examine this scenario.

4.1.2 Lower Carbonate Aquifer

As suggested above (Section 3), the deep Lower Carbonate Aquifer is of special concern at Yucca Mountain; it provides one of the important pathways from beneath the repository back to the earth's surface. Figure 4.1.2 is a water table map for Southern Nevada and Eastern California (Waddell, 1984). This map suggests the extent of the Lower Carbonate Aquifer; it underlies most of the area. The springs on the East side of Death Valley that emanate from the deep Lower Carbonate Aquifer are thought to be one of the important ultimate discharge points from the deep system.

However, there is a debate in the scientific community whether the major discharge from the springs on the east side of Death Valley are fed predominantly from local recharge in the Funeral Mountains or is regional discharge from the Deep Carbonate Aquifer. Winograd and Thordarson (1975), based upon the chemical signature of the spring water, suggested the springs were feed by regional flow from the Deep Carbonate Aquifer. There are now better isotope analysis tools available that might resolve this issue. Resolution will depend upon additional sampling in the area, especially springs high in the Funeral Mountains.

UE-25p1 Drill Hole

The UE-25p1 drill hole penetrated the deep Lower Carbonate Aquifer in the vicinity of Yucca mountain, as previously noted. Data from this hole are especially important in evaluating far field impacts. We reviewed the data from this hole, especially the earlier analysis of earth-tide water-level fluctuations (Galloway and Rojstaczer, 1988; Bredehoeft, 1995). These analyses provide estimates of fault permeability and information on flow within the mountain.

In the UE-25p1 test hole the hydraulic head in the deep Lower Carbonate Aquifer is 20 meters (65 feet) higher than the head in the overlying tuff aquifer. This indicates that the ground-water flow potential is upward out of the carbonate. This is a favorable condition for the repository. As long as this condition continues ground water will not move contaminants downward to the deep aquifer; the potential for ground-water movement is in the opposite direction-upward.

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4.2 Yucca Mountain Regional Aquifer Characteristics

In 1989 Jerry Szymanski raised the issue that the water table could rise within Yucca Mountain and flood the repository. This scenario, if it were probable, would be of great concern to the safety of the repository. We wish to examine several of the ground-water issues raised by Szymanski:

1) the high hydraulic gradient,
2) the water table temperature,
3) the Szymanski hypothesis,
4) alternative hypotheses,
5) earth tide water-level fluctuations, and
6) the impact of faults.

4.2.1 High Gradient

Figure 4.2.1 is a isometric projection of the water-table for the vicinity of Yucca Mountain (Dudley, 1990). Of special interest is the high hydraulic gradient just north of the Repository site. In this area the water table rises from 2400 feet (730 m) at the repository site to 1000 meters (3,000 ft) several kilometers to the north. Modeling of the Tuff Aquifer by Czarnecki (1985) suggested that this high gradient was caused by a permeability barrier of several orders of magnitude lower permeability in the area of the high gradient. There is still much discussion of a geologic explanation for the high gradient. Recently Fridrich et al. (1994) suggested several hypotheses for the barrier. The one most plausible to us is recharge to the Lower Carbonate Aquifer in this area. Interestingly, the high gradient is oriented East-West while the near-surface faults in the area are generally North-South.

4.2.2 Water Table Temperature

The temperature near the top of the water table suggests several anomalous areas. Figure 4.2.2a is an isometric projection of the water table temperature. There are higher water table temperatures associated with the series of faults to the East in Midway Valley--Paintbrush and Bow Ridge faults, and to the West--the Solitario Canyon fault. Yucca Mountain is situated in the temperature low indicated on Figure 4.2.2b.

Szymanski (1989) suggested upwelling of water along the faults bonding Yucca mountain to explain the temperature anomalies in the water-table temperature Fridrich et al. (1994) also suggest upwelling of Lower Carbonate Aquifer water to explain the water-table temperature. As we will show, upwelling of water from the Lower Carbonate Aquifer along the faults is consistent with our interpretation of the current information.

4.2.3 The Szymanski Hypothesis

In the 1980s, Jerry Szymanski, working for DOE in Las Vegas, suggested that the tectonics of the Basin Range is cyclical. Most geologists agree with this cycle of tectonics. The cycle entails:

1. continued stretching of the region, placing a tension on the rocks;
2. finally the region breaks with an earthquake along a normal fault that bounds one mountain front;
3. once the earthquake (the break) occurs the tension is released and the rocks go into normal compression.

Szymanski (1989) then went on to suggest that the water table could rise by as much as several hundred feet during the compression cycle. He suggested Yucca mountain was currently in the tension phase, and that the water table could rise during a compression phase by several hundred feet to flood the repository. This is a major concern especially since the design of the repository is above the water table--ostensibly dry.

The National Academy of Sciences/National Research Council (NAS/NRC) convened a panel to investigate the possibility of the water table rising into the repository. This panel concluded that while the water table might rise several 10's of feet, a rise of 100 or more feet was highly unlikely (National Research Council, 1992). Even given the NAS/NRC Report, there is still a group of scientists who continue to actively support the Szymanski hypothesis (Archambeau and Price, 1991).

4.2.4 Alternative Hypotheses

Heat in ground water is an excellent tracer (Bredehoeft and Papadopulos, 1965). Usually the only significant source of heat in the earth is the natural heat flow from depth in the earth, especially in areas without young intrusive rock masses that act as sources of anomalous heat. Moving ground water readily transports heat; even slow ground-water movement will perturb the conductive heat flow in the earth. Sass et al. (1988) speculated on the cause of perturbations observed in the regional heat flow at Yucca Mountain. They related the observed anomalies to the transport of heat by moving ground water associated with the deep Carbonate Aquifer.

Because heat is a good ground-water tracer, others have attempted to use the temperature as indicating alternative scenarios of ground-water flow. Of particular interest is the work of Lehman and Associates, supported by the

State of Nevada (Lehman and Johnson, 1995; Lehman and Brown, 1995). These alternative conceptual models parallel those of Szymanski in which there is close coupling between active tectonics and the hydrologic system. The alternative models envision compartments in the Tuff Aquifer. Their early attempts sought to explain the observations in the Tuffs without considering the potential impact of the Lower Carbonate Aquifer on the system. This is a deficiency in their conceptual models to date.

4.2.5 Earth Tide Water-Level Fluctuations

Galloway and Rojstaczer (1988) analyzed tidal and atmospheric water-level fluctuations in the saturated zone in a set of wells with varying depths at the UE-25 site at Yucca Mountain. The site of the UE-25p1 hole is in Midway Valley, about 2 kilometers (6,000 feet) east of the proposed repository at Yucca Mountain.

The Lower Carbonate Aquifer penetrated in UE-25p1 has an especially good earth-tide response. Frequency analysis by Galloway and Rojstaczer (1988) indicated that the amplitude of the M2, lunar component of the earth tide, was 2.05 cm (0.067 ft) and is within 2 degrees of being in phase with the tidal potential. This indicates that the deep Carbonate Aquifer is:

1) well confined by an overlying low-permeability confining layer, and

2) has relatively large transmissivity (Hsieh et al., 1987).

The confined nature of the Lower Carbonate Aquifer was also suggested by the high rock compressibility (small specific storage) determined by Galloway and Rojstaczer (1988).

4.2.6 The Impact of Faults

Faults in the subsurface can function either as barriers, partial barriers, or conduits for flow. In the case of conduits, which we will suggest seems to be the case at Yucca Mountain, the amount of flow through the fault zone depends upon: 1) its permeability, and 2) the hydraulic head gradient. Simply because a fault is a conduit does not mean there is potentially a huge amount of flow.

Yucca Mountain is broken by a series of parallel north-south trending normal faults. Figure 4.2.6 is an East-West cross-section through Yucca Mountain showing both the stratigraphy and the major faults. From East to West the major faults are Fran Ridge, Paintbrush Canyon, Bow Ridge, Ghost Dance, Solitario Canyon and Windy Wash (Figure 4.2.6). The faults are spaced roughly 1 to 2 kilometers (1/2 to 1 mile) apart. The UE-25p1 hole penetrated the Fran Ridge fault just at the top of the Paleozoic carbonates (Carr et al., 1986). A critical question to ask is how permeable is this fault, or fault zone?

The tidal response of the deep carbonate well depends upon the aquifer having a "tight" confining layer (Galloway and Rojstaczer, 1988). The "tightness" of the confining layer depends upon its hydraulic continuity. The hydraulic continuity of the confining layer can be broken by the fault zones. The fault zones provide potential permeable pathways through the confining layer.

The temperature depth profile has been measured in the UE-25p1 well. It was measured repeatedly until the effects of the drilling disturbance had decayed away (Sass et al., 1988; Sass et al., 1995). Sass et al. (1995) suggested that the temperature profile in UE-25p1 indicated upward flow into the Paintbrush and Bow Ridge faults) and flow up the faults to the west of the mountain (Solitaro Canyon fault), tuff aquifer. Bredehoeft (1995) demonstrated that the temperature profile in the UE-25p1 hole is consistent with flow up the fault zones both to the east of Yucca Mountain (Fran Ridge, Paintbrush, and Bow Ridge faults) and to the West of Yucca Mountain (Solitario Canyon fault).

Faults at Yucca Mountain

Conclusions from the UE-25p1 Hole, Bredehoeft (1995), computed a fault zone hydraulic conductivity from the tidal analysis that is a maximum value; it is the highest value that preserves the tidal signal in the well. The regional water-table temperature, Figure 4.2.2a, suggests that there is a fault zone approximately 10 km (6.2 miles) long in Midway Valley to the east along which upwelling ground water could occur. A similar situation is suggested in Solitario Canyon where there is also a similar fault zone approximately 10 kilometers (6.2 miles) long with suggested upwelling ground water. Bredehoeft integrated the upward flow out of the Lower Carbonate Aquifer along both fault zones, and suggested a flow of approximately 370,000 cubic meters (300 acre feet) per year. The upward flow is sufficient to cause a temperature anomaly in the tuff aquifer. The vertical extent of the temperature anomaly is dependent upon the fault zone permeability; at a permeability 10 times that of the tuff country rock the temperature anomaly extends to the water table. This computed temperature anomaly approximates the observed temperature profile in the tuff aquifer in the UE-25p1 hole reasonably well. While upward discharge in the faults is significant, it is not large enough to destroy the upward head gradient--an important fact.

5.0 GEOCHEMISTRY OF GROUND WATER

The chemistry of ground water provides a means to identify the source of the water, as previously discussed. Winograd and Thordarson (1975), White (1979), and Claassen (1973) utilized the geochemical signature of the ground water to understand the regional Lower Carbonate Aquifer flow system. Their initial studies were based upon the major ion analysis of the water. Early studies used the isotopic composition of oxygen, hydrogen and carbon to study the flow system. Clebsch (1961) used Tritium to study the age of ground water at NTS. Winograd and Friedman (1972) used Deuterium as a tracer to study the carbonate flow system.

Winograd and Pearson (1976) used Carbon-14 as a tracer to study the Carbonate flow system. This study provides one of a limited number of quantitative estimate of the time of flow through the Lower Carbonate Aquifer.

In recent years there has been an increased effort to other examine isotopes of particular ions in the water from the Lower Carbonate Aquifer. Some of the more interesting data comes the Strontium isotopes, especially the ratio of 87Sr/86Sr (Peterman and Stuckless, 1993). These data tend to better define recharge and discharge areas in the flow system. For example, recent analyses in the Ash Meadows area suggest more of the recharge from this area comes from the Spring Mountains than previously realized (Peterman and Laczniak, 1995). The Strontium isotopes are a powerful method to continue to study the Lower Carbonate Aquifer. They seem to directly reflect the presence of Precambrian granitic rocks.

A modest, collective effort directed at analyzing more wells and springs associated with the Lower Carbonate Aquifer could provide additional information at a relatively low cost. For example, one of the nagging questions is how much of the spring discharge on the East side of Death Valley comes from the regional flow system and how much is from local recharge in the Amargosa and Funeral mountains? This question can be answered by careful sampling and further analysis of isotopes from spring water in the area, especially high level springs in the mountains.

6.0 REGIONAL GROUND WATER MODEL REVIEW AND DISCUSSION

Computer models provide a tool for the hydrogeologist to analyze ground water flow. In the best possible world they provide the direction and velocity of flow. Their degree of accuracy depends upon the information available.

Models provide a means of evaluating of our understanding of the ground-water system with limited geologic and hydrologic data. There has been a great effort at Yucca Mountain to utilize ground water models to try to assess the safety of the repository.

The U.S. Geological Survey completed a one layer regional ground-water flow model that has undergone several iterations (Waddell, 1982: Czarnecki and Waddell, 1984; Czarnecki, 1985). These models were single layer models; the aquifer analyzed was the water-table, Tuff Aquifer.

The NAS/NRC Panel (National Research Council, 1992) that reviewed Ground Water at Yucca Mountain criticized these models as incomplete. There concern was that the models did not include the Lower Carbonate Aquifer, the most permeable aquifer in the region. They suggest it is hard to understand the ground-water hydrology of the area by simply analyzing the less permeable, water-table aquifer, and neglecting the Lower Carbonate Aquifer.

There are two new regional ground-water models under development. As discussed, one is being completed by the USGS with support from the Yucca Mountain program (D'Agnese, 1995). The second model was developed by GeoTrans/IT Corporations (Price, 1995) with support from the Nevada Test Site Weapons Program. Rick Waddell, who completed the first one layer model for the USGS, is now employed by GeoTrans, and is doing the regional flow model for the Weapons Program.

Both models require extensive interpretive geologic input, especially since there are only a limited number of holes that penetrate the Paleozoic carbonate rocks below the valley fill. The USGS used a three dimensional Geographic Information System to integrate the geology of the area for its model (Faunt et al., 1992; Faunt and D'Agnese, in progress; D'Agnese, 1995). The GeoTrans/IT approach relied upon numerous geologic cross-sections through the region as basic input. These cross-sections were prepared by geologists working in the area. The geology was then interpreted between cross-sections (Price, 1995). The GeoTrans/IT approach was reviewed extensively under the discussion **3.0 GEOLOGY** above.

7.0 GROUND WATER TRAVEL TIME

The ground-water flow time is of concern should contaminants reach the Deep Carbonate Aquifer. Only a limited number of estimates of ground-water travel time in the Lower Carbonate Aquifer have been made. These estimates come from studies of isotopes in the ground-water (Winograd and Friedman, 1972: Winograd and Pearson, 1976). By analyzing Carbon 14 in the carbonate water Winograd and Pearson (1976) found large scale mixing of the ground water. They suggested various hypotheses to explain the mixing, none of which was fully satisfying. The two most satisfying were: 1) mega-channeling exist within the Lower Carbonate Aquifer, and the mixing would be explained by the channeling; or 2) paleoclimatic controls on the recharge to the aquifer.

Winograd and Pearson (1976) dated water in the springs of Ash meadows. They suggested that the water in the majority of the springs was 19,000 to 28,000 years before present. Among the springs, Crystal Pool was an anomaly. They dated the water in Crystal Pool at 8,000 to 13,000 years before present. Winograd and Pearson qualified their work. There were many assumptions that were included in arriving at Carbon 14 dates, especially in this terrain.

The early dates of Winograd and Pearson have been discredited by more recent work (Winograd, personal communication). A 100,000 year climeate record has been developed from cave wall carbonate deposits in Devil's Hole. The climate record from Devils Hole correlates chronologically with other climate records around the world (Winograd et al., 1988). Comparison of the Devil's Hole record to the other records shows that they are synchronous; there is no phase lag. A phase lag in time would be present with slow water travel times through the Lower Carbonate Aquifer. This lack of a lag in phase indicates that water moves through the Lower Carbonate Aquifer in a time less than 1000 to 2000 years.

The USGS is attempting to make estimates of travel time through the Lower Carbonate Aquifer based upon Darcy's Law. These estimates also suggest travel times through the carbonates of several thousand years. In the hydraulic estimates the sticky problem is: What is the regional porosity of the Lower Carbonate Aquifer? The highest estimate seems to be two percent porosity. Winograd (personal communication) thinks the regional porosity of the carbonates could be less than one percent.

Winograd's current Devil's Hole studies, our best current information, suggests that flow times through the Lower Carbonate Aquifer are rapid, probably less than a few thousand years. The Lower Carbonate Aquifer is a potentially good and relatively rapid path by which contaminants can migrate back to the biosphere. Radionuclides must somehow enter the Lower Carbonate Aquifer.

8.0 AQUIFER CONNECTIONS

The issue of concern is: Can radionuclides be transported from the repository to the Deep Carbonate Aquifer where they move quickly to the biosphere? This is especially important with regard to Inyo County where the springs in Death Valley are thought to form the ultimate point of discharge.

Geologic model data indicates the Lower Carbonate Aquifer exists at depth below Yucca Mountain and extends south into Death Valley. It also indicates that geologically deep faulting may only be a partial barrier to ground water flow. Geologically the Deep Carbonate Aquifer is a potential pathway for contaminate transport from Yucca repository. In addition, geochemical data indicates that ground water travel times in the Lower Carbonate Aquifer are relatively rapid, which further supports the hydrologic connectivity of aquifer systems.

As previously discussed, only one hydrologic test hole, UE-25p1, penetrates the Lower Carbonate Aquifer in the vicinity of Yucca Mountain. As pointed out above, the head in the Lower Carbonate Aquifer was 20 meters (65 feet) higher than the head in the overlying Tuff Aquifer. This head difference indicates a tight confining layer between the Tuff and the Lower Carbonate Aquifers. Tidal analysis by Galloway and Rojstaczer (1988) and Bredehoeft (1995) further indicated the presence of a tight confining layer separating the two aquifers in the vicinity of Yucca Mountain. GeoTrans/IT preliminary geological model also indicates the presence of confining clastic layer between the tuff and carbonate aquifers, which is absent west of the repository site.

Several investigators suggested vertical flow in the faults in the vicinity of Yucca Mountain, with upward movement of water in the faults both East and West of the mountain--Fran Ridge, Paintbrush Canyon and Bow Ridge faults to the east, and Solitario Canyon fault to the West (Sass, et al., 1987; Szymanski, 1989; Fridrich et al., 1994; Sass et al., 1995; Bredehoeft, 1995). Bredehoeft's analysis supported vertical flow large enough to create a temperature anomaly at the water table, but insufficient to eliminate the higher head in the Lower Carbonate Aquifer.

The potential for upward flow from the Lower Carbonate Aquifer to the overlying Tuff Aquifer is especially important. The upward head gradient protects the deep carbonate from contamination form the repository. As long as this upward head gradient persists regionally flow will be upward from the carbonate toward the water table. This is a natural barrier to contaminant migration in the Lower Carbonate Aquifer. Data limitations (a single hydrologic test hole) leave a question as to how regionally extensive is the upward head gradient observed at the UE-25p1 test hole.

9.0 DATA ADEQUACY

The discussion of the head in the Lower Carbonate Aquifer has important implications for Yucca mountain Repository. As suggested above, two factors indicate vertical flow from the Lower Carbonate Aquifer upward into the overlying tuffs:

1) the head is 20 meters (65 feet) higher in the deep carbonate than in the overlying tuffs at the UE-25p1 drill site,

2) the observed temperature anomaly (both the thermal profile in the UE-25p1 hole, Figure 4.2.1a, and the map of water table temperature, Figure 4.2.2a) is consistent with upward flow along major fault zones as indicated above. The regional ground-water models should help indicate the regional extent of the higher head in the Lower Carbonate Aquifer.

The data from the Deep Carbonate Aquifer is very limited. Due diligence suggests:

1) There should be sufficient drilling in the vicinity of Yucca Mountain to indicate that the high head, observed in UE-25p1, persists everywhere beneath the proposed repository. Currently UE-25p1 and Felderhoff-Federal No. 25-1 are the only hole in the vicinity of the repository that penetrated the Lower Carbonate Aquifer.

2) Assuming the upward gradient is extensive, no action should be taken either through construction and filling of the repository, or through development of the Lower Carbonate Aquifer for water supply to reduce the deep carbonate head.

Aquifer modeling would be helpful in providing an estimate of the area over which the potential for flow is upward out of the Carbonates into the Tuffs. It may also suggest optimal places for further deep confirmatory drilling.

Were the head in the Lower Carbonate Aquifer to be lowered, one of the natural barriers at the site would be destroyed. We wish to emphasize--as a potential barrier to nuclide transport, it is important that the high head in the Lower Carbonate Aquifer be preserved in the vicinity of the repository.

Even if man does not interfere, changes in climate can affect the ground-water flow system of the region. A large climate change can perhaps reverse the gradients in head, making flow downward to the Deep Carbonate Aquifer possible. Again, modeling may suggest if this is possible.

The UE-25p1 test hole and isotope water chemistry also indicates the value of the empirical data gained from drilling and monitoring at Yucca Mountain.

10.0 CONCLUSIONS AND RECOMMENDATIONS

The major conclusions of our study are summarized below. Our conclusions have policy implications for both Inyo and Esmeralda Counties. We also have suggestions for further work.

10.1 Conclusions

The repository is underlain by an extensive permeable Lower Carbonate Aquifer at approximately 2 km (6,000 feet) that is a potential pathway for the transport of radionuclide. Our study indicates that:

1) data from UE-25p1 exploratory hole suggests that it is unlikely that radionuclide contaminants will move to the Lower Carbonate Aquifer in the vicinity of Yucca Mountain because the potential for ground water movement is upward out of the carbonates into the tuff;

2) should contaminants get to the Lower Carbonate Aquifer they will be moved by ground water back to the biosphere, over a relatively short period (several thousand years);

3) the ultimate discharge points for the Lower Carbonate Aquifers appears to be the springs on the east side of Death Valley, within Inyo County;

4) Esmeralda County is up gradient from Yucca Mountain and has little chance of ground water contamination from a Yucca Mountain repository through the carbonate aquifer; and

5) there are geohydrologic data gaps that make predicting the repository performance including the transport of contaminants in the Lower Carbonate Aquifer uncertain.

10.2 Recommendations

Our investigation suggested a number of activities that would enhance our understanding of the potential for contaminate transport into and through the Lower Carbonate Aquifer system. The following oversight study activities are recommended.

10.2.1 Amargosa River Basin Hydrology Studies

The HyMet Amargosa River basin rainfall-runoff model suggests there may be significant transfer of ground-water inflow into the basin through the Lower Carbonate Aquifer in adjacent areas. It is recommended that the

HyMet model be used to further evaluate this relationship. The transfer of ground-water inflow into the Amargosa River basin from the Lower Carbonate Aquifer has not been quantified in previous studies. Further analyses of the stream record would help in the evaluation of ground-water transfer to the Amargosa River basin. It is also suggested that the Amargosa River stream gage be reinstalled to assist in this analysis.

10.2.2 Lower Carbonate Aquifer Studies

Other investigations of the Lower Carbonate Aquifer are recommended below:

1) There should be sufficient test drilling in the vicinity of Yucca Mountain to indicate that the high head, observed in UE-25p1, persists everywhere beneath the proposed repository. The experience with the UE-25p1 test hole demonstrates the value of the empirical data gained from drilling and monitoring at Yucca Mountain. Numerical ground-water modeling could be used to suggest drilling locations.

2) It is further suggested that connectivity of the Lower Carbonate Aquifer be evaluated by geochemical analysis of spring water associated with the Death Valley basin to help determine the source of these waters. A spring sampling and analysis program in the Amargosa and Funeral Mountains is warranted.

3) A numerical transport model of the deep Lower Carbonate Aquifer would provide important insights into the potential migration of contaminants from the Yucca Mountain repository. A regional numerical model of the deep aquifer system would provide a means to evaluate:

   - the suggested higher head in the Lower Carbonate Aquifer,
   - ground water travel times of contaminates,
   - aquifer connectivity, and
   - the significance of geologic and hydrologic data gaps.

   In particular, society cannot guarantee that large climate changes will preserve the upward flow potential between the Lower Carbonate Aquifer and the overlying Tuffs. Aquifer modeling can be used to estimate the impact of climate changes on the flow system. The modeling may provide an indication of how stable the potential for upward flow is. It should provide an estimate of over what area the upward potential currently exists.

4) Were the head in the Lower Carbonate Aquifer to be lowered, one of the natural barriers at the site would be destroyed. We wish to emphasize--as a potential barrier to nuclide transport, it is important that the high head in the Lower Carbonate Aquifer be preserved in the vicinity of the repository. No action should be taken either through construction and filling of the repository, or through development of the Lower Carbonate Aquifer for water supply to reduce the deep carbonate head.

10.2.3 Yucca Mountain Technical Oversight

It is suggest that technical oversight of the nuclear waste program continue. Current nuclear waste policy may change to include a Interim Federal Storage (IFS) facility. The potential for a significant release of radionuclides from an IFS facility near Yucca Mountain is uncertain, and should be reviewed. With regard to Inyo County, the focus of oversight activities should be on studies concerning regional ground water issues, geology and hydrology, and criteria for licensing regarding ground water travel times. Oversight activities should include:

- Attend meetings related to ground water issues at Yucca Mountain,
- Review DOE and research reports on repository performance,
- Technical support to county personnel, and
- Review waste storage policy plans.

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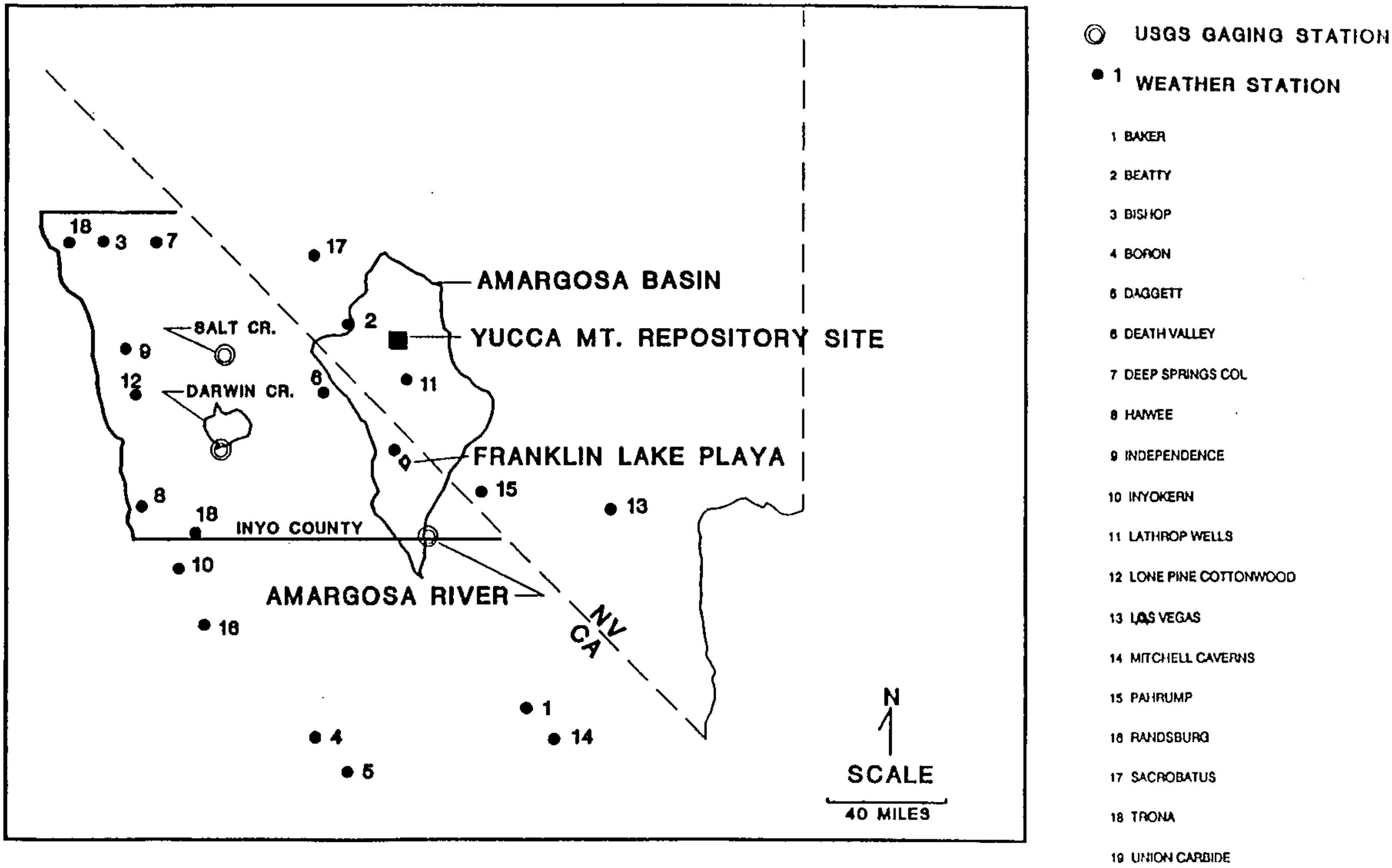

Figure 2.0 Location Of The Amargosa River, Darwin And Salt Creek Basins And Gauging Stations, And The 19 Weather Stations Used In The Analysis.

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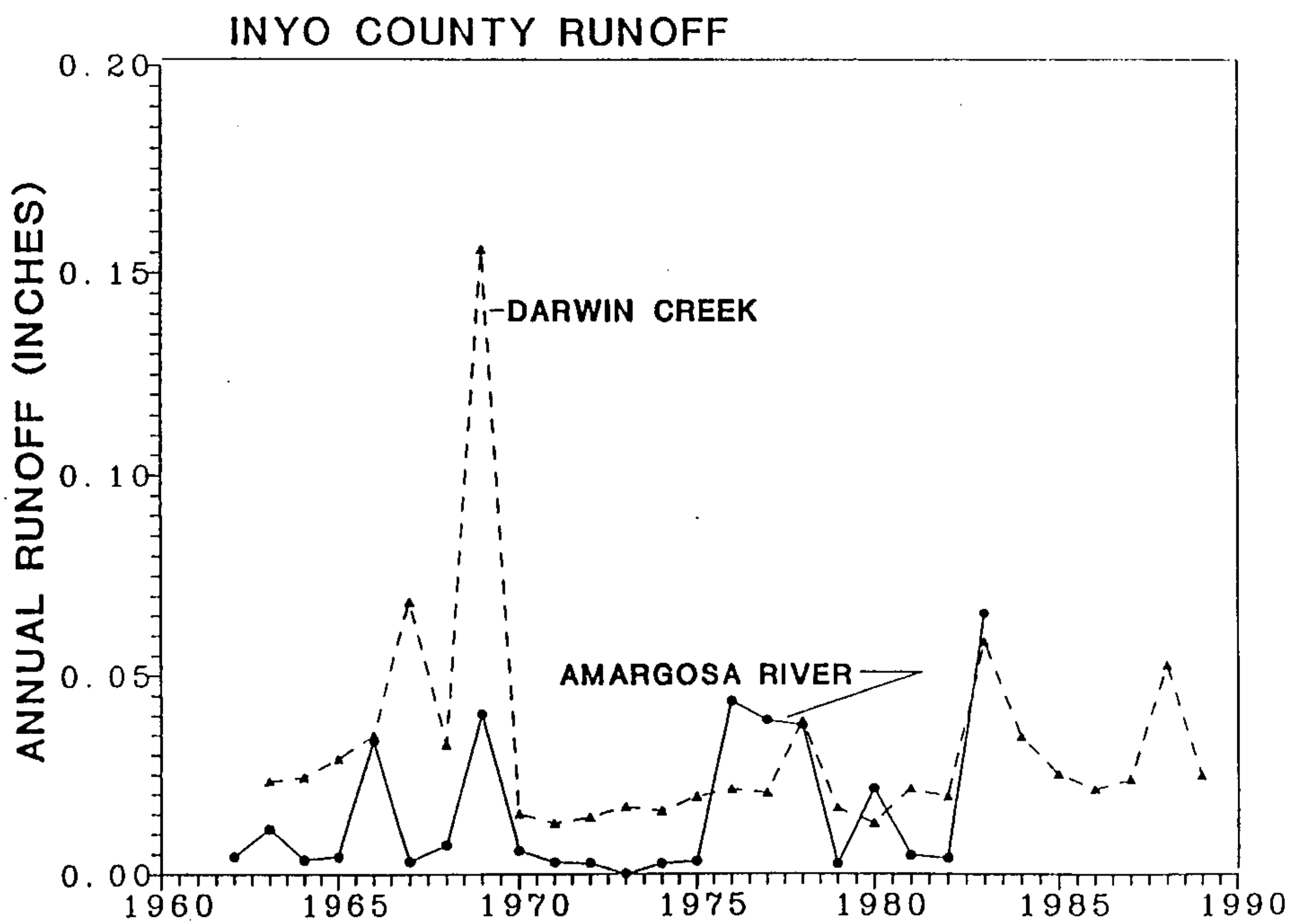


Figure 2.1 Annual Runoff Of The Amargosa River (3090 square miles) And Darwin Creek (173 square miles) For The Available Periods Of Record.

Runoff is in inches of water averaged over each basin's drainage area. Amargosa discharge records for the 1973 water year are missing.

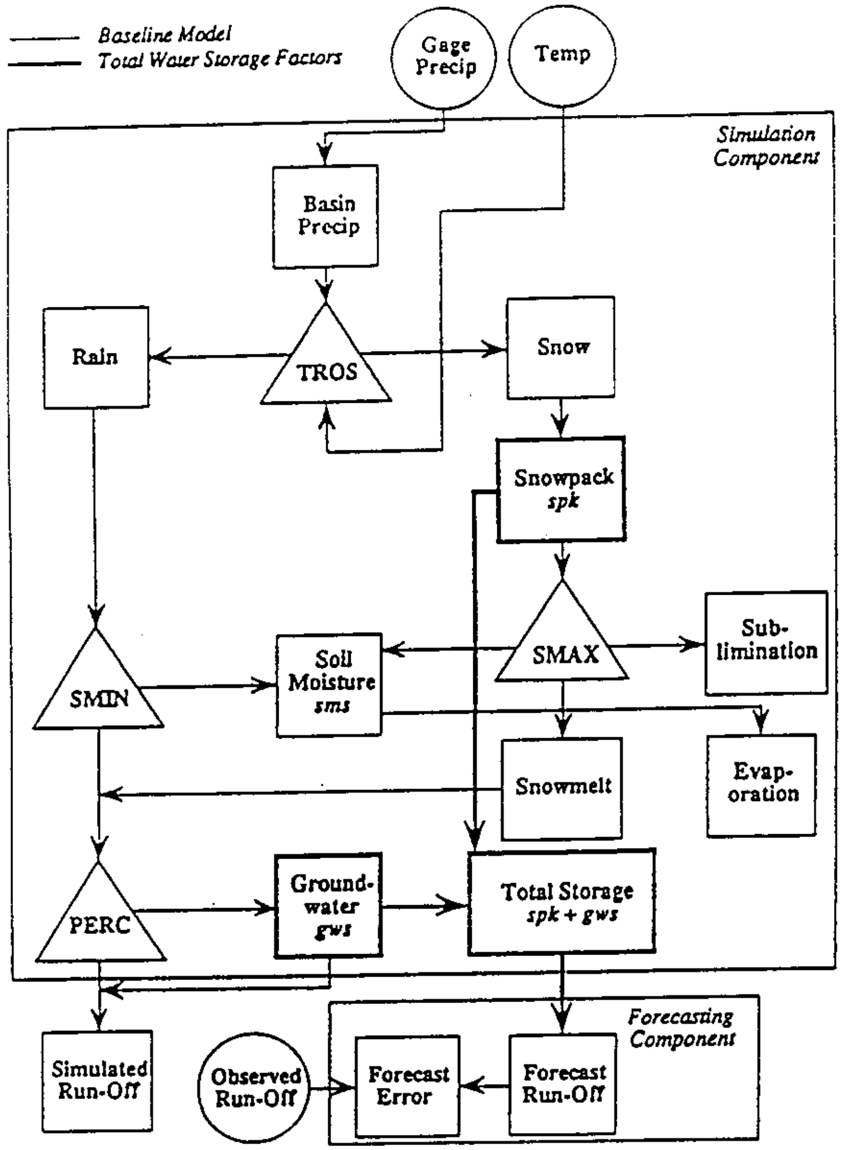
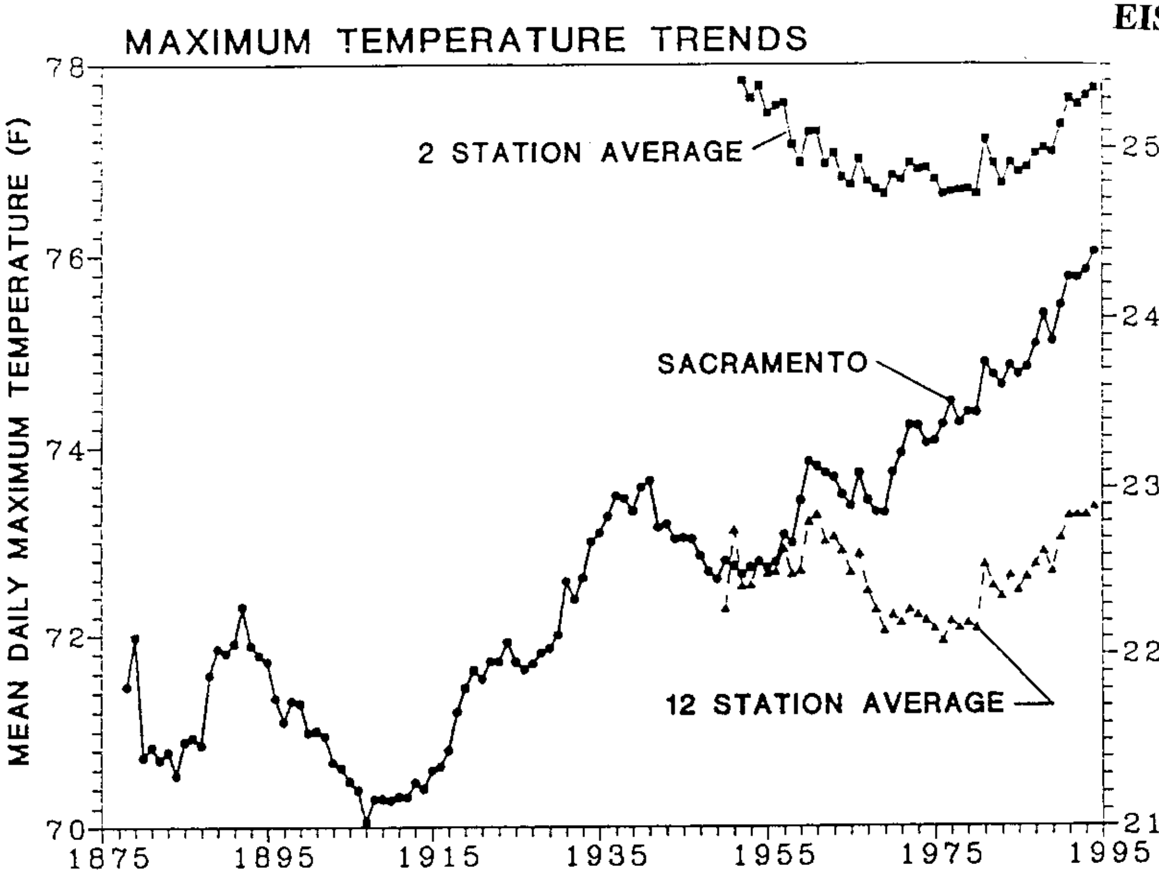


Figure 2.2 **Flow Diagram For The HyMet Simulation Model Used In Simulating Discharge And Other Hydrologic Parameters.**



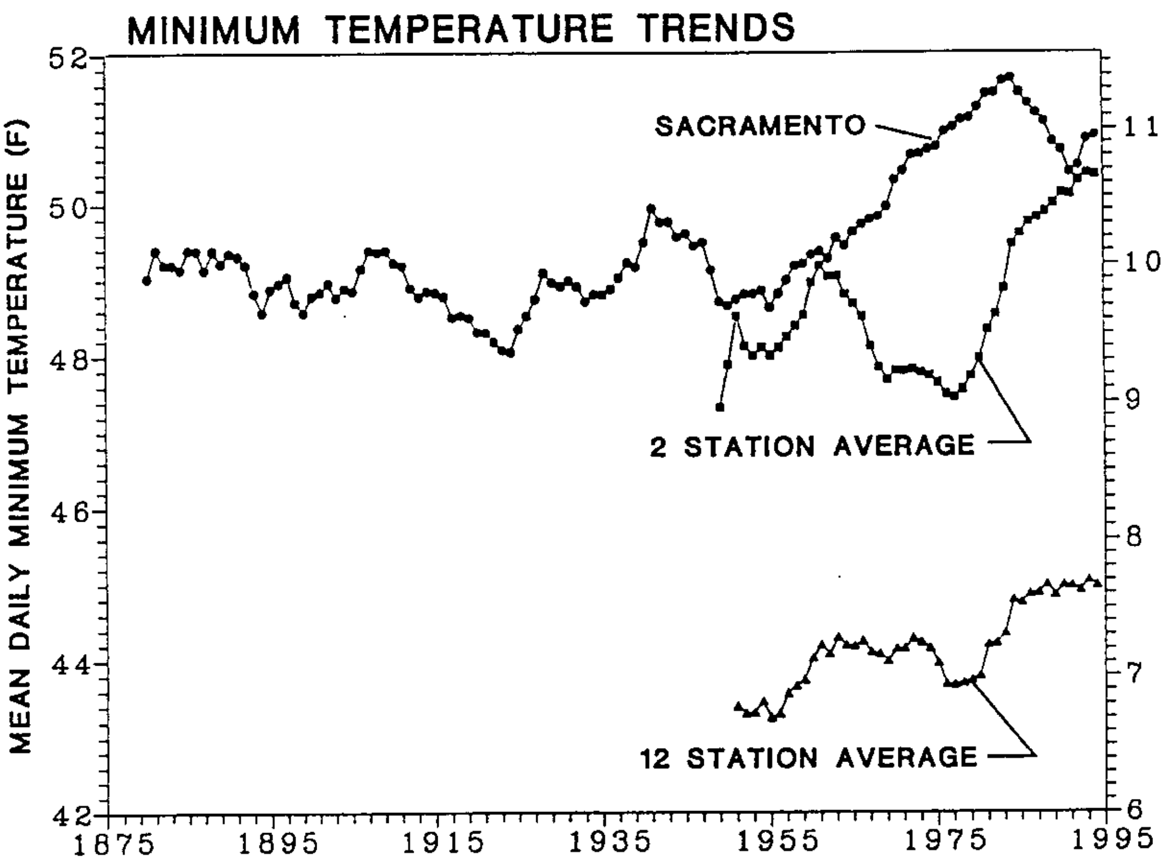


Figure 2.3a Maximum (top) and Minimum (bottom) Temperature Trends Averaged For The Two Stations Used In The Simulation Model.

Annual averages are smoothed with an 8-year running mean.

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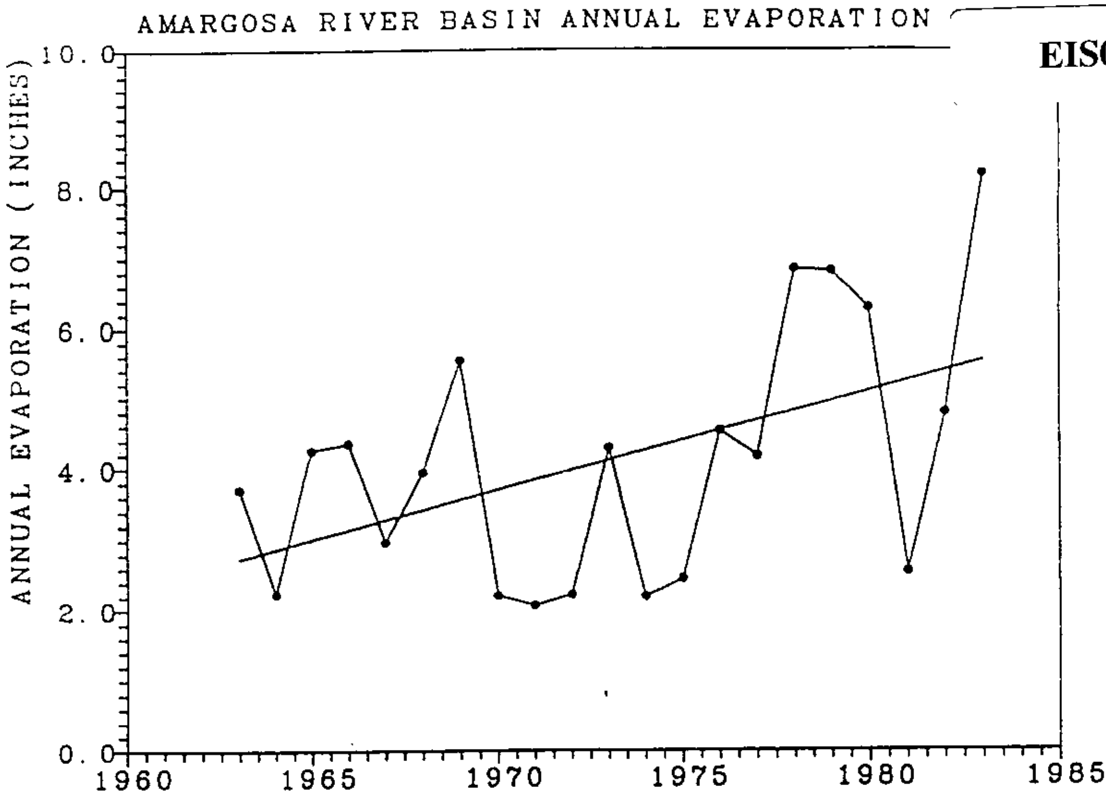

Figure 2.3b Annual Evapo-Transpiration From The Amargosa River Basin As Calculated On A Dail Basis By The Hymet Model.

Although observed (potential) pan evaporation is decreasing, as shown in Figure 2.3c, actual evaporation is increasing, likely because precipitation is increasing (more moisture is available to evaporate).

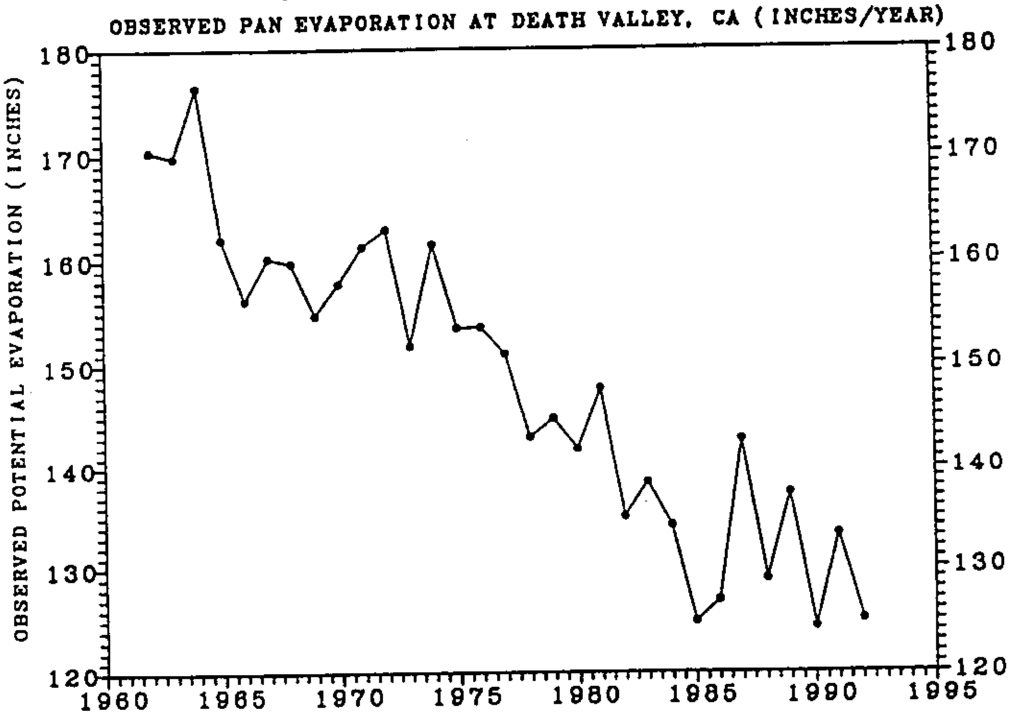

Figure 2.3c Annual Pan Evaporation At The Death Valley Weather Station Observed By The National Park Service For The 1962-92 Period.

The reason for the decline in potential evaporation may be due to an increase in cloud-cover and precipitation during this period.

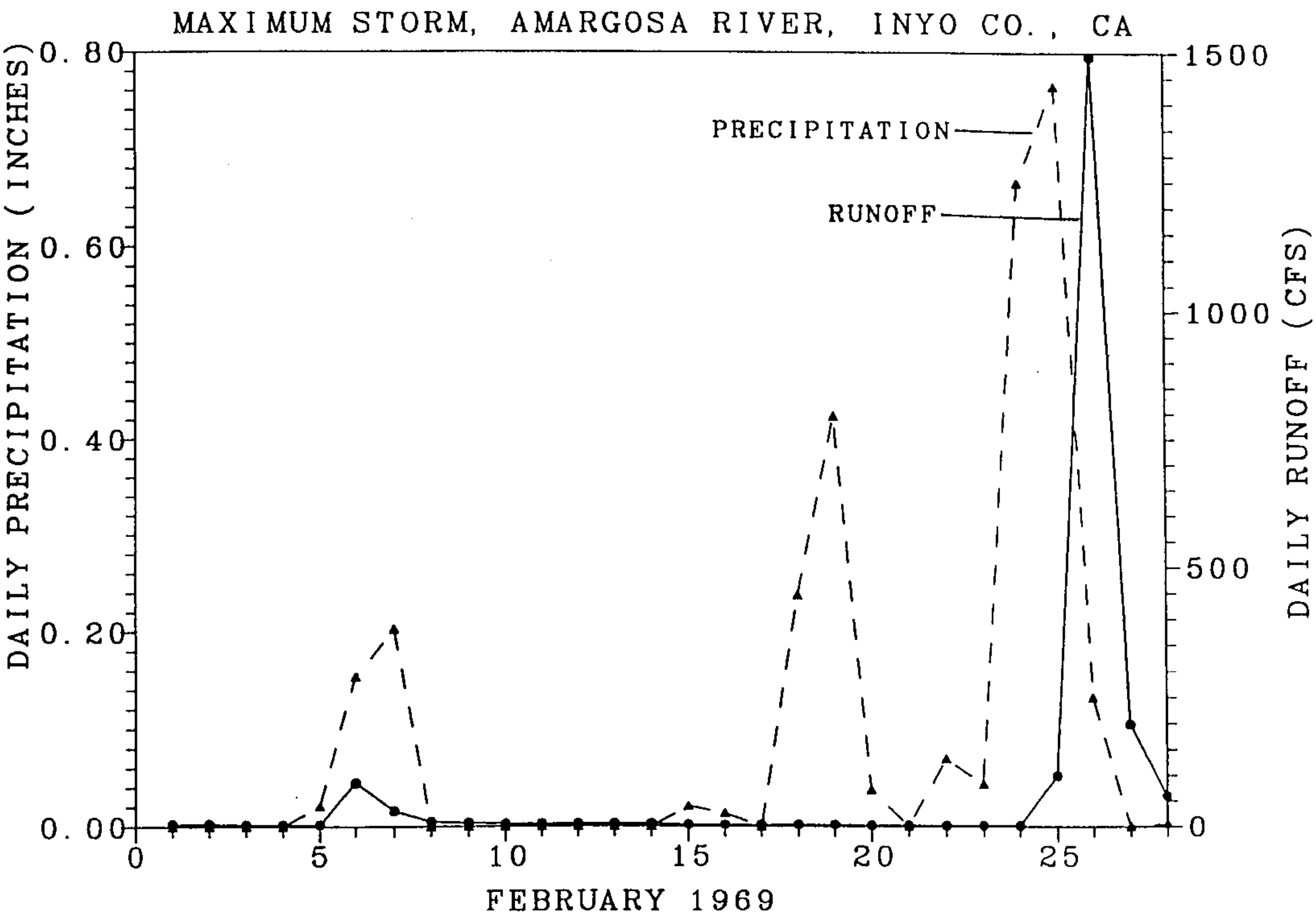

Figure2.3d Storm Runoff Of The Amaragosa River.

The storm that produced the maximum observed runoff of the Amargosa River occured 26 February, 1969, and was preceded by one day by precipitation of 0.80 inches (average of the four key precipitation gages). The precipitation of 15 February, 1969, (0.45 inches) did not generate observable discharge, likely because the soil was extremely dry.

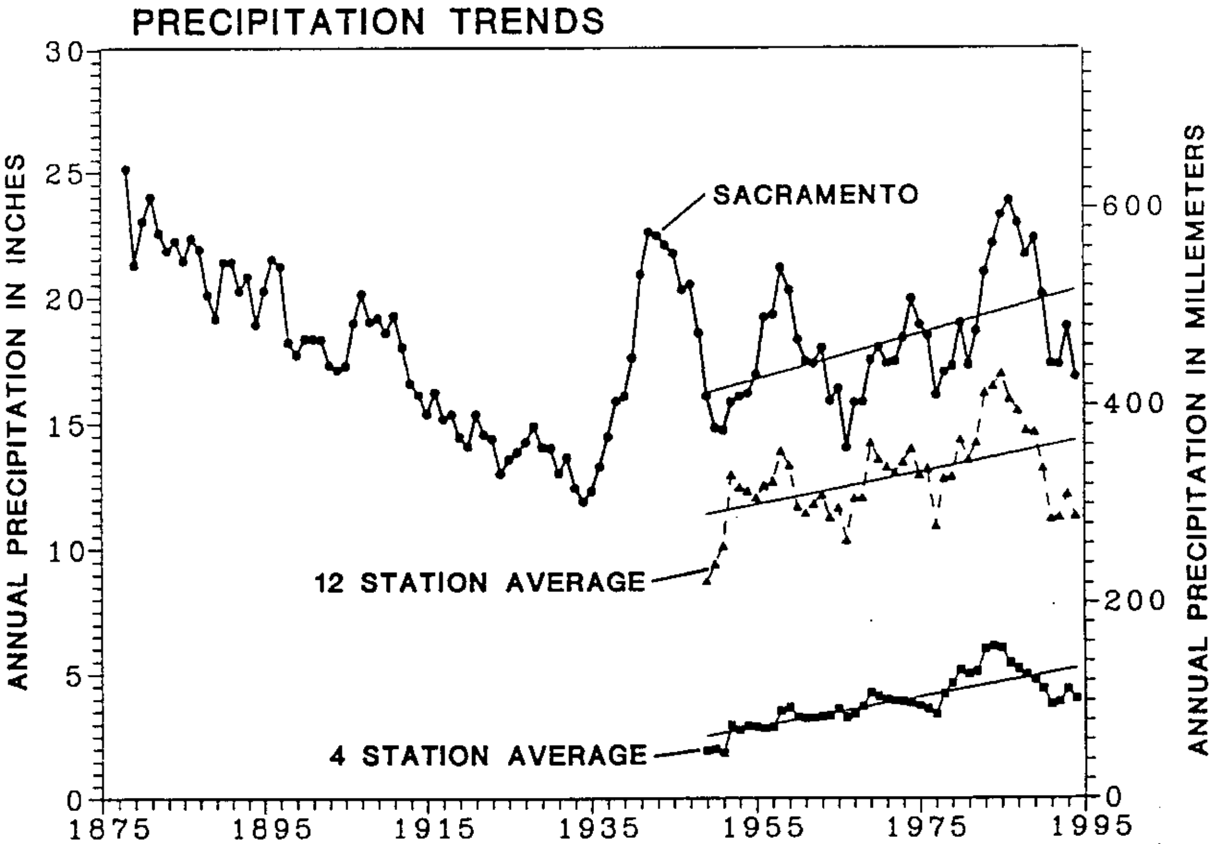

Figure 2.3e Trends Of Annual Precipitation Averaged For The Four Stations Used In The Simulation Model.

Precipitation is increasing at most sites in this region as indicated by these twelve stations in or near Inyo County.

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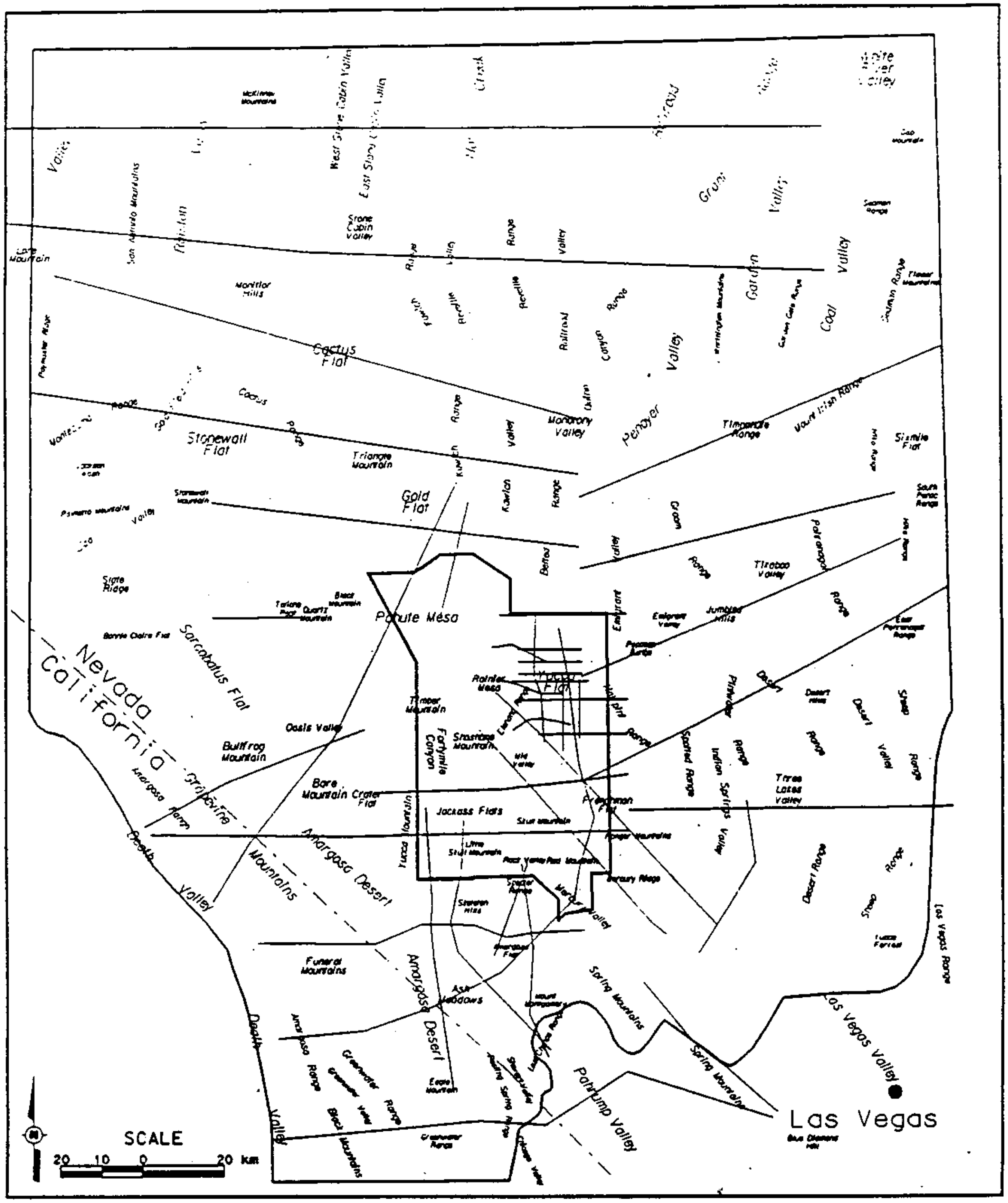

Figure 3.1 GeoTrans/IT Preliminary Regional Geological Model Study Area (adapted from from GeoTrans/IT, 1995).

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System	Series	Stratigraphic unit	Major lithology	Maximum thickness (feet)	Hydrogeologic unit	Water-bearing characteristics and extent of saturation [1]
Quaternary and Tertiary	Holocene, Pleistocene, and Pliocene	Valley fill	Alluvial fan, fluvial, fanglomerate, lakebed, and mudflow deposits	2,000	Valley-fill aquifer	Coefficient of transmissibility ranges from 1,000 to 35,000 gpd per ft; average coefficient of interstitial permeability ranges from 5 to 70 gpd per sq ft; saturated only beneath structurally deepest parts of Yucca Flat and Frenchman Flat.
Tertiary	Pliocene	Basalt of Kiwi Mesa	Basalt flows, dense and vesicular.	250	Lava-flow aquifer	Water movement controlled by primary (cooling) and secondary fractures and possibly by rubble between flows; intercrystalline porosity and permeability negligible; estimated coefficient of transmissibility ranges from 500 to 10,000 gpd per ft; saturated only beneath east-central Jackass Flats.
		Rhyolite of Shoshone Mountain	Rhyolite flows.	2,000		
		Basalt of Skull Mountain	Basalt flows.	250		
		Piapi Canyon Group — Timber Mountain Tuff — Ammonia Tanks Member	Ash-flow tuff, moderately to densely welded; thin ash-fall tuff at base.	250	Welded-tuff aquifer	Water movement controlled by primary (cooling) and secondary joints in densely welded part of ash-flow tuff; coefficient of transmissibility ranges from 100 to 100,000 gpd per ft; intercrystalline porosity and permeability negligible; unwelded part of ash-flow tuff, where present, has relatively high interstitial porosity (35-50 percent) and modest permeability (2 gpd per sq ft) and may act as leaky aquitard; saturated only beneath structurally deepest parts of Yucca, Frenchman, and Jackass Flats.
		Piapi Canyon Group — Timber Mountain Tuff — Rainier Mesa Member	Ash-flow tuff, nonwelded to densely welded; thin ash-fall tuff at base.	600		
	Miocene	Piapi Canyon Group — Paintbrush Tuff — Tiva Canyon Member	Ash-flow tuff, nonwelded to densely welded; thin ash-fall tuff near base.	300-350		
		Piapi Canyon Group — Paintbrush Tuff — Topopah Spring Member	Ash-flow tuff, nonwelded to densely welded; thin ash-fall tuff near base.	890		
		Piapi Canyon Group — Paintbrush Tuff — Bedded tuff (informal unit)	Ash-fall tuff and fluvially reworked tuff.	1,000	Bedded-tuff aquifer	Coefficient of transmissibility ranges from 200 to 1,000 gpd per ft; saturated only beneath structurally deepest parts of Yucca Flat, Frenchman Flat, and Jackass Flats; Occurs locally below ash-flow tuff members of Paintbrush Tuff and below Grouse Canyon Member of Indian Trail Formation.
		Wahmonie Formation	Lava-flow and interflow tuff and breccia; locally hydrothermally altered.	4,000	Lava-flow aquitard	Water movement controlled by poorly connected fractures; interstitial porosity and permeability negligible; coefficient of transmissibility estimated less than 500 gpd per ft; contains minor perched water in foothills between Frenchman Flat and Jackass Flats.
			Ash-fall tuff, tuffaceous sandstone, and tuff breccia, all interbedded; matrix commonly clayey or zeolitic.	1,700	Tuff aquitard	Coefficient of transmissibility ranges from 100 to 200 gpd per ft; interstitial porosity is as high as 40 percent, but interstitial permeability is negligible (6×10 [illegible] to 6×10 [illegible] gpd per sq ft); owing to poor hydraulic connection of fractures, interstitial permeability probably controls regional ground-water movement; perches minor quantities of water beneath foothills flanking valleys; fully saturated only beneath structurally deepest parts of Yucca Flat, Frenchman Flat, and Jackass Flats; Grouse Canyon and Tub Spring Members of Indian Trail Formation may locally be aquifers in northern Yucca Flat.
		Salyer Formation	Breccia flow, lithic breccia, and tuff breccia, interbedded with ash-fall tuff, sandstone, siltstone, claystone, matrix commonly clayey or calcareous.	2,000		
		([2])				
		Indian Trail Formation — Grouse Canyon Member	Ash-flow tuff, densely welded.	200		
		Indian Trail Formation — Tub Spring Member.	Ash-flow tuff, nonwelded to welded.	300		
		Indian Trail Formation — Local informal units	Ash-fall tuff, nonwelded to semiwelded ash-flow tuff, tuffaceous sandstone, siltstone, and claystone; all massively altered to zeolite or clay minerals; locally, minor welded tuff near base; minor rhyolite and basalt.	2,000		
		([2])				
		Rhyolite flows and tuffaceous beds of Calico Hills	Rhyolite, nonwelded and welded ash flow, ash-fall tuff, tuff breccia, tuffaceous sandstone; hydrothermally altered at Calico Hills; matrix of tuff and sandstone commonly clayey or zeolitic.	>2,000		
	Miocene and Oligocene	Tuff of Crater Flat	Ash-flow tuff, nonwelded to partly welded, interbedded with ash-fall tuff; matrix commonly clayey or zeolitic.	300		
		Rocks of Pavits Spring	Tuffaceous sandstone and siltstone, claystone; fresh-water limestone and conglomerate; minor gypsum; matrix commonly clayey, zeolitic, or calcareous.	1,400		
	Oligocene	Horse Spring Formation	Fresh-water limestone, conglomerate, tuff.	1,000		

System	Series	Stratigraphic unit	Major lithology	Maximum thickness (feet)	Hydrogeologic unit	Water-bearing characteristics and extent of saturation [1]
Cretaceous to Permian		Granitic stocks	Granodiorite and quartz monzonite in stocks, dikes, and sills.		(A minor aquitard)	Complexly fractured but nearly impermeable.
Permian and Pennsylvanian		Tippipah Limestone	Limestone.	3,600	Upper carbonate aquifer	Complexly fractured aquifer; coefficient of transmissibility estimated in range from 1,000 to 100,000 gpd per ft; intercrystalline porosity and permeability negligible; saturated only beneath western one-third of Yucca Flat.
Mississippian and Devonian		Eleana Formation	Argillite, quartzite, conglomerate, conglomerite, limestone.	7,900	Upper clastic aquitard	Complexly fractured but nearly impermeable; coefficient of transmissibility estimated less than 500 gpd per ft; interstitial permeability negligible but owing to poor hydraulic connection of fractures probably controls ground-water movement; saturated only beneath western Yucca Flat and Jackass Flats.
Devonian	Upper ?	Devils Gate Limestone	Limestone, dolomite, minor quartzite.	>1,380	Lower carbonate aquifer	Complexly fractured aquifer which supplies major springs throughout eastern Nevada; coefficient of transmissibility ranges from 1,000 to 1,000,000 gpd per ft; intercrystalline porosity and permeability negligible; solution caverns are present locally but regional ground-water movement is controlled by fracture transmissibility; saturated beneath much of study area.
	Middle	Nevada Formation	Dolomite.	>1,525		
Devonian and Silurian		Undifferentiated	Dolomite.	1,415		
Ordovician	Upper	Ely Springs Dolomite	Dolomite.	305		
	Middle	Eureka Quartzite	Quartzite, minor limestone.	340		
	?	Pogonip Group — Antelope Valley Limestone	Limestone and silty limestone.	1,530		
	Lower	Pogonip Group — Ninemile Formation	Claystone and limestone, interbedded.	335		
		Pogonip Group — Goodwin Limestone	Limestone.	>900		
Cambrian	Upper	Nopah Formation Smoky Member	Dolomite, limestone.	1,070		
		Halfpint Member	Limestone, dolomite, silty limestone.	715		
		Dunderberg Shale Member	Shale, minor limestone.	225		
	Middle	Bonanza King Formation Banded Mountain Member	Limestone, dolomite, minor siltstone.	2,440		
		Papoose Lake Member	Limestone, dolomite, minor siltstone.	2,160		
		Carrara Formation	Siltstone, limestone, interbedded. Upper 1,050 feet predominantly limestone; lower 950 feet predominantly siltstone.	1,050		
				950	Lower clastic aquitard [3]	Complexly fractured but nearly impermeable; supplies no major springs; coefficient of transmissibility less than 1,000 gpd per ft; interstitial porosity and permeability is negligible, but probably controls regional ground-water movement owing to poor hydraulic connection of fractures; saturated beneath most of study area.
	Lower	Zabriskie Quartzite	Quartzite.	220		
		Wood Canyon Formation	Quartzite, siltstone, shale, minor dolomite.	2,285		
Precambrian		Stirling Quartzite	Quartzite, siltstone.	3,400		
		Johnnie Formation	Quartzite, sandstone, siltstone, minor limestone and dolomite.	3,200		

[1] Coefficient of transmissibility has the units gallons per day per foot (gpd per ft) width of aquifer; coefficient of permeability has the units gallons per day per square foot (gpd per sq ft) of aquifer.

[2] The three Miocene sequences occur in separate parts of the region. Age correlations between them are uncertain. They are placed vertically in table to save space.

[3] The Noonday(?) Dolomite, which underlies the Johnnie Formation, is considered part of the lower clastic aquitard.

Table 3.2a Winograd's and Thordarson's, 1975, Stratigraphic And Hydrogeologic Units At Nevada Test Site And Vicinity (from Winograd and Thordarson, 1975).

		NEVADA TEST SITE	BARE MOUNTAIN	CACTUS RANGE TRAPPMAN HILLS	BELTED RANGE	PAHRANAGAT RANGE	SHEEP RANGE	SPRING MOUNTAINS	MONTGOMERY MOUNTAINS/ NOPAH RANGE	FUNERAL MOUNTAINS	ESMERALDA COUNTY
PENNSYLVANIAN		Tippipah Ls.	X	X	X	Pennsylvanian Ls. (undiff.)	Bird Spring Ls.	Bird Spring Ls.	Bird Spring Ls.	X	X
MISSISSIPPIAN		Eleana Fm.	Eleana Fm.	Eleana Fm.	Eleana Fm.	Scotty Wash Chainman Sh. Joana Ls. Pilot Sh.	Chainman Sh. Joana Ls. Narrow Canyon	Monte Cristo Ls.	Monte Cristo Ls.	Perdido Fm. Tin Mountain Ls.	X
SILURIAN/ DEVONIAN	U. DEVON. M. DEVON. L. DEVON.	Guilmette Ls. Simonson Fm. Sevy Ds.	Rocks of Tarantula Canyon Lone Mountain Ds.	Simonson Fm. Sevy Ds.	Simonson Fm. Sevy Ds.	Guilmette Ls. Simonson Fm. Sevy Ds.	Guilmette Ls. Simonson Fm. Sevy Ds.	Sultan Ls.	Guilmette Ls. Simonson Fm.	Lost Burro Fm.	X
	SILURIAN	Laketown Ds.	Roberts Mountain Fm.	Roberts Mountain Fm.	Laketown Ds.	Laketown Ds.	Laketown Ds.	Laketown Ds.	Hidden Valley Fm.	Hidden Valley Fm.	X
ORDOVICIAN	UPPER	Ely Springs Dolostone Eureka Quartzite (spans all columns through Funeral Mountains)									X
	MIDDLE	Antelope Valley Ls.	Pogonip Group (spans Bare Mountain through Funeral Mountains)								Palmetto Fm
	LOWER	Ninemile Fm. Goodwin Ls.									Palmetto Fm
CAMBRIAN	UPPER	Nopah Formation (spans all columns through Funeral Mountains)									Emigrant Fm
	MIDDLE	Bonanza King Formation (spans all columns through Funeral Mountains)									Emigrant Fm
	LOWER	Carrara Formation Wood Canyon Formation (span all columns through Funeral Mountains)									Mule Springs Ls. Harkless Fm. Poleta Fm.
PRECAMBRIAN (PROTEROZOIC)		Stirling Quartzite Johnnie Formation Older Precambrian Metamorphic Rocks (span all columns)									Campito Fm. Deep Spring Fm. Reed Ds. Wyman Fm.

'In the southeastern portion of the NTS, the Mississippian section is represented by the Mercury Limestone, which is correlative to the Monte Cristo Limestone.
The Upper Carbonate Aquifer consists of all Pennsylvanian strata, plus Mississippian sections that do not include Eleana Formation.
The Upper Clastic Aquitard consists of the Eleana Formation.
The Lower Carbonate Aquifer consists of all Devonian, Silurian, and Ordovician strata, plus the Nopah Formation, The Bonanza King Formation, and the upper half of the Carrara Formation
The Lower Clastic Aquitard consists of the lower half of the Carrara Formation, the Wood Canyon Formation, and all Precambrian units. The predominantly-clastic facies of Esmeralda County is also included in the Lower Clastic Aquitard.

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Table 3.2b GeoTrans/IT's, 1995, pre-Tertiary Stratigraphic Correlation/Death Valley Drainage Basin (from GeoTrans/IT, 1995).

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Cenozoic Units

Formation Name/ Rock Unit	Symbol	Predominant Lithology	Estimated Thickness ft(m)	Hydrostratigraphic Unit
Alluvium Undifferentiated	QTa	Alluvium	Variable	Alluvial Aquifer (AA)
Basalt Flows Undifferentiated	QTb	Basalt Flows	Variable	Allluvial Aquifer (AA)
Tuffaceous Sedimentary Deposits	Tts	Tuffaceous sediments	Variable	Alluvial Aquifer (AA)
Tuff of Saulsbury Wash	Tsw	Ash Flow Tuffs	0-1000 (0-300)	Volcanics Undifferentiated (VU)
Horse Camp Formation	Thcp	Fluvial/lacustrine, volcaniclastic sediments	0-3000 (0-915)	Volcanics Undifferentiated (VU)
Rocks of the Reveille Range	Trr	Silisic Tuff & intrusive bodies	0-500 (0-150)	Volcanics Undifferentiated (VU)
Granitic Intrusives	Tg	Granitic Intrusives	Variable	Intrusives (I)
Rhyolite Intrusives	Tr	Rhyolite Intrusives	Variable	Volcanics Undifferentiated (I)
Young Volcanic Rocks Undifferentiated	Tvy	Volcanic rocks undifferentiated	Variable	Volcanics Undifferentiated (VU)
Intermediate lavas and ash flow tuffs Undifferentiated	Twa	Intermediate lavas and ash flows	0-9000 (0-2750)	Volcanics Undifferentiated (VU)
Shingle Pass Tuff	Tsh	Ash flow tuffs	0-500 (0-150)	Volcanics Undifferentiated (VU)
Monotony Tuff	Tm	Ash Flow Tuffs	0-1100 (0-335)	Volcanics Undifferentiated (VU)
Old Tuffs of the Pancake Range	Tpo	Ash Flow Tuffs	0-1000 (0-300)	Volcanics Undiferentiated (VU)
Stone Cabin Formation	Tsc	Ash Flow Tuffs	0-3000 (0-915)	Volcanics Undifferentiated (VU)

Mesozoic Units

Formation Name / Rock Unit	Symbol	Predominant Lithology	Estimated Thickness ft (m)	Hydrostratigraphic Unit
Granitic Intrusions	TKg	Granitic	Variable	Intrusive (I)
Dunlap Formation	Jd	Conglomerate,siltstone, mudstone	1000-3500 (300-1070)	Lower Clastic Confining Unit (LCCU)
Luning Formation	TRl	Limestone, dolomite	1000-3000 (300-915)	Lower Clastic Confining Unit (LCCU)
Excelsior Formation	TRe	Chert,volcanics and clastics	1000-9000 (300-2750)	Lower Clastic Confining Unit (LCCU)

Paleozoic Units

Formation Name / Rock Unit	Symbol	Predominant Lithology	Estimated Thickness ft (m)	Hydrostratigraphic Unit
Pablo Formation	Pp	andesite flows,breccias,chert	3000-4000 (915-1220)	Lower Clastic Confining Unit (LCCU)
Diablo Formation	Pd	conglomerate,quartzite, slate	800-1100 (250-335)	Lower Clastic Confining Unit (LCCU)
Mississippian limestones undifferentiated	Ml	Limestone	500-800 (150-250)	Upper Clastic Confining Unit (UCCA)
Eleana Formation Chainman Shale Joana Limestone	MDe Mc Mj	Shales,chert Shales, chert Limestone	200-2000 (60-600)	Upper Clastic Confining Unit (UCCA)
Guilmette Formation	Dg	Limestone	500-1100 (150-335)	Lower Carbonate Aquifer (LCA)
Nevada Formation Simonson Formation Sevy Formation	Dn Dsi Dse	Dolostone Dolostone Dolostone	800-1000 (245-300) 200-700 (60-215) 650-900 (200-275)	Lower Carbonate Aquifer (LCA)
Laketown Dolomite Roberts Mountain Fm. Lone Mountain Dolomite	Sl Srm Slm	Dolostone Limestone,silty Dolomite	100-300 (30-90) 100-300 (30-90) 100-300 (30-90)	Lower Carbonate Aquifer (LCA)
Ely Springs Dolomite	Oes	Dolomite	100-150 (30-45)	Lower Carbonate Aquifer (LCA)
Eureka Quartzite	Oe	Quartzite	100-250 (30-75)	Lower Carbonate Aquifer (LCA)
Pogonip Group Ord/Cambrian Undifferentiated Shales and limestones	Op OCsl	Limestone Limestones and shales	1850-3100 (565-945)	Lower Carbonate Aquifer (LCA)
Lower Pogonip/Windfall Fm. Undifferentiated Windfall Formation	OCpw Cw	limestone limestone cherty	300-600 (90-180) 200-400 (60-120)	Lower Carbonate Aquifer (LCA)
Limestone, Dolomite and Dunderburg ShaleUndif Dunderburg Shale Limestone, shale undifferentited	Cld Cd Csl	Limestone, dolomite and shale Shale Limestone, shale	3000-4500 (915-1370) 3000-6000 (915-1830) 3500-5000 (1067-1525)	Lower Clastic Confining Unit (LCCU)
Harkless Formation	Ch	shale,mudstone,siltstone	2700-3500 (825-1070)	Lower Clastic Confining Unit (LCCU)
Campito Formation Poleta Formation	Cc Cp	quartzite,siltstone siltstone,limestone	2500-3000 (762-914) 200-300 (60-90)	Lower Clastic Confining Unit (LCCU)
Pioche Shale	Cpi	shale	200-300 (60-90)	Lower Clastic Confining Unit (LCCU)

Precambrian Units

Formation Name/ Rock Unit	Symbol	Predominant Lithology	Estimated Thickness	Hydrostatigraphic Unit
Gold Hill Formation Prospect Mountain Quartzite Wood Canyon Formation/Zabriskie Quartzite	CZgh CZpm CZzw	quartzite,shale quartzite schist,quartzite	2000-3000? (610-915) 4500-5000 (1370-1525) 2500-3000 (762-914)	Lower Clastic Confining Unit (LCCU)
Precambrian rocks undifferentiated	pCu	crystalline,metamophic rocks undifferentiated	????????	Lower Clastic Confining Unit (LCCU)

Table 3.2c GeoTrans/IT's, 1995, Coorelation And Hydrostratigraphic Unit Assignment For Geological Model (from GeoTrans/IT, 1995).

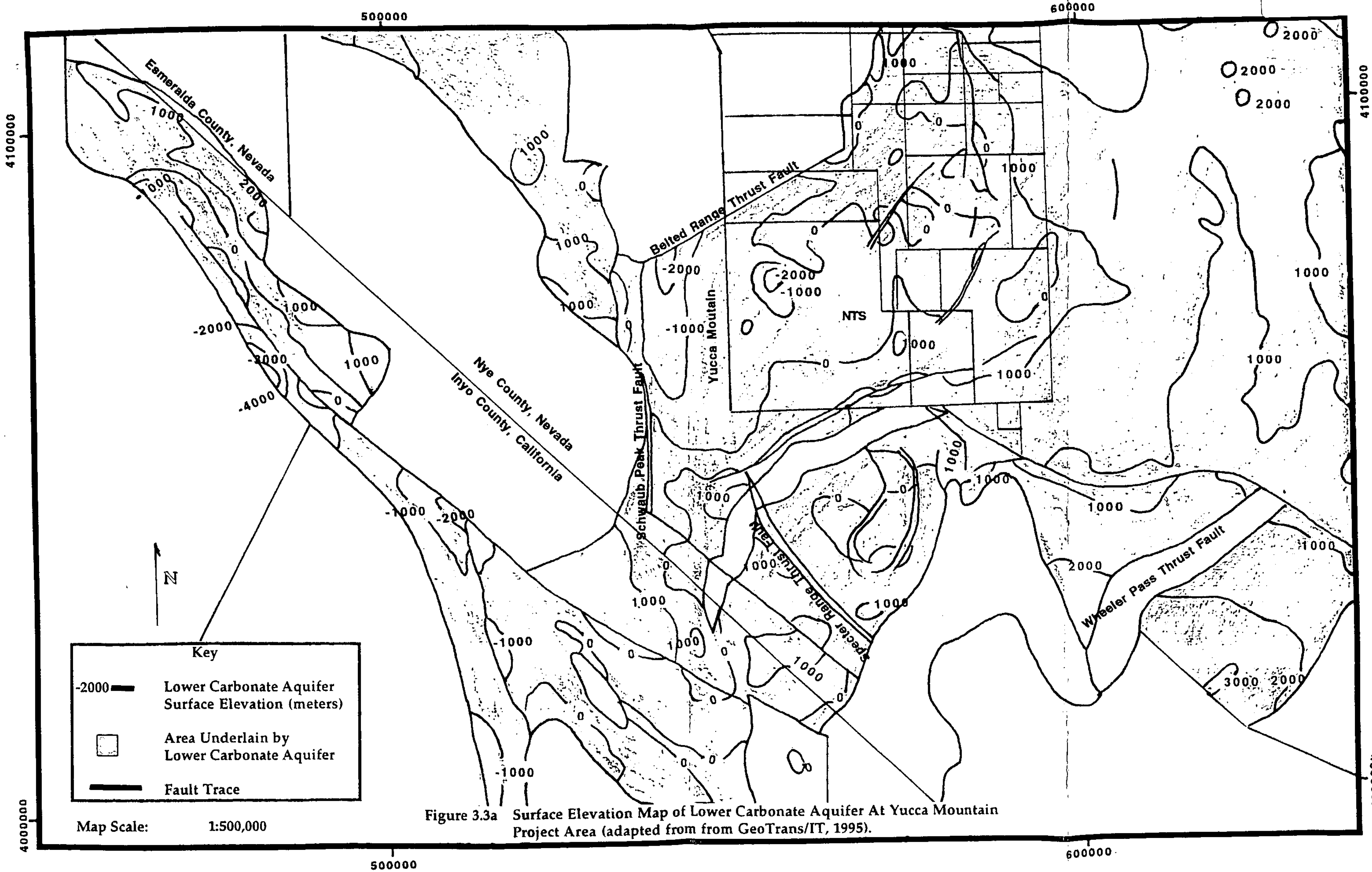

Figure 3.3a Surface Elevation Map of Lower Carbonate Aquifer At Yucca Mountain Project Area (adapted from from GeoTrans/IT, 1995).

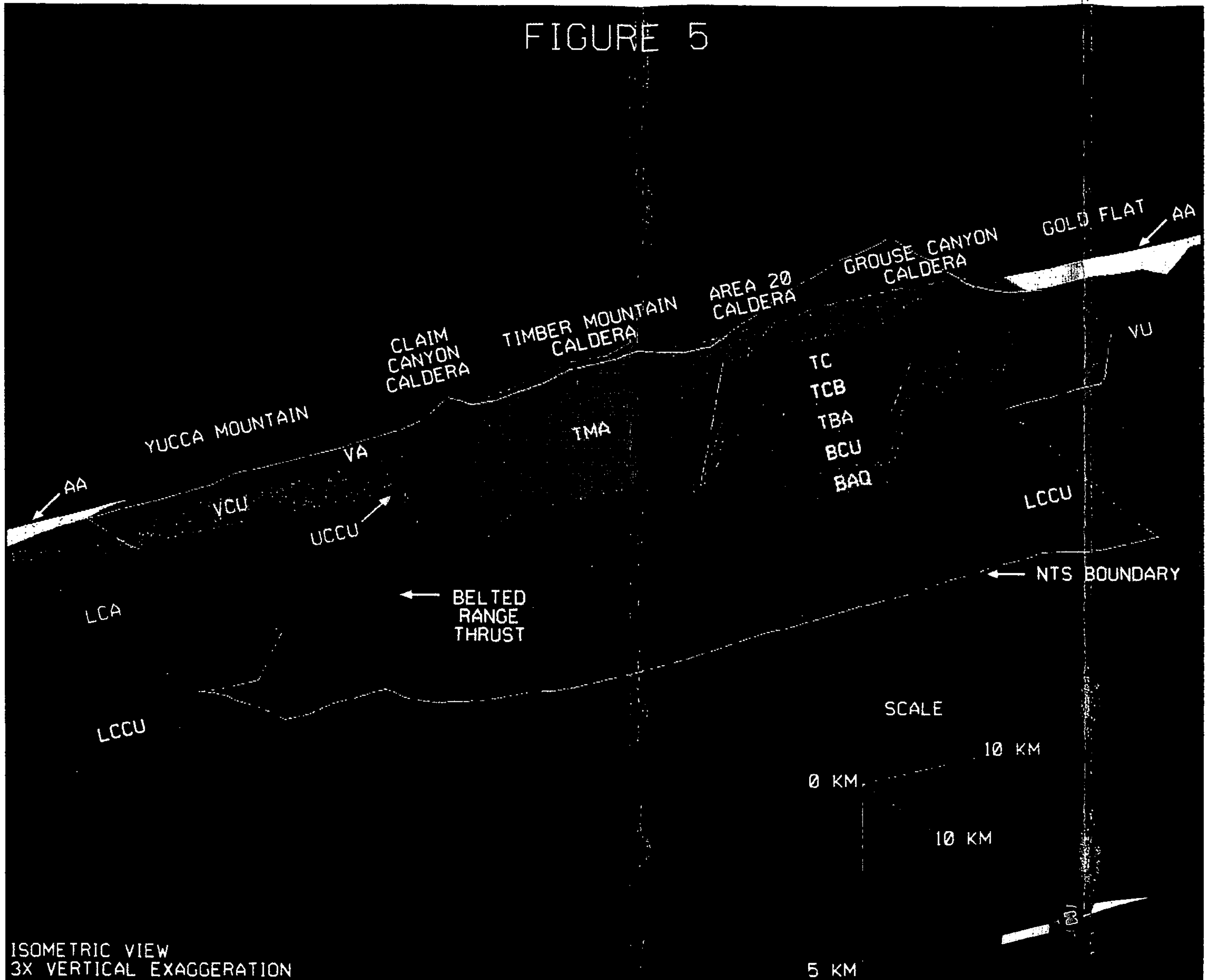

Figure 3.3b North-South Geologic Cross-Section Through Yucca Mountain (from GeoTrans/IT, 1995).

View is looking toward the north from an inclination of 23 degrees.

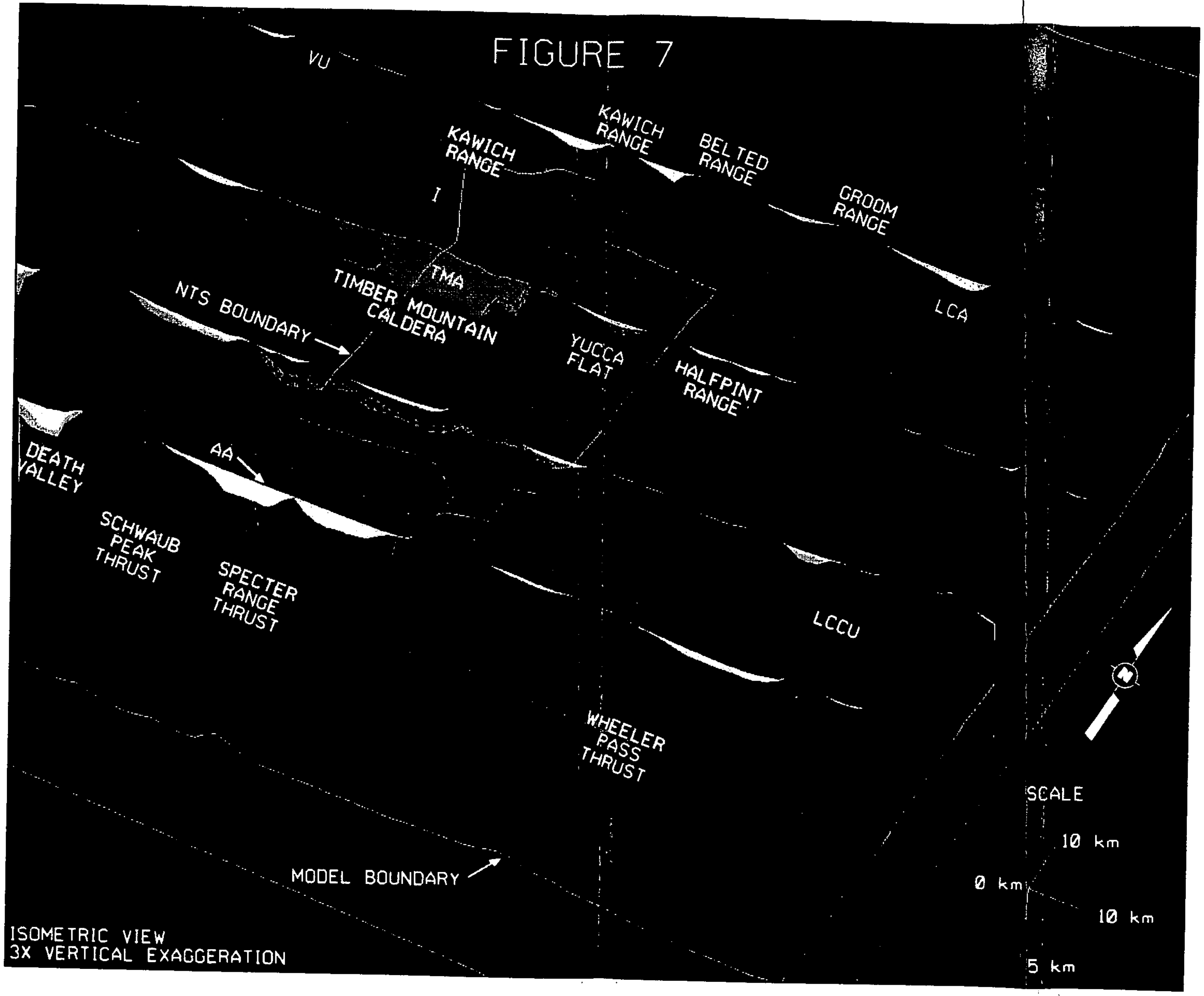

Figure 3.3c Series Of Four East-West Geologic Cross-Sections Through The Area East Of The Nevada Test Site (from GeoTrans/IT, 1995).

View is toward the northwest at an inclination of 41 degrees. The unlabled pink unit is the TS mentioned in GeoTrans/IT, 1995.

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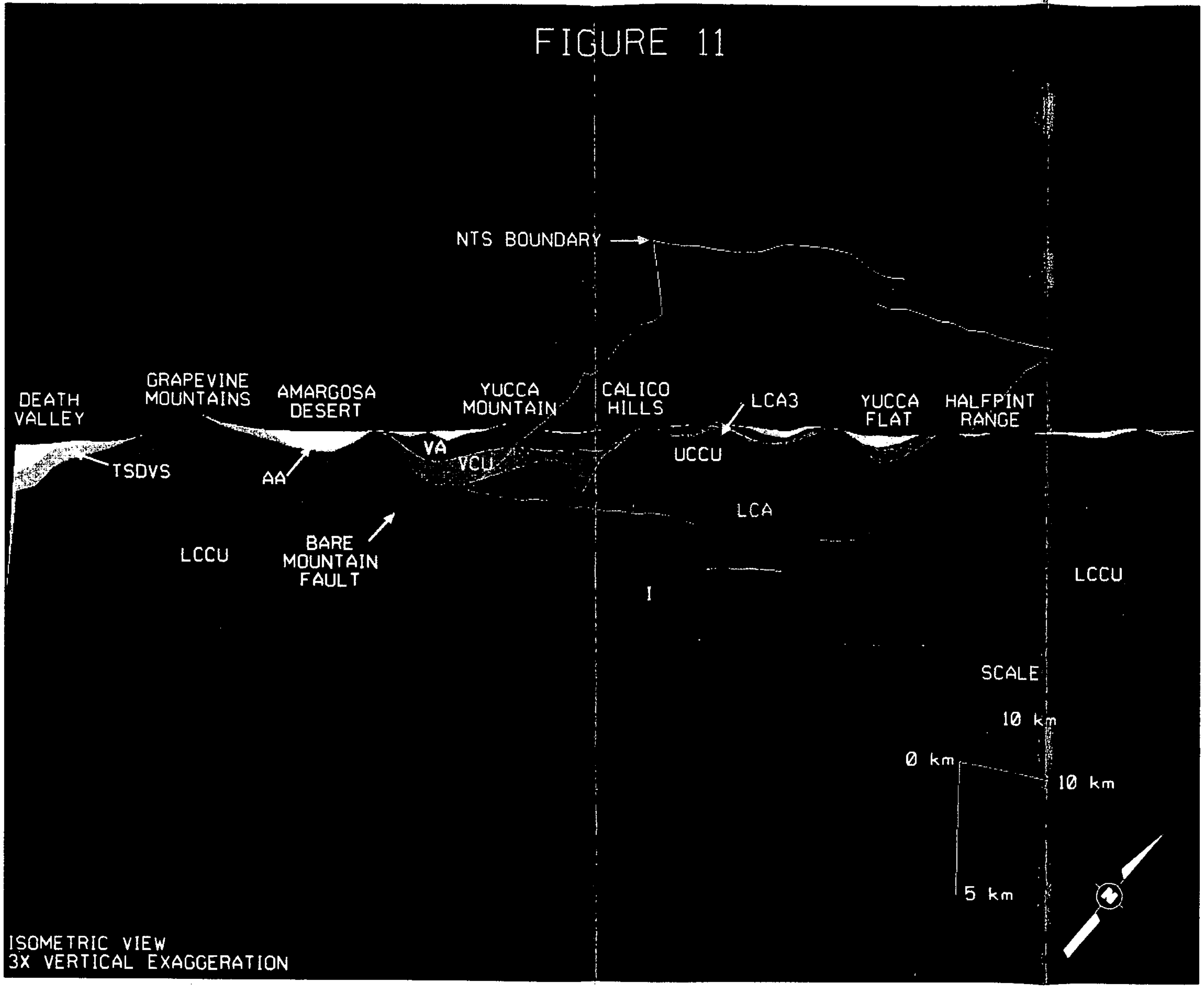

Figure 3.3d Generally East-West Geologic Cross-Section From Death Valley To The Halfpint Range Across The Bare Mountain Fault (from GeoTrans/IT, 1995).

View is toward the northeast from an inclination of 23 degrees.

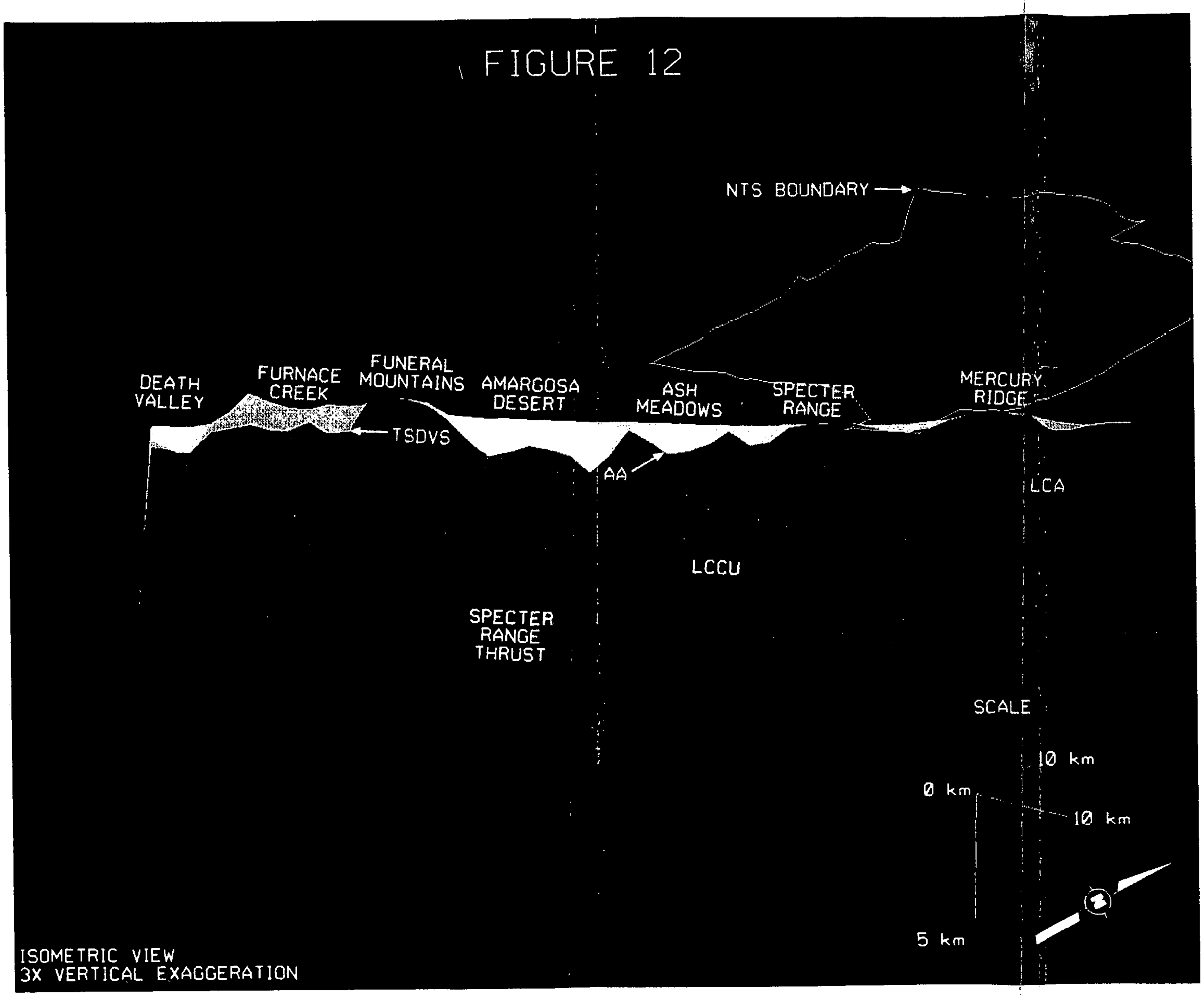

Figure 3.3e Northeast-Southwest Geologic Cross-Section From Mercury To Death Valley (from GeoTrans/IT, 1995).

View is toward the northwest from an inclination of 18 degrees.

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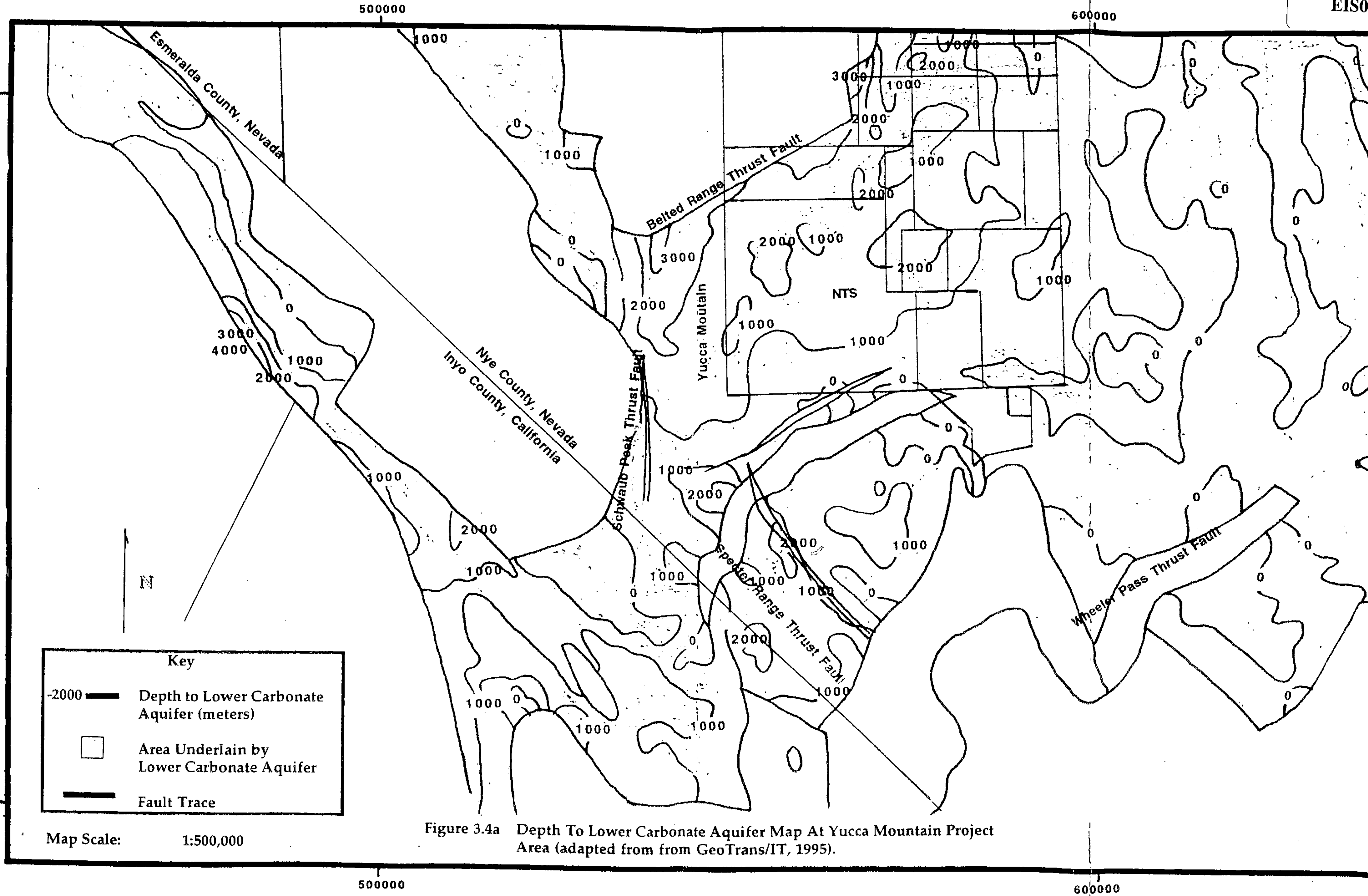


Figure 3.4a Depth To Lower Carbonate Aquifer Map At Yucca Mountain Project Area (adapted from from GeoTrans/IT, 1995).

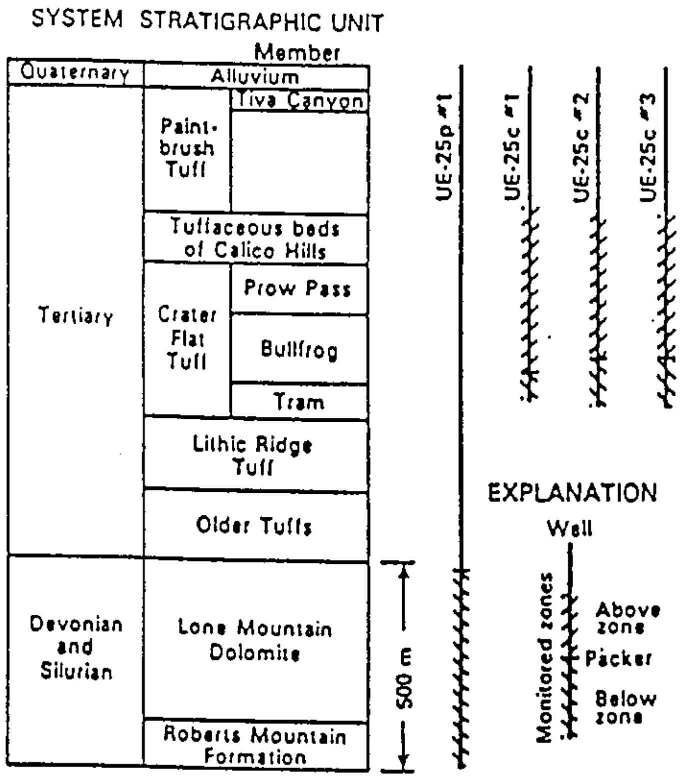
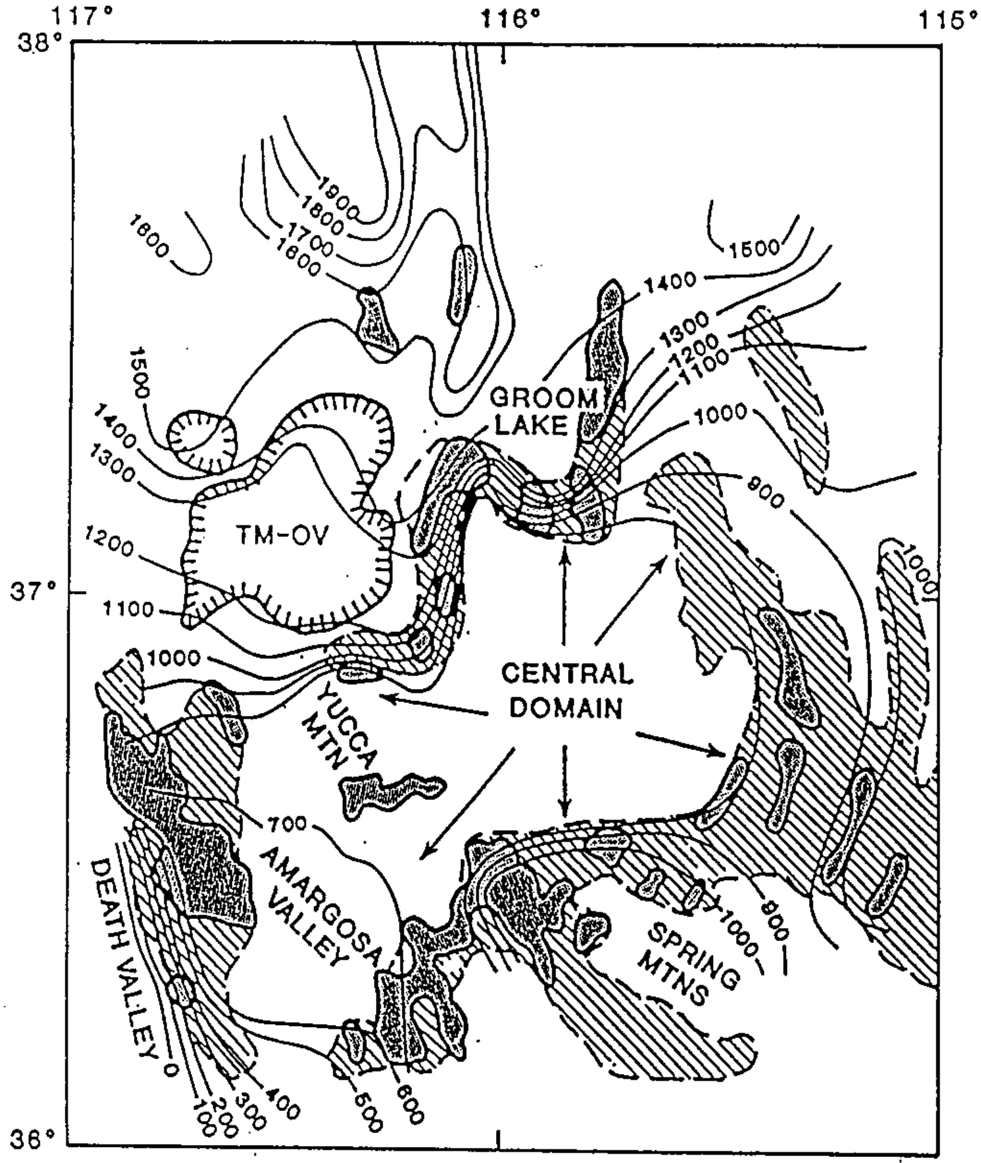


Figure 4.1.1 **Schematic Stratigraphic Column Showing The Rock Units Penetrated By The Various Holes Used For Analysis By Galloway and Rojstaczer (1988).**



0 10 20 30 40 Kilometers
0 10 20 Miles

Clastic Confining Unit Outcrops

Inferred Distribution of Clastic Confining Units in the Subsurface, at or Near the Water Table

TM-OV Timber Mountain – Oasis Valley Caldera Complex

Water Table Contour, Elevations in Meters Above Sea Level

Figure 4.1.2 Water Table Map For Southern Nevada And Eastern California (Waddell, 1984).

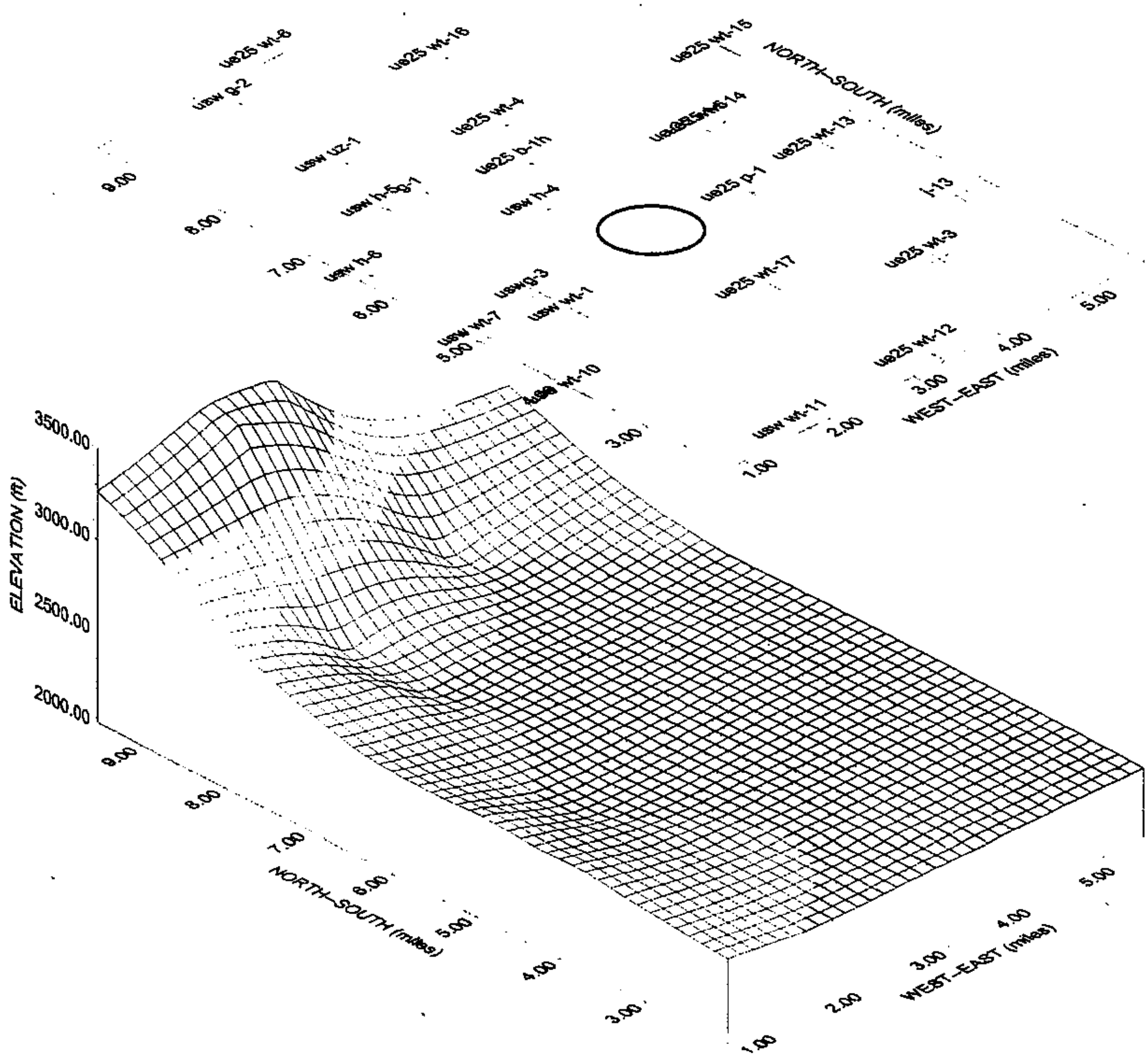


Figure 4.2.1 Isometric Projection Of The Water Table In The Vicinity Of Yucca Mountain.

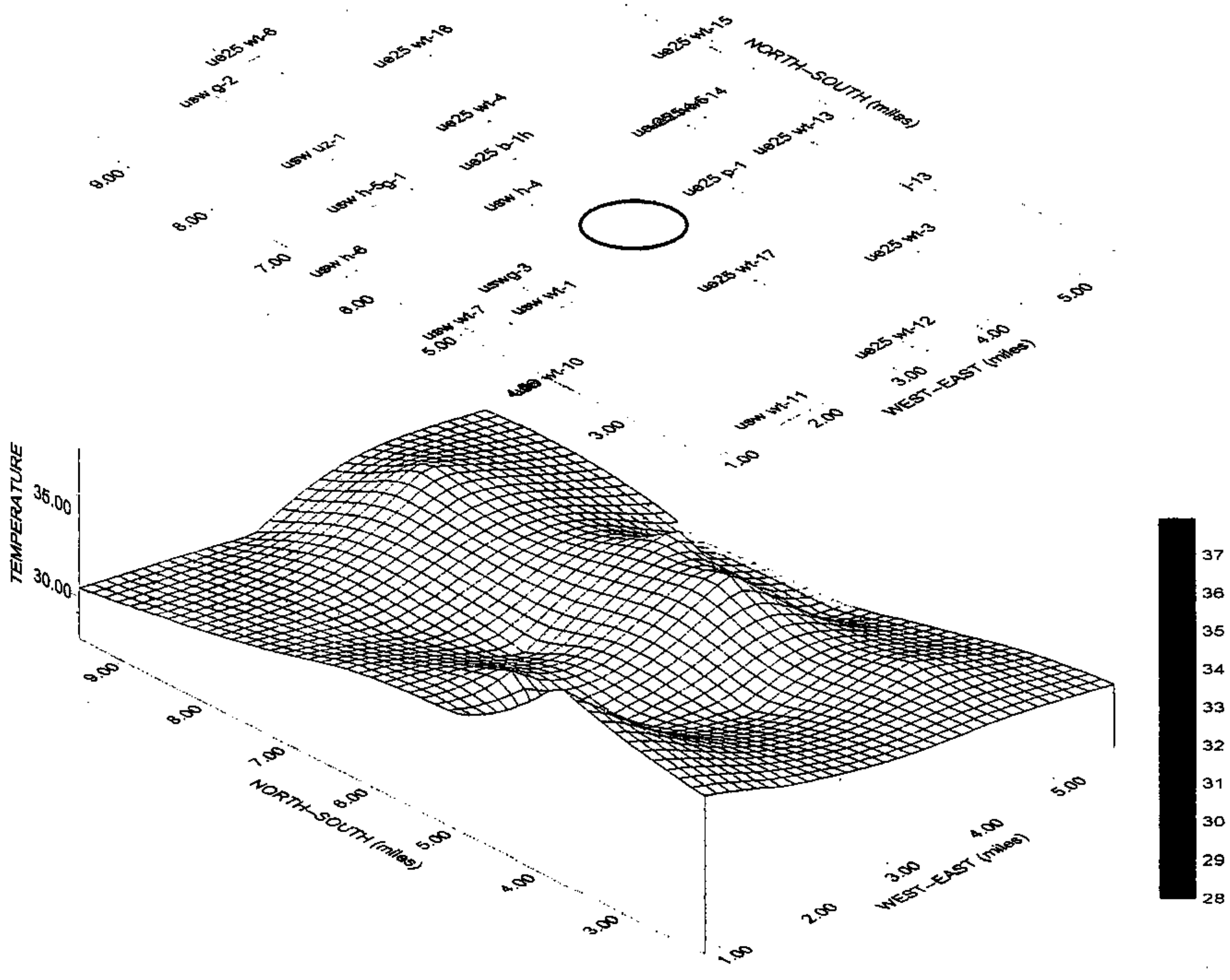


Figure 4.2.2a Isometric Projection Of The Water-Table Temperature--View Looking From North To The South.

Yucca Mountain is situated above the low in the temperature in middle of the view.

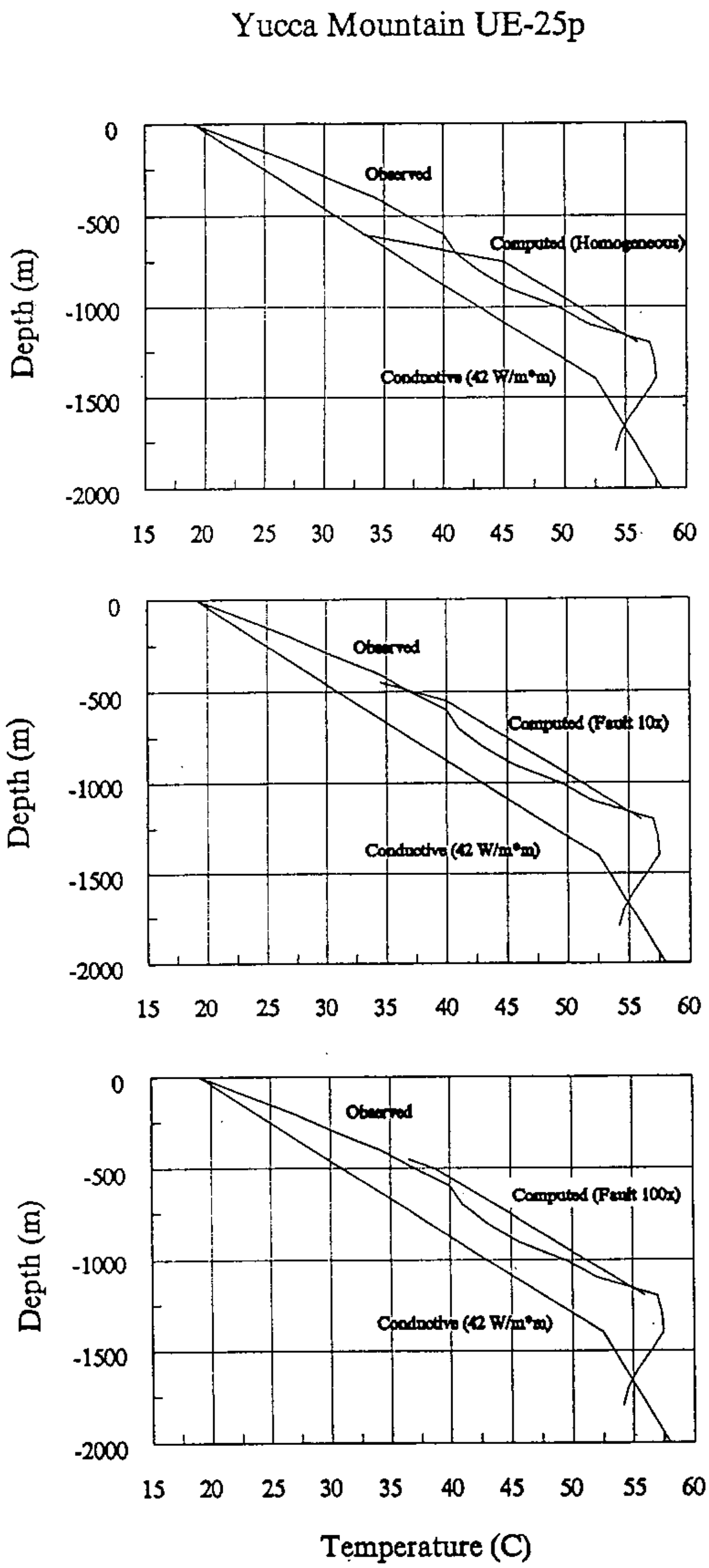


Figure 4.2.2b Observed And Computed Temperature Profiles For The UE-25p1 Hole (Bredehoeft, 1995).

The 42mW/m² conductive temperature profile is the minimum conductive profile suggested by Sass et al. (1995).

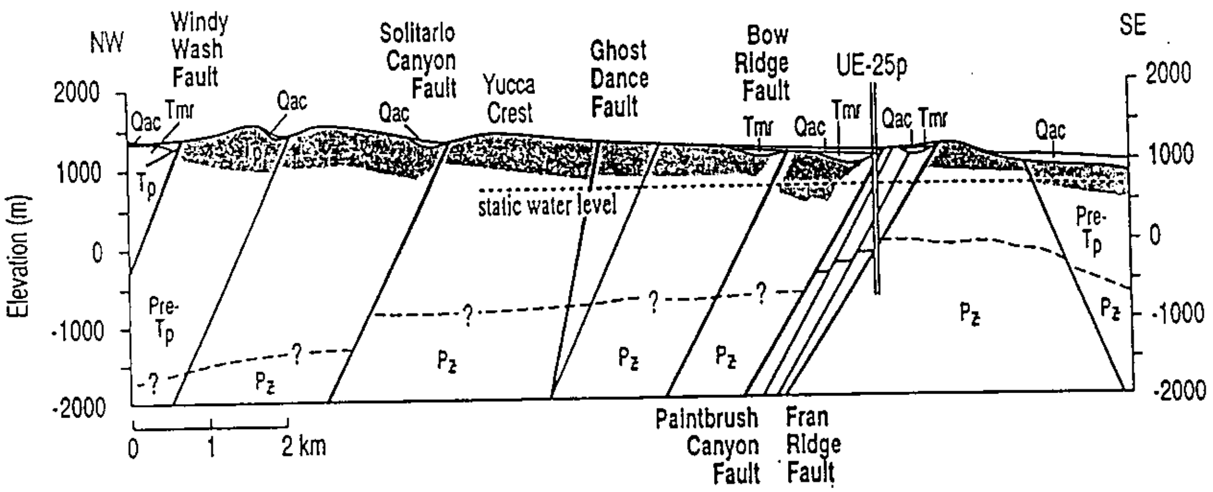


Figure 4.2.6a East-West Cross-Section Through Yucca Mountain Showing The Faults And The Deep Carbonate Well--UE-25p1.