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PRELIMINARY

YUCCA MOUNTAIN PROJECT

A Summary of Technical Support Activities

January 1987 to June 1988

By:

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Las Vegas, Nevada

Submitted to:

State of Nevada
Agency for Nuclear Projects
Nuclear Waste Project Office
Carson City, Nevada

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Volume I

TABLE OF CONTENTS

INTRODUCTION

The Nevada Nuclear Waste Project Office, State of Nevada, has developed a technical oversight program as provided for in the Nuclear Waste Policy Act of 1982 (NWPA). This Act and subsequent amendments has led to the selection of Yucca Mountain in Nevada for site characterization as a high-level nuclear waste repository. The intent and letter of the Nuclear Waste Policy Act is to establish a geologic repository for high-level nuclear waste that is predicated on long-term waste isolation soley supported by a combination of the geologic environment and engineered barriers. A 10,000 year time frame for waste isolation is required due to the long-lived nature of the radionuclides associated with high-level radioactive waste and the need to prevent these radionuclides from reaching the accessible environment in any significant concentrations. The technical and scientific challenge of establishing such a repository is unprecedented due to a combination of factors, including: the large volumes and heat-producing nature of the waste, the long period of time necessary for waste isolation from hydrologic or other natural systems, and the impossibility of using or relying upon engineered barriers for prolonged waste isolation.

The U. S. Department of Energy (DOE) has been charged with executing the selection, construction, and operation of the high-level nuclear waste repository program; and the U. S. Nuclear Regulatory Commission (NRC) has the regulatory responsibility of issuing the varying licenses for construction and operation of the repository. The State of Nevada, as an affected party under the NWPA, has an oversight role. The Nuclear Waste Project Office of the State of Nevada executes the technical oversight, and Mifflin & Associates, Inc. (MAI) is one of its technical support contractors in hydrogeology and closely-related technical areas.

This report is a summary of the technical support activities of Mifflin & Associates, Inc., during the 18-month period beginning 01 January 1987 and ending on 30 June 1988. It covers the following topics:

- Vadose Zone Drilling Site Selection, Permits, and Quality Assurance (QA) Procedures
- Climate Change
- Geochemistry and Mineralogy
- Disturbed Zone
- Hydrogeology
- Review of Technical Documents

The report is organized by generally discussing each topic from the following perspectives:

- Issue(s)
- Objective(s) of Activity
- Finding(s)
- Interpretation of Finding(s)
- Additional Work Needed
- Recommended Program
- Existing Program

Each Topic/Section has its own Appendix and is preceded by a general introduction. In order to keep the size of the report reasonable, while at the same time, ensuring coverage of crucial points, only lists of technical procedures and research plans contained in the past monthly reports are provided as well as three samples of such technical documents: Technical Procedures for Documentation of Research Activities and Daily Drilling Activity Summary Form; Research Plan for Sampling at or near Yucca Mountain; Research Plan for Vadose Drilling and Cuttings Sampling at or near Yucca Mountain. However, all published works and important progress reports or findings emanating from our activities are included in the Appendices for each section.

Section A

Vadose-Zone Drilling Program

Vadose-Zone Drilling Program

Introduction

Review of the DOE vadose-zone drilling program and borehole history reports indicate that water or water-based fluids have been injected into all drillholes which fully penetrated the vadose zone at Yucca Mountain. In addition, UZ-1 borehole was drilled with a vacuum method at great expense but failed to fully penetrate a zone of (perched?) saturation. UZ-1 is so large in diameter that moisture conditions may not equilibrate to predrilling conditions before the useful lives of the emplaced monitoring instruments terminate. UZ-6 also did not fully penetrate the vadose zone using the same method and it also proved extremely costly. UZ-6 is also too large in diameter for useful monitoring of moisture with conventional instruments. Numerous shallow moisture-monitoring holes (N-series neutron logging) were drilled with the ODEX method using air as the circulation fluid, but the depths achieved (maximum is less than 400 ft.) are insufficient to study the full thickness of the vadose zone. The WT-series holes were drilled with air-foam, which requires addition of large amounts of water. The G and H series holes were drilled using conventional drilling fluids. Therefore, not one borehole at Yucca Mountain project area exists for quality data development in the vadose zone below about 400 feet. The ideal drilling method should be capable of air drilling to 2,000 feet for full penetration of the vadose zone in some areas.

The proposed State of Nevada vadose-zone drilling program sites are located to sample as many of the unsaturated tuff zones as possible without drilling on the repository block or in the DOE "core" area. The first round of drilling would establish the methodology in terms of drilling and sampling in the hydrogeologic environment of Yucca Mountain and allow analytical results on samples to be compared with DOE postulates. DOE samples of either water or rock from the repository block would not be comparable to sample obtained utilizing the proposed drilling methodology. Eventually, similar data must be developed from several boreholes on the repository block to confidently characterize the site.

The proposed State of Nevada sites are located to allow penetration in the vadose zone for suspected key hydrostratigraphic horizons at the repository block. The uppermost zone, which includes near-surface fractured rock, soils, and alluvial deposits, is hydrologically varied by surface topography and associated surface-water drainages. The uppermost zones are of interest because of the importance of determining the magnitude, timing, and distribution of recharge events that result from precipitation and surface-water runoff events. The second zone of special interest is the bedded and unwelded tuffs below the welded tuffs of the Tiva Canyon Member of the Paintbrush Tuff. This zone may act to perch and redistribute infiltration. Matrix as well as fracture flow may be important in this zone. The third zone of interest is the repository horizon and near-field environments in the welded tuff of the Topopah Spring Member of the Paintbrush Tuff. Here both matrix moisture and fracture moisture are of great interest from the perspective of characterizing the ground-water travel time and the disturbed zone with respect to the regulatory criteria. The fourth zone of interest consists of vitric and zeolitic tuffs of the Calico Hills which underlie the proposed repository horizon. This unit appears to be locally saturated near the repository block, and matrix flow may be important. The geochemistry of water in this unit is critical to the resolution of ground-water travel times in the vadose zone. The fifth and deepest zone targeted in the State of Nevada vadose-zone drilling program is "first fracture water" in the phreatic (saturated) zone. Some of the uppermost saturated fractures in the zone of regional saturation may contain relatively young water if active recharge is occurring. Boreholes finished in these fractures will provide uppermost water samples of the saturated zone. These waters may also yield definitive information on travel times.

The proposed drilling method, the dual-tube reverse circulation (DTRC) air-rotary method, is known to be capable of producing the desired rock and water samples as well as a useful borehole for monitoring; however, it has not been tested in the terrane of Yucca Mountain. Therefore, one objective of State of Nevada-sponsored vadose-zone drilling at Yucca Mountain is to demonstrate the utility of the dual-tube reverse circulation air-rotary method. This technique should permit hydrologically compatible exploration of the full vertical extent of the vadose zone at Yucca Mountain. It allows for the recovery of representative samples of rock and subsurface fluids that are unaffected by water-based drilling additives. The sampling of saturated regions (perched) in the vadose zone permits the execution of associated geochemical and isotopic studies of vadose-zone water samples. In addition, the resulting boreholes are of small diameter, rapidly constructed, and therefore have utility for temporal monitoring of relatively undisturbed soil gas and moisture conditions (using a variety of monitoring techniques, including: thermal couple psychrometers, lysimeters, tensiometers, heat-dissipation probes, and neutron logging).

The Nuclear Waste Project Office recognized the critical role air drilling should play in establishing useful information from the vadose zone at Yucca Mountain as early as 1984. Since that year, the State of Nevada has attempted to enter into a vadose-zone drilling program but has been blocked by a series of federal government actions. The nondrilling aspects of the State of Nevada's drilling effort have been pursued to date in order to maintain drilling preparedness should both funding and approval be established.

Vadose-Zone Drilling

ISSUES:

Vadose-zone drilling addresses the following issues:

Ground-Water travel time from the repository horizon to the regional water table under the prewaste emplacement condition of 10CFR60.113(2), and

Overall performance of the fractured-tuff vadose zone from the waste isolation perspective as related to 10CFR60.112 and 40CFR191.13.

OBJECTIVES:

The fundamental objective of State of Nevada sponsored vadose-zone drilling at Yucca Mountain is to establish a useful drilling technique, specifically, the dual-tube reverse circulation air-rotary method, for the exploration of the full vertical extent of the vadose zone without the use of water near the Yucca Mountain Site.

This drilling technique should permit the recovery of representative rock samples and water held within the rocks with very little disturbance to the ambient conditions found in the field.

The following site characteristics of Yucca Mountain are addressed by the vadose-zone drilling program:

The distribution of perched water (i.e. localized saturated zones) within the vadose zone in time and space;

The distribution of fracture flow in the vadose zone and its importance to water movement through tuff formations; and

The natural recharge water flux to the repository horizon and its distribution in time and space below the repository horizon.

ACTIVITIES:

A review of potential drilling sites was completed, taking into consideration geology, hydrogeology, political boundaries, and drilling-rig access. Field reconnaissance of road conditions was carried out on the western and eastern sides of Yucca Mountain.

Potential drilling sites located west and east of Yucca Mountain have been selected based on hydrogeology, geology, and access for drilling equipment.

In anticipation of the commencement of the vadose-zone drilling program (tentatively scheduled for November 1987), sample containers and storage facilities were obtained and equipment for water sampling was ordered for the drilling operations. The storage facility, which was leased in August of 1987, is used for equipment and sample container storage and archiving preparation prior to the actual drilling.

Two polycarbonate air-exclusion flow cells were built. During water-sampling operations, these will allow simultaneous measurement of pH, electrical conductivity, temperature, redox potential, and dissolved oxygen, while leaving four ports free for buffers and/or standard solutions.

QA procedures were finalized and forwarded to the State of Nevada QA Manager. Furthermore, the staff at MAI developed draft technical procedures for the drilling program (for a complete list see Appendix A-II).

After MAI staff reviewed the geology and hydrogeology of the proposed drilling sites, the sites were archaeologically surveyed by Dr. R. K. Rafferty (Environmental Research Center, University of Nevada, Las Vegas) and application has been made to the U. S. Bureau of Land Management (BLM) for drilling permits, Appendix A-II).

The vadose-zone drilling program start-up (Phase I) was delayed due to the lack of a timely response by the BLM to MAI's right-of-way drilling application (submitted on September 30, 1987). The delay in granting approval to the MAI drilling permit, as explained by M. Moran (BLM, Las Vegas) was due to the fact that BLM felt that DOE's application takes precedence over MAI's application and because the drilling sites proposed by MAI application dated September 30, 1987 are located within the DOE right-of-way area as presented to BLM in their application. Additional drilling-site applications outside of the DOE requested right-of-way area but in the Yucca Mountain tuff sequence were then developed by MAI.

On April 26, 1988, Drs. M. D. Mifflin and Atef Elzeftawy met M. Moran (BLM, Las Vegas) and staff and a BLM adjudicator (Denver office) at Moran's request, to discuss the second group of MAI drilling permit applications for vadose-zone drilling sites AZ-9 and AZ-10, located beyond the DOE right-of-way. Mifflin explained the technical objectives and goals of the vadose-zone drilling project. Moran stated that his staff have been uncertain as to how to proceed with MAI's first group of applications, presently under litigation with the State of Nevada. Moran asked whether MAI wants his office to process the two applications together or separately (the first group was submitted October 1, 1987; the second group was submitted on April 4, 1988). Mifflin's response was that MAI needs the drilling permits for all drilling areas submitted (Areas AZ-1 through AZ-10 as soon as possible. Moran stated that his office could proceed only with the second applications for areas AZ-9, and AZ-10, submitted on April 4, 1988, because of litigation involving the first permit applications.

The U. S. BLM office in Las Vegas was in contact with Dr. A. Elzeftawy (MAI) concerning the second MAI drilling permit applications for areas AZ-9 and AZ-10. We were informed that a drilling permit for area AZ-9 (Site on the Nellis Air Force Bombing Range) may not be granted by BLM due to disagreement between BLM and the Air Force on air space restrictions. However, the BLM office in Las Vegas sought additional advice from their Washington, D. C. Headquarter office and their opinion was to be transmitted in writing to MAI. In addition, we were informed by E. Arellano (BLM) that the permit for area AZ-10 would be issued within the month of July 1988.

As promised by E. Arellano of the U.S. BLM, we received two drilling permits Nos. N-48327 and 48282 on 30 June 1988 (see attached letters and permits from BLM in Appendix A-V).

ADDITIONAL WORK NEEDED:

It is necessary to maintain the warehouse, sample containers, etc. as well as test the equipment to be used for sampling.

RECOMMENDED PROGRAM:

We judge that the same issues and associated objectives remain to be resolved and accomplished. The DTRC drilling is a key element in the State of Nevada oversight program that allows for independent sample collection and associated verification vadose-zone hydrology. Neither useful site-specific data nor plausible or conservative conceptual models of the vadose-zone hydrology have been put forth by the DOE program to date.

The drilling capability is being maintained by continued operation of the warehousing of necessary sample containers and the refinement and testing of sampling equipment.

Appendix A

Vadose-Zone Drilling Program

List of Appendices

Appendix A-1

List of MAI Research Plans and Technical Procedures

LIST OF MAI RESEARCH PLANS AND TECHNICAL PROCEDURES

MRP-1.0	Research Plan for Drilling at or near Yucca Mountain.
MRP-2.0	Research Plan for Water Sampling at or near Yucca Mountain.
MTP-3.01	Position Titles, Descriptions, and Minimum Qualifications.
MTP-3.02	Technical Procedure for Documentation of Research Activities.
MTP-3.12	Technical Procedure for Installation of Surface Casing in Yucca Mountain Exploratory Boreholes.
MTP-3.13	Technical Procedure for Daily Drilling Activity Summary Form.
MTP-3.14	Technical Procedure for Drilling Time Form.
MTP-3.15	Technical Procedure for Neutron Probe Moisture Data Form.
MTP-3.16	Technical Procedure for Photographic Log Form.
MTP-3.17	Technical Procedure for Sample Identification (ID) Form.
MTP-3.18	Technical Procedure for Record of Sample Custody Form.
MTP-3.19	Technical Procedure for Dual-Tube Drilling Flow Test and Field Chemistry Form.
MTP-3.21	Technical Procedure for Collection and Sampling of Yucca Mountain Drill Cuttings.
MTP-3.22	Technical Procedure for Collection and Preservation of Colloid Samples for Laboratory Analysis.
MTP-3.23	Technical Procedure for Thief-Type Sampling of Natural Waters in the Field.
MTP-3.24	Technical Procedure for Water Sampling with a Double-Valve Purge Pump System.
MTP-3.31	Technical Procedure for Field Filtration of Natural Water Samples.
MTP-3.41	Technical Procedure for Relative Field Measurement of Water Level in a Borehole with an Electrical Tape.
MTP-3.51	Technical Procedure for Preparation of Water Samples for Carbon-14 Analysis by Accelerator Mass Spectrometry.
MTP-3.71	Technical Procedure for Field Measurement of pH.
MTP-3.711	Technical Procedure for Determination of Aluminum in Samples of Natural Water.
MTP-3.72	Technical Procedure for Measurement of Electrical Conductivity of Water Samples in the Field.
MTP-3.73	Technical Procedure for Field Measurement of Reduction-Oxidation Potential: including

Preparation and Storage of Reduction-Oxidation Solutions of Standard Potential, and Calibration of REDOX Electrodes.

MTP-3.74 Technical Procedure for Field Measurement of Dissolved Oxygen in Water Samples by Membrane Electrode Probe.

MTP-3.75 Technical Procedure for Field Measurement of the Total Alkalinity of Water Samples.

MTP-3.76 Technical Procedure for Field Measurement of Dissolved Sulfate in Natural Water Samples by Portable Spectrophotometer.

MTP-3.77 Technical Procedure for Determination of Ferrous Iron in Natural Waters.

MTP-3.78 Technical Procedure for Field Measurement of Dissolved Oxygen in Water Samples by Titration.

MTP-3.79 Technical Procedure for Field Measurement of Aqueous Sulfide in Water Samples by Portable Spectrophotometer.

MTP-3.80 Technical Procedure for Field Measurement of Total Dissolved Iron in Water Samples by Portable Spectrophotometer.

MTP-3.81 Technical Procedure for Measuring Air Temperature Statically and with a Wet-Bulb Thermometer near a Borehole Drilling Site.

MTP-3.9 Technical Procedure for Operating a Downhole Video Camera System with Gyro.

MTP-12.1 Technical Procedure for Calibration of pH Meter.

MTP-12.2 Technical Procedure for Calibration of Electrical Conductivity Meter.

MTP-12.3 Technical Procedure for Air Calibration of Dissolved Oxygen Meter and Membrane Electrode Probe.

MTP-13.1 Technical Procedure for Preparation of Water Sample Containers.

Appendix A-II

Research Plan for Vadose Zone Drilling and Cuttings Sampling at or near Yucca Mountain, MRP-1.0.

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MRP-1.0 RESEARCH PLAN FOR VADOSE ZONE DRILLING AND CUTTINGS SAMPLING AT OR NEAR YUCCA MOUNTAIN.

BACKGROUND

Review of DOE hole history reports indicates that water has been injected into most drillholes which fully penetrated the vadose zone at Yucca Mountain; an exception is UZ-1, which was drilled with a vacuum method at great expense and failed to fully penetrate a zone of perched saturation. Numerous shallow moisture-monitoring holes (the N-series) were drilled with the ODEX method using air as the circulation fluid, but the depths achieved are insufficient to consider these holes representative of the full thickness of the vadose zone. The WT-series holes were drilled with air-foam, which requires addition of large amounts of water. The fundamental objective of State-sponsored vadose-zone drilling at Yucca Mountain is to develop and demonstrate a drilling technique, specifically the dual-tube reverse circulation (DTRC) air rotary method, that permits exploration of the full vertical extent of the vadose zone at Yucca Mountain without addition of water. This drilling technique should permit recovery of representative samples of rock and subsurface fluids that are unaffected by water based drilling additives, and may allow geochemical studies of saturated regions in the vadose zone.

A significant component of this plan is methodology assessment with respect to DTRC air-rotary drilling. Monitoring system design has been specifically excluded from the drilling plan. The Plan mandates collection of all drill cuttings and associated fluid, with specific criteria for initiating and terminating activities that support the (separate) water sampling research plan, MRP-2.0.

Site characteristics of Yucca Mountain addressed by vadose zone drilling, sampling, and hydrogeologic testing are:

1. The three-dimensional distribution of perched water in the vadose zone;

2. The three-dimensional distribution and importance of fracture flow in the vadose zone;

3. The natural flux of recharge waters to the repository horizon, and the distribution, in both time and space, of that flux from the repository horizon to the saturated zone;

4. The paleohydrologic conditions of saturation and flux in the vadose zone during a pluvial climate (a wetter/colder climate of the Pleistocene); and

5. The three-dimensional pattern of gas circulation within the vadose zone (air and water vapor).

Issues that may be addressed include:

1. Travel time of water from the repository horizon to the water table under pre-waste-emplacement conditions;

2. The sorption that might be expected and the geochemical and mineralogical reactions (including water release) under the thermal load of the repository;

3. Climate change hydrology;

4. Disturbed zone extent, as viewed from the hydrogeological perspective; and

5. Overall performance of the fractured-tuff, vadose-zone environment from a waste-isolation perspective.

The vadose-zone drilling is designed to systematically obtain the samples of rock, water, and gas for analytical work while constructing boreholes for in-situ hydrologic monitoring. Drilling will be distributed over three years.

Rationale for Borehole Locations

Ten proposed borehole locations (Figure MRP-1.0-1. and Table MRP-1.0-1.) were based on the following criteria:

- Proximity to the repository block;
- Hydrogeologic setting;
- Surface hydrologic environment;
- Estimated depth to regional saturation; and
- Access.

Five zones will be investigated by vadose-zone drilling. The uppermost zone, which includes near-surface fractured rock, soils, and alluvial deposits, is hydrologically varied by surface topography and associated surface-water drainages. The uppermost zones are of interest because of the importance of determining the magnitude, timing, and distribution of recharge pulses that result from precipitation events.

The second zone of interest is the bedded and unwelded tuffs below the welded tuffs of the Tiva Canyon Member of the Paintbrush Tuff. This zone may act to perch and redistribute infiltration. Matrix as well as fracture flow may be important in this zone.

The third zone of interest is the repository horizon and near-field environments in the welded tuff of the Topopah Spring Member of the Paintbrush Tuff. Here both matrix moisture and fracture moisture are of great interest from the perspective of characterizing the disturbed zone.

The fourth zone targeted for investigation consists of vitric and zeolitic tuffs of the Calico Hills which underlie the proposed repository horizon. This unit is locally saturated, and matrix flow may be important. The geochemistry of water in this unit is critical to the resolution of ground-water travel times in the vadose zone.

The fifth and deepest zone targeted in the vadose-zone drilling is "first water" in the phreatic zone. Some of the uppermost saturated fractures in the zone of regional saturation may contain relatively young water if active recharge is occurring. Boreholes finished in these fractures will provide uppermost water samples of the saturated zone.

Drilling Activity Decision Criteria

Figure MRP-1.0-2. is a logic flow chart that illustrates criteria that shall be used to initiate and terminate the various field activities associated with drilling and sampling. A Staff Geoscientist (minimum position required, see MTP-3.01) designated by the Principal Investigator as Drilling Supervisor, will make the field decisions required in the Figure MRP-1.0-2 Logic Chart. These decisions are in response to variable field conditions.[1]

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1. Drilling Supervisor is an informal title applied to the designated person responsible for all activities at the drilling site. The person designated as Drilling Supervisor may change from morning to afternoon, day to day, week to week, etc., and when this person leaves the drill site, he/she is no longer Drilling Supervisor.

This plan calls for selection of a drill pad area to accommodate research objectives, followed by acquisition of drilling and right-of-way permits. If drilling pad preparation is required, it is without water (normally used to assist compaction and dust suppression), followed by setup of the rig and support equipment and calibration of moisture analyzers and any other instruments used to monitor the drilling process. The Staff Geoscientist shall determine whether it is feasible to proceed with drilling or repeat the setup process. Once drilling has begun, the drilling and cuttings sampling activity (governed by MTP-3.21) apply until the alluvium is penetrated or free water is encountered.

When the drill cuttings indicate that alluvium has been fully penetrated, a steel surface casing will be set approximately one meter into the underlying rock to prevent caving of alluvial materials, and will extend a convenient distance above ground level. Drilling and cuttings sampling will resume until free water is evident in the drill cuttings returns, at which time drilling will pause. The drill pipe string will be broken at the first drill pipe joint above ground level, and static water level will be measured.

If standing water can be detected in the drill pipe, a thief-type water sample (BAT hypoprobe sampling system)will be attempted immediately; if no standing water is detected in the drill pipe, the drill pipe will be pulled and an insert bit will be installed and run downhole prior to attempting the thief-type water sampling. Thief-type sampling will continue until the hole goes dry or the Drilling Supervisor determines that sample quantity and quality is sufficient. The water sample research plan (MRP-2.0) will take effect upon completion of thief-type sampling if sufficient standing water is available for production using the Solinst pump. Drilling may or may not be continued below the sampling zone, depending upon the information established in the drilling area. If a flow test is conducted, water will be collected in a water truck(s) or tank to prevent perturbation of the surface moisture regime by air-lifted ground water.

Minimum Equipment:

1. Drill rig: The drill rig utilized for vadose zone drilling at Yucca Mountain shall consist of an Ingersoll-Rand TH100A Angle Drill or equivalent.

   a. Torque: The rig shall be fully hydraulic and equipped with a tophead drive capable of delivering 1,233 kg-m (107,000 inch-lb) of torque at zero to 130 revolutions per minute (rpm).

   b. Mast capacity: Mast capacity shall be at least 29,500 kg (65,000 lb).

   c. Pullback (hoist capacity): Pullback shall be at least 26,760 kg (59,000 lb).

   d. Air compressor: The air compressor shall deliver at least 750 cubic feet per minute (cfm) at 250 pounds per square inch (psi).

   e. Drill pipe: The drill rig shall be supported with sufficient 114 mm (4-1/2 inch) dual-tube drill pipe for the specific depth objective.

   f. Recorder: The drill rig shall be configured to allow continuous recording of clock time, compressor output (pressure, temperature, and flow rate), and mast load.

   g. Wireline and deviation tool: The drill rig shall be equipped with at least 2,000 feet of logging cable for conducting deviation surveys, and a deviation tool shall be provided.

2. Heavy-duty truck with enclosed bed and lift gate for hauling cuttings from drill site to warehouse and returning with supplies.

3. Water truck or tank configured to receive any excess water airlifted during flow tests.

Documentation of Drilling Activities:

Documentation of Vadose-Zone Drilling and cuttings sampling shall be governed by the following Research Plan and technical procedures:

1. MRP-2.0, Research Plan for Water Sampling at or near Yucca Mountain.
2. MTP-3.01, Position Titles, Descriptions, and Minimum Qualifications.
3. MTP-3.02, Technical Procedure for Documentation of Research Activities.
4. MTP-3.13, Technical Procedure for Daily Drilling Activity Summary Form.
5. MTP-3.14, Technical Procedure for Drilling Time Form.
6. MTP-3.16, Technical Procedure for Photographic/Video Log Form.
7. MTP-3.17, Technical Procedure for Sample Identification (ID) Form.
8. MTP-3.18, Technical Procedure for Record of Sample Custody Form.
9. MTP-3.19, Technical Procedure for Dual-Tube Drilling Flow Test and Field Chemistry Form.
10. MTP-3.21, Technical Procedure for Collection and Sampling of Drill Cuttings.
11. MTP-3.23, Technical Procedure for Thief-Type Sampling of Natural Waters In the Field.
12. MTP-3.41, Technical Procedure for Relative Field Measurement of Water Level in a Borehole with an Electrical Tape.

In addition, a bound Drilling Summary Notebook (log of drill-site activities) shall be established. Drilling Supervisor shall summarize the day's activities at the drill site, including but not limited to the following:

1. Drilling progress, and associated problems;
2. Samples collected;
3. Samples shipped (picked up for transport to storage); and
4. Personnel, weather, and any unusual conditions.

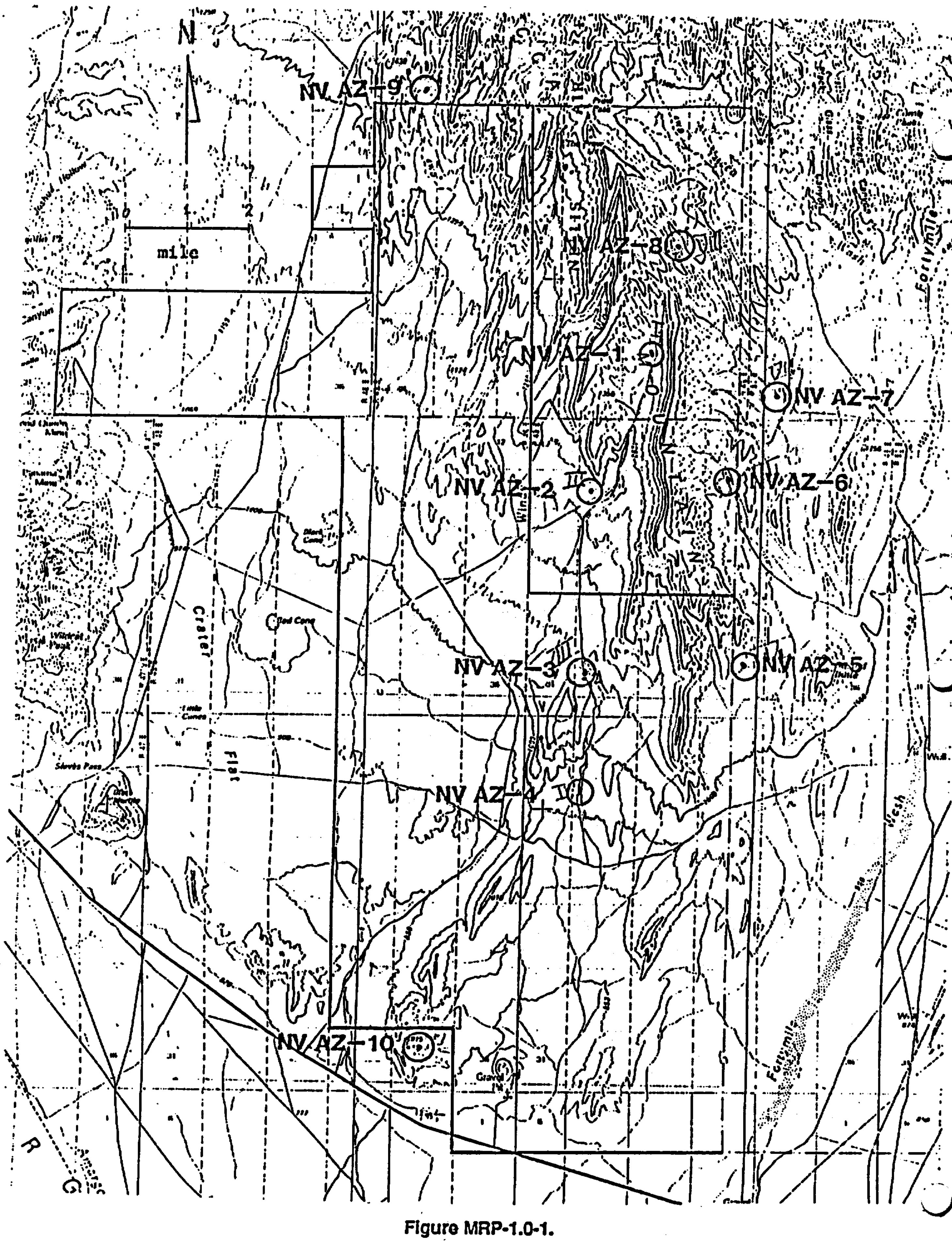

Figure MRP-1.0-1.

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STATE OF NEVADA
AGENCY FOR NUCLEAR PROJECTS
NUCLEAR WASTE PROJECT OFFICE

STATE OF NEVADA PROPOSED DRILLING SITES AREAS*

Milflin & Associates, Inc.
Las Vegas, Nevada

AREA	NV AZ-1	NV AZ-2	NV AZ-3	NV AZ-4	NV AZ-5	NV AZ-6	NV AZ-7	NV AZ-8	NV AZ-9	NV AZ-10
Approximate Location	N 767, 200 E 557, 100 SE1/4, SE1/4, SW1/4. Sec. 26, T12S, R49E (about 0.4 mi west of USW H-5 well)	N 754, 000 E 552, 400 SE1/4, SW1/4, NW1/4. Sec. 9, T12S, R49E (about 1/2 mi southwest of USW WT-7 well)	N 741, 000 E 552, 150 NE1/4, NW1/4, NW1/4, Sec. 32 T13S, R 49E (about 1.5 mi south USW WT-10 well)	N 728, 850 E 551, 800 NW1/4, SW 1/4 NW1/4, Sec. 8, T14S, R49E (about 1.5 mi southwest of USW WT-11 well)	N 740, 200 E 565, 300 (about 0.4 mi northwest of UE25 WT-12 well at N 739, 725 E 567, 011)	N 755, 300 E 564, 000 (about 0.4 mi north of USW WT-1 well at N 753,651 E 563, 739)	N 762, 400 E 565, 550 (about 1.4 mi north-west of UE25 WT-14 well at N 761,650 E 575, 210)	N 771, 000 E 560, 000 (about 300 ft north-west of USW UZ-1 well at N 771, 275 E 560, 220)	N 789, 000 E 538, 000 SE1/4, SE1/4, Sec. 6, T12S, R49E (about 5.5 mi north-west of USW UZ-1 well at N 771, 275 E 560, 220)	from N 707, 500 to 708, 000 from E 538, 000 to 541, 000 SE 1/4, NE 1/4 and SE 1/4, NW 1/4, Sec. 35, T14S, R48E (about 6.5 mi southwest of USW WT-11 well)
Approximate Site Elevation AMSL	1323 m 4340 ft	1162 m 3810 ft	1055 m 3460 ft	960 m 3150 ft	1098 m 3600 ft	1213 m 3980 ft	1195 m 3920 ft	1349 m 4425 ft	1450 m• 4350 ft	966-1050 m 2900-3150 ft
Approximate Water Table Elevation AMSL	775 m 2543 ft	775 m 2543 ft	775 m 2543 ft	774 m 2539 ft	730 m 2395 ft	731 m 2398 ft	732 m 2402 ft	800 m 2642 ft	1150 m• 3450 ft	700 m• 2100 ft
Approximate Lithology thickness in feet	15-30 QTac 220 cu 1100 tu 110 Tht >200 Tcpp-Tcb	10-30 QTac 400 cu 1100 tu 130 Tht >100 Tcpp	10-50 QTac 310 cu 950 tu >150 Tht	0-80 QTac 300 cu 1000 tu >130 Tht	20-50 QTac 180 cu 900 tu >30 Tht/ Tcpp-Tcb	20-50 QTac 480 cu 900 tu 180 Tht >100 Tht	20-40 QTac 450 cu 1100 tu 504 Tht/ Tcpp-Tcb	15-40 QTac 50 cu 150 pc 50 bt >1200 tu	10-100 QTac 30-300 Tht 30-600 Tcpp 0-50 bt 50-500 Tcb	0-20 QTac 0-350 cu 0-650 tu 0-60 Tw• 150-600 Tcpp 300-600 Tcb 0-120 Tbx• 0-600 Tbt•

LEGEND**

QTac Alluvium	pc Pah Canyon Member	Tht Tuffs of Calico Hills	Tw• Bedded Tuff (Miocene)	mi miles
cu Tiva Canyon Member	bt Bedded Tuff	Tcpp Prow Pass Member	Tbx• Depositional breccia from Bullfrog member	m meters
bt Bedded Tuff	tu Topopah Spring Member	Tcb Bullfrog Member	Tbt• Bedded Tuff (Miocene)	ft feet

* Data compiled based on DOE published reports.

** Geologic legend from USGS-OFR-84-494 by Scott and Bonk, 1984.

• Swadley and Carr-Geology, Big Dune Quad., Nevada-California (MAP 1-1767).

Table MRP-1.01-1.

MY880527a

Research Plan for Vadose Zone Drilling and Cuttings Sampling

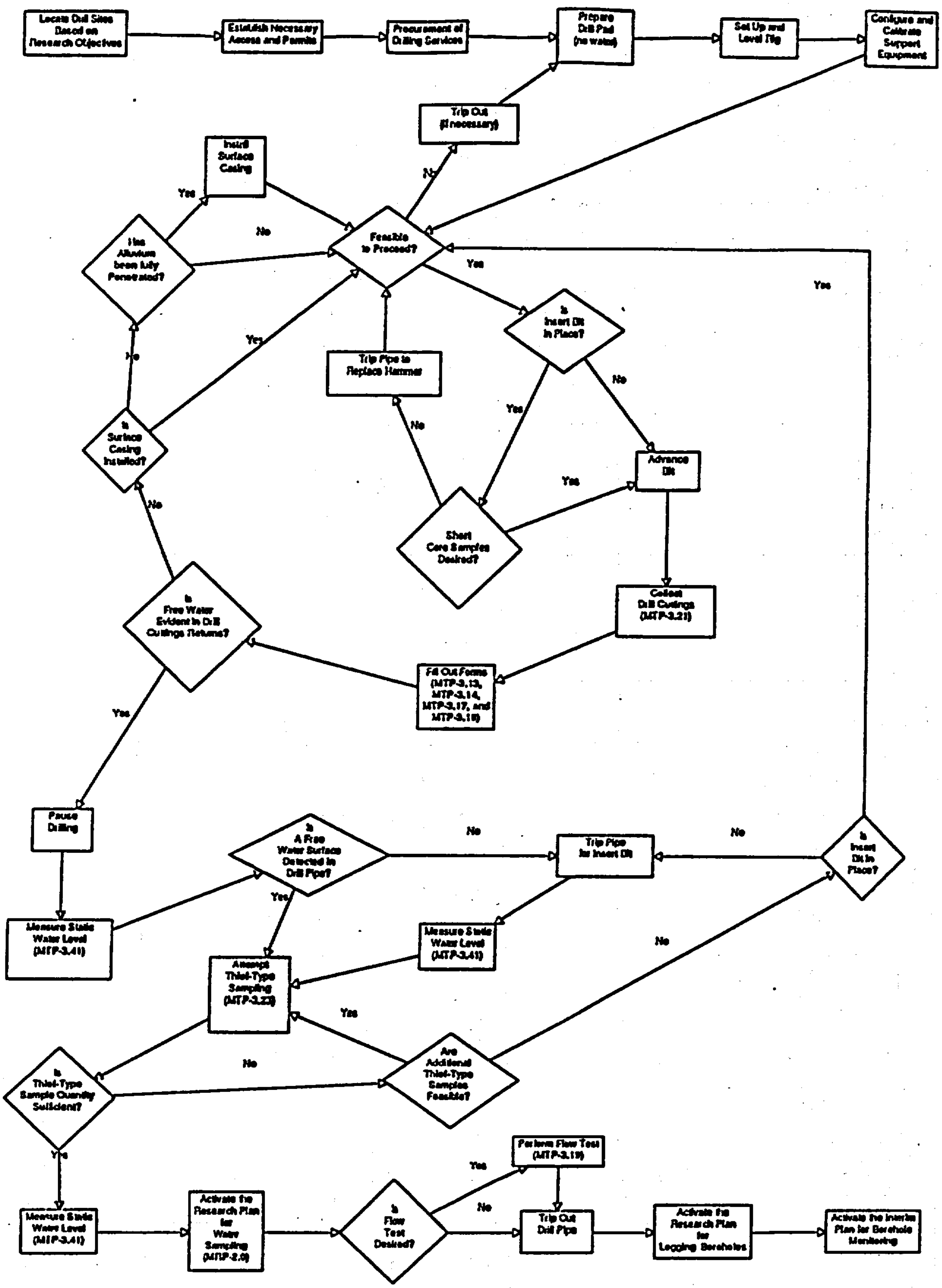

Figure MRP-1.0-2.

Appendix A-III

Research Plan for Water Sampling at or near Yucca Mountain, MRP 2.0.

Mifflin & Associates, Inc.
2700 East Sunset Road, Suite C25
Las Vegas, Nevada 89120
(702)798-0402 & 3026

MRP-2.0 RESEARCH PLAN FOR WATER SAMPLING AT OR NEAR YUCCA MOUNTAIN.

Objective

As stated in the Research Plan for Vadose Zone Drilling (MRP-1.0), when free water is encountered in a borehole, as indicated by a fine mist emerging from the cyclone or as wet or dripping cuttings, drilling ceases, the static water level is measured, and a thief-type water sampling method is attempted. If sufficient thief-type samples are collected and if sufficient free water remains in the borehole (as determined by another static water level measurement), then the following research plan is activated.

The objective of this research plan is to obtain water samples and associated chemical, isotopic, and colloidal analyses of any free water encountered in the vadose zone(may include uppermost part of saturated zone) during drilling research activities. This will be accomplished by pumping water encountered during drilling to the surface to: (1) fill appropriate sample containers for laboratory analysis of various chemical and isotopic constituents; (2) establish field analyses of certain unstable constituents; and (3) obtain samples for colloid analyses. Appropriate preservative treatments and environmental control of samples will ensure that the water samples brought to the surface and shipped to various laboratories are representative of the subsurface geochemical environment. Appropriate sample containers and container preparation techniques will minimize contamination of the water samples by leaching of the container or loss of constituents to the container's walls by sorption.

The period of performance of this research plan is at the minimum three years, the duration of planned research drilling activities.

Field Activities

The field activities at the drilling site are: (1) collection of water samples for various laboratory analyses, (2) measurement of certain unstable constituents of the water as it emerges at the surface, and (3) collection of representative colloid samples.

The logic flow diagram (Figure MRP-2.0-1.) outlines the various procedures that will take place in the field after free water is encountered, all thief-type water samples have been obtained, and sufficient water remains in borehole to justify pumping. These conditions are part of the research plan for vadose zone drilling and cuttings sampling (MRP-1.0) and the water sampling research plan is activated only if all these conditions are met.

After free water is encountered, in a borehole, a designated Field Technician or Designee (see MTP-3.01) shall calibrate the instruments for field measurements (pH meter and electrode, electrical conductivity meter and cell, dissolved oxygen meter and membrane probe, the redox electrode, and the portable spectrophotometer). Calibration may begin during the thief-type sampling, but shall be completed before any water from the pump reaches the land surface.

When pumping of water from the borehole begins, simultaneous activities occur that require several people. A trained person (minimum position required: Field Assistant) is required to operate and constantly monitor the Solinst pump during its operation (for example: if the borehole is pumped dry, gas pressure must be shut off immediately). The second activity involves operation of the flow cell: obtaining all the operation of the flow cell constitutes another activity requiring measurements from the probes penetrating into the flow stream (temperature, pH, electrical conductivity, and dissolved oxygen content). If dissolved oxygen is below detection limit, then a redox (Eh) measurement is performed, followed by determination of sulfide content. Total alkalinity is determined, followed by spectrophotometric , total iron content, and sulfate content. One person may be sufficient to perform all of these measurements, as well as the aluminum extraction.

Filling water sample containers with filtered and unfiltered water samples is the third and last major activity. A minimum of two trained Field Assistants or Designee (MTP-3.01) are required for filling water sample containers: one to fill and operate the pressure vessel for filtered samples and the other to collect the unfiltered samples. Upon arrival of water at land surface from the Solinst pump, the first 11 liters of output (capacity of water line from pump) should be used to rinse sample containers (for unfiltered samples only) and the pressure vessel. Thereafter, the pressure vessel shall be filled first until all filtered samples are obtained; however while the pressure vessel is in operation, personnel shall also be collecting the unfiltered samples. Thus, in practice, the two subtasks of collecting filtered and unfiltered water samples may be more integrated than is apparent from the flow chart. Table MRP-2.0-1. is a summary of all water samples collected according to this plan and interfacing Technical Procedures.

In summary, a minimum of four persons are needed are required to carry out the water sampling research plan.

Equipment Required

In addition to equipment specified in the Technical Procedures listed in this research plan, the following are necessary:

1. Solinst pump system - double valve purge pump capable of pumping lifts to 2,000 feet and with appropriate support equipment (nitrogen gas cylinders, generator, and tubing, fittings, and valves for controlling sample stream at the surface).

2. Laboratory facility - a small 12 to 15 foot air-conditioned trailer outfitted for performing all required field measurements related to the flow cell, aluminum extractions, and sample preparations.

3. Polycarbonate flow cells (minimum of two, one for backup) - with ports for electrodes, cells, and temperature sensors.

Documentation

The following Technical Procedures provide for all appropriate documentation related to personnel, samples, custody, field measurements, calibrations, extractions, and preparations.

MTP-3.01, Position Titles, Descriptions, and Minimum Qualifications.

MTP-3.02, Technical Procedure for Documentation of Research Activities.

MTP-3.17, Technical Procedure for Sample Identification (ID) Form.

MTP-3.18, Technical Procedure for Record of Sample Custody Form.

MTP-3.22, Technical Procedure for Field Collection and Preservation of Colloid Samples for Laboratory Analysis.

MTP-3.23, Technical Procedure for Thief-Type Sampling of Natural Waters in the Field.

MTP-3.24, Technical Procedure for Water Sampling with a Double-Valve Purge Pump System.

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MTP-3.31, Technical Procedure for Field Filtration of Natural Water Samples.

MTP-3.51, Technical Procedure for Precipitation and Extraction of Dissolved Inorganic Carbon from Natural Water Samples for Carbon-14 Analysis.

MTP-3.71, Technical Procedure for Field Measurement of pH.

MTP-3.711, Technical Procedure for Determination of Aluminum in Samples of Natural Water.

MTP-3.72, Technical Procedure for Measurement of Electrical Conductivity of Water Samples in the Field.

MTP-3.73, Technical Procedure for Field Measurement of Reduction-Oxidation Potential: including Preparation and Storage of Reduction-Oxidation Solutions of Standard Potential, and Calibration of REDOX Electrodes.

MTP-3.74, Technical Procedure for Field Measurement of Dissolved Oxygen in Water Samples by Membrane Electrode Probe.

MTP-3.75, Technical Procedure for Field Measurement of Total Alkalinity of Water Samples.

MTP-3.76, Technical Procedure for Field Measurement of Dissolved Sulfate in Natural Water Samples by Portable Spectrophotometer.

MTP-3.78, Technical Procedure for Field Measurement of Dissolved Oxygen in Water Samples by Titration.

MTP-3.79, Technical Procedure for Field Measurement of Aqueous Sulfide in Water Samples by Portable Spectrophotometer.

MTP-3.80, Technical Procedure for Field Measurement of Total Dissolved Iron in Water Samples by Portable Spectrophotometer.

MTP-12.1, Technical Procedure for Calibration of pH meter.

MTP-12.2, Technical Procedure for Calibration of Electrical Conductivity Meter.

MTP-12.3, Technical Procedure for Air Calibration of Dissolved Oxygen Meter and Membrane Electrode Probe.

MTP-13.1, Technical Procedure for Preparation of Water Sample Containers.

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Las Vegas, Nevada 89120
(702)798-0402 & 3026

Summary of Water Samples

	Sample	Container[2]	Filter[3]	Preservation
1.	Major Cations	1 L cubitainer	0.45 µm	1 mL Ultrex HNO_3, chill
2.	Major anions	"	0.45 µm	chill
3.	Deuterium	12 mL scintillation vials	no	"
4.	Oxygen Isotopes	"	no	"
5.	Carbon-13	1 L glass bottle	0.45 µm	"
6.	Tritium	1 L glass	no	"
7.	Uranium-series	20 L cubitainer	no	
8.	Sulfur Isotopes	1 L cubitainer	no	"
9.	Carbon-14 by A.M.S.[1]	1 L glass	0.45µm	"
10.	Carbon-14 by Liq. Scint.	50 L carboy with spigot	no	"
11.	Aluminum	12 mL scint. vials for extract		"
		0.5 mL glass for total Al	0.1 & 0.45 µm	
12.	Thief samples by BAT hypoprobe	500 mL special glass bottles	0.45µm	"
		2 x 150 mL special glass bottles	0.45µm	
13.	Chlorine-36	4 L cubitainer	no	"
14.	Colloids	2 x 60 mL B.O.D. bottles	no	"
		2 x 300 mL B.O.D. bottles	no	
15.	Trace Metals	125 mL HDPE bottle	no	1 mL Ultrex HNO_3, chill
16.	Colloid Identification	0.5 mL thru 5 mL thru	30 nm filters in culture dishes	N/A

1 A.M.S. = accelerator mass spectrometry.

2 L = liter, mL = milliliter, B.O.D. - biological oxygen demand, HDPE = high-density polyethylene.

3 µm = micron or micrometer, nm = nannometer.

Table MRP-2.1-1.

Research Plan for Water Sampling

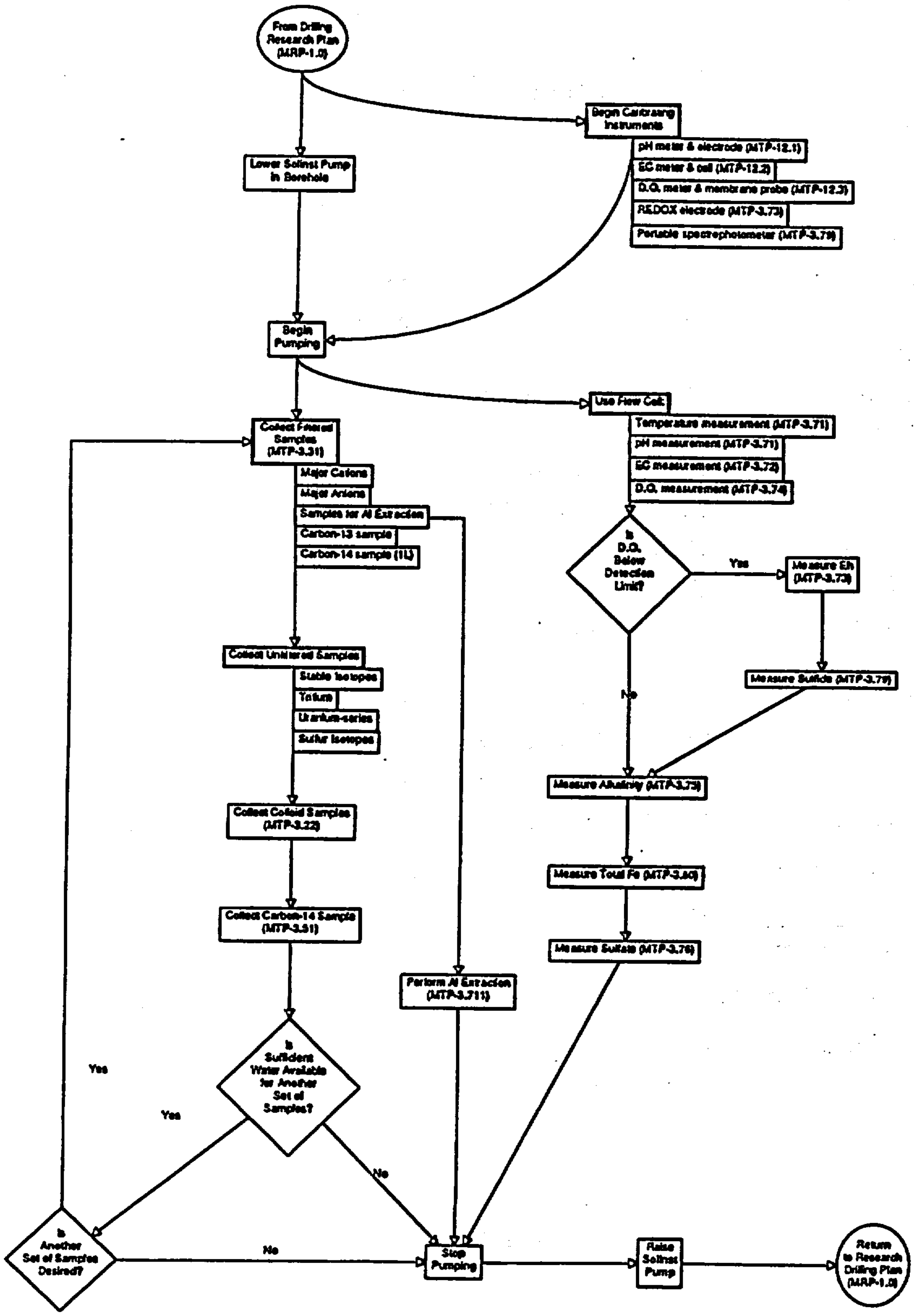

Figure MRP-2.0-1.

Appendix A-IV

Technical Procedures MTP-3.02 AND MTP-3.13

STATE OF NEVADA
AGENCY FOR NUCLEAR PROJECT
NUCLEAR WASTE PROJECT OFFICE
TECHNICAL PROCEDURE

MTP-3.02
REVISION 1 (DRAFT 1)
MAY 20, 1988

TITLE: Technical Procedure for Documentation of Research Activities

APPROVED:

______________________ Project Manager

______________________ Quality Assurance Manager

______________________ Administrator of Technical Programs

1.0 PURPOSE

1.1 This procedure describes the requirements for documentation of research activities that are not covered by technical procedures.

1.2 This procedure governs the activities of Mifflin & Associates, Inc. (MAI) personnel and their subcontractors under contract to the State of Nevada, Nuclear Waste Project Office (NWPO).

2.0 DEFINITIONS

2.1 Research Activity - work of an experimental nature that is to be accomplished before or as part of the preparation of approved detailed technical procedures. A recognized part of these efforts involve the change of concepts and subsequent experimental methods. The discovery and interpretation of the results of the activity will be performed under controlled conditions by procedures that may or may not be established or qualified. The activities that are designated as research activities must be documented according to an approved procedure that will ensure that all aspects of the activity area adequately documented and tracked to allow the preparation of a governing technical procedure, if appropriate, in a timely manner.

3.0 INTERFACING PROCEDURES

3.1 QAP-2.2, Preparation and Control of Technical Procedures.

3.2 QAP-6.1, Document Distribution List and File Index.

3.3 QAP-17.1, Quality Assurance Records.

4.0 REQUIREMENTS AND ACTIVITIES

4.1 The Principal Investigator (P.I.) or Designee shall indicate in writing to the Project Manager which activities performed by the P.I. and/or MAI personnel or subcontractors should be classified as research activities based on the above definition and one or more of the following:

1) Degree of operator skill required to perform activity

2) Complexity and sensitivity of equipment required for the task

3) Degree of professional judgment required to organize the activity and interpret the results

4) The likelihood of inspection yielding meaningful results

4.2 The Project Manager shall recommend in writing the to NWPO Administrator of Technical Programs the activity/activities to be classified as a research activities.

4.3 Upon the classification of an activity as a research activity, the Principal Investigator shall prepare a Research Plan for submittal to the Project Manager. If Project Manager finds the Research Plan satisfactory he/she shall submit the plan to the Administrator of Technical Programs for review and approval.

4.3.1 If the Research Plan is not approved, the Principal Investigator shall revise the plan and resubmit the plan to the Project Manager, per Section 4.3 above.

4.4 The Research Plan shall consist of, but not be limited to, the following items, as appropriate:

1) Activity Title

2) Name of the Principal Investigator responsible for the research activity

3) Objectives.

4) Period of Performance.

5) Description of Field Work: purpose; duration; frequency; type of samples to be taken; equipment to be used and calibration requirements; methods to be attempted or utilized.

6) Description of Laboratory Work: purpose; duration; type and number of samples to be analyzed; preparation and analytical methods to be attempted or utilized; equipment calibration/standardization requirements.

4.5 Complete and thorough documentation of the actual process of the activity shall be performed during the activity and shall be submitted by the Principal Investigator to the Project Manager. The Project Manager shall submit the activity documentation to the QA Manager and Administrator of Technical Programs per Subsection 4.6.1.3 and Section 5.0 of this procedure.

4.6 Documentation or research activities shall include, but not be limited to, the following:

1) Fieldbooks, logbooks, and laboratory notebooks

2) Hardcopy output from equipment or instrumentation

3) Drawings, figures, and maps

4) Calculations

5) Photographs (micro- and/or macro-) and/or video tape recordings

6) Paper tapes or magnetic media containing data output by equipment or instruments

7) Copies of computer codes/software utilized in data reduction or in performing calculations for interpretation of results.

8) Records of custody of samples and sample transmittal forms.

4.7 Fieldbooks, logbooks, and laboratory notebooks shall contain the following daily entries, as applicable, in a clear and legible manner.

1) Date of entry and Preparer's name

2) Name of the Principal Investigator in charge of the research activity

3) Description of work in progress

4) Equipment used and calibration performed

5) Sample (core specimen, section, thin section, etc.) identification history while in preparer's possession

6) Data entries; data sheets

7) Comments relative to work in progress, such as expected or unexpected results, limiting factors known or possible, immediate goal or objective

8) Any changes in the basic approach

9) Interim conclusions, if appropriate

10) Summary describing any results

4.7.1 All entries to fieldbooks, logbooks, and/or laboratory notebooks shall be made in ink. Successive entries shall be made on consecutively numbered pages, leaving no open spaces for additional entries on partially filled pages. Entries shall be signed and dated by the Preparer on the date the entry is made. If revisions to the entries are necessary, the original entry shall be lined out, initialed and dated by the Preparer making the revision. The initial entry shall remain legible. White-out or erasures are not acceptable.

4.7.2 All fieldbooks, logbooks, and laboratory notebooks shall be reviewed and verified by the Principal Investigator, or, if the Principal Investigator is the Preparer, the Project Manager, at regular intervals but no less than monthly. The Principal Investigator or Project Manager shall sign and date the section of the books reviewed and shall also indicate the dates of the entries reviewed. Copies shall be made of the reviewed and verified entries and these copies shall be submitted to the QA Manager.

4.7.3 Completed fieldbooks, logbooks, and laboratory notebooks are considered Quality Assurance Records and these books shall be submitted to the Qa Manager as required in Section 5.0 of this procedure.

4.8 Each piece of output from an instrument, each drawing, figure, map, photograph, tape, floppy diskette, or calculation, etc., shall be signed and dated by the Preparer or Instrument Operator, and verified, signed, and dated by the Principal Investigator or Designee. The Designee shall have the necessary expertise and experience to be able to understand and verify the documentation.

4.9 Calculations developed during the research activity shall be prepared, documented, reviewed, and approved according to QAP-3.1, Calculations.

4.10 Documentation of computer software utilized in the research activity shall conform to the content of NUREG-0856, as applicable.

4.11 The adequacy of the research activity documentation shall be determined by the Project Manager, Administrator of Technical Programs, and the QA Manager.

4.12 After the research activity is completed, the Principal Investigator shall prepare a report, summarizing the results of the activity, the methods used, and the determination of whether the activity has led to the development of a governing technical procedure.

4.12.1 The Principal Investigator shall submit the summary report to the Project Manager for review. The Project Manager shall review the report and, if the report is satisfactory, shall indicate approval by signing and dating the report.

4.12.2 If the report is not satisfactory, the Project Manager shall return the report to the Principal Investigator for revision, as necessary. The Principal Investigator shall resubmit the report after making any revisions, according to Subsection 4.12.1.

4.13 The Project Manager shall submit the approved summary report to the Administrator of Technical Programs for review.

5.0 OUTPUT DOCUMENTS

5.1 The Principal Investigator or Designee shall ensure marking of the category file index designation on the records listed below, per QAP-6.1, and the transmittal of these records to the QA Manager for processing and filing in the NWPO Records Center, per QAP-17.1.

Written recommendations for activities to be classified as research activities

Research Plans

Fieldbooks, logbooks, and laboratory notebooks.

Hardcopy output for equipment/instrumentation

Drawings, maps, figures

Calculations

Photographs, videotapes

Paper tapes, magnetic media (floppy diskettes, magnetic tapes)

Optical storage media (compact discs - read-only memory)

Computer software listings and documentation

Copies of Custody of Samples and Transmittal Forms

5.2 The Principal Investigator or Designee shall ensure distribution of the above documents to the Project Manager, Administrator of Technical Programs, and others, as necessary, per the Document Distribution List of QAP-6.1.

5.4 The Principal Investigator or Designee shall maintain copies of documents on file.

6.0 REVISIONS

6.1 Revisions to the documents resulting from this procedure shall be prepared, reviewed, verified, approved, and distributed in the same manner as the original issue and in accordance with QAP-2.1 and QAP-2.2 as applicable.

6.2 Revisions may be made to a single page, several pages, or the entire document.

6.2.1 If single page revisions are made, only the revised page(s) need be issued as replacement pages.

6.2.2 Revised portions of documents shall be identified by bold-face type, except as noted in Subsection 6.2.3 of this procedure. When later revisions are made, the earlier revision indicators shall be deleted.

6.2.3 Technical documents from this procedure marked "Preliminary" or "DRAFT" may be revised without adherence to Subsections 6.1 and 6.2.2 above. Preliminary documents shall be controlled by the Preparer to prevent distribution and use before review, verification, and approval. The "Preliminary" or "DRAFT" markings shall be removed before submission for approval.

6.3 A revision summary shall be included as a part of all revised technical documents. The dated signatures of the revision Preparer, Reviewer, Verifier, and Approver shall be included as a part of the revision summary. The revision summary shall indicate the pages revised.

6.4 The Recipients of technical documents shall destroy superseded pages or mark them "VOID" or "SUPERCEDED."

7.0 REFERENCES

7.1 NWPO, 1988, Quality Assurance Manual, Sections 3.0.

7.2 NUREG-0856, Final Technical Position on the Documentation of Computer Codes for High-Level Waste Management

8.0 FLOW CHART

8.1 None

STATE OF NEVADA
AGENCY FOR NUCLEAR PROJECTS
NUCLEAR WASTE PROJECT OFFICE
TECHNICAL PROCEDURE

MTP-3.13
REVISION 1 (DRAFT 1)
June 3, 1988

TITLE: Technical Procedure for Daily Drilling Activity Summary.

APPROVED:

Project Manager

Quality Assurance Manager

Administrator of Technical Programs

1.0 PURPOSE

1.1 A record of daily drilling activity is based on individual activities, recorded by date and clock time. The NWPO/MAI Daily Drilling Activity Summary form is intended to portray the full scope of each day's activities in chronologic fashion, overlapping the time intervals as necessary. Categories of activities should be general and provide an overview of each work day.

1.2 This procedure governs the activities of Mifflin & Associates, Inc. (MAI) personnel and their subcontractors under contract to the State of Nevada, Nuclear Waste Project Office (NWPO).

2.0 DEFINITIONS

2.1 Refer to the NWPO Quality Assurance Manual Glossary for any other terms.

3.0 INTERFACING PROCEDURES

3.1 QAP-2.2, Preparation and Control of Technical Procedures.

3.2 QAP-6.1, Document Distribution List and File Index.

3.3 QAP-17.1, Quality Assurance Records.

3.4 MTP-3.01, Position Titles, Descriptions, and Minimum Qualifications.

3.5 MTP-3.12, Technical Procedure for Installation of Surface Casing in Exploratory Boreholes.

4.0 REQUIREMENTS AND ACTIVITIES

4.1 **Requirements:**

4.1.1 NWPO/MAI Daily Drilling Activity Summary form (MTP-3.13-1.).

4.1.2 Ink pens.

4.2 **Activities:**

4.2.1 The Principal Investigator or Designee shall designate and train Field Technician (minimum position requirement, see MTP-3.01) to perform activity specified in this procedure.

4.2.2 The Field Technician shall ensure that all requirements are on hand before departing for the field, drill site, or sampling site.

4.2.3 The Field Technician shall record the following information on the NWPO/MAI Daily Drilling Activity Summary form using an ink pen:

4.2.4 Beginning and ending times of each activity, and a description of each activity, shall be entered on the Daily Drilling Activity Summary form. Examples of activities include: drilling, welding casing, rig maintenance, etc. Each NWPO/MAI Daily Drilling Activity Summary form shall be signed and dated by the preparer.

4.2.5 The Field Technician shall sign and date as preparer each page of the NWPO/MAI Daily Drilling Activity Summary form as completed or at end of the day.

4.2.6 Each person authorized to make entries into a notebook or onto a form shall use a separate page each day. Only one authorized person as preparer shall use any single page of a notebook or any single form.

4.2.7 Upon review and approval, the Principal Investigator or Designee shall sign and date the NWPO/MAI Daily Drilling Activity Summary form as verifier.

5.0 OUTPUT DOCUMENTS

5.1 The Principal Investigator or Designee shall ensure marking of the category file index designation on the following documents per QAP-6.1, and transmittal of same to the QA Manager for processing and filing in the NWPO Records Center per QAP-17.1.

5.1.1 NWPO/MAI Daily Drilling Activity Summary form (Figure MTP-3.13-1.).

5.2 The Principal Investigator or Designee shall ensure distribution of copies of the above documents to the Project Manager, Administrator of Technical Programs, and to others on the Document Distribution List per QAP-6.1.

5.3 The Principal Investigator or Designee shall maintain copies of documents on file.

6.0 REVISIONS

6.1 Revisions to output documents shall be prepared, reviewed, verified, approved, and distributed in the same manner as the original issue and in accordance with QAP-6.1 and QAP-2.2 as applicable, and requirements stated in these procedures for the original documents.

6.2 Revisions may be made to a single page, several pages, or the entire document.

6.2.1 If single page revisions are made, only the revised page(s) need be issued as replacement pages.

6.2.2 Revised portions of documents shall be identified by boldface type, except as noted in Subsection 6.2.3 of this procedure. When later revisions are made, the earlier revision indicators shall be deleted.

6.2.3 Technical documents marked "Preliminary" or "DRAFT" may be revised without adherence to Subsections 6.1 and 6.2.2. above. Preliminary documents shall be controlled by the preparer to prevent distribution and use before review and approval. The "Preliminary" or "DRAFT" markings shall be removed before submission for approval.

6.3 A revision summary shall be included as part of all revised technical documents. The dated signatures of the revision preparer, reviewer, and approver shall be included as a part of the revision summary. The revision summary shall indicate the pages revised.

6.4 Recipients of revised technical documents shall destroy superseded pages or mark them "VOID" or "SUPERSEDED".

7.0 REFERENCES

7.1 NWPO, 1988, Quality Assurance Manual, Section 3.0.

7.2 MRP-1.0, Research Plan for Vadose Zone Drilling at or near Yucca Mountain.

8.0 FLOW CHART

8.1 None.

STATE OF NEVADA
AGENCY FOR NUCLEAR PROJECTS
NUCLEAR WASTE PROJECT OFFICE
Mifflin and Associates, Inc.
Las Vegas, Nevada

MTP-3.13-1

DAILY DRILLING ACTIVITY SUMMARY

Borehole ID ______
sheet _____ of _____

MAI job no. ________

Project Name:
Location:
Client:
Date:

Contractor:
Equipment type:
Driller and crew:
MAI crew:

Item	Description	Time From	Time To	See Note	Unit	Quantity	Rate	Amount

notes: weather: description of site:

signed Preparer: Date:
signed Verifier: for Mifflin and Associates, Inc. Date: for Contractor Date:

distribution: original to office, copy 1 to contractor, copy 2 remains in the field book.

Figure MTP-3.13-1.

Appendix A-V

Drilling Permits from BLM

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
LAS VEGAS DISTRICT OFFICE
4765 Vegas Drive
P.O. Box 26569
Las Vegas, Nevada 89126

TAKE PRIDE IN AMERICA

IN REPLY REFER TO:

N-48327
2800
(NV-050.1)

JUL 2 8 1988

CERTIFIED MAIL NO. 13969
RETURN RECEIPT REQUESTED

Mifflin & Associations
2700 E. Sunset Rd C-25
Las Vegas, NV 89120

Gentlemen:

Enclosed is a copy of Mifflin & Associates R/W grant (serial number N-48327) which has been approved by the Bureau of Land Management along with a receipt for the rental and monitoring payments thereto.

Sincerely,

Charles Frost
for Ben F. Collins
District Manager

2 Enclosures
1. Right-of-Way Grant
2. Receipt

Form 2800-14
(August 1985)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
RIGHT-OF-WAY GRANT/TEMPORARY USE PERMIT

Issuing Office
Las Vegas District
Serial Number
N-48327

1. A (right-of-way) (permit) is hereby granted pursuant to:

   a. /X/ Title V of the Federal Land Policy and Management Act of October 21, 1976 (90 Stat. 2776; 43 U.S.C. 1761);

   b. /_/ Section 28 of the Mineral Leasing Act of 1920, as amended (30 U.S.C. 185);

   c. /_/ Other (describe) ______________________.

2. Nature of Interest:

   a. By this instrument, the holder Mifflin & Associates receives a right to construct, operate, maintain, and terminate a Right-of-Way for site characterization studies on public lands (or Federal land for MLA Rights-of-Way) described as follows:

      T. 13S., R. 49E., section 32, SE¼NW¼NW¼. (Site III)
      T. 14S., R. 49E., section 8, SE¼NW¼NW¼. (Site IV)

      A map showing the location of the right-of-way is on file with the Bureau of Land Management, Las Vegas District (N-48327).

   b. The right-of-way or permit area granted herein is 150 feet wide, 10 feet long and contains 0.03 acres, more or less. If a site type facility, the facility contains 4.0 acres.

   c. This instrument shall terminate on July 27, 1998, 10 years from its effective date unless, prior thereto, it is relinquished, abandoned, terminated, or modified pursuant to the terms and conditions of this instrument or of any applicable Federal law or regulation.

   d. This instrument /X/ may /_/ may not be renewed. If renewed, the right-of-way or permit shall be subject to the regulations existing at the time of renewal and any other terms and conditions that the authorized officer deems necessary to protect the public interest.

   e. Notwithstanding the expiration of this instrument or any renewal thereof, early relinquishment, abandonment, or termination, the provisions of this instrument, to the extent applicable, shall continue in effect and shall be binding on the holder, its successors, or assigns, until they have fully satisfied the obligations and/or liabilites accruing herein before or on account of the expiration, or prior termination, of the grant.

3. Rental:

For and in consideration of the rights granted, the holder agrees to pay the Bureau of Land Management fair market value rental as determined by the authorized officer unless specifically exempted from such payment by regulation. Provided, however, that the rental may be adjusted by the authorized officer, whenever necessary, to reflect changes in the fair market rental value as determined by the application of sound business management principles, and so far as practicable and feasible, in accordance with comparable commercial practices.

4. Terms and Conditions:

a. This grant or permit is issued subject to the holder's compliance with all applicable regulations contained in Title 43 Code of Federal Regulations parts 2800 and 2880.

b. Upon grant termination by the authorized officer, all improvements shall be removed from the public lands within 120 days, or otherwise disposed of as provided in paragraph (4)(d) or as directed by the authorized officer.

c. Each grant issued pursuant to the authority of paragraph (1)(a) for a term of 20 years or more shall, at a minimum, be reviewed by the authorized officer at the end of the 20th year and at regular intervals thereafter not to exceed 10 years. Provided, however, that a right-of-way or permit granted herein may be reviewed at any time deemed necessary by the authorized officer.

d. The stipulations, plans, maps, or designs set forth in Exhibit(s) A, dated July 28, 1988, attached hereto, are incorporated into and made a part of this grant instrument as fully and effectively as if they were set forth herein in their entirety.

e. Failure of the holder to comply with applicable law or any provision of this right-of-way grant or permit shall constitute grounds for suspension or termination thereof.

f. The holder shall perform all operations in a good and workmanlike manner so as to ensure protection of the environment and the health and safety of the public.

IN WITNESS WHEREOF, The undersigned agrees to the terms and conditions of this right-of-way grant or permit.

[signature]	[signature]
(Signature of Holder)	(Signature of Authorized Officer)
President, M. + Flin + Assoc Inc	Acting District Manager
(Title)	(Title)
July 21, 1988	July 28, 1988
(Date)	(Date)

EXHIBIT A
SPECIAL STIPULATIONS
N-418327

1. Holder shall clearly mark the exterior boundaries of the right-of-way. All activities directly or indirectly associated with construction or maintenance on this right-of-way must be conducted within the boundaries thereof.

2. If cultural resources are discovered during operations under this grant, the Holder shall immediately bring them to the attention of the Authorized Officer. The Holder shall not disturb such resources except as may be subsequently authorized. Within two working days of notification, the Authorized Officer will evaluate or have evaluated any cultural resources discovered and will determine if any action may be required to protect cultural resources discovered. The cost of data recovery for cultural resources discovered during operations shall be borne by the BLM unless otherwise specified by the Authorized Officer of the BLM. All cultural resources shall remain under the jurisdiction of the United States until ownership is determined under applicable law.

3. Holder shall comply with the applicable Federal and State laws and regulations concerning the use of pesticides (i.e., insecticides, herbicides, fungicides, rodenticides, and other similar substances) in all activities/operations authorized under this grant. The Authorized Officer shall approve a written plan prior to the use of such substances. The plan must provide the type and quantity of material to be used; the pest, insect and fungus to be controlled; the method of application; the location of or storage and disposal of containers; and other information that the Authorized Officer may require. The plan should be submitted no later than December 1 of any calendar year that covers the proposed activities for the next fiscal year (i.e., December 1, 1988, deadline for a fiscal year 1990 action). Emergency use of pesticides may occur. The use of substances on or near the right-of-way shall be in accordance with the approved plan. A pesticide shall not be used if the Secretary of the Interior has prohibited its use. A pesticide shall be used only in accordance with its registered uses and within other limitations if the Secretary has imposed limitations. Pesticides shall not be permanently stored on public lands authorized for use under this grant.

4. The BLM retains the right ot occupy and use the right-of-way, and to issue or grant rights-of-way or other land uses for other purposes, upon, over, under, and through the lands, provided that the occupancy and use will not unreasonably interfere with the rights granted herein.

5. No hazardous materials will be disposed of on public lands.

6. All desert tortoise found in area where their continued presence constitutes a hazard to themselves, will be removed to a safe shady area (at least 150 yards from surface disturbance). Construction personnel will be informed that collection of tortoises is prohibited and punishable by a minimum $100,000 fine.

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
LAS VEGAS DISTRICT OFFICE
4765 Vegas Drive
P.O. Box 26569
Las Vegas, Nevada 89126

TAKE PRIDE IN AMERICA

IN REPLY REFER TO:
N-48282
2800
(NV-050.1)

CERTIFIED MAIL NO. 13968
RETURN RECEIPT REQUESTED

JUL 28 1988

Mifflin & Associates
2700 E. Sunset Rd. C-25
Las Vegas NV 89120

Gentlemen:

Enclosed is a copy of Mifflin & Associates R/W grant (serial number 48282) which has been approved by the Bureau of Land Management along with a receipt for the rental and monitoring payments thereto.

Sincerely,

Charles Grant

for Ben F. Collins
District Manager

2 Enclosures
1. Right-of-Way Grant
2. Receipt

Form 2800-14
(August 1985)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
RIGHT-OF-WAY GRANT/TEMPORARY USE PERMIT

| Issuing Office
| Las Vegas District
| Serial Number
| N-48282

1. A (right-of-way) (permit) is hereby granted pursuant to:

a. /X/ Title V of the Federal Land Policy and Management Act of October 21, 1976 (90 Stat. 2776; 43 U.S.C. 1761);

b. /_/ Section 28 of the Mineral Leasing Act of 1920, as amended (30 U.S.C. 185);

c. /_/ Other (describe)____________________.

2. Nature of Interest:

a. By this instrument, the holder Mifflin & Associates receives a right to construct, operate, maintain, and terminate a right of way for site characterization studies on public lands (or Federal land for MLA Rights-of-Way) described as follows:

Mount Diablo Meridan
T14S., R.48E., Section 35, SE¼NE¼,
SE¼NW¼.

A map showing the location of the right-of-way is on file with the Bureau of Land Management, Las Vegas District (N-48282).

b. The right-of-way or permit area granted herein is 10' feet wide, 7,920 feet long and contains 1.82 acres, more or less. If a site type facility, the facility contains 3.0 acres.

c. This instrument shall terminate on July 27, 1998, 10 years from its effective date unless, prior thereto, it is relinquished, abandoned, terminated, or modified pursuant to the terms and conditions of this instrument or of any applicable Federal law or regulation.

d. This instrument /X/ may /_/ may not be renewed. If renewed, the right-of-way or permit shall be subject to the regulations existing at the time of renewal and any other terms and conditions that the authorized officer deems necessary to protect the public interest.

e. Notwithstanding the expiration of this instrument or any renewal thereof, early relinquishment, abandonment, or termination, the provisions of this instrument, to the extent applicable, shall continue in effect and shall be binding on the holder, its successors, or assigns, until they have fully satisfied the obligations and/or liabilites accruing herein before or on account of the expiration, or prior termination, of the grant.

3. Rental:

For and in consideration of the rights granted, the holder agrees to pay the Bureau of Land Management fair market value rental as determined by the authorized officer unless specifically exempted from such payment by regulation. Provided, however, that the rental may be adjusted by the authorized officer, whenever necessary, to reflect changes in the fair market rental value as determined by the application of sound business management principles, and so far as practicable and feasible, in accordance with comparable commercial practices.

4. Terms and Conditions:

a. This grant or permit is issued subject to the holder's compliance with all applicable regulations contained in Title 43 Code of Federal Regulations parts 2800 and 2880.

b. Upon grant termination by the authorized officer, all improvements shall be removed from the public lands within 120 days, or otherwise disposed of as provided in paragraph (4)(d) or as directed by the authorized officer.

c. Each grant issued pursuant to the authority of paragraph (1)(a) for a term of 20 years or more shall, at a minimum, be reviewed by the authorized officer at the end of the 20th year and at regular intervals thereafter not to exceed 10 years. Provided, however, that a right-of-way or permit granted herein may be reviewed at any time deemed necessary by the authorized officer.

d. The stipulations, plans, maps, or designs set forth in Exhibit(s) A, dated July 28, 1988, attached hereto, are incorporated into and made a part of this grant instrument as fully and effectively as if they were set forth herein in their entirety.

e. Failure of the holder to comply with applicable law or any provision of this right-of-way grant or permit shall constitute grounds for suspension or termination thereof.

f. The holder shall perform all operations in a good and workmanlike manner so as to ensure protection of the environment and the health and safety of the public.

IN WITNESS WHEREOF, The undersigned agrees to the terms and conditions of this right-of-way grant or permit.

[signature]	[signature]
(Signature of Holder)	(Signature of Authorized Officer)
President M. Heflin & Assoc Inc	Acting District Manager
(Title)	(Title)
July 21, 1988	July 28, 1988
(Date)	(Date)

EXHIBIT A
Special Stipulations
N-48282

1. Holder shall clearly mark the exterior boundaries of the right-of-way. All activities directly or indirectly associated with construction or maintenance on this right-of-way must be conducted within the boundaries thereof.

2. If cultural resources are discovered during operations under this grant, the Holder shall immediately bring them to the attention of the Authorized Officer. The Holder shall not disturb such resources except as may be subsequently authorized. Within two working days of notification, the Authorized Officer will evaluate or have evaluated any cultural resources discovered and will determine if any action may be required to protect cultural resources discovered. The cost of data recovery for cultural resources discovered during operations shall be borne by the BLM unless otherwise specified by the Authorized Officer of the BLM. All cultural resources shall remain under the jurisdiction of the United States until ownership is determined under applicable law.

3. Holder shall comply with the applicable Federal and State laws and regulations concerning the use of pesticides (i.e., insecticides, herbicides, fungicides, rodenticides, and other similar substances) in all activities/operations authorized under this grant. The Authorized Officer shall approve a written plan prior to the use of such substances. The plan must provide the type and quantity of material to be used; the pest, insect and fungus to be controlled; the method of application; the location of or storage and disposal of containers; and other information that the Authorized Officer may require. The plan should be submitted no later than December 1 of any calendar year that covers the proposed activities for the next fiscal year (i.e., December 1, 1988, deadline for a fiscal year 1990 action). Emergency use of pesticides may occur. The use of substances on or near the right-of-way shall be in accordance with the approved plan. A pesticide shall not be used if the Secretary of the Interior has prohibited its use. A pesticide shall be used only in accordance with its registered uses and within other limitations if the Secretary has imposed limitations. Pesticides shall not be permanently stored on public lands authorized for use under this grant.

4. The BLM retains the right to occupy and use the right-of-way, and to issue or grant rights-of-way or other land used for other purposes, upon, over, under, and through the lands, provided that the occupancy and use will not unreasonably interfere with the rights granted herein.

5. No hazardous materials will be disposed of on public lands.

6. All desert tortoise found in areas where their continued presence constitutes a hazard to themselves, will be removed to a safe shady area (at least 150 yards form surface disturbance). Construction personnel will be informed that collection of tortoises is prohibited and punishable by a minimum $ 100.00 fine.

7. Trenches, shafts, and bores shall be marked, fences, or otherwise protected so as not to constitute a hazard to the public or to wildlife.

8. Core holes or wells containing potentially usable water should be left in a manner which facilitates their development as water sources and prior to termination of the agreement or abandonment of the holes/wells, MAI will consult with BLM to determine if they will be sealed and capped, plugged back, or turned over to the BLM as is.

9. The District Manager, Las Vegas District Office, Las Vegas, Nevada, shall act as a BLM's authorized officer for implementation of this right-of-way reservation.

Section B

Climate Change Program

Climate Change Program

Introduction

The State of Nevada recognizes that the climate-change issue for Yucca Mountain is complex and critical to repository performance under the regulatory requirements (see: 10CFR60.112, .113, .122(c)(23)). A conservative analysis of the existing database indicates that several of the Potentially Adverse Conditions (10CFR 960.4-2-4(c) (2)) exist:

> "Evidence that the climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and the surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment."

Vadose-zone changes in response to climates with increased effective moisture would conservatively include increases in the hydraulic conductivity (due primarily to greater degrees of fracture flow) and ground-water flux (due to marked increases of infiltration). The database suggests increased local saturation (perched water) and a rise in the position of the water table. The Qualifying Condition (10CFR960.4-2-4(a)) states:

> "The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in 960.4-1. In predicting the likely future climatic conditions at a site, the DOE will consider the global, regional and site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting."

Licensing criteria therefore recognize the potential adverse impacts that a climate change may have on site hydrology. The vadose-zone repository, by its very position in the hydrologic system, is an environment that is potentially subject to significant hydrologic change if the climate changes. An increase in effective moisture (moisture from precipitation which escapes evapotranspiration and is either rejected as surface-water runoff or infiltrates as ground-water recharge) is caused by a climate change to either greater precipitation or lower temperature, or a combination of both. The present Great Basin arid and semiarid climates are such that most precipitation is lost to evapotranspiration in many environments. However, on both a short-term and long-term basis, relatively small deviations from the normal climatic conditions can markedly impact the hydrology by producing more or less effective moisture. There is abundant paleohydrologic evidence in the Great Basin of past climates which produced significant increases in effective moisture during the Quaternary.

The vadose-zone position of the repository over a 10,000 year period of performance with potentially differing moisture conditions is a key issue. The best available evidence indicates that a climate change to a pluvial climate (more effective moisture for runoff and infiltration) is likely to occur within the next 10,000 years. The climate of the last pluvial period in the Great Basin, and its associated hydrologic impact, is the most reasonable pluvial climate and hydrology likely to occur in the next 10,000 years. The increased availability of effective moisture for infiltration due to a pluvial climate may markedly increase the vadose-zone flux, increase the extent of local perched saturation, establish a shallower position of the regional water table, and cause new patterns of ground-water flow and ground-water discharge. As these factors directly affect waste isolation, the fundamentally important climate-change issue must be fully explored in establishing the performance of the proposed repository at Yucca Mountain. Appendix B-I established a Nevada draft technical position on the climate-change issue.

The DOE, in dealing with climate-change issue in their Environmental Assessment of the Yucca Mountain site, interpreted that the available data indicated that there would be no significant impact on the repository performance. Our response to this theme is found in Appendix B-II.

Both site-specific and regional analyses are necessary to confidently characterize the pluvial hydrology of Yucca Mountain. Ideally, hydrologic evidence demonstrating the conditions of saturation and flux in the vadose zone of Yucca Mountain during the past pluvial climate should be based on site-specific data. These data should be distributed to confidently assess the heterogeneity of both the subsurface and the surficial or near-surface hydrogeologic environments that give rise to varied infiltration rates and percolation paths. Unfortunately, only a few techniques are recognized that may establish site-specific information on the paleohydrologic conditions, and these are unproven at this time. Therefore, regional analyses, using proven methodologies, must refine and constrain anticipated uncertainties represented by the site-specific evidence.

Confident assessment of the site-specific pluvial hydrologic conditions in the vadose zone at Yucca Mountain constitutes a research challenge. Even confidently characterizing the existing hydrology of the vadose zone at the site is yet to be achieved after years of characterization activities. The climate-change issue is recognized as one of the most fundamental questions for waste isolation over protracted time, and the State of Nevada oversight effort has incorporated several activities designed to further explore this issue:

I. Investigate the site-specific authigenic mineral assemblages in the vadose zone, particularly those associated with fractures, in an attempt to determine the history and perhaps (technique development necessary) timing of fracture flow. Also, on the basis of plant macrofossils from packrat middens, determine the available record of the last 50,000 years of vegetative cover in the general area of Yucca Mountain.

II. Investigate the regional paleohydrologic evidence within the surrounding basins (such as the extent of late Pleistocene pluvial lakes as indicated by the associated lacustrine deposits) and basin deposits related to former areas of ground-water discharge.

III. Investigate the long-term paleohydrologic record within the Yucca Mountain drainage basin (Amargosa River) as recorded by the Tecopa "Lake Beds".

IV. On the basis of the above investigations, establish the order of magnitude of the increase in pluvial climate vadose-zone flux, the distribution of ground-water discharge, the position and extent of perched water, the former position of the water table (paleowater table), and the increase in fracture flow within the vadose zone that would attend a shift in climate to a full pluvial climate.

Climate Change

ISSUE:

Key Issue:

Will the proposed repository in the vadose zone at Yucca Mountain provide the required waste isolation for the 10,000 year period after emplacement if the climate changes to a full pluvial climate of the Quaternary?

OBJECTIVE OF ACTIVITY:

Establish the paleohydrologic history of the Quaternary in the Amargosa River drainage basin (which includes Yucca Mountain) through the study of the "Lake Tecopa" deposits.

ACTIVITY SUMMARY:

A field study of the Tecopa "Lakes beds" is being made in an attempt to establish the history of lake cycles and their associated extents in the Tecopa basin during the Quaternary. The study includes basinwide stratigraphic studies of the exposed basin deposits, using volcanic ashes (and remnant magnetism) for marker horizons and dating.

FINDINGS:

The exposures indicate several high standing lakes occupied the Tecopa basin during the Quaternary. The well-exposed stratigraphic record is estimated to include most of the Quaternary, extending from greater than 2 millions years B.P. to perhaps about 250,000 years B.P. The maximum extents of the larger lakes suggest former basin closure significantly higher than the apparent closure offered by the terrane at the south end of the basin, and there are tufa deposits indicating zones of former spring discharge on both sides of the basin. Those on the east side occur high on the basin flank.

INTERPRETATION OF FINDINGS:

In general, the maximum (highest recognized) lake extent seems too large for the Amargosa River catchment basin and associated effective moisture (hydrologic index, Mifflin and Wheat, 1979) when compared to the late Pleistocene pluvial-lake hydrologic indices of the adjacent Great Basin region. Preliminary regional correlation with other long climatic records do not seem particularly close (see Appendices B-III and B-IV).

ADDITIONAL WORK REQUIRED:

Refinement of the stratigraphic positions of previously determined magnetic reversals and identified ash beds as well as more detailed analyses of the origin of carbonate units will increase the confidence level in the pluvial-lake cycle history. In addition, more work on the tectonic history of the basin and surrounding region may establish the reason for the anomalous size of the ancient lakes and the poor correlations with other long records of the region.

RECOMMENDED PROGRAM:

The dating control on the exposed sequences needs to be refined. Morrison's careful stratigraphic work, including marker units, needs to be firmly tied to previously establish magnetic profiles and ash identifications. Areas that may have been formerly integrated with the Amargosa River basin should be examined for evidence of connection, such as Pahrump Valley. Careful comparative regional correlations of the pluvial cycles, including careful reviews of previous work in the Searles Lake basin and the Great Basin, are warranted.

EXISTING PROGRAM:

A modest level of field-data reduction and analysis, and an effort to confidently tie the established magnetic-reversal sections and dated ashes into the stratigraphic sequences established by R. B. Morrison is underway for the 1989 effort.

Principal Investigator

Dr. R. B. Morrison (MAI consultant) .

Climate Change

ISSUE:

Key Issue:

Will the proposed repository in the vadose zone at Yucca Mountain provide the required waste isolation for the 10,000 year period after emplacement if the climate changes to a full pluvial climate of the Quaternary?

OBJECTIVE OF ACTIVITY:

Determine the approximate magnitude of the increase in ground-water recharge/discharge in the region surrounding Yucca Mountain that corresponds to full pluvial climates such as those experienced between 20,000 yrs. B.P. and 11,000 yrs. B.P. Also, establish the associated changes in pattern of ground-water discharge and water-table position in the areas of former ground-water discharge.

ACTIVITY SUMMARY:

The basin deposits that relate to the former extents of ground-water discharge are being studied and mapped on either a reconnaissance basis or a detailed basis in terms of distribution, age, and details of depositional environments and associated ecology. In addition, modern-analog environments of ground-water discharge have been studied to verify interpretations of former depositional environments based on the sedimentological and faunal records. On the basis of these data of extent and type of discharge, quantitative comparisons will be made with respect to the associated ground-water discharge, water levels, and flow patterns now present.

FINDINGS:

A number of areas of former ground-water discharge have been recognized and studied in southern Nevada and adjacent areas of California. All of these areas extend well beyond areas of current ground-water discharge. Some have no current discharge, whereas other areas have residual, but much diminished, discharge still occurring. In general, there has been established clear evidence of important changes in the distribution and amount of ground-water discharge, and major changes in the position of saturation. Some deposits have been confidently radiocarbon dated back to approximately 15,000 years, and the general patterns of discharge are understood for the areas mapped in detail. Ground-water levels have declined in some areas by over 100 m. Appendices B-V and B-VI are reports that summarize some of the results from these efforts.

INTERPRETATION OF FINDINGS:

The extents and character of the ground-water discharge areas indicate that effective moisture, in a regional sense, was significantly greater during the last major pluvial climate as well as earlier pluvial climates. A preliminary evaluation suggests that the magnitude of increase in ground-water discharge over modern discharge is similar to the regional increase of effective moisture indicated by Great Basin pluvial-lake hydrologic indices. Mifflin and Wheat (1979) found effective moisture to be about one order of magnitude greater than that indicated by modern lake indices in the Great Basin region. Should this quantitative relationship be affirmed by additional studies of the paleoground-water discharge areas, it suggests that a full pluvial climate would, in a regional sense, increase the ground-water recharge and discharge rates over modern rates by about 10 times. This increase in recharge rate would tend to greatly decrease travel times in the vadose zone by forcing fracture flow to increase proportionally. The release rates of radionuclides from the repository would also proportionally increase due to the rapidity of travel time within the vadose zone, the only possible geologic barrier offering the possibility of long travel times (matrix flow only).

ADDITIONAL WORK REQUIRED:

Several areas warrant additional field studies, either detailed mapping and sampling or reconnaissance mapping and sampling. These include Coyote Springs Valley and possibly Garden Valley and Hot Creek Valley. The latter two basins occur in the region of the Great Basin normally characterized by pluvial lake deposits rather than ground-water discharge deposits. These areas may give an opportunity to compare ground-water discharge rates of pluvial climate in the higher basin of central Nevada. In addition, careful analyses of the modern ground-water conditions in terms of water-table position and flow are needed for each studied area of former ground-water discharge.

A third area of study is directed towards establishing reliable temperature indicators for the full pluvial climate. One method to establish estimates of former ground-water discharge rates requires annual temperature estimates for evapotranspiration rates. Several approaches using stable isotopes are under investigation, and considerable progress is being made in the use of soil carbonates (see Appendix B-VII).

RECOMMENDED PROGRAM:

The climate-change analyses planned in the DOE characterization studies do not approach the pluvial climate ground-water recharge rate change issue from the above perspective. Therefore, the Nevada program should include:

Reconnaissance mapping of all areas of ground-water discharge deposits in the regions surrounding Yucca Mountain, including enough detailed studies and sampling to establish age relationships,

Detailed mapping and sampling studies in the areas with favorable exposures to allow for ground-water discharge estimates,

Stable isotope studies designed to increase the confidence of establishing paleoclimate temperatures, and

Ground-water analyses of water-table position changes, and estimated total flux changes based on flow net analyses in the areas of ground-water discharge deposits.

EXISTING PROGRAM:

Field work and analytical efforts have been reduced due to budget constraints. The present program is analytical work on areas already studied and limited field work at Coyote Springs Valley (see Appendix B-VI). In addition, ground-water data that are available in each area are being assembled. Sampling of buried paleosoil carbonates is planned.

Principal Investigators:

Mr. J. Quade (MAI and University of Utah); Dr. T. E. Cerling (University of Utah); Dr. J. D. Bowman (University of Utah); and Dr. M. D. Mifflin. (MAI).

Reference:

Mifflin, M. D. and M. Wheat, 1979, Pluvial lakes and estimated pluvial climates of Nevada: Nevada Bureau of Mines and Geology, Bull. 94, 57 p.

Climate Change

ISSUE:

Key Issue:

Will the proposed repository in the vadose zone of Yucca Mountain provide the waste isolation required for the 10,000 year period after emplacement if the climate changes to the pluvial climates of Quaternary.

OBJECTIVE OF ACTIVITY:

Establish the site specific evidence, if present, for shallow saturation in the vicinity of Yucca Mountain that may be preserved as macrofossils and pollen from past communities of phreatophytic plants.

ACTIVITY SUMMARY:

Reconnaissance search, sampling, and analyses of packrat middens were made in a scoping effort to establish the feasibility of locating, collecting, and analyzing packrat middens to determine the existence and timing of former areas of phreatophytic vegetation. Phreatophytes are plants with deep root systems that tap near-surface saturation in arid and semiarid climates.

FINDINGS:

The study indicates that macrofossils of phreatophytic vegetation occur in at least one midden collected near Fortymile Canyon. Packrat midden sampling near areas of former ground-water discharge in basin lowlands may not be feasible due to the absence of favorable terrane for midden preservation in the low relief areas. Analytical results to date demonstrate plant macrofossils indicative of former moist subsurface conditions in a section of Fortymile Canyon.

INTERPRETATION OF FINDINGS:

The method has the potential to demonstrate the presence and timing (within the last 50,000 years) of areas of shallow saturation on a site specific basis at and around Yucca Mountain. Because of the requirement for rugged terrane that provides stable rock overhangs and fissures for the preservation of ancient middens, it is not as useful in many bolson areas where the former extent and timing of ground-water discharge has been documented and dated by other criteria.

ADDITIONAL WORK REQUIRED:

A careful sampling and associated analysis of packrat middens needs to be made along and around all terrane features which are plausible sites of former seeps, springs, or streams in and around Yucca Mountain. In addition, all bedrock terrane closely adjacent to known or suspected areas of paleoground-water discharge areas in the region should also be sampled. Stable isotope studies of plant macrofossils may prove useful in characterizing soil moisture/ground-water isotopic signatures. More scoping work is required to test this approach. Appendices B-VIII and B-IX are reports that discuss and interpret the findings within the context of previous work and regional relationships.

RECOMMENDED PROGRAM:

The magnitude of the needed program is such that staged studies are most appropriate, concentrating sequentially on either areas or terrane features, and refining the field collection focus on the basis of analytical results.

EXISTING PROGRAM:

Analytical work on the scoping-study middens (determination of macrofossils of plants and animals and pollen) and development of quality-assurance procedures constitutes the existing program. Budgeting constraints have prevented the expanded sampling and analytical studies since the feasibility of the approach has been established.

Principal Investigator:

Dr. W. G. Spaulding (University of Washington).

Appendix B

Climate Change Program

List of Appendices

B-I Draft Technical Position on Climate Change by Mifflin & Associates, Inc.

B-II Response to the DOE-EA on Climate Change by Mifflin & Associates, Inc.

B-III Quaternary NonGlacial Geology: Conterminous U. S., DNAG, vol. K-2, 16 March 1989 by R. B. Morrison.

B-IV Excerpts from Progress Report on the Lake Tecopa Project for fiscal Year 1987 - 1988, 06 November 1988 by R. B. Morrison.

B-V Progress Report -Groundwater Discharge Deposits by J. Quade.

B-VI Late Wisconsin Ground-Water Discharge Environments of the Southwestern Indian Springs Valley, Southern Nevada by J. Quade and W. L. Pratt.

B-VII Systematic variations in del^{13}C and del^{18}O of soil carbonate along elevation transects in the southern Great Basin, USA by J. Quade and T. Cerling.

B-VIII Paleohydrology and Paleoclimate of the Yucca Mountain Area by W. G. Spaulding.

B-IX The Paleohydrology and Paleoenvironments in the Vicinity of the Proposed Yucca Mountain Nuclear Waste Repository by W. G. Spaulding.

Appendix B-I

Draft Technical Position on Climate Change by Mifflin & Associates, Inc.

Draft Technical Position on Determination of the Plenipluvial Climatic Conditions to Evaluate Adverse Climate Change Impacts for the Proposed Yucca Mountain High-Level Nuclear Waste Repository.

1.0 Purpose.

This document presents site-specific objectives and approaches for determining the plenipluvial hydrologic changes in the hydrogeology at Yucca Mountain so the impacts on repository performance can be judged for licensing purposes.

2.0 Regulatory Framework.

The State of Nevada recognizes that the climate change issue for Yucca Mountain is complex and key with respect to repository performance under the regulatory requirements (see: 10CFR60.112, .113, .122(c)(23)). A conservative analysis of the existing data base indicates that several of the Potentially Adverse Conditions (10CFR 960.4-2-4(c)(2)) exist:

> "Evidence that the climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and the surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment."

Vadose zone changes in response to the plenipluvial climate would conservatively include important perturbations in the hydraulic conductivity (due to a greater degree of fracture flow) and ground-water flux (due to markedly increased effective moisture). The data base is less clear with respect to increased local saturation (perched water) and the change in the position of the water table. The Qualifying Condition (10CFR960.4-2-4(a)) states:

> "The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in 960.4-1. In predicting the likely future climatic conditions at a site, the DOE will consider the global, regional and site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting."

The proposed vadose-zone repository in fractured volcanic tuff would occupy an environment that is sensitive to changes in climate and the associated changes in effective moisture (changes in the amount of precipitation that is either rejected as runoff or accepted as infiltration). In the fractured rock terrane of Yucca Mountain, increased infiltration of effective moisture would result in potential increases in ground-water flux through the repository horizon and increasingly significant fracture flow, which is believed to be several orders of magnitude more rapid than matrix flow. The aridity of the current climate creates the potential for a small flux of infiltrated effective moisture (but as yet it has not been site-specifically demonstrated as to how small the flux is, and what proportions of the flux percolate as matrix flow and as fracture flow).

3.0 Issue.

The Yucca Mountain repository performance in terms of waste isolation is highly dependent upon the flux rate and distribution of moisture in the vadose zone (that zone which is commonly called the unsaturated zone, where hydraulic continuity over broad areas does not exist because of discontinuous saturation). The waste-containment concept of the Yucca Mountain repository is that of little or no flux of moisture through the vadose zone due to the aridity of the climate, and that flux which does occur is primarily in the very low-permeability rock matrix. The repository is positioned above the regional zone of saturation.

Licensing criteria (section 2.0, above) recognize the potential impacts that a climate change may have on site hydrology. The vadose-zone repository, by its very position in the hydrologic system, is an environment that is potentially subject to significant hydrologic changes if the climate changes. An increase in effective moisture (moisture from precipitation which escapes evapotranspiration and is either rejected as surface-water runoff or infiltrates as ground-water recharge) caused by a climate change to greater precipitation, lower temperature, or a combination of both, will produce greater effective moisture. The Great Basin arid and semi-arid climates are such that most precipitation is lost to evapotranspiration in many environments. However, on both a short-term and long-term basis, relatively small deviations from the normal climatic conditions can markedlv impact the hydrology by producing more or less effective moisture. There is abundant paleohydrologic evidence in the Great Basin of past climates which produced significant increases in effective mositure during the Quaternary.

The vadose zone of Yucca Mountain is likely to be immediately impacted bv any short or long-term climatic changes which produce a change in the rate of infiltration, as rate of travel of infiltrated moisture via fracture networks is measured in months or years. The vadose-zone position of the repository creates a key issue with respect to climate change in the forthcoming 10,000 years, the required period of assured waste containment. The best evidence available indicates that a climate change toward a pluvial climate (more effective moisture for runoff and infiltration) is likely to occur in the future. The State of Nevada currently accepts that the last major pluvial climate to occur in the Great Basin is a reasonable measure of the degree of future climate change to anticipate for future pluvial climates of the Great Basin during the forthcoming 10,000 years. Therefore, the paleoclimate and associated paleohydrology of the last pluvial climate, indicative of the magnitude of increase in effective moisture over that which occurs in the modern climate, is a currently accepted measure of climatic and hydrologic conditions under which the site should successfully isolate the repository waste with respect to standards of radionuclide releases and other performance criteria.

The State of Nevada recognizes that the increased availability of effective moisture for infiltration due to the plenipluvial climate may markedly increase the vadose zone flux, the extent of local perched saturation, and establish a shallower position of the regional water table. As these factors directly affect waste isolation, the fundamentally important climate change issue must be fully explored in establishing the performance of the proposed repository at Yucca Mountain. Also associated are the potentials for local areas of ground-water discharge and changes in paths of flow to the accessible environment.

4.0 <u>Technical Position</u>:

The vadose zone at Yucca Mountain may be subjected to major changes in moisture regimes induced by climates producing more effective moisture. Such climates producing more effective moisture are anticipated in the future based on the past record of climatic change and associated paleo-hydrologic evidence on a regional scale in the Great Basin. Support for a vadose-zone repository in highly fractured rock is predicated upon very small moisture flux conditions and the general absence of fracture flow to ensure acceptable performance in waste isolation. Therefore, the proposed repository site must be confidently demonstrated in site characterization studies to not have been subjected to the following conditions during the plenipluvial climates:

I. Extensive or dominance of fracture flow;

II. Extensive zones of perched water;

III. Water-table rise sufficient to flood the repository zone; and

IV. Markedly shortened flow paths from the repository horizon to the accessible environment.

Both site-specific and regional analyses are necessary to confidently characterize the plenipluvial hydrology of Yucca Mountain. Part of the evidence to demonstrate the absence of the above conditions during the past plenipluvial climate must be based on site-specific data and be distributed to confidently assess the heterogeneity of both the subsurface and the surficial or near-surface hydrogeologic environments that could give rise to varied infiltration rates and percolation paths. At least two investigative objectives are appropriate for site-specific evaluations at Yucca Mountain:

I. Establish the site-specific distributions, concentrations, conditions of genesis, and age relationships of secondary minerals in the fractures and rock matrix to characterize the past hydrologic regimens operating in the vadose zone.

II. Establish the climatic conditions of the plenipluvial climate at Yucca Mountain and immediately surrounding terrane through comprehensive sampling and analysis of the site-specific evidence (fossil plant remains, paleosol, surficial deposits, and landform evidence).

In order to confidently evaluate the available site-specific data, regional analyses also must be established to refine and constrain anticipated uncertainties represented by the site-specific evidence. The following regional analyses currently are recognized as necessary to establish:

I. Regionalized characterization of ground-water flux during the plenipluvial climate. Regional scope should include ground-water flow systems within and proximal to the NTS region.

II. Distribution of plenipluvial ground-water discharge and associated positions of shallow saturation. Regional scope should include ground-water flow systems within and proximal to the NTS region.

III. Regionalized characterization of plenipluvial plant communities. Regional scope should include both basin and mountain range environments of south central Nevada, southern Nevada, and closely adjacent areas of California.

IV. Long-term climatic variations as recorded by the paleohydrologic evidence in hydrographically closed basins in the Great Basin.

V. Direct <u>in situ</u> analysis of vadose zone hydrology in appropriate analog environments (welded tuff terranes in plenipluvial climate settings). Position of saturation, occurrences of perched water, relative importance of fracture and matrix flow, and ground-water recharge and discharge relationships are of basic interest in the plenipluvial climate and terrane analog environments.

Appendix B-II

Response to the DOE-EA on Climate Change by Mifflin & Associates, Inc.

B. Climate Change:

Climate Change Guideline, Section 6.3.1.4 (10 CFR 960.4-2-4).

> "The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1." (DOE, 1986, vol. II, page 6-227).

Several repository-performance issues are directly related to climatic change in the southern Nevada region, since waste isolation is predicated on the aridity of the site. Evidence for paleoclimates creating significantly greater effective moisture and dramatic differences in hydrology has been recognized since the earliest 19th-century geological surveys in the Great Basin. In many currently arid basins pluvial lakes were present as recently as 10,000 years BP and ancient shoreline deposits are often easily recognized. Therefore, a vadose-zone repository in the region raises the question: Will future climatic shifts to climates similar to paleoclimates adversely affect the performance of the repository? The EA theme is that great uncertainty exists in analyses but the available data indicate no significant impact on repository performance. We believe climate change to a plenipluvial climate (significantly more effective moisture for runoff and recharge) creates repository performance issues of: 1) water-table position; 2) extent of perched water; 3) ground-water travel time in the vadose zone; 4) recharge rates; and 5) in general, the ability of the proposed repository to isolate the waste. In-depth treatments of these issues <u>within the context of existing data</u> have been avoided in the EA. We therefore focus our review on the EA postulate that has been used to avoid dealing with available quantitative estimates.

The EA (pages 6-238 and 6-239) discounts the results of preliminary modeling by Czarnecki (1985) of the potential hydrologic impacts of a pluvial climate as based on the estimate by Spaulding, et al. (1984) of 100% precipitation increase above modern values. We think the Czarnecki (1985) model is a reasonable and conservative scoping analysis. By adopting the 100% greater-than-modern precipitation and then establishing recharge by considering the Maxey-Eakin estimates for such precipitation, his model recharge rate became 15 times the modern recharge rate. Mifflin and Wheat (1979, page 46) also demonstrate at least one order of magnitude greater total effective moisture between modern climates and pluvial climates in Nevada. The 100% greater-than-modern precipitation increase in the Czarnecki (1985) model also compares reasonably well with the Mifflin and Wheat (1979) estimates (from 52% to 80% greater-than-modern).

The EA adopts the possibility mentioned in Czarnecki (1985, page 20) that two-thirds of the markedly increased moisture available for recharge in a pluvial climate (15 times modern) may constitute surface runoff. This idea was apparently developed by Rush in 1984 from comparing a newly developed Maxey-Eakin recharge estimate of 86,000 acre-ft/yr for Huntington Valley in northeast Nevada with a 30,000 acre-ft/yr discharge estimate (Rush and Everett, 1966, Table 8). However, we find little evidence to demonstrate the accuracy of the 30,000 acre-ft/yr discharge estimate or evidence for less recharge/ more runoff in that portion of the basin analogous to the Yucca Mountain terrane. The following discussion summarizes our findings.

In arid and semi-arid terrane, there are numerous factors which may influence runoff, infiltration, and net ground-water recharge. Among the most important are: 1) how the precipitation occurs in time and space; 2) the temperature regimen of the climate; 3) the hydrogeologic characteristics of the terrane, including regional transmissivity; and 4) the position of saturation with respect to closely related surface-water drainages. Mifflin (1968) discusses some of these relationships observed in Nevada, including the regional transmissivity or flow capacity of terrane and its effect on the position of saturation, recharge, discharge, and response of ground-water flow systems to climate changes. Mifflin and Wheat (1979) review factors such as the relative importance of temperature and precipitation on runoff rates and evapotranspiration, and the associated effects on hydrologic budgets for both the modern and plenipluvial climates of the Great Basin. A good understanding of these above principles and observations helps establish if the Yucca Mountain/Huntington Valley hydrologic analog is reasonable.

Huntington Valley, cited as providing suggestive evidence that two-thirds of the increased effective moisture for recharge would become surface-water runoff, is a reasonable choice in terms of a homoclimate for the plenipluvial climate of Yucca Mountain. Mifflin and Wheat (1979, pages 45 to 46), independently reached a similar conclusion based on the distribution and size of plenipluvial lakes in Nevada. However, we believe that it is not an accurate analogy in terms of basinwide hydrogeologic characteristics. The fractured volcanic tuffs of Yucca Mountain are markedly more transmissive than extensive crystalline-rocked areas of the Huntington Valley hydrographic basin. In addition, the range of terrane altitude within Huntington Valley is greater than that of the Yucca Mountain area. If both the hydrogeologic and the climatic analogies were to be accepted, the Huntington Valley analog would demonstrate that: 1) Fortymile Wash and its major tributaries experienced perennial stream flow during the plenipluvial climates; 2) regional saturation was at or near the principal drainage channel levels; and therefore 3) an important part of the repository horizon may have been in the regionally saturated zone.

To explore in more detail the EA postulate of surface-water runoff limiting recharge, Tables 1 and 2 have been included to demonstrate the importance of the hydrogeologic characteristics of terrane in the Huntington Valley hydrographic basin. Table 1 tabulates estimated ground-water recharge based on the Maxey-Eakin method, with the recharge estimates grouped based on two broad hydrogeologic terrane categories: 1) volcanic and carbonate rocks of significantly greater transmissivity than 2) low-permeability igneous and metamorphic crystalline rock terrane of the northern Ruby Mountains. The volcanic and carbonate rock types establish a closer terrane analog to the fractured tuff terrane of Yucca Mountain in terms of regional transmissivities. It should be noted that the Maxey-Eakin recharge estimate method, as applied in Table 1 to large areas (534,600 and 284,000 acre subbasins), probably results in reasonably good approximations of recharge. This may not be the case for small areas.

Table 1 demonstrates that, even though the crystalline rock terrane represents only one-third of the total basin area, it should receive a little less than one-half of the recharge according to Maxey-Eakin recharge estimates. However, Table 2 compiled by Moore, in Rush and Everett (1966), illustrates that almost 75% of the runoff from the entire basin is derived from the crystalline terrane. The more transmissive terrane, representing two-thirds of the basin and receiving nearly two-thirds of the precipitation, produces only 25% of the runoff. There are several causative

Table 1. Estimated Recharge to Huntington Valley Using the Eakin, *et al.*, (1951) Method.

(1) Ruby Mountains south of Harrison Pass, ranges on west side of Huntington Valley (volcanic and limestone bedrock).

Elevation	Acres	Average Annual Precip. (feet)	Average Annual Precip. (acre-feet)	Estimated Recharge % precip.	Estimated Recharge Acre-feet/yr.
above 8000	24,300	2.0	43,600	25	12,150
7000-8000	43,700	1.46	63,800	15	9,570
6000-7000	207,600	1.12	232,500	7	16,275
below 6000	259,000	.83	215,000	3	6,450
Totals for Area 1	534,600		554,900		44,445

(2) Ruby Mountains north of Harrison Pass (igneous and metamorphic crystalline bedrock).

Elevation	Acres	Average Annual Precip. (feet)	Average Annual Precip. (acre-feet)	Estimated Recharge % precip.	Estimated Recharge acre-feet/yr.
above 8000	47,600	2.0	95,200	25	23,800
7000-8000	34,300	1.46	50,100	15	7,515
6000-7000	50,000	1.12	56,000	7	3,920
below 6000	152,300	.83	126,400	3	3,792
Totals for Area 2	284,200		327,700		39,027
Basin Total	818,800		882,600		83,472

Table 2: Table 4 from Rush and Everett, 1966; prepared by D. E. Moore.

— Estimated average annual runoff

(Based on the years of record at South Fork Humboldt River near Elko: 1869-1909, 1910-18, 1920-22, 1923-32, 1936-63)

Mountain segment	Location	Area		Estimated runoff	
		Acres	(percent of runoff area)	(Acre-feet per year)	(percent of total runoff)
Ruby Mountains	West flank of mountains north of Harrison Pass above 6,000 feet	120,000	16	124,000	73
Ruby Mountains	West flank of mountains south of Harrison Pass above 6,000 feet	69,000	9	13,000	8
Sulphur Spring Range & Diamond Mountains	East flank of mountains on west side of valley above 6,000 feet	144,000	20	17,000	10
Valley uplands	Valley uplands below 6,000 feet, which contributes to runoff only in northern two-thirds of valley	398,000	55	16,000	9
Total (based on years of record)		731,000	100	170,000	100
(Adjusted to long-term average period 1912-63)		731,000	100	a 148,000	—

a. Of this total, 134,000 acre-feet is the runoff at the mountain front and 14,000 acre-feet is generated on the valley uplands.

factors recognized. The crystalline rock terrane has over twice as much area above 8000 feet MSL and thus receives about twice as much high-country precipitation, and much of this precipitation eventually becomes snowmelt runoff. However, the crystalline terrane also has a very limited capacity to accept and transmit this abundance of moisture available for recharge. The terrane saturates to near land surface, and rejects most of the moisture.

Farvolden (1963) was the first to demonstrate varying hydrogeologic behavior of mountainous terrane in Nevada. Dudley (1967) studied differences in runoff behavior and hydrogeology of the crystalline and carbonate rock terranes in the central Ruby Mountains, including portions of Huntington Valley. Mifflin (1968, pages 17 to 19) used the contrasting hydrogeology of carbonate and crystalline rock terrane of these same Ruby Mountains to illustrate the concept of ground-water flow capacity of terrane. Depending upon the availability of moisture for recharge and the transmissive capacity of the terrane, a saturated condition may be reached where no additional <u>net</u> ground-water recharge can occur, and the local discharge to the incised drainages and topographic depressions constitutes the excess infiltration which maintains perennial streams, as well as seeps, and springs. In the Huntington Valley drainage basin, this phenomenon is widespread in the northern Ruby Mountains crystalline-rock terrane, whereas, in the southern mountainous part underlain by carbonate rocks, there are few perennial streams, seeps or springs. Here, similar mean annual precipitation and availability of moisture for recharge does not exceed the ground-water flow capacity of the terrane, and therefore there is little local rejection of the infiltrated moisture.

Assuming that the present Huntington Valley climate represents an accurate homoclimate of plenipluvial climatic conditions for Yucca Mountain, Tables 1 and 2 provide considerable insight into the Yucca Mountain plenipluvial hydrologic conditions. First, it should be noted that the Maxey and Eakin recharge estimates of Table 1 suggest that, overall, about 10% of the estimated basin precipitation becomes recharge, or about 1.2 in/yr (30.48 mm/yr). Czarnecki (1985, page 20) presents similar conclusions for both Huntington Valley and his Yucca Mountain model. Following the Maxey-Eakin estimation method, the recharge rates within the basin vary from 0.3 in/yr (7.6 mm/yr) below 6,000 feet MSL to 6.0 in/yr (154.4 mm/yr) above 8,000 feet MSL. Thus, even the <u>lowest</u> estimated rate of recharge in the plenipluvial climate analog area markedly exceeds (by one order of magnitude) the small modern values estimated in the EA (0.5 mm). <u>It should be carefully noted that 15 x 0.5 mm/yr is equal to 7.5 mm/yr</u>. This is the source of the recharge estimate in the Czarnecki (1985) model.

Table 2 illustrates that the orders of magnitude of these recharge estimates are reasonable, if not of detailed accuracy. Note that based on streamflow measurements, 170,000 acre-feet/yr was estimated to have runoff from the basin (Table 2) from a total of 882,600 acre-feet/yr of estimated precipitation (Table 1). In summary, about 19% of the estimated precipitation becomes surface-water runoff, whereas Table 1 estimates that about 9.5% of estimated precipitation become ground-water recharge. <u>However, only about 5% of the estimated precipitation appears to become surface-water runoff in that part of the basin underlain by the carbonate and volcanic rocks</u>. We conclude that, as a very conservative minimum estimate, 5% of total estimated precipitation becomes recharge in this part of the basin;

and based on the runoff data of the crystalline terrane, up to a maximum of around 20% of total estimated precipitation may become recharge in that part underlain by carbonate and volcanic rocks. In summary, the hydrologic relationships in the Huntington Valley basin support recharge rates comparable to or greater than those estimated in Czarnecki's plenipluvial model.

We believe repository performance issues during a plenipluvial climate have not been appropriately addressed in the EA nor resolved with respect to the existing paleohydrologic evidence in the region. Available evidence indicates that recharge rates during a plenipluvial climate may greatly exceed the transmissive capacity of the rock matrix, and hence fracture flow may constitute the majority of the recharge flux in the vadose zone and zones of perched water could become extensive. If fracture flow dominates, the ground-water travel time for majority of flux through the vadose zone would be very rapid. In addition, perched zones of saturation, the site-specific position of regional saturation, and the total flux rate of recharge to the thermal envelope all become serious and unresolved repository performance issues.

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Appendix B-III

Quaternary NonGlacial Geology: Conterminous U. S., DNAG, vol. K-2,
16 March 1989 by R. B. Morrison.

K2intro 8-15-86; 12-18-88; 2-20-89; 3-16-89

DNAG VOL. K-2 "QUATERNARY NONGLACIAL GEOLOGY: CONTERMINOUS U.S."

(PREFACE)

"When the work of the geologist is finished and his final comprehensive report is written, the longest and most important chapter will be on the latest and shortest of the geological periods."

Grove Karl Gilbert, 1890, p. 1

INTRODUCTION

Roger B. Morrison

This volume attempts to provide an up-to-date overview of the Quaternary geology of the conterminous United States beyond the glacial limits. Knowledge of this "young geology" has become increasingly important because of its application to engineering geology, hydrogeology, neotectonics, environmental geology, and even to exploration for mineral and hydrocarbon deposits.

If the Tertiary-Quaternary boundary is placed at the Gauss-Matuyama geomagnetic Chron boundary, 2.48 Ma (which seems preferable to the currently widely accepted boundary at 1.65 Ma, see footnote 5 to Table 1), the Pleistocene Epoch began approximately when glaciers started in the Northern Hemisphere (after >50 m.y. without significant glaciation), and also about when modern Man's ancestors originated. *Homo sapiens* evolved in the late Pleistocene, and began to change from a hunter-gatherer to an agrarian society (the start of "civilized" man) 10-9 k.y. ago, soon after the start of the present interglacial, the Holocene. From this perspective it is easy to understand why knowledge of the climatic, tectonic, erosional, and depositional history of the Quaternary Period is important in attempts to comprehend our status in a changing environment and to try to predict our future.

Flint (1957, chapter 1; 1971, chapter 2) gives in-depth summaries of the development of concepts about the Quaternary and Pleistocene. The Pleistocene was first defined (Lyell, 1839) on the basis of fossil mollusks; later it became equated to widespread glaciation (the Great Ice Age), and to the appearance of humanoids (the Age of Man) and other vertebrates. Modern research proves that all these criteria are fuzzy and contadictory as to the chronologic and stratigraphic conditions that are necessary for precise chronostratigraphic definition of an internationally acceptable boundary between the Pliocene and Pleistocene Epochs (Tertiary and Quaternary Periods). Formal decision about this period boundary and selection of an internationally acceptable boundary stratotype has not yet been achieved either by INQUA (International Association for Quaternary Research) or by the International Geological Congress (See footnote 5 to Table 1, this chapter). Therefore, the time range of the regional chapters in this volume extends back at least to 2.5 Ma.

This volume begins with reviews of topics of general interest to students of the Quaternary: paleoclimatology, applicable dating methods, volcanism, and tephrochronology. A proposed chapter on Quaternary tectonism was eliminated because this subject is treated comprehensively in the volume accompanying the Neotectonic Map of North America (Schwartz, 1989), in GSA's Decade of North American Geology (DNAG) series. Therefore, the authors of the regional chapters have been encouraged to provide data on Quaternary tectonism within their regions, and many have done so.

Most of this book is given to regional syntheses that summarize the Quaternary non-glacial geology of various physiographic provinces of the conterminous U.S., mostly as delineated by Fenniman (1933) but in places with minor boundary adjustments in order to accomodate new information, and also a few extensions into adjoining provinces in order to accomodate the wishes and expertise of various authors.

Despite the primary focus on Quaternary geology, all the regional chapters summarize the pertinent features of the pre-Quaternary substrate (bedrock units and late Tertiary tectonic, erosion-deposition, and geomorphic history). A few chapters give correlations with local glacial stratigraphy, but discussion of glacial geology usually is avoided because this topic is covered in a recent comprehensive synthesis of the glacial geology of the entire U.S. (Richmond and Fullerton, 1986).

The regional chapters in this volume emphasize stratigraphy rather than geomorphology and geomorphic processes because the regional geomorphic aspects for North America are given in another DNAG volume (Graf, 1987). Most space is given to regions west of the Mississippi River because of the considerably better degree of accumulation and preservation of Quaternary sediments west of the Mississippi, and because few people have done definitive studies of Quaternary stratigraphy in the eastern U. S.

This volume also tends to subordinate the Holocene and late Wisconsin records, because "Late Quaternary Environments" (Wright and Porter, 1984) focuses on these records; also, another DNAG volume (Ruddiman and Wright, 1987) covers part of this time span.

<u>The Quaternary Period is different</u>

Climatic change is the outstanding characteristic of Quaternary time, compared to most of the Phanerozoic. Starting about 2.4 Ma, the amplitude of climatic cycles increased greatly (Fig. 1), causing frequent large changes in rate and type of deposition in both marine and terrestrial environments, to a degree that makes the better Quaternary stratigraphic records exceptional in geologic time.

Fairbridge (1962) commented:

> "Seen from the vantage point of the whole geologic time scale,...we must say: the present climatic, oceanographic, structural, and sedimentological picture of the Earth is abnormal. If we use the Lyellian philosophy of assuming the present is the key to the past we run a grave danger of being wrong. There is nothing wrong with that basic logic, but processes and relative factors are liable to great changes in velocity, scope, volume, etc."

Butzer (1961, p.35) stated the contrast of Quaternary climates with those usual for the Phanerozoic as follows:

> "During the greater part of geologic time...world temperatures were higher and, above all, more uniform. There were no polar ice caps and the temperature gradient between the Equator and poles was very considerably less than today, subtropical fauna and flora being able to survive at the Arctic Circle during a number of stages of earth history. As can be expected with such temperature distributions the general circulation of the atmosphere was slack, with widespread aridity even in higher latitudes during several geological epochs. This then is the 'normal climate of geologial time.' Those few Ice Ages which have occurred--periods in which polar and continental ice sheets drastically changed the climatological picture- were of comparatively brief duration."

The most comprehensive record of late Cenozoic climatic change on a global scale is the oxygen-isotope (delta $^{18}O-^{16}O$) record from deep-sea cores (Emiliani, 1955, 1967, 1970, 1972; Shackleton, 1969; Hays and others, 1969; Shackleton and Opdyke, 1973; Shackleton and others, 1984; Johnson, 1982; Imbrie and others, 1984; Ruddiman and Kidd, 1985; Ruddiman and Wright, 1987). This record shows chiefly changes in the volume of ice stored on the continents during glaciations, and subordinately, temperature changes in the ocean-surface layer (Mix, 1987). According to this record, major cooling began about 2.4 Ma, shown by an abrupt decrease in calcium carbonate in cores from the North Atlantic, marking the onset of ice rafting into the North Atlantic and appearance of moderate-sized ice sheets in the

Site 552A

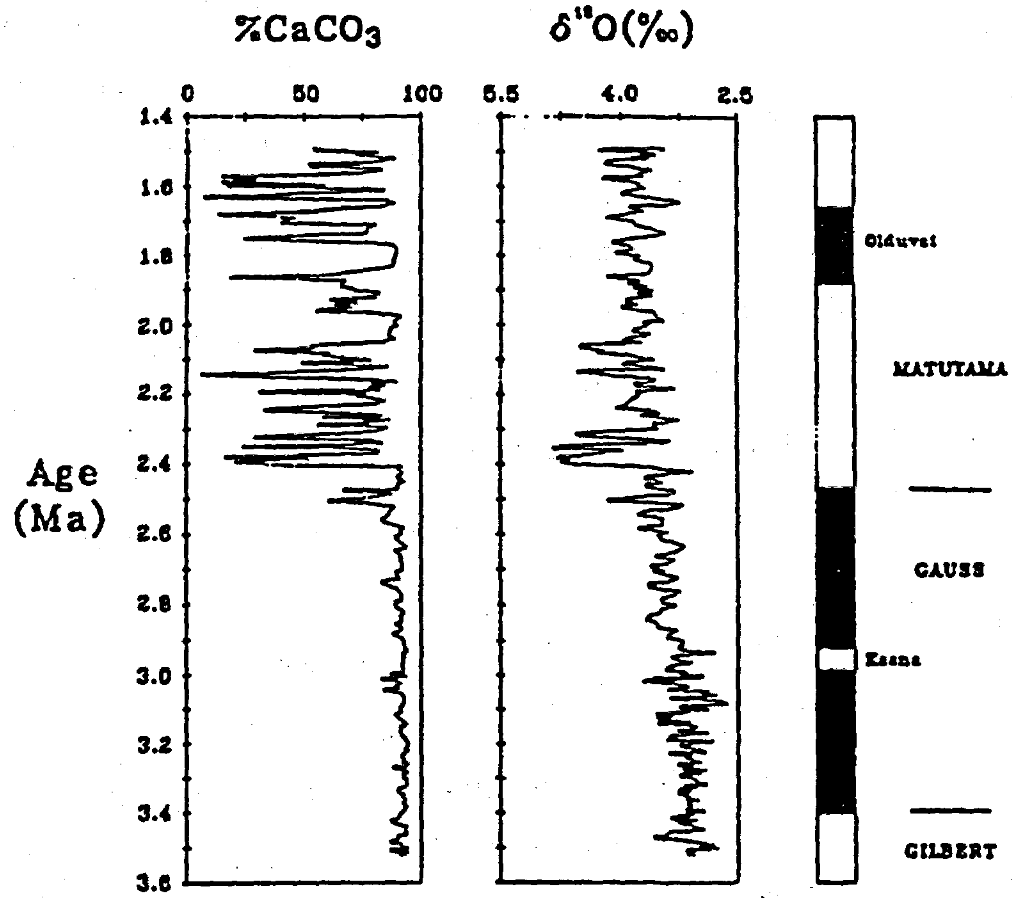

Figure 1. Late-Pliocene and early-Pleistocene records of percent $CaCO_3$ and benthic foraminiferal $\delta^{18}O$ from Site 552 in the North Atlantic at 56°03'N, 23°14'W (after Shackleton and others, 1984; Zimmerman and others, 1985). Abrupt decrease in $CaCO_3$ near 2.55 to 2.4 Ma marks the onset of ice rafting into the North Atlantic brought about by appearance of Northern Hemisphere ice sheets of moderate size. (From Ruddiman and Wright, 1987). Note the lack of distinctive features in these parameters associated with the Olduvai Subchron.

Northern Hemisphere (Blackmon, 1979; Shackleton and others, 1984; Zimmerman and others, 1985; Ruddiman and Kidd, 1986; Ruddiman and Wright, 1987). This cooling ended a Pliocene warm period characterized by small-scale climatic changes and initiated the larger-amplitude climatic cycles that characterize the Quaternary (Fig. 1).

Quaternary deep-sea oxygen-isotope cycles correlate strongly with 'Milankovich'-type earth-orbital cycles, suggesting that various earth-orbital mechanisms were 'pacemakers' for Quaternary climatic cycles (Hays and others, 1976; Johnson, 1982; Imbrie and others, 1984; Ruddiman and Wright, 1987). These correlations indicate:

(1) From about 2.4 to 0.9 Ma the early ice-accumulation cycles oscillated chiefly in a 41 k.y. rhythm, corresponding to that of orbital tilt (changes in obliquity, from perpendicular, of the earth's axis to its orbital plane) (Fig. 1).

(2) After 0.9 Ma (end of the Jaramillo normal polarity Subchron), the amplitudes of changes in delta ^{18}O and $CaCO_3$ concentrations increased about two times, suggesting that in the Northern Hemisphere ice-volume maxima became twice as big as they were before the Jaramillo Subchron. The first really large delta ^{18}O maximum (indicating a huge buildup of ice on continents) occurred during O-isotope stage 22, about 0.89 to 0.79 Ma.

(3) Between 0.9 and 0.65 Ma the precession (of equinoxes) orbital mechanism (cycles lasting 19-23 k.y.) tended to modify the effect of the tilt cycles, albeit with a lag of several thousand years.

(4) After 0.65 Ma, a ~100 k.y. cycle dominated, corresponding

to the Earth's eccentricity cycle. This poses an enigma: The eccentricity cycle produces almost negligible changes in insolation. Various hypotheses are proposed to explain this serious nonlinearity vs known inputs from the earth-orbital mechanisms (Kukla, this volume; Ruddiman and Wright, 1987).

<u>Significant conclusions from the marine oxygen-isotope record and correlative loess records in central Europe and China</u>

The deep-sea oxygen-isotope record has become a standard for Quaternary chronology, even among geologists studying terrestrial deposits, because the better deep-sea-core records are far more complete, with fewer time-gaps than any terrestrial records. Also, the deep-sea record has been dramatically reinforced by correlation with long loessial records from central Europe (Kukla, 1975, 1977; Fink and Kukla, 1977) and China (Liu Tung-sheng and others, 1985; Kukla, 1987; Kukla and others, 1988; Kukla and An, 1989).

These data lead to the following conclusions:

(1) At least seventeen complete interglacial-glacial cycles (IG-G cycles) occurred since the end of the Olduvai normal-polarity Subchron (about 1.65 Ma) and perhaps as many as 44 such cycles since the Gauss-Matuyama Chron boundary (about 2.48 Ma) in the loess record in China (Kukla and An, 1989). [Both paleomagnetic boundaries currently are candidates for selection of the international Tertiary-Quaternary (Pliocene-Pleistocene) boundary; see note 5 in Table 1.] Individual IG-G cycles were mostly within the range of 70 to 120 k.y.; thus they were similar but not identical in duration. Also, they commonly differ in their

amplitude of climatic change. Some cycles were cooler than normal during their glacial or interglacial phases and others were warmer than normal during either or both phases. Therefore, early investigators of terrestrial sequences tended to recognize only the more pronounced, larger-amplitude manifestations, essentially megacycle sets of more than one IG-G cycle.

(2) Between 12 and 15 percent of the last 500 k.y. was as warm or warmer than now. About the same percentage of the youngest complete IG-G cycle (Sangamon through Wisconsin) also was as warm or warmer than today (Emiliani, 1967, 1970, 1972; Johnson, 1982; Imbrie and others, 1984).

(3) The last (Wisconsin) glacial (oxygen-isotope stages 5d-2) began about 115 ka, and markedly increased about 70 ka (O-stage 4/5 boundary); its deglaciation began about 14 ka, and the current interglacial (O-isotope stage 1) began 12-10 ka (footnote 1, Table 1). The previous interglacial (Sangamon in the strict sense, O-isotope stage 5e) lasted about 13,000 years (Table 1).

(4) From this record and earth-orbital insolation data projected into the future, it is likely that within several thousand years the Earth will commence upon another glacial phase lasting at least several tens of millenia--an environment that civilized man has never experienced. It portends crises in energy and food supplies far more severe than any that "Civilized Man" has previously experienced. We are priviliged to live in an exceptional time by paleoclimatic standards.

Chronostratigraphic division of the Quaternary

In the past, glaciations, the most striking manifestations of climatic change in the terrestrial stratigraphic record, have been the basis of division of the Pleistocene. The "classic" divisions in North America and Europe were based on the few then-recognized glaciations and interglaciations, and these divisions commonly were used akin to chronostratigraphic units. Now, as a result of more advanced stratigraphic and chronometric research, many more glaciations (and interglaciations, stadials, and interstadials) are recognized throughout the Northern Hemisphere (Sibrava and others, 1986). Also understood is the fact that the boundaries of the physical units in glaciated areas (tills, outwash deposits, paleosols, etc.) in all the stratigraphic sequences are strongly time-transgressive ("diachronous") (Richmond and Fullerton, 1986, p. 6, 8, 183-184, Chart 1).

Consequently, Quaternary workers are moving toward defining chronostratigraphic boundaries on the basis of geologically isochronous units, such as tephra layers and geomagnetic reversals. Geomagnetic Chron and Subchron boundaries have global extent and are deemed the most suitable for international boundaries. This is illustrated by the recommendation of the INQUA 1987 Congress that the Matuyama-Brunhes Chron boundary be adopted internationally as the boundary between the Lower and Middle Pleistocene. Also, both the upper boundary of the Olduvai Subchron and (preferably) the Gauss-Matuyama Chron boundary currently are candidates for marking the Pliocene-Pleistocene [Tertiary (Neogene)-Quaternary] boundary internationally (see footnote 5, Table 1).

Additional significant revisions- Much of the "classical" chronostratigraphic/morphostratigraphic structure of classifying Quaternary deposits is now revised on a global basis (Sibrava and others, 1986). Quaternary geologists in the U.S. should note that terms such as Yarmouth(ian), Kansan, Afton(ian), and Nebraskan are recommended to be abandoned (Richmond and Fullerton, 1986, p. 6-7, 183-184), because they have been widely misused as chronostratigraphic names; although originally based on litho- and pedostratigraphic units, they oversimplify a complex stratigraphic record, and have led to much miscorrelation of units. Other classical terms, including Sangamon, Illinoian, and parts of the Wisconsin are more narrowly redefined (Richmond and Fullerton, 1986, p. 6-7, 189-194, Chart 1).

Quaternary boundary dates used in this volume

Table 1 gives the boundary dates of key chronostratigraphic divisions of the Quaternary according to usage in this volume. The boundary dates are based chiefly on correlations between astronomical data on variations in Earth's orbit (eccentricity, axial tilt, and precession of equinoxes) and oxygen-isotope data from deep-sea cores (these chiefly record the amount of ice build-up on land). These correlations provide the best currently available chronometry for the entire Quaternary, although they remain somewhat controversial (see footnotes 2 and 4 to Table 1).

TABLE 1

QUATERNARY BOUNDARY DATES USED IN THIS VOLUME

	Unit	Boundary date
	HOLOCENE (Oxygen-isotope stage 1)	
		10-12 ka 1/
LATE PLEISTOCENE	LATE WISCONSIN (Oxygen-isotope stage 2)	
LATE PLEISTOCENE		~28 ka 2/
LATE PLEISTOCENE	MIDDLE WISCONSIN (O-isotope stages 3 & 4)	
LATE PLEISTOCENE		~70 ka 2/
LATE PLEISTOCENE	EARLY WISCONSIN (O-isotope stage 5a - 5d)	
LATE PLEISTOCENE		~115 ka 2/
LATE PLEISTOCENE	SANGAMON (*sensu strictu*; O-isotope stage 5e)	
		~128 ka 2/
MIDDLE PLEISTOCENE	LATE-MIDDLE PLEISTOCENE ("Illinoian" of Richmond and Fullerton, 1986; O-isotope stages 6-8)	
MIDDLE PLEISTOCENE		~300 ka 2/
MIDDLE PLEISTOCENE	MIDDLE-MIDDLE PLEISTOCENE (O-isotope stages 9-15)	
MIDDLE PLEISTOCENE		~620 ka 3/
MIDDLE PLEISTOCENE	EARLY-MIDDLE PLEISTOCENE (O-isotope stages 16-19)	
	(Matuyama-Brunhes Chron boundary)	750-770+ ka 2,4/
	EARLY PLEISTOCENE	
	Upper boundary of Olduvai Subcron	1.65 Ma 5/
OR	Gauss-Matuyama Chron boundary	2.48 Ma
	PLIOCENE	
		5.0-5.5 Ma 6/
	MIOCENE	

FOOTNOTES FOR TABLE 1, QUATERNARY BOUNDARY DATES

1. Based on the deep-sea record, the Pleistocene-Holocene boundary should be placed at the boundary between O-isotope stages 2 and 1 (Termination I), commonly given as 11-12 ka (e.g., Rudiman and Wright, 1987a; Imbrie and others, 1984, Tables 6 and 7). However, in deep-sea-cores throughout the world this boundary is time-trangressive between about 9 and 13 ka. Its best terrestrial litho/biostratigraphic representations in North America and western Europe appear to be at about 10 ka. Hopkins (1975) proposed an abritary date of 10,000 yrs as a compromise for divergent opinions based on land data. However, this proposal does not meet the requirement of an internationally acceptable stratotype for this important chronostratigraphic boundary. Richmond and Fullerton (1986) accept 10 ka as a provisional date for the Pleistocene-Holocene boundary; however, they note (p.186) that it is a geochronometric boundary without stratigraphic basis; it does not date the termination of continental glacial activity in the U.S. and it has no significance in the overall record of glaciation in the United States. Neither INQUA nor the International Geological Congress have decided upon a suitable stratotype and date for this boundary.

2. Astronomical age of marine O-isotope stage boundary based on Tables 6 and 7 in Imbrie and others (1984) and, older than 620 ka, corrected as described below.

Many deep-sea core-record chronologies were presented before Johnson (1982) published the first attempt to link the deep-sea oxygen-isotope and earth-orbital records by statistical analysis, using O-isotope data from one core from the central-western

Pacific Ocean. Imbrie and others (1984) used data from this and four other deep-sea cores (from the Southern Atlantic, Indian, and Southern Oceans, and the Caribbean Sea; three of these cores penetrated the M/B boundary) and more sophisticated statistical techniques to correlate these deep-sea records with earth-orbital parameters. They initially used two calibration points: 127 ka for the O-stage 5/6 boundary, and 730 ka (from Mankinen and Dalrymple, 1979) for the M/B Chron boundary. After the oxygen-isotope curves were "tuned" to the precessional parameters and averaged, the final ages of these calibration points were 128 and 734 ka, respectively. Most knowledgeable workers in Quaternary science believe that Imbrie and others (1984) product is the most accurate available chronology for the deep-sea oxygen-isotope record; most of its data are used as a standard in this volume, in Table 1, Figure 2 and elsewhere.

However, minor correction seems to be indicated because Imbrie and others (1984) used too young a date (734 ka) for the Matuyama-Brunhes Chron boundary, one of their calibration points. (Likely, the correct date is somewhere between 750 and 770 ka; see footnote 4.) Nevertheless, their deep-sea O-isotope data are fine-tuned to close agreement with astronomical data back to about 620 ka, before which they are discordant, particularly with terrestrial data (G.J. Kukla, written and oral commun., 1989). Fig. 2 graphs their data on O-isotope variation with time, showing both their original time scale and a modified time scale (beginning at 620 ka in order to adjust the Matuyama-Brunhes Chron boundary to 760 ka instead of 734 ka; Table 2).

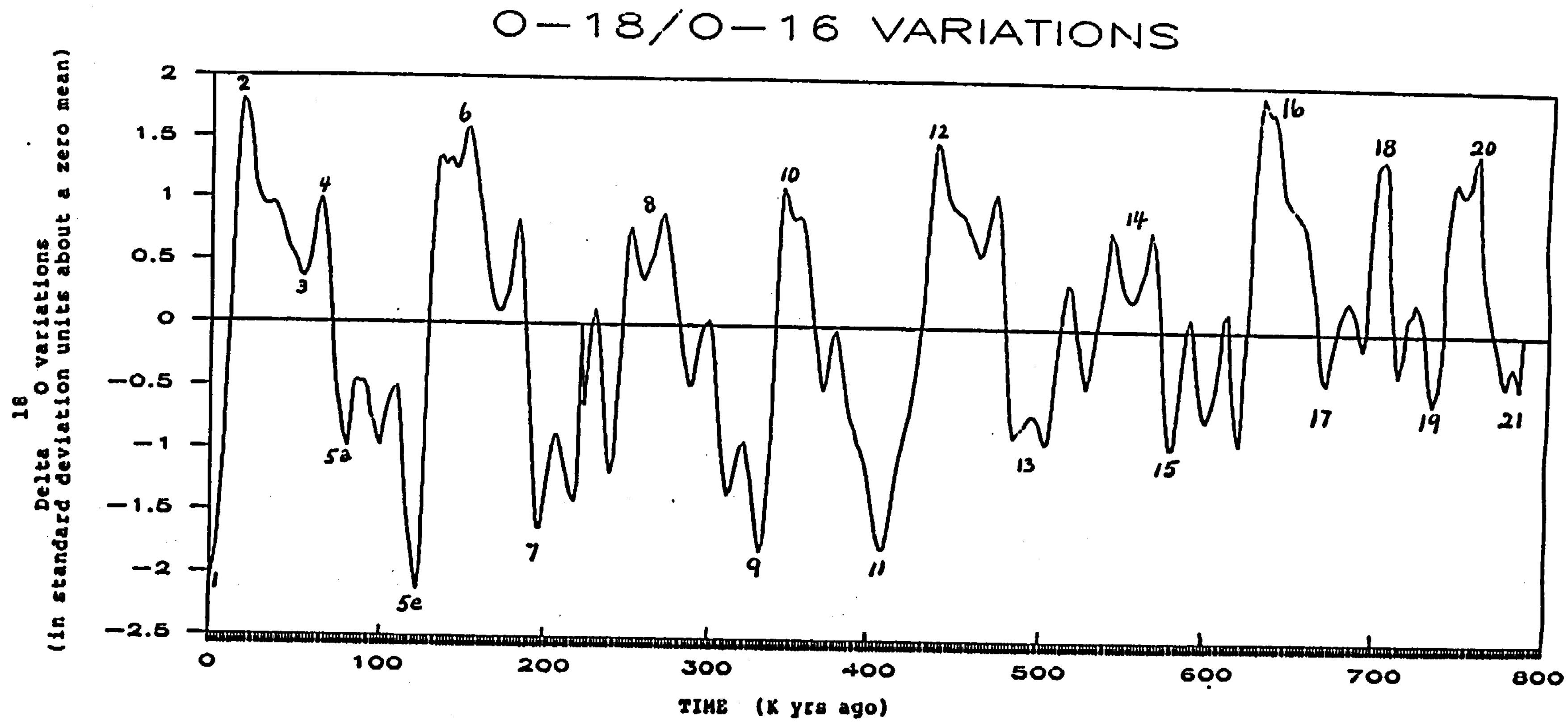

Fig. 2. Record of 18O/16O variations in five deep-sea cores, tuned to each other and to earth-orbital parameters, as a function of time, from Imbrie and others, 1984, Table 7. The graph in color shows an incremental adjustment of the data for the period before 620 ka, based on better data for the M/B Chron boundary (see Table 1, footnote 4, for explanation). The numbers along the graph refer to oxygen-isotope stages; the even-numbered peaks are glacial maxima, and odd-numbered troughs are interglacial minima.

Note to reviewers: The "graph in color" is in preparation.

Table 2. Proposed time-interval changes from those given in Imbrie and others (1984, Table 7), between 620 and 800 ka (see Table 1, footnote 4, for explanation).

Original time scale (k.y.)	Original data	Modified time scale (k.y.)	Original time scale (k.y.)	Original data	Modified time scale (k.y.)
620	0.09	620	700	1.42	718
622	0.86	622	702	1.36	721
624	1.42	625	704	0.76	723
626	1.77	627	706	0.08	726
628	1.92	630	708	-0.21	728
630	1.84	632	710	-0.32	731
632	1.77	635	712	0.16	733
634	1.79	637	714	0.10	736
636	1.69	640	716	0.15	738
638	1.49	642	718	0.18	740
640	1.25	645	720	0.26	743
642	1.10	647	722	0.21	745
644	1.05	649	724	0.08	748
646	1.01	652	726	-0.14	750
648	0.98	654	728	-0.43	753
650	0.94	657	730	-0.55	755
652	0.90	659	732	-0.49	758
654	0.86	662	734	-0.42	760
656	0.74	665	736	-0.18	762
658	0.51	667	738	0.39	764
660	0.23	669	740	0.91	767
662	-0.05	672	742	1.19	770
664	-0.25	674	744	1.25	772
666	-0.38	676	746	1.18	775
668	-0.40	679	748	1.14	777
670	-0.23	681	750	1.15	780
672	-0.02	684	752	1.22	782
674	0.11	686	754	1.40	784
676	0.18	689	756	1.48	787
678	0.24	691	758	1.18	789
680	0.26	694	760	0.75	792
682	0.21	696	762	0.40	794
684	0.11	699	764	0.18	797
686	-0.01	701	766	0.03	799
688	-0.12	704	768	-0.10	802
			770	-0.23	804
			772	-0.36	807
			774	-0.40	809
			776	-0.30	812
			778	-0.24	814
			780	-0.31	816
			782	-0.42	819

3. Richmond and Fullerton (1986) use the Lava Creek B tephra layer, dated 620 ka (K-Ar & fission-track; G.A. Izett, U.S. Geological Survey, oral commun., 1987) to define this boundary. This tephra is widespread in the western U.S. This is the approximate age of the boundary between oxygen-isotope stages 15 and 16 (Fig. 2).

4. The Matuyama-Brunhes (M/B) geomagnetic Chron boundary is now proposed by an international body as marking the boundary between the lower and middle Pleistocene (INQUA Subcommission on boundaries of subdivisions of the Pleistocene, 1987).

The age of the M/B Chron boundary cannot be ascertained directly; this age (like all paleomagnetic ages) must be determined by proxy, by dating closely underlying and overlying strata by independent means (isotopic, fission-track, or other methods) at many localities. The best approximation of the age of this Chron boundary appears to be about midway between the estimates of Mankinen/Dalrymple (1979), Imbrie and others (1984), and Johnson (1982) (respectively, 730±11, 734±5 and 788 ka) for the following reasons:

(1) Johnson's (1982) date of 788 ka is somewhat too old, because it does not allow enough time between the M/B Chron boundary and the end of the Jaramillo Subchron (well-dated at 0.89 Ma), as evinced by deposition rates in many deep-sea cores (G.J.Kukla, personal commun., 1989). [Nevertheless, Richmond and Fullerton (1986) accept Johnson's date as a provisional age for the M/B boundary.]

(2) Both the Mankinen/Dalrymple and Imbrie and others ages clearly are too young because they disagree with the re-determination of the age of the Bishop Ash by Glen Izett (U.S. Geological

Survey, personal commun.,1988) as 738±3 ka, obtained as a weighted mean of 14 dates (K-Ar on sanadine and fission-track on zircon). This normal-polarity tephra layer lies 3.5 m above the M/B boundary in a Lake Bonneville (Utah) sequence cored at the southern edge of Great Salt Lake, and a strongly developed paleosol lies just below the Bishop Ash; the M/B Chron boundary is estimated (by deposition rate and disregarding time for soil development) to be at least 15 ka older than the Bishop Ash (i.e., at least 753 ka) (Eardley and others, 1973, Fig. 1 and p. 212).

In two borehole cores near Bakersfield, California, the M/B boundary was identified (in lacustrine clay deposited during a major deglaciation) 3.7 and 4.9 m below the Bishop Ash; the average deposition rate including gaps is 11.7 cm/1000 yr, making the approximate age of the M/B boundary about 775 Ma (using 738 ka as the age of the Bishop Ash; Davis and others, 1977).

Because of the above considerations, the Matuyama-Brunhes Chron boundary is tentatively dated 750-770+ ka in this volume.

The Bishop tephra layer lies <1 m to rarely >3 m above this boundary in remnants scattered widely over the western U.S. (Chapters 5, 6, 7, 9, 10, 13, 14 and Plate , this volume).

5. Two quite different stratigraphic horizons/ages currently are being proposed for the Pliocene-Pleistocene boundary:

(A) The end of the Olduvai normal-polarity subchron, dated 1.64-1.65 Ma. This is the provisional boundary selected in 1981 by joint resolution of the Working Group of the International Geological Correlation Program Project 41 (Neogene-Quaternary Boundary) and the International Union for Quaternary Research (INQUA)

Subcommission 1-d on the Pliocene-Pleistocene Boundary (International Commission on Stratigraphy Working Group on the Pliocene-Pleistocene Boundary).

Nevertheless, THIS CANDIDATE FOR AN INTERNATIONAL STRATOTYPE FOR A GEOLOGIC PERIOD BOUNDARY IS SERIOUSLY UNSUITABLE, for these reasons:

(i) The proposed stratotype area in southern Italy is much deformed and faulted, with many tectonic and erosional hiatuses; even the proposed stratotype, the "Vrica section", is truncated.

Aguirre and Pasini (1985) propose that the international stratotype for the Plio-Pleistocene boundary be designated as the top of the Olduvai normal-polarity Subchron in the Vrica section. However, its paleomagnetic, tephrochronologic, biostratigraphic, and chronologic data are ambiguous and may be in serious error (Kukla, 1987, p. 214-216). Identification of the Olduvai Subcron here is questionable; the normal-polarity strata may represent an older Subchron such as the Reunion (Tauxe and Opdyke, 1981; Arrias and Bonnadona, 1987).

(ii) The relatively short Olduvai Subchron cannot be identified paleomagnetically in many Pliocene-Pleistocene sequences, marine and terrestrial-- and even less frequently, the precise position of its upper boundary.

(iii) The Olduvai Subchron does not mark a substantial climatic event on a global basis, and therefore is not a world-wide distinctive litho- or biostratigraphic unit.

Published comments adverse to placing the Plio-Pleistocene boundary at the top of the Olduvai Subchron include:

(1) From Richmond and Fullerton (1986, p. 186):

"...there are no criteria by which the Pliocene-Pleistocene boundary thus defined can be located accurately in the stratigraphic sequences in the U.S.A."

Also, "The Pliocene-Pleistocene boundary thus defined has no significance in the stratigraphic and chronologic framework of glaciation in the United States. ...It has no significance with respect to the dispersal of microtine rodents ...or other vertebrate faunas...that distinguish the North American land mammal ages; ...no clear significance with respect to climatic or environmental changes in North America based on biotic criteria."

(2) G. I. Smith (Chapter 11, this volume) observes regarding the deep-core record at Searles Lake, California:

"...the 1.6 Ma "beginning of Quaternary time" falls near the middle of a virtually uninterrupted intermediate hydrologic regime that lasted about 0.75 m.y."

(3) Kukla (1987) comments that the proposed Pliocene-Pleistocene boundary has no lithostratigraphic or biostratigraphic representation in the loess sequences of China.

(4) The Olduvai Subchron lacks distinctive features (other than paleomagnetic) in deep-sea-core records (Fig. 1; Jenkins, 1987, p. 41).

(B) <u>The Gauss-Matuyama Chron boundary, currently dated 2.48 Ma</u>.

This paleomagnetic boundary should become the internationally accepted boundary between the Pliocene and Pleistocene Epochs (Tertiary and Quaternary Periods) because:

(i) It is a widespread global stratigraphic marker horizon approximately coeval with the initiation of moderate-sized ice sheets in the Northern Hemisphere, between 2.5 and 2.4 Ma. Throughout the early Pliocene, climate in the Northern Hemisphere, even at high latitudes, was consistently warmer than

Pleistocene climates; the climatic cycles had much smaller amplitudes than those of the Pleistocene and never became colder than the Pleistocene interglacials. The striking climatic shift (Figure 1) that occurred close in time to the Gauss-Matuyama Chron boundary -- the true beginning of the "Great Ice Age" -- is recorded in marine deposits by marked decrease in percent $CaCO_3$ (along with a similar increase in ice rafting and delta ^{18}O) in cores from the subpolar North Atlantic and the Labrador and Norwegian Seas (Backman, 1979; Shackleton and others, 1984; Zimmerman and others, 1985; Ruddiman and Kidd,1986; Eldholm and others, 1987; Arthur and others, 1987; Ruddiman and Wright, 1987). This catastrophic change is recorded on land in middle latitudes of the Northern Hemisphere by the start of loess deposition (Kukla, 1987, 1989).

(ii) Furthermore, the Gauss-Matuyama polarity reversal can be identified widely and unambiguously in terrestial and marine sequences throughout the world.

<u>Some proposals for Pliocene-Pleistocene boundary stratotypes</u>: A suitable stratotype for placing this important period boundary at 2.4-2.5 Ma has not yet been officially proposed. I have several candidates:

(a) <u>Loess sections at either Xifeng or Luochuan, China</u>. The loess sequences of north-central China surpass those anywhere else in the world in depth of exposure (>200 m) and stratigraphic detail, as documented by intensive sedimentologic and magnetostratigraphic study (Kukla, 1987; Kukla and An, 1989; Liu, X.M., 1985; Liu, T.S. and others, 1985). The exposures provide excellent, well-accessible potential holo- or parastratotypes for this period boundary. The Gauss-Matuyama boundary (and the earliest loess) are exposed in the uppermost part of the Pliocene Red Clay Formation, at a depth of about 180 m in Xifeng and 135 m in Luochuan (Kukla and others, 1988).

(b) The Pliocene-Pleistocene sequence (Pico Formation, etc.) in the Ventura basin, California. This sequence is in a long-active tectonic depocenter and has an exceptionally complete, thick, detailed, chiefly marine record (including eight tephra layers, many foraminiferal biozones, the Olduvai Subchron, and extending far below and above the Gauss-Matuyama boundary (Yeats, Chapter 7, this volume). Also, it is well-exposed, explored extensively in depth by drillhole coring, and intensively studied by micropaleontologists, sedimentologists, tephrochronologists, structural and other geologists. Thus, it can be correlated, chiefly via magnetostratigraphy and tephrochronology, with other important terrestrial sequences, ranging from Clear Lake to Lake Tecopa (see Chapters 7 and 10).

(c) The Hueso and Vallecito members (Woodard, 1963) of the Palm Springs Formation in the Vallecito-Fish Creek basin, on the west side of the Salton Trough about 60 km northwest of El Centro, California. This section, several hundred meters of chiefly Colorado River deltaic sediments, is well exposed due to strong deformation and deep badland-type erosion. Its magnetostratigraphy is well studied and indicates that the Hueso and Vallecito members range from 2.8 to 0.9 Ma (Johnson and others, 1983; Johnson, 1985); both the Olduvai Subchron and G/M Chron boundary have been identified, as well as several tephra layers. Winker (Chapter 11, this volume) states: "this section ... contains the most precisely located Plio-Pleistocene boundary in the Salton Trough." The Hueso and Vallecito members also yield a diverse vertebrate fauna of Blancan to Irvingtonian age (White and Downs, 1961; Woodard, 1963; Downs and White, 1968).

6. The Miocene-Pliocene boundary currently is dated 5.0-5.5 Ma (Odin, 1982).

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Appendix B-IV

Excerpts from Progress Report on the Lake Tecopa Project for fiscal Year 1987 - 1988
06 November 1988
by R. B. Morrison.

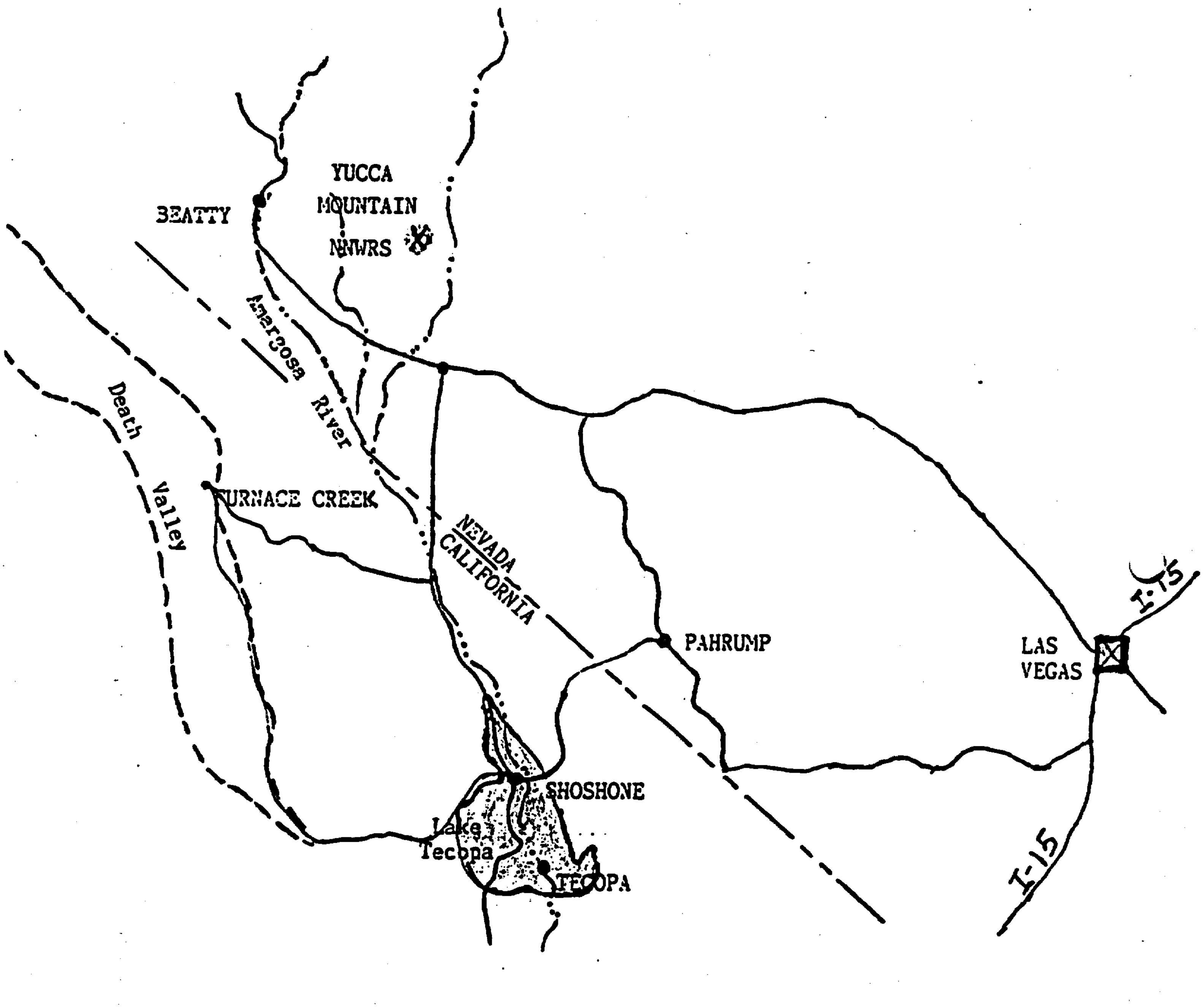


Figure 1. Location map.

1:1 million scale; 1 mm = 1 km

more intensively measured/sampled/studied stratigraphic sections. The various transects utilize the best-available badland exposures throughout the Lake Tecopa basin, that range in age from beyond 2.0 Ma (late to middle Pliocene) to Holocene (see Appendices A, B, C).

Background data

Ancient Lake Tecopa, at its highest stages, covered about 235 sq km near the towns of Tecopa, Tecopa Springs, and Shoshone, in Inyo County, California. "Lake Tecopa" is the name for a long series of alternating lacustral and desiccation episodes, that began about 2.5 Ma and ended sometime in latest middle Pleistocene (about 0.25 Ma), after the lake basin became breached and completely drained by the Amargosa River. Thus, for at least two m.y. Lake Tecopa was the sump for about 6000 sq km of the upper drainage basin of this river, including a large part of the Yucca Mountain area.

Subsequent dissection of the barrier that enclosed Lake Tecopa (a massive late Tertiary fan-gravel complex at the southern end of the Lake Tecopa basin) provides fine exposures of a partly lacustrine, partly playa/subaerial stratigraphic sequence, about 150 m in total exposed thickness. This sequence, from middle Pliocene through lower and most of middle Pleistocene, is one of the longest and most complete exposed "pluvial-lake" records in the western U.S. It contains at least 15 separate tephra, including several dated ones: the Lava Creek B (~0.62 Ma), Bishop (0.735 Ma), Glass Mountain G (1.0-1.1 Ma), and Huckleberry Ridge (~2 Ma) tephra layers (Sarna-Wojcicki et al., 1984 and in press). The tephra layers facilitate regional correlation between Lake Tecopa and other sites with important long-ranging paleoclimatic records, such as Manix Lake, Searles Lake, Salton trough/Anza-Borrego, Ventura/ South Mountain/Balcom Canyon, San Joaquin Valley/Tule Lake, Clear Lake (all in California), and Lake Lahontan (Nevada).

A superb fluvial record complements the lacustrine record. The fluvial record is partly contained in tongues of alluvium intercalated with Lake Tecopa's lacustrine sediments, and also in alluvial units that mantle four well-defined erosion surfaces that developed during and after the draining of Lake Tecopa.

The late-Pliocene/Pleistocene climatic record preserved in Lake Tecopa strata is important not only because it is the best-exposed long record in this region but also because it lies in a critical paleoclimatic zone. This climatic region is one of fluctuation of the boundary between the north-temperate and north-subtropical-arid climatic zones. This boundary probably fluctuated north and south as much as 900 km with the various interglacial and glacial climatic episodes of the later Pliocene and Pleistocene, with big effects upon stream flows, lake levels, watertables and ground-water piezometric surfaces in this region. The migrations of this boundary from the last glacial through the Holocene are becoming fairly well known (Spaulding, 1985; Spaulding et al., 1983; Van Devender and Spaulding, 1979), but almost nothing is known about earlier changes and their effect upon hydrogeologic regimes.

SIGNIFICANT RESULTS FROM THIS PROJECT

The most important results to date from the Lake Tecopa project are:

1) Determined the basic pattern of the complex stratigraphy of deposits in the Lake Tecopa basin -- a >2 m.y.-long series of alternating playa to deep-lake deposits that intertongue with alluvial and some eolian and spring/seep sediments, with many changes in lithology from basin margins to basin interior, as well as local faulting and tilting. Chiefly studied were deposits younger than the Bishop Ash (735 ka), particularly those younger than the Lava Creek B Ash (620 ka), because the younger part of the Lake Tecopa record is most relevant to concerns about NNWR. (See Appendices A to E for details on stratigraphic procedures and findings).

2) On the basis of information from (1), determined the basic outlines of the following histories:

a) Paleohydrologic--the long history of changing lake levels, with many alternations from playa to shallow- to moderate- and deep-lake levels before Lake Tecopa became drained (Appendix Figure F-1). Also determined the history of the four chief post-Lake Tecopa cycles of stream erosion and deposition.

b) Paleohydrogeologic--the groundwater history, of fluctuations in water table and piezometric surface (Appendix Figure F-2). This is particularly relevant to NNWRS because it pertains chiefly to changes in the piezometric surface of a complex artesian aquifer system that is widespread in southern Nevada and adjoining California.

c) Paleoclimatic--the history of the climatic changes that controlled the hydrologic and hydrogeologic histories (Appendix Figure F-3.)

d) Neotectonic--the history of faulting and warping during and after Lake Tecopa's >2 m.y. life, including the locations of intra- and post-Lake Tecopa tectonic features (Appendix Figure H-1). Much more neotectonism has occurred in this basin than has been recognized by USGS workers (Dohrenwend, 1985; Hillhouse, 1987).

3) Prepared a provisional correlation chart, correlating the Lake Tecopa sequence with the Amargosa Desert, Searles Lake, and Lake Lahontan stratigraphic records (see below and Appendix Figure G-1).

PREVIOUS STUDIES OF LAKE TECOPA

Notwithstanding the paleoclimatic importance of the long and well exposed Lake Tecopa sequence in a key part of the southwestern U.S., the history of the repeated deep-lake and desiccation episodes of Lake Tecopa remained completely unknown until this project was started.

Also unknown until this project was how the lacustrine history correlates with the above-lake, chiefly fluvial, erosional and depositional history. Such a correlation is a basic need if a regional paleoclimatic synthesis is to be achieved.

Also unknown was a great deal of striking evidence on marked changes in groundwater conditions: episodes of strong spring discharge (chiefly artesian) alternated with times without such discharge.

For about seventy years preceding 1986, Lake Tecopa received various reconnaissance studies that recognized it as an unusual "pluvial lake" and determined its general outline and lithology (Noble, 1926; Thompson, 1929; Blackwelder, 1936; Sheppard and Gude, 1968; Starkey and Blackmon, 1979). The more intensive studies were directed toward finding commercially useful minerals from the lake beds; none of them attempted to decipher the intricate lake history. Only recently has its approximate age range been determined correctly, by tephrochronology (Sarna-Wojcicki et al., 1984, 1985, and in press).

The recent (Hillhouse, 1987) USGS map of the late Cenozoic deposits of the Lake Tecopa basin was a big step forward toward understanding the complex stratigraphy of this basin. It is helpful for showing most of the exposures of three chief tephra layers, Tuff A (Lava Creek B, 0.62 Ma), Tuff B (Bishop, 0.738 Ma), and Tuff C (Huckleberry Ridge, ~2 Ma); also a few paleomagnetic data; also it is the best published attempt at documentation of exposures of Lake Tecopa and related deposits. However, Hillhouse did not attempt anything approaching a detailed, comprehensive study of the stratigraphy of the Pliocene and Quaternary deposits in the Lake Tecopa basin, nor an interpretation of Lake Tecopa's history (not even unambiguous indication of its highest strandline). Also, his map has many deficiencies (see Appendix I for a detailed analysis).

SUMMARY DESCRIPTION OF THE LATE CENOZOIC DEPOSITS IN THE LAKE TECOPA BASIN AND OUTLINE OF LAKE TECOPA'S HISTORY

(See also Appendices A, B, C, and F.)

Beneath the lacustrine and subaerial deposits comprising the Lake Tecopa Allogroup are hundreds of meters of Pliocene and Miocene sediments, chiefly fan gravel units that are moderately consolidated to strongly cemented, with many paleosols. These deposits and older Tertiary to Precambrian rocks are exposed in places at the periphery of the Tecopa basin, and also in Tecopa Hills and small areas elsewhere within the basin.

The deposits of Lake Tecopa, here collectively called the Lake Tecopa Allogroup, cover a roughly triangular area 18 x 24 km below the highest strandline at about 550 m altitude (1800 ft); the lowest exposures are at about 396 m (1300 ft), at the Amargosa River outlet at the south end of the former lake basin. They include shallow to deep-lake sediments and intercalated alluvium and other subaerial deposits. In most places they are nearly horizontal, rarely sloping as much as one degree basinward; however, in some fault blocks they are tilted, usually only a few degrees but occasionally to high angles, including vertical.

Lake Tecopa has a long <u>lacustrine</u> history, of many shallow to deep-lake cycles (not just high-water-table/paludal conditions), interspersed with many desiccation episodes. Until about 900 ka playa to shallow-lake conditions prevailed, with slow sedimentation rates (Appendix Figures F-1 and F-4). Then began a gradual (but irregular) trend of generally rising lake levels and higher sedimentation rates. This trend accelerated after deposition of the Bishop Tuff (738 ka). Lake Tecopa's highest lake level was reached close to the end of its long history, probably between 300 and 200 thousand years ago (a tentative age estimate based on 30-45 m of chiefly lake sediment that overlie the Lava Creek tephra layer, dated 620 ka (Morrison, 1986-1988 field data; Hillhouse, 1987). At its all-time maximum Lake Tecopa is estimated to have been between 45 and 90 m deep, based on various projections/extrapolations from remnant exposures near its margins.

<u>Pre-Huckleberry Ridge (Tuff C) deposits and history, ~2.5-2 Ma</u>

Exposed pre-Tuff C sediments (Spanish Trail Alloformation) are limited to a few sq km in the southern part of the Lake Tecopa basin, below 440-420 m. [The term "alloformation" is the fundamental unit in a new category of stratigraphic classification (North American Commission on Stratigraphic Nomenclature, 1983). An allostratigraphic unit is a mappable stratiform body of sedimentary rock that is defined and identified on the basis of its bounding discontinuities, rather than by content. Its boundaries are laterally traceable discontinuities.] These deposits have not yet been studied intensively for this project. Our reconnaissances found them to be at least 20 m in maximum exposed thickness and mostly moderately to well-indurated clay and silt (claystone and mudstone), in places with a few thin interbeds of silty very fine to fine sandstone, and perhaps a few paleosols--chiefly playa and playa-margin sediments, with some shallow-lake and distal piedmont to basin-interior alluvium. Nearly all these strata are more or less completely recrystallized by authigenesis except in small upfaulted blocks a few miles NE of Tecopa.

The age of the lowest exposed beds in the Spanish Trail Alloformation (AF) is unknown, but at least 2.5 Ma (late-middle Pliocene) and perhaps [if the sedimentation rate was the same as that between the Huckleberry Ridge and Glass Mountain G tephra (Appendix Figure F-4)] to around the Miocene-Pliocene boundary. Thus, this unit records a few hundred thousand to several million years of playa to occasional shallow-lake conditions, but apparently no deep lakes. At this time, global climatic circulations were quite different from now: The amplitude of interglacial-glacial-type climatic oscillations was much smaller than in the Quaternary (Ruddiman and Wright, 1987). Also, the interface between the North-Temperate and North Subtropical-Arid zones probably was farther north and its north-south fluctuations smaller and slower. In addition, very important for this region, the Sierra Nevada were much lower than now (Huber, 1981; Morrison, in press; Smith and others, 1983), allowing much more moisture to reach the desert areas to the east.

Huckleberry Ridge Tuff to Bishop Tuff sediments (Greenwater Fan Alloformation) and history, ~2 to 0.735 Ma

Deposits of this ~1.3 m.y. interval, about 15 to more than 30 m thick, are well exposed in the badlands near and south of Shoshone, below the Bishop Ash, which ranges in altitude from 445 to 495 m. They generally resemble those of the Spanish Trail Alloformation but are more widely and commonly better exposed. They are chiefly monotonous sequences of moderately to well-indurated clay and silty clay (mudstone) and silt and sandy silt (siltstone), grading to siltstone and fine-grained sandstone toward the basin margins. They appear to have been deposited chiefly in playa and shallow-lake environments, therefore toward the basin margins the Greenwater Fan AF includes increasing amounts of alluvium, even paleosols.

This unit also has not yet been studied in detail for this project. Preliminary interpretation is that its depositional environment was relatively monotonous on a nearly flat basin-interior plain. Its sediments indicate mostly playa, playa-margin, and distal piedmont (fine-grained alluvium) deposition, but also occasional brief shallow-lake episodes. No deeper lakes are apparent--until shortly before deposition of the Bishop Tuff. Wave-ripplemarks in this tephra layer and closely associated fine sandstone beds at several localities at about 450 m altitude in the southwestern part of the basin testify to a lake 15-20 meters deep at this time.

Bishop to Lava Creek B Ash sediments (Shoshone Springs Alloformation) and history, 735-620 ka

Sediments of the Shoshone Springs AF, about 8 to 20 m thick, are widely exposed except north of Shoshone, where they disappear beneath the flood plain of the Amargosa River. They are commonly less indurated and altered than the older deposits. In the northern part of the Lake Tecopa area this unit is chiefly alluvium and loessial deposits, but southward it grades through fluctuating-strandline sandy sediments into 2 to 7+ meters of deep-lake clayey silt and clay in the southwestern part of the basin.

Thus, this ~115 k.y. interval started with a lake about 15-20 m deep, in the southern part of the basin. This lake undoubtedly fluctuated considerably, but during the later part of this interval it was commonly 20 to perhaps occasionally 30 m deep, while alluviation and some loessial eolian deposition continued in the northern part of the Lake Tecopa area. The interval ended with a lake standing at about 480-490 m (present) altitude, on the basis of wave-ripple-marked beds in the Lava Creek tephra layer at several localities, and other evidence of strandline deposition.

Lake Tecopa sediments younger than the Lava Creek B Ash (Amargosa Alloformation) and their history, 620 to ~200 ka

Sediments younger than the Lava Creek Ash have received the most intensive study because their record is most relevant to NNWRS concerns. Erosion after Lake Tecopa was breached has entirely removed them from the central part of the lake basin, but remnants are preserved in many places close to the margins of Lake Tecopa. The remnants are chiefly in ridges capped by pediment gravel of the older post-Lake Tecopa pediments--but unfortunately these pediments slope basinward at an angle considerably greater than the dip o these strata; thus the pediments progressively truncate these deposits basinward. Fortunately, two large areas in the northern part of the basin were not pedimented; both preserve impressive chiefly lacustrine but partly alluvial sequences that rise to or nearly to the highest Lake Tecopa strandline.

The Amargosa Alloformation, commonly 25 to 35 and about 45 m maximum thickness, records two main deep-lake periods, here called lake megacycles. Its lower member (in the northern part of the basin) records a lake megacycle (whose trend started shortly before deposition of the Bishop Ash, but accelerated after Lava Creek Ash time) that peaked about 500 ka at about 520 m altitude, Then came lake regression to below 440 m. The upper member records another lake megacycle that rose with oscillations to Lake Tecopa's all-time maximum at about 550 m, with a maximum depth of 45-90 m. (This altitude varies from place to place about the former lake periphery because of small-scale faulting and tectonic warping since the ultimate lake maximum.) Thus, Lake Tecopa, close to the end of its >2 m.y. life, had two successive all-time-high lake maxima that went above 500 m altitude.

Amargosa AF sediments were deposited on a flat to very gently sloping plain, that sloped generally less than 1 degree at the northern and mountain margins toward a level interior. This is indicated by the horizontal to sub-horizontal strata (where not later deformed) and the fact that along the ancestral Amargosa River northward from Shoshone, fluvial scour/fills rarely exceed 1 m in depth. Deposits of this AF, in the northern 1/3 of Lake Tecopa and marginal to the Sperry Hills/Tecopa Peak are chiefly small-pebble gravel, sand, and silt, with minor clay, marl, limestone, and calcareous siltstone and sandstone. They represent chiefly near-shore, strandline, and deltaic deposits with fluvial intercalations. In contrast to older units, they typically are poorly consolidated to unconsolidated and little altered by authigenesis. However, locally they are moderately to well-cemented and include travertine to tufa-like beds (see below). I found several new proven or probable tephra layers in this unit.

The Amargosa AF is especially rich in carbonate deposits of several genetic modes. The northern part of the basin, particularly within 5 km of Shoshone, displays an ancient "carbonate delta" of the Amargosa River. The carbonate delta is conspicuous (compared to drab sediments elsewhere in the Lake Tecopa area) by predominant white to very pale gray strata, clay to fine sand (stone), whose light tones are due chiefly to fine-grained carbonate. This carbonate likely is a chemical precipitate formed in the zone where relatively lower pH water of the Amargosa River mixed with high pH water of Lake Tecopa (Shepard and Gude, 1968).

The chief other genetic mode of unusual degree of carbonate deposition in this AF is local carbonate-cemented siltstone, sandstone, and pebble gravel, and marl to travertine (chiefly due to spring/seepage discharge in basin-interior to near-offshore lake environments; Mifflin and Wheat, 1979; Quade, 1986). Such deposits occur throughout the Lake Tecopa basin, but are individually very localized (commonly in linear orientation as if along fracture zones), and most common within 20 m of the highest strandline of Lake Tecopa. My present interpretation is that this class of carbonate deposits was deposited from artesian upwelling carbonate-charged water, probably moving first along bedrock fault/fissure zones and then more diffusely through the mostly poorly consolidated Amargosa AF.

Another genetic class of carbonate deposit is tufa that seems to have been deposited by algal action on strandlines (at and within several meters below lake level). These deposits are preserved in only locally, especially at sites prone to strong wave action. Samples currently are being studied.

The uppermost stratigraphic remnants of the Amargosa AF are preserved only locally in the highest strandline zone, due to post-Lake Tecopa erosion. They consist of lacustrine pebble gravel, sand, and silt intercalated with varying amounts of alluvium--also local marl to travertine "tufa mound" deposits that grade into carbonate-cemented sandstone and gravel, likely formed at sites of artesian groundwater discharge. The uppermost lacustrine tongues are much thinner than the main lacustrine units in this alloformation and suggest two or three very brief rises to the high-shore level at the end of Amargosa time. Apparently Lake Tecopa had a rapid demise; no deposits from this final lake regression seem to be preserved.

[Parenthetic note about the Amargosa AF:]
An ambiguity is apparent in the earlier part of the lacustrine record from this unit, between the northern and southern parts of the Lake Tecopa basin. In the northern part, widespread exposures of strandline and offshore deposits above the Lava Creek Ash evince a major lake cycle with lake levels above present 500 m altitude lasting at least several tens of thousands of years. On the other hand, in the southwestern part of the basin at about 465 m altitude, 8 to 10 m of silty and fine-sandy silt beds overlie the Lava Creek Ash, indicating that here playa and playa-margin conditions existed at what is now a lower altitude than the lake to the north. Perhaps tectonism has lowered the southwestern area with respect to the northern; both areas have faults that were active during Amargosa Alloformation time; these faults are particularly numerous in the southwestern area.

Post-Lake Tecopa alluvial deposits and history

Four main fluvial erosion-deposition surfaces developed during and after the draining of Lake Tecopa. They are chiefly pediments that toward the periphery of the basin digitate into strath terraces along principal washes. Typically they bear a veneer 1 to several meters thick of alluvial cobble to pebble gravel with some pebbly sand locally; however, the youngest surface commonly bears much finer (sand to clay) sediments in the lower parts of the basin interior. These post-Lake Tecopa surfaces and their alluvial veneers are here designated numbers 1 (oldest) to 4 (youngest)(see Appendix B).

NOTE: Dohrenwend (1985) gave names for three erosion surfaces in this basin, pre- to post-Lake Tecopa: Sperry (chiefly Pliocene and early Pleistocene, pre-Lake Tecopa maximum), Greenwater, and Amargosa (Holocene)]. His descriptions of these surfaces are so over-simplified and inexplicit (no real definitions or type localities are given) that his nomenclature ought to be abandoned; I do not use it.

The #1 and #2 surfaces/deposits seem to be close in age and will be discussed together. Their remnants are the relatively few highest ridges (between major washes) on the piedmonts o this basin. The alluvial veneers likely are ancient channel-bed deposits of principal washes These narrow mesa-like remnants have a veneer of <1 to rarely >2 m of "pediment gravel". Their surfaces are strongly desert-varnished, nearly smooth (have lost original fluvial irregularities), and their alluvium bears a very strongly developed paleosol. John Rosholt (Chief of Branch of Isotope Geology, USGS) obtained a uranium-trend date of about 160 ka from the relict paleosol on the pediment surface at the Shoshone town dump, which is either the #1 or #2 surface (likely the former; its correlation is uncertain due to faulting).

The #3 surface is a lesser one, expressed chiefly by strath terrace remnants.

NOTE: The #1, #2, and #3 surfaces (my classification) all correspond to Dohrenwend's (1985) "Greenwater Surface", the only post-Lake Tecopa, pre-Holocene surface that he recognized.

The #4 (youngest) surface is equivalent to Dohrenwend's "Amargosa Surface". This surface includes moderately widespread pediments in the southern part of the basin-- surprisingly extensive considering their youth. I believe that this surface formed during both the later Wisconsin and Holocene [not just in the Holocene, as Dohrenwend (1985) believes], on the basis of soil development on the higher remnants of its alluvial veneer in many places throughout the basin.

CORRELATIONS WITH AMARGOSA DESERT (ASH MEADOWS), SEARLES LAKE, LAKE LAHONTAN, AND THE SIERRA NEVADA

Correlation of the Lake Tecopa Allogroup with middle Pliocene deposits of the Amargosa Desert

The Amargosa Desert (Amargosa Flat-Ash Meadows area) is noted for its middle Pliocene deposits of high-magnesium clays and carbonate rocks that are overlain unconformably by much younger Quaternary fluvial and eolian sediments (Denny and Drewes, 1965; Papke, 1970, 1972; Pexton, 1984). The clay-rich Pliocene beds are estimated to be about 4 to 2 Ma on the basis of their relations to dated basalts and tuffs (Hoover, 1985; Pexton, 1984).

Two tephra layers, the Nomlaki, near the base of the exposed section, and the Huckleberry Ridge, close to its top, are dated 3.2-3.4 and 2.0 Ma, respectively (Sarna-Wojcicki and others, in press). Therefore, on a tephrochronologic basis, the middle Pliocene deposits in the Amargosa Desert may range older than those exposed at Lake Tecopa, but likely overlap with the lowermost exposed Lake Tecopa strata (all of the Spanish Trail Alloformation and perhaps the lower part of the Greenwater Fan Alloformation).

Correlation with the Searles Lake record

Lake Tecopa has a stratigraphic/climatic record superior to that of Searles Lake in several respects (see Appendix K).

The Searles Lake record is based chiefly on core data; its exposed record is relatively meager, disjunct, and ambiguous, and goes back not much farther than the last interglacial. The lacustrine part of the 930-m "long" core from Searles Lake begins about 3.2 Ma (Smith et al., 1983; Smith, 1984), perhaps older than the lowest exposed deposits of Lake Tecopa and comparable to the oldest exposed deposits in the Amargosa Desert.

Preliminary comparisons indicate considerable differences in the interpretations of the history of lake fluctuations between Lakes Tecopa and Searles. The following summary for Lake Searles is based entirely on Smith's interpretation of the long core at Searles (Smith, 1986), and ends at 0.25 Ma, because Tecopa's lacustrine history ends before the more detailed short-core and exposed-deposit history at Searles (Appendix Figure G-1):

(a) Between 3.2 and 2.5 Ma, was a series of deep lakes. At ca. 2.5 Ma is a transition from deep-water to playa sediments.

(b) Between ~2.5 and ~2 Ma, low lake levels appear to have alternated with desiccation episodes at Searles Lake. [This part agrees with the Lake Tecopa record.]

(c) At Searles Lake, between ~2 and ~0.6 Ma, "intermediate" to "wet" conditions prevailed, with a series of perennial lakes (lasting 10 ka or longer) that rose to intermediate or high levels. Wet conditions peaked between 1.3 to 1.0 Ma.
[In contrast, Lake Tecopa appears to have had playa to shallow-lake conditions during the earlier part of this interval, changing to intermediate lake conditions about 0.75-0.8 Ma, and remained at intermediate (not high) levels to 0.6 Ma.]

(d) There was a long dry interval at Searles Lake between about 0.57 and 0.31 Ma. [In contrast, at Lake Tecopa two major deep-lake megacycles (with a moderate recession between them) occupied this interval, and Lake Tecopa reached its all-time lake maximum near the end of the second megacycle--and became breached at or soon after the end of this interval.]

(e) From 0.3 Ma to 10 ka intermediate to wet conditions prevailed at Searles, with desiccation between 130 and ~100 ka..

Correlation of Lake Tecopa with Lake Lahontan

Pluvial Lake Lahontan was 335 to 675 km north of Lake Tecopa and definitely in the North-Temperate climatic zone. Lahontan's stratigraphic record is one of the very best exposed records in the western U.S., in terms of stratigraphic completeness, range (from well beyond 1 Ma thru Holocene), detail of exposed record, and unambiguity. There is little controversy about intra-Lahontan basin stratigraphic correlations, much less than for the Lake Bonneville basin, partly due to better exposures and partly because more than 50 different tephra layers facilitate correlations within the Lahontan basin (Morrison and Davis, 1984a, 1984b and Appendix Figure G-1).

The lower part of Lake Lahontan's exposed sequence overlaps the upper part of Lake Tecopa's sequence, probably as follows:

The Lovelock Alloformation of Lake Lahontan contains the Bishop Ash in its upper part and is younger than the 1.0 Ma Glass Mountain G Ash. It represents several hundred thousand years when the Lahontan basin was nearly to completely desiccated, but dozens of strong paleosols testify to mild semiarid climate. It likely is equivalent to the upper part of the Greenwater Fan AF and the lower part of the Shoshone Springs AF.

The Rye Patch AF of Lake Lahontan has the Lava Creek Ash near the top of its upper lacustrine member. This AF records two moderately deep lake cycles separated by a brief but moderately deep lake recession. It likely is equivalent to the upper part of the Shoshone Springs AF and the lower part of the Amargosa AF, on the basis of tephrochronology. This signifies significant diachronism between the deep-lake history of Lakes Lahontan and Tecopa, an asynchroneity of more than 100,000 years in ages of respective lake maxima. Lahontan had two deep-lake cycles chiefly before the Lava Creek Ash (Rye Patch AF), but Tecopa's first deep lake cycle came after this tephra (Appendix Figure G-1).

The Paiute AF of Lake Lahontan records a long desiccation period between Rye Patch and Eetza time. It contains the 400 ka Rockland Ash near its top. Likely it correlates approximately with the desiccation interval represented by the subaerial member in the middle of the Amargosa AF, although it may represent twice as long a time interval. [Flash! A previously unknown moderate lake cycle (maximum below 1260 m) within the Paiute AF was discovered this summer (J.O. Davis, oral communication, Oct 1988). Its relation to the Rockland Ash still is uncertain.]

The Eetza AF of Lake Lahontan probably ranges in age from about 350 to 130 ka -- and its lower part likely correlates with the upper part of the Amargosa AF (Appendix Figure G-1).

Sierra Nevada glaciations

Sierra Nevada glaciations have been highly controversial as to number of significant glaciations and especially as to their chronology. Appendix Figure G-1 (Sierra Nevada) is based on the important synthesis by Fullerton (1986), which is by far the best analysis and summary to date.

Again, significant diachronism appears at all age levels, from Wisconsin to mid-Pliocene. One example: the Sherwin Glaciation (~780 - ~900 ka), one of the biggest on basis of end moraines, appears to have taken place during Lovelock AF time in the Lahontan basin, and near the end of Greenwater Fan AF time at Lake Tecopa--but the Searles and Tecopa basins held only shallow lakes probably alternating with playas.

Note also that a major glaciation is postulated between 0.9 and 2.3 Ma, a time interval when the Lakes Searles and Tecopa usually were playas.

Conclusion about correlations with the above areas:

Significant diachronism is demonstrated among the long-histories of these key areas; these histories show both (1) at times more-or-less in-phase relations -- but also and commonly (2) lacustral, glacial, and climatic phenomena that are significantly out-of-phase, by as much as the 100,000-year magnitude.

The indicated diachronism between beginnings, maxima, and endings of pre-late Pleistocene lake megacycles in the three "pluvial-lake" areas is impressive. This diachronism, commonly in the order of hundreds of thousands of years, is much greater (by 10^2 order of magnitude) than that demonstrated among the late Wisconsin lake maxima in the Great Basin [1 to 5 ka between Lake Bonneville and Lakes Lahontan and Mono (Morrison, in press)].

PALEOCLIMATOLOGY NEAR LAKE TECOPA FROM 3 MA TO THE PRESENT

This section purposely is not called "regional paleoclimatology" because of the concerns about long-term asynchoneity of climatic changes between various parts of the Mojave Desert-Great Basin during Quaternary time, that were raised in the preceeding section.

3.2 to 2 Ma

For this middle Pliocene interval, the paleoclimatic analysis of Hay and others (1986) of conditions in the Amargosa Desert is most relevant to conditions at Lake Tecopa (the Amargosa Desert exposed record also ranges somewhat older than that at Lake Tecopa).

According to Hay and others (1986), the climate was substantially wetter than at present, likely because the Sierra Nevada and Transverse Ranges were much lower than now (Huber, 1981; Winograd and others, 1985), permitting more moisture to travel eastward into the Great Basin. Climate also may have been at times cooler than now, because a gastropod occurs in the mid-Pliocene deposits that lives in seasonal ponds and marshes farther north and at elevations higher and cooler than the Amargosa Desert today (Taylor, 1983). They apparently (p.1502) found evidence of a change from wetter to drier climate about 2.5 Ma, as also was found at Searles Lake (Smith and others, 1983; see "Correlations" above). [Interestingly, a major global shift to cooler climate and increased ice volume also is recorded at about 2.5 Ma in the oxygen-isotope records in deep-sea cores (Ruddiman and Wright, 1987).]

Spring discharge was much more abundant and widespread than at present, much of it coming from Paleozoic rocks to the east of the chief present-day springs, as well as along the western margin of the basin, indicating generally higher piezometric surface and watertable conditions.

Greenwater Fan AF to Shoshone Springs AF time, 2 Ma to 620 ka

In this project, no quantitative data have yet been obtained about temperature and precipitation conditions at specific times during Greenwater-Shoshone Springs AF time in the Lake Tecopa area. Following are qualitative conclusions from our preliminary reconnaissance observations.

At Lake Tecopa this long interval was a time of continued low effective precipitation, with low stream flows and playa to occasional shallow-lake conditions, until near the end of Greenwater Fan time, when somewhat increased effective precipitation caused lake level to rise to about 450 m present altitude, shortly before the Bishop Ash was deposited. Effective precipitation continued to increase slightly during Shoshone Springs time, as documented by slightly higher lake level in the southern part of the Tecopa basin.

Spring and high-water-table deposits are lacking to rare in the exposed Greenwater Fan sediments, suggesting that piezometric surfaces and watertables then were too low for more than local artesian discharge at a few large springs. However, such deposits occur in places in the upper part of the Shoshone Springs AF, notably near Shoshone, indicating a rise in piezometric-water-table levels with the start of the mega-pluvial that caused the first Amargosa deep-lake period, shortly before deposition of the Lava Creek Ash.

In contrast, at Searles Lake Smith and others (1983) postulate from the "long" core data an intermediate to deep-lake period between 2.0 to 0.6 Ma! (Appendix Figure G-1)

Amargosa AF time, 620 to about 250 ka

Amargosa time was marked by two mega-pluvials (mega-deep-lake cycles) separated by a moderate lake recession (Appendix Figure F-1). Obviously, effective precipitation was greater, the highest in Lake Tecopa's history (Appendix Figure F-3). The fan-delta of the Amargosa River at the head of Lake Tecopa (north of Shoshone) has copious pebble-cobble river gravel (interbedded with high-level lake sediments), testifying to augmented river discharge. Likewise, widespread spring and groundwater seepage activity took place in many places in the basin, in places to the highest strandline zone. Stratigraphic evidence shows that commonly spring/seepage deposition slightly preceeded lake deposition at a given altitude, and also continued for a short time after lake level had fallen below this elevation (Appendix Figure F-2).

APPENDIX B.

PROPOSED ALLOSTRATIGHRAPHIC UNITS IN THE LAKE TECOPA AREA

LAKE TECOPA ALLOGROUP
(lacustrine and subaerial sediments of Lake Tecopa age, middle Pliocene to late-middle Pleistocene)

Amargosa Alloformation

Lacustrine and subaerial sediments above the base of the Lava Creek B tephra bed (Tuff A), up-section to the youngest Lake Tecopa deposits.

Upper lacustrine allomember:

Upper unit (fluctuating high and regressive lake stands; small-pebble gravel and small-pebbly sand).

Middle unit (chiefly lacustrine sand, silt, some clay, some sandy small-pebble gravel lenses locally).

Lower unit (transgressive; lacustrine small-pebble gravel and small-pebbly sand).

Middle subaerial allomember (upper "yellow zone"):

Lower lacustrine allomember

Lava Creek B tephra layer (Tuff A), ~0.62 Ma.

Shoshone Springs Alloformation

Upper lacustrine allomember

Middle subaerial allomember (lower "yellow zone")

Lower lacustrine allomember

Bishop tephra layers/complex (Tuff B), ~ 0.735 Ma.

Greenwater Fan Alloformation

Subaerial allomember(s)/tongues

Lacustrine allomembers/tongues

Huckleberry Ridge tephra layer (Tuff C), ~2.1 Ma.

Spanish Trail Alloformation

Post-Lake Tecopa alluvial units

#1 PLT alluvial complex

Cobble (rarely sm bldr) gravel to cobble-pbl gravel on pediments, discontinuously preserved, chiefly at margins of LT basin. Several meters above #2 surface. Class 2+ surface parameters. Intermediate in age between Dohrenwend's (1985) Greenwater and Sperry surfaces [although perhaps youngest members of the Sperry complex (which is chiefly pre-Lake Tecopa) may overlap into this unit].

#2 PLT alluvial complex

Cobble and pebble gravel veneer chiefly on pediments (preserved mostly on narrow mesa-like ridges in the interior of the LT basin), tonguing up side washes into strath-terrace gravels. (1985) "Greenwater Surface". Class 2 surface parameters.

#3 PLT alluvial complex.

Pediment and strath-terrace gravels of all side-washes; strath-terrace gravel of AR. Late-middle Pleistocene. Several meters above #4 surface (top of #4 unit). Bears relict (surface) paleosol with moderate Bt and stage 2+ Bk development. Class 3 surface parameters (desert-varnish development and levelling of swale morphology plus relict paleosol development). Intermediate between Dohrenwend's (1985) "Amargosa" and "Greenwater" surfaces.

#4 PLT alluvial complex. Chiefly Holocene but probably in part Wisconsin; equivalent to "Amargosa Surface" of Dohrenwend (1985). Underlies moderately extensive pediments on LT sediments both E and W of Tecopa Hills, and the Holocene flood plain of the Amargosa River; also wide young "flood plain" embayments along larger side washes, as well as flood plains of all minor washes.

Silt and clay, commonly sandy, near Amargosa River in S part of basin, to sandy pebble-cobble gravel, rarely boulder gravel, along Amargosa River and all the side washes.

Soil and desert-varnish development: nil to trivial (very weak).

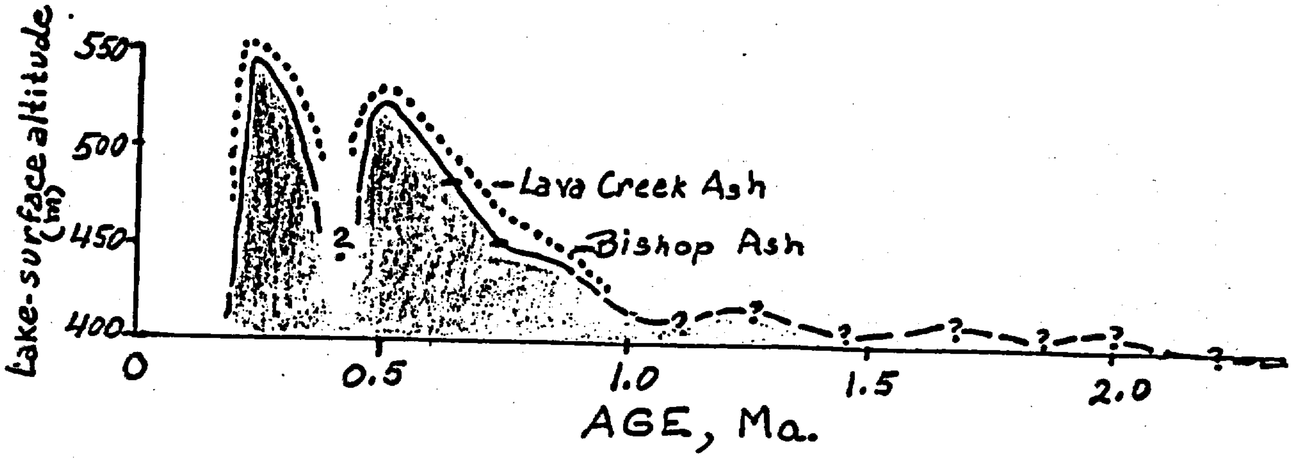
APPENDIX C.

Examples of diagrammatic measured stratigraphic sections
[See Figures C-1 to C-14]

Explanation

1) Vertical scale: 1/2-inch = 1 meter (starting from left columns)

2) See Appendix D for explanation of symbols used in all columns.



Appendix Figure F-1 (black solid line) Changes in lake level in the Lake Tecopa basin between 2.2 and 0.2 Ma

Notes: (1) This curve is smoothed and does not show the many small-scale brief oscillations in lake level in this closed lake basin. The portion from 2.2 to 0.75 Ma is particularly generalized because our present data provide only a general history for this time interval; more intensive stratigraphic research on its deposits, including reliable dating of key strata, will be necessary to find out details on elevations and timing of specific lake fluctuations.

(2) Our present stratigraphic data from exposed deposits, however, show clearly that Lake Tecopa remained at low levels and at times was a playa from 2.2 to probably between 1 and 0.8 Ma. A trend of gradual rise in lake level commenced somewhat before Bishop Ash time (0.735 Ma), that attained about 450 m and then about 480 m when the Bishop and Lava Creek tephra layers, respectively were deposited. Thus began the early part of the first deep-lake megacycle of Lake Tecopa. This megacycle culminated at about 520 m altitude probably around 0.5 Ma. It was followed by a deep lake recession to at least as low as 440 m, that probably lasted at least a few tens of thousands of years. Next came the second and final deep-lake megacycle, which rose to about 550 m altitude--the all-time maximum for Lake Tecopa. Breaching and commmencement of draining of this lake seems to have occurred at the end of this maximum, probably between 0.2 and 0.3 Ma.

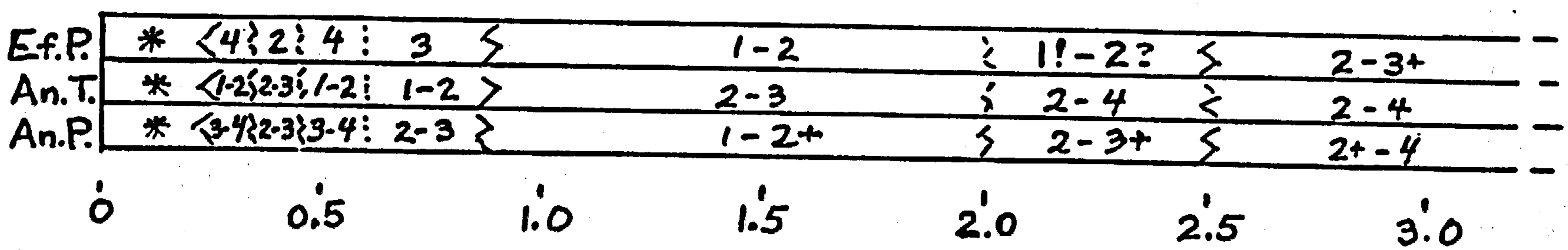
(3) The portion of the curve from 0.4 to 0.62 (Lava Creek Ash time) Ma is from the north part of the Lake tecopa basin, because in the southwestern part lake levels were anomalously lower perhaps due to tectonism.

Appendix Figure F-2 (dotted line) Changes in altitude of piezometric surface and watertables, inferred from exposures of spring /seepage carbonate cementation, travertine, and tufa at and within 1-2 m of the original landsurface.

Note that during the lake transgressions the piezometric surface/watertable rose faster than lake level; conversely, during lake regressions, it fell more slowly than the lake level.

APPENDIX FIGURE F-3

INFERRED PALEOCLIMATIC HISTORY OF THE LAKE TECOPA AREA FROM 3.2 TO 0.2 MA



EXPLANATION

Ef. P. = effective precipitation.

An. T. = annual temperature.

An. P. = annual precipitation.

Relative-value numerals in the figure:
1: Minimal, less than present values in this area.
2: Low-intermediate, values about like now.
3: High-intermediate, values somewhat higher than now.
4: Maximal, values appreciably greater than now.

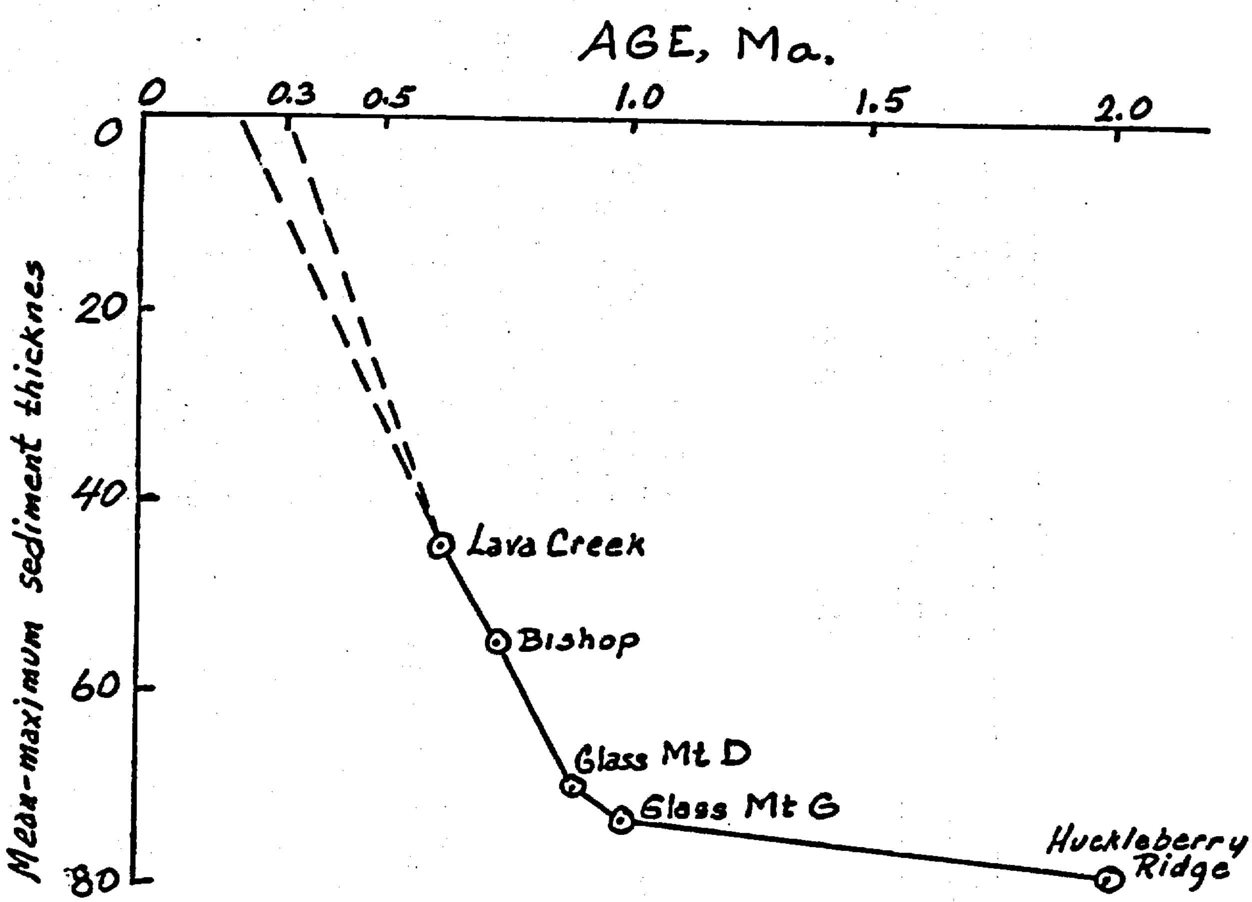
* After breaching of Lake Tecopa, four major erosion surfaces were formed. Each started with strong downcutting by streams, then lateral stream planation, followed by alluviation and then a time of landscape stability and soil development [erosion-deposition-stability (EDS) cycles (Morrison, 1987); the post-Lake Tecopa cycles correspond to Morrison's meso- to macro- EDS cycles]. These EDS cycles were induced by marked cyclic changes in effective precipitation through later Illinoian, Wisconsin, and Holocene time in this area.

At present, our climatic data are relatively crude and qualitative, pending inputs from various specialists who are analyzing samples collected from key horizons (particularly from deposits younger than the Bishop Ash). We hope to have more quantitative information about climatic conditions during specific episodes in Lake Tecopa's history as we get more climatic and chronometric data from our sampling program. The interpretations in this diagram are based chiefly on the lacustrine and fluvial history (lake levels and stream runoff) as determined from many measured stratigraphic sections throughout the Lake Tecopa area.

Data for the 2.5 to 3.2 Ma interval are from Hay and others (1986).

APPENDIX FIGURE F-4.

DIAGRAM OF SEDIMENTATION RATES IN THE LAKE TECOPA AREA



Depth in the Lake Tepoca sequence (Lake Tecopa Allogroup) versus age, from about 0.2 to 2 Ma. Age control is from well-dated tephra layers (Sarna-Wojcicki and others, 1987). Depths are my mean-maximum thicknesses down to the Bishop Ash, and from Sarna-Wojcicki and others (1987) below this tephra layer. The two diverging lines above the Lava Creek Ash show the probable uncertainty as to time of breaching of Lake Tecopa.

APPENDIX FIGURE G.

CORRELATIONS OF THE LAKE TECOPA SEQUENCE WITH THE STRATIGRAPHIC RECORDS FROM SEARLES LAKE, LAKE LAHONTAN, AND THE SIERRA NEVADA

Appendix Figure G-1, Explanation and Comments:

Horizontal scale is Ma for all 4 diagrams.

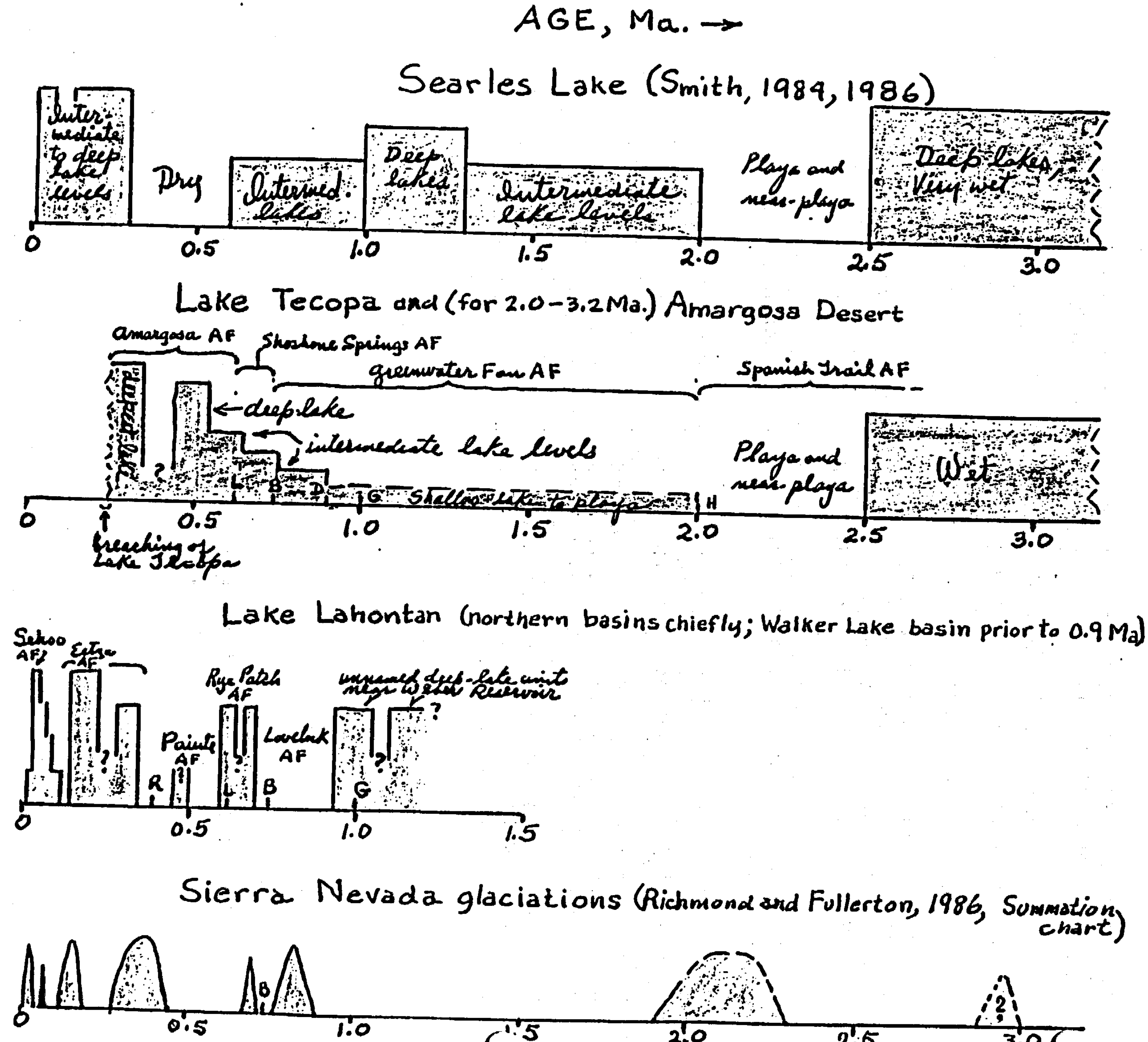
Vertical scale is schematic.

Capital letters just above age lines indicate positions of tephra layers: R = Rockland (400 ka); L = Lava Creek B (620 ka); B = Bishop (738 ka); D = Glass Mountain D (0.9 Ma); G = Glass Mountain G (1 Ma); H = Huckleberry Ridge (2 Ma).

For discussion, see text section "Correlations with Amargosa Desert (Ash Meadows), Searles Lakes, Lake Lahontan, and the Sierra Nevada".

Lake Tecopa interpretation is based on my own stratigraphic field studies, 1986-1988; Amargosa Desert data are from Hay and others, 1986. Lake Lahontan interpretation is chiefly from my own field studies (Morrison, 1964, 1965; Morrison and Frye, 1965; Morrison and others, 1965; Morrison and Davis, 1984a, 1984b; and unpublished field data), supplemented by tephrochronologic and stratigraphic data from J. O. Davis (oral and written communications, 1984-1988). Searles Lake data are from Smith (1979, 1984, 1983) and Smith and Street-Perrott (1983). A.M. Sarna-Wojcicki (and colleagues, 1984, 1985, 1987, and in press) supplied tephrochronologic control for all these areas.

APPENDIX H. NEOTECTONIC MAP OF THE LAKE TECOPA AREA
[Figure H-1, in preparation]



APPENDIX FIGURE G-1. CORRELATIONS OF THE LAKE TECOPA SEQUENCE WITH THE STRATIGRAPHIC RECORDS FROM SEARLES LAKE, LAKE LAHONTAN, AND THE SIERRA NEVADA

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Appendix B-V

Progress Report -Groundwater Discharge Deposits by J. Quade.

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PROGRESS REPORT - Ground-Water Discharge Deposits

by J. Quade

Well-exposed fine-grained deposits abound in the valleys of southern Nevada. However, for reasons of age or poor exposure, only a few are appropriate for detailed study, though nearly all contain useful paleohydrologic information in some form. Geologic mapping and sampling has therefore been pursued at two scales: reconnaissance and detailed. Both scales contribute to construction of a regional paleohydrologic framework for the last "full" pluvial roughly 18,000 years ago. Detailed studies, in addition, should supply a more quantitative picture of the ground-water flux passing through the last full pluvial hydrologic system.

Reconnaissance fieldwork Several of these types of study, which entail several days of mapping and sampling, and weeks of laboratory follow-up have been completed or added to in the past 18 months:

Piute Valley--southern Clark County, Nevada
Valley Wells-- San Bernadino County, Calif.
Diatomite of Lathrop Wells--Nye County, Nevada
Coyote Springs Valley--deposits in the southern end of the valley (Clark County) and the northern end (Lincoln County).
Chicago Valley-- Inyo County, California

Detailed fieldwork Only a few valleys have proven to contain deposits of appropriate age or sufficient exposure for detailed work. This fieldwork entails several weeks to months of mapping, and description and sampling of all known major exposures. Mapping was conducted on 1:62,500 scale black and white aerial photographs, and then transferred to orthophotos on the completion of each area. All paleofauna sample sites were described in detail and often photographed, as were localities containing datable materials.

The following areas were completed or added to in the past 18 months:

Corn Creek Springs (Clark County, Nevada)
Indian Springs (Nye and Clark Counties, Nevada)
Pahrump Valley (Nye County, Nevada and Inyo County, California)
Sandy Valley (Clark County, Nevada)

Laboratory Work

Faunal samples About 250 samples have been processed in the past eighteen months. Processing has entailed disaggregation of sample matrix, sieving, and handpicking of each for mollusks. These are then forwarded for analysis to Dr. W. L. Pratt at the Natural History Museum in Las Vegas. Some samples have been found to contain diatoms as well. Eleven of these are being examined by Dr. L. Burckle at Lamont-Doherty Laboratories, Palisades, New York. Ostracodes from a few samples have been isolated; no analyses are planned.

Amino-Acid Analyses Large faunal samples from key localities were picked and cleaned; forty-five were submitted for amino acid dating, most of which have been completed.

Radiocarbon analyses Ten samples have been pretreated for analysis in the Utah laboratory in the past 18 months. Others pretreatments were handled by the University of Arizona, which is performing all of the dating.

Pollen analysis Eight samples were isolated for pollen, and sent to Dr. O. Davis at the University of Arizona for counting.

RESULTS

Piute Valley Fine-grained deposits are located on the west side of the Paulte Valley just over the California-Nevada border about 80 kilometers south of Boulder City, Nevada. Relative to other areas they fairly limited in extent, covering about 4 km^2. They are nonetheless of interest, being (1) the southernmost deposits studied, (2) not immediately adjacent to any major mountain range, and (3) situated in alluvium dominated by volcanic clasts. In the last two respects the Piute Valley deposits are closely analogous to the Diatomites of Lathrop Wells near Yucca Mountain. Mollusks are not abundant. Sample PteVF87-1 (Table 1) indicates locally ponded conditions, and PteVF87-4 the surrounding moist terrestrial habitat. Fluvial silt and mudstone are more common than ponded units, which are not laterally continuous. Several paleosols were mapped within the deposits. Diatomite is abundant and was sampled at six localities. No identifications are completed. In overall aspect, the deposits in Piute Valley are consistent with a ground-water discharge, not lacustrine setting.

Megafaunal remains, particularly camel and mammoth teeth, are very common, and indicate a mid-Pleistocene age (B. Reynolds, San Bernadino County Museum, pers. comm., 1988). This is consistent with amino-acid ratios on *Gyraulus* sp. (Table 2, PteVF87-1) which are largest--and therefore oldest--of any sample taken thus far in southern Nevada, except for perhaps the ratios on clams from Chicago Valley. No Wisconsin-age deposits are present.

Two north-south trending lineaments bound the eastern, downslope extent of the deposits. It is quite likely that these structures have in some manner localized discharge upslope, either by juxtaposition of impermeable layers against a gravel aquifer, or by infilling of the fault with impermeable cements. Other examples of tectonic control on paleodischarge can be found in many valleys described below.

Valley Wells Valley Wells (or Shadow Valley) is located near the California-Nevada border in San Bernadino County, California, about 70 km west of Piute Valley. Fine-grained deposits cover about 4.5 km^2.

Deeply-incised bluffs end abruptly downslope against several north-south trending lineaments.The bluff exposures contain a long history of spring discharge in the area. Amino-acid ratios (Table 2, VWF87-5 and 9) on pond snails indicate they are slightly younger than Piute Valley snails. Irvingtonian-age megafauna found by B. Reynolds are also consistent with a mid-Pleistocene age. Black mats from thin deposits inset into the older bluff units yielded a radiocarbon age of 10,250 ±160 (Table 3, A-4899). Artifacts were found eroding from the mat, and mammoth teeth are common in the underlying pale-green clays clays.

The older bluff deposits are mainly composed of bedded pale-brown silts and sands which are dominantly fluvial in character. Green clay pond units increase downslope, although they remain thin and difficult trace laterally. All mollusk samples are consistent with a ponded setting and fringing wet meadow environments (Table 1, VWF87-1,4,5,6,7, and 9). The younger, late Wisconsinan deposits are inset into the bluffs along at least one drainage. As such, they are of rather limited extent. Pale-green clays and organic mats entirely compose them. Habitats indicated by mollusks are similar to those of the bluff deposits. In all, pond, wet meadow, and phreatophyte flat settings account for the long history of sedimentation in the area. Several stands of phreatophytes (cottonwood and mesquite) attest to ongoing high water table in the area of the fine-grained sediments.

Like Piute Valley, at least three north-south trending lineaments bound the downslope extent of the three adjacent areas of fine-grained deposits. They likely localized former and modern discharge along the upslope side. It is interesting that the deposits are the highest in elevation at 1,100 m of any identified in southern Nevada. The Clark Mountains, reaching over 2,400 m, bound the east side of the valley. This nearby recharge source, and the faults likely account for the fine-grained deposits at such a high elevation.

Chicago Valley Chicago Valley is located in Inyo County, California, about 110 km west of Las Vegas. The valley opens onto the Tecopa Basin at its south end. A fairly broad expanse (5.8 km^2) of low-lying sediments cover the lower piedmont areas on the east-central side of the valley. At least two lineaments bound the downslope extent of the two adjacent expanses of deposits. As in other valleys, these faults likely served as a barrier to ground-water flow, damming water at depth and forcing it to the surface. Twelve Mile Spring still discharges from along the upper lineament. Mesquite is extensive in washes cut into the fine-grained deposits and over the small flats in the valley floor.

Poor-exposure limits what can be said about the deposits. As in other areas, the deposits appear to be dominantly fluvial, and are accompanied by extensive nodular carbonate. In other areas this material is of ground-water origin. Ponded units are very limited; previous descriptions of the deposits as lacustrine do not appear to hold up. The few faunal samples (Table 1, CV-mol. 1 a-1 and 2) obtained attest to ground-water discharge well upslope from the active springs . The spring mollusks show strong affinities with presettlement faunas in Ash Meadows springs. Amino-acid racemization dates on freshwater clams indicate an age at least equal to the Piute Valley deposits, i.e. mid-Pleistocene. No late Wisconsinan spring deposits were located, but this may well be the result of poor exposure given that ground water is so close to the surface even in the modern climate.

The Chicago Valley is bordered on the east and west by the Nopah and Resting Springs Ranges, respectively. Neither exceeds 2,000 m, which raises the question of a recharge source for the modern and Pleistocene springs in the valley. One distinct possibility is that underflow through the Nopah Range from neighboring Pahrump Valley has and is occurring. The low point in the adjacent Pahrump Valley playa is about 90 m higher than Twelve Mile Springs. Moreover, the Chicago Valley ground-water discharge deposits are found only on the east side of the valley, the right location if underflow from the east is occurring.

Coyote Springs Valley Exposures of fine-grained sediments are very extensive in the Coyote Springs Valley, located immediately east of the Sheep Range. Description will begin with the relatively restricted deposits in the northeast part of the valley and end with the more widespread ones in the south.

The North Coyote Springs Valley deposits cover about 8 km^2. In many respects these deposits are similar to those in Valley Wells. At least two lineaments bound the downslope extent of the deposits. Deeply-incised bluffs expose over 12 m of alternating pale-brown to green silts and mudstones. Inset into the bluffs are much younger, likely late Wisconsin age units. Mesquite chokes most of the main washes cutting through the deposits. Several active seeps occur along the lineament.

The age of the bluff beds remains unknown, but a very thick, dense caliche layer capping them belies their antiquity. A few poorly-preserved mollusks were found. Standing water is indicated by the faunas but the greenish clays containing them are neither thick nor laterally extensive. Several paleosols are also present.

The inset deposits contain abundant mollusks, green clays, and black mats. The green clays are laterally very discontinuous and generally follow the local wash gradient. This makes substantial extent to standing water unlikely. This is supported by identified mollusks (Table 2, NCySF-2,3,5,8,9, and 11) which are typical of wet meadows and very localized ponding. Dating of the mats is in progress at the

University of Arizona. Some of the spring deposits contain artifacts, suggesting a Holocene as well as Pleistocene component to discharge.

The south Coyote Springs deposits cover about 17 km^2. Work in this large area is in progress and results presented here are preliminary. The deposits almost certainly represent a spectrum of ages. Muddy Creek age deposits, probably late Miocene in age, are exposed in large bluffs on the east side of the valley. Much younger deposits crop out all along the west side, including one small area containing an organic mat and mammoth teeth almost certainly late Wisconsin in age. Organics from the mat are now with the Arizona radiocarbon lab. Other units are tilted up to 10 degrees, and clearly antedate the Wisconsin. The age of the majority of the fine-grained beds is unclear, and may be anywhere from early Pleistocene to late Pleistocene. Earlier this year three key localities were sampled for amino-acid racemization dating. These mollusks are now with the Amherst lab.

The deposits are dominantly fluvial pale-brown silts and occasional gravels. Green mudstones accompanied by dense caliche caps are also common toward the basin center. The facies pattern is similar in most respects to ground-water discharge systems described elsewhere. SCySF-1, the only sample counted thus far, contains a typical "wet meadow" faunal suite. Other mollusks examined in the field are entirely consistent with this setting and with fringing moist terrestrial environments. No marsh fauna, such as are found in the Tule Springs, Corn Creek, and to a lesser extent in the Pahrump Valley deposits, have been found. Ponding must therefore have been quite limited throughout the history of deposition.

The Pleistocene age ground-water discharge deposits are all concentrated on the west flank of the valley, probably because the high Sheep Range bounds that side of the valley and was certainly a principle recharge source for the valley. The deposits are cut by several small faults which have uplifted several small horsts of older material. These horsts were subsequently beveled and capped by dense caliche. The deposits are abruptly truncated in the valley center by the extension of the Arrow Canyon Range bounding fault. To the east, only Muddy Creek age deposits crop out. As in other valleys, this structure may have dammed subsurface aquifers, forcing flow to the surface and producing the large area of ground-water discharge deposits we observe today on the west side.

DETAILED MAPPING AND SAMPLING

Four valleys contain deposits of late Wisconsin age that are sufficiently well exposed to warrant detailed mapping and sampling: Indian Springs Valley, Pahrump Valley, Corn Creek Springs Valley, and Sandy Valley. Except for the Pahrump Valley, the intent is to construct as detailed a picture as possible of the whole full-pluvial ground-water discharge environment. This then will serve as a basis for a semi-quantitative estimate of paleodischarge in each area. The Pahrump Valley deposits, because of their complexity, do not lend themselves well to this kind of analysis. Nonetheless, a long and well-exposed history of deposition has made the Pahrump Valley a focus of much detailed work. The Indian Springs Valley deposits have already been described in a series of other reports; journal publication of these results will be in *Quaternary Research* sometime in the first half of 1989.

Sandy Valley Also known as Mesquite Valley, this basin sits astride the California-Nevada border immediately south of the Pahrump Valley. The mapped deposits are concentrated in the northeast corner of the valley, and cover about 5 km^2. They are separated from similarly appearing units in the south end of the Pahrump Valley by only a few kilometers.

The deposits are mostly late Wisconsin in age. This is based on generally weak induration of the deposits, thin carbonate caps, well-preserved mollusks, and common organic mats. Five of the mats are currently being dated. Amino-acid ratios (SVF-14, 16, and 22) are generally consistent with late Wisconsin mollusks from other valleys. The one determination inconsistent with a late Wisconsin age comes from a sample that may have experienced very high surface temperatures.

Pale-green to white mudstones are widespread and contain abundant mollusks. These units grade into pale-brown to white silts on the upslope margins of the deposits. Nineteen mollusk samples (Table 1, SVF and SAV series) have been counted. Nearly all the samples contain *Gyraulus parvus*, which in these systems generally inhabits small ponds. However, no open-water marsh forms were observed. Several samples also contained *Pyrgulopsis* sp., which favors fast-flowing fresh water generally proximal to spring-discharge points. Nearly all samples contained terrestrial mollusks in some percentage, as is typical of these systems, indicating the very discontinuous nature of the standing water. Both the sedimentology and and fauna indicate a very wet overall environment with ponding, and fringing wet meadows covering most of the 5 km^2 area.

The deposits wrap around the southern nose of the low-lying Black Hills and then spread into a triangular-shaped area downgradient. The hills may well have intercepted and dammed the water table as it sloped away from the adjacent Spring Mountains. Beyond the hills, the triangular area of deposits are bounded on its downslope side by two parallel faults which are extensions of the Black Hills bounding fault. As in other valleys, they clearly have localized discharge on their upslope side. Even today, mesquite and associated coppice dunes clog drainages in the immediate vicinity of the faults, although no surface discharge is occurring. A 1,300 $\pm$ 50 yrs B.P. age (Table 3, A-4860) was obtained on hearth charcoal deep within one coppice dune.

Corn Creek Springs Valley This valley is actually a sub-basin of the Las Vegas Valley, occupying its upper northwest end. The high Spring and Sheep Ranges bound the basin on the west and east sides, respectively. Fine-grained deposits in the valley center are well exposed and cover about about 40 km^2. As almost all the exposed sediments are late Wisconsin in age, this is the second largest exposure of such deposits in southern Nevada after those in the Las Vegas Valley.

The Quaternary geology of this area has already been the subject of one publication by the author. Subsequent to that, several months of additional fieldwork and many months of labwork have considerably refined the stratigraphic and depositional history of the deposits. About half of the 100 additional mollusk samples have been counted but results could not be tabulated in time for this report. A few additional radiocarbon dates have been completed, with many more pending at Arizona.

Additional radiocarbon analyses do not significantly alter the basic stratigraphy presented in Quade (1986). All (Table 3, A-44861, 4862, 4901) fall within the latest Pleistocene to earliest Holocene. This fits with the stratigraphic position of the dated horizons near or at the top of the late pluvial ground-water discharge deposits. A single analysis on marsh snails underlying these horizons produced a date of $28{,}420^{+1080}_{-950}$ yrs B.P. (Table 3), consistent with the full-pluvial position of the sample. Amino acid ratios from Corn Creek Flat (Table 2, CS85-5,17, 20 and CSF-15, 27, 65, 79) confirm that the majority of the deposits are late Wisconsin in age. They also corroborate (CSF-22 and 33) the existence a few outcrops of a pre-late Wisconsin beds on lower Corn Creek Flat and next to Corn Creek Station.

A revised preliminary map of the full-pluvial setting of a part of Corn Creek Flat is given in Mifflin and Quade (1988). An additional map of the sedimentology and fauna is being compiled as analyses come in. Sedimentologically, most of the fine-grained deposits are pale-brown fluvial silts. White to pale-green mudstones cover a much smaller area, mainly at the southern end of the valley, along a narrow belt on the valley's east side, and in three small patches on the west side. The overall impression of the full-glacial setting is that the majority of the 16 km^2 exposed area was covered by a phreatophyte flat in which no direct flow discharge occurred. However, a belt of springs discharged along the east side of the valley. These and two small spring complexes on the west side supported a series of small ponds on the upper flat along the valley axis, as well as a marsh at the bottom of the flat. The marsh covered about 1.5 km^2. A narrow marshy stream complex in turn fed out of the marsh through some narrows into Tule Springs Flat downvalley.

The aerial extent of all the major facies, including wet meadows and phreatophyte flats form the basis for quantitative estimates of the amount of discharge occurring in the valley during the full-pluvial climate. Such estimates of discharge appear to be possible to established for Corn Creek Flat, Indian Springs, and Sandy Valley, and will be the subject of further work.

Pahrump Valley The Pahrump Valley contains the longest and the best exposed record of ground-water discharge of any valley studied in the southern Great Basin. However, the outcrop is so extensive and the stratigraphic relations are sufficiently complex that many years could be spent in their characterization. Efforts to date have focused on identifying deposits associated only with the last full-glacial. Deposits related to the waning phases of that pluvial period, from about 11,500 years B.P. to present are relatively easy to map and characterize. However, units related to the full-pluvial, i.e., ca. 18,000 have not been successfully differentiated from the many other ground-water discharge units antedating the last full-glacial climate. As in other valleys, organic matter does not preserve well beyond about 15,000 years, and so the deposits cannot be identified by dating alone. And stratigraphic relations in all but a few areas are too complex to confidently reconstruct the full-pluvial setting. For these reasons, Pahrump Valley ground-water discharge can not be as confidently used in estimating pluvial maximum discharge. Considerable effort has been expended in deciphering its rich history of ground-water discharge.

Tilting and faulting of fine-grained beds has exposed over 150 m of section in several areas in the center of the valley. They are composed of alternating fluvial siltstones, paleosols, white to pale green mudstones, and occasional gravels. One major ridge in the lower third of the tilted section is composed of massive travertines which include textbook examples of flowstones and ripplestones over a large areas. No such travertine is associated with modern spring discharge in the valley. No mollusks have been found preserved in the sediments after a careful search. However, the sedimentary patterns observed in these beds are consistent with those of later periods of clear ground-water origin.

Untilted beds exposed in deeply incised bluffs stretching for kilometers along the valley axis constitute the next generation of sediments. A dense caliche caps the bluffs in most areas. Stratigraphy is often not traceable from one major wash exposure to the next. The beds are dominantly pale to medium brown silts and sands interrupted by many paleosols and erosional disconformities. Pale-green mudstones are common but tend to be laterally discontinuous. Mollusks and occasional megafaunal remains have been observed. Amino-acid dates (Table 2, PV Mol. 31) on pond snails and clams suggest in both cases an age younger than the Valley Wells, Chicago Valley, or Piute Valley deposits, but older than late Wisconsin. The samples counted to date from the green mudstones suggest wet meadow and pond environments. No open-water fauna such as typify lower Corn Creek Flat in the full-pluvial have been located.

Two major drainages in the southern half of the valley contain a well exposed and basically concordant record of latest Wisconsin deposition. These are deeply incised into the older bluff sediments described above. Sometime before about 11,300 years B.P. both the Hidden Valley and the Stump Springs drainages began to fill with sediment. Broad wet meadows at the heads of the drainages coalesced into flowing streams with marshy borders. The wet areas were never wider than 30 or so meters in the drainages, and the sediments associated with them generally lapped against but never entirely over the adjacent bluff sediments. Fauna is extremely abundant, including moist terrestrial, flowing stream, and pond snails (Table 1, Pah. Mol. series) to tens of mammoth molars. The wet meadows persisted along these two drainages from 11,200 to at least 8,500 years B.P. (Table 3, A-4590 to 4595, 4606, and 4607), after which discharge decreased dramatically. Though both drainages are filled with mesquite, the only spring discharge in the area up to the 1920's was a few gallons per minute from Stump Spring.

Exposure of the beds end abruptly in a series of major faults running along the north-south axis of the valley. West of the faults no fine-grained ground-water discharge deposits are exposed but a moderately sized dry playa is present in the valley bottom. Cuttings from three 24 ft. hand augured boreholes were extracted from the playa in order to ascertain the pre-Holocene environment. Two cuttings profiles revealed a full 24 ft of brown silt such as is being deposited on the playa today. A third cutting profile contained pale-green clays starting at 14 ft. Pond snails from the clays have been submitted for amino-acid racemization dating. The appearance of the clays and the overlying thickness of brown silt suggest that the clays antedate the Wisconsin. The preferred interpretation is that little or no ground-water discharge was occurring in the playa area.

Brown Spring, now dry but which in historical times discharged 20 or more gallons per minute, is located on the main north-south lineament of the valley along which the oldest beds are uplifted and tilted. A dead cottonwood marks the spot. Massive incision in the last few decades has exposed an excellent stratigraphy. Debris and midden left by pioneers (the spring is on the old Santa Fe Trail) form the uppermost exposed beds and aboriginal artifacts occur in neighboring dunes. Pleistocene and Holocene discharge spread several hundred meters down from the present site of the cottonwood. Artifacts in the outflow facies date to 8,510 ± 190 years B.P. (A-4609). Several meters of spring deposits underlie this dated layer.

Many square kilometers of fine-grained beds occurs in the northern part of the valley. The exposed ones, which include three separate areas are clearly associated with faults on their downslope sides. Two paleospring areas have been identified. One ceased to flow at about 10,920 ± 160 yrs. B.P. (Table 3, A-4609). Other paleospring areas may exist in the beds, but the vast majority of these exposures are composed of monotonous brown silts, likely deposited in a phreatophyte flat. The existing exposures become buried by Holocene silts toward the valley center, probably obscuring a very extensive paleoground-water discharge system. This northern area is the focus of most modern discharge in the valley. It is probable that this was also true of the Pleisotocene, but the extent can not be mapped.

REFERENCES

Mifflin, M.D. and Quade, J., 1988, Paleohydrology and hydrology of the carbonate rock province of the Great Basin (East-central to southern Nevada): Geological Society of America Guidebook no. 12 (Centennial national meeting, Denver), p. 305-336.

Quade, J., 1896, Late Quaternary geology of the upper Las Vegas Valley: Quaternary Research v. 26, p. 340-357.

Mollusk Samples

Species	CV-mol-1a	CV-mol-2	NCySF-11	NCySF-2	NCySF-3	NCySF-5	NCySF-8	NCySF-9	PteVF-1
Amnicola sp.	3.4	2.2							
Catinella	12.2	2.9		19.2	11.4		14.6	5.9	0
Deroceras			4.8	1.4			1.2		
Discus cronkhitei									
Euconulus fulvus									
Fossaria modicella							0.6		
Fossaria parva	1.69	0.4	3.2	1.4				3.2	
Gastrocopta pellucida			6.3				0.6		
G. tappaniana			6.3	49.3	32.9	6.3	76	66.2	
Gyraulus parvus						31.3	0.6		
G. circumstriatus	0.8	0.4							100
Hawaiia sp.			3.2	8.2			1.8	0.6	
Oxyloma sp.			3.2						
Physa gyrina	1.2								
P. virgata									
Pisidium casertanum	1.3	0.4	73	4.1		62.5		4.6	
P. rotudatum				2.7					
Pupilla hebes									
P. muscorum				1.4					
Pupoides sp.									
Pyrgulopsis ar.							1.2	1.3	
Pyrgulopsis mi.	59.1	82.5							
Pyrgulopsis sp.					55.8		3.5	0.6	
Stagnicola caperata									
S. elodes									
S. montanensis									
S. pilsbryi	1.69	0.7							
Succinea									
Tryonia v.	3.4	8							
Vallonia cyclophorella									
V. gracilicosta				6.8					
Vallonia sp.									
Vertigo berryi	15.2	2.5		5.5				17.5	

mollusks/kilogram sediment

TABLE 1

Mollusk Samples

Sample no.

Species	PteVF-4	SAV-carb-1	SCySF-1	SV87-6	SVC-1	SVC-2	SVC87-3	SVF87-16	SVF87-1
Assiminea sp.									
Catinella gabbi	62.5	13	39.7	27.7	16.1	18.7	27.8	48.6	0.5
Deroceras		0.5	0.5		1.1	0.4		1.9	
Discus cronkhitei									
Euconulus fulvus		0.5		0.3		0.4			
Fossaria modicella			7.5						
Fossaria parva		14.1		14	29.9	13.5	8.3	7.2	2.6
Gastrocopta pellucida	12.5								
G. tappaniana		6.5		0.3	12.6	18.7			
Gyraulus parvus		14.6	8	7.4		15.9	8.3	6.5	0.5
G. circumstriatus		17.3		13.7		8.8		9.2	0.5
Hawaiia sp.									
Oxyloma sp.						0.4			0.5
Physa gyrina									
P. virgata				0.6		3.6			1.5
Pisidium casertanum		6.5	0.5	7.1	23	0.8		2.7	25.5
P. rotundatum		5.4			17.2				4.1
Pupilla hebes									
P. muscorum		0.5	17.1	12.9			27.8	6.5	
Pupilla sp.									0.5
Pupoides albilabris	25								
Pyrgulopsis av.									
Pyrgulopsis mi.									
Pyrgulopsis sp.		0.5				2.4			63
Stagnicola caperata									
S. elodes									
S. montanensis									
S. pilsbryi								0.9	
Succinea									
Tryonia v.									
Vallonia cyclophorella									
V. gracilicosta		7							
Vallonia sp.									
Vertigo berryi		13.5	26.3	16.1		16.3			

mollusks/kilogram sediment

Species	[illegible] Samples SVF87-4	SVF87-5	SVF87-7	VWF87-1	VWF87-4	VWF87-5	VWF87-6	VWF87-7	VWF87-9
Assiminea sp.									
Catinellidae	9.8	40.5	16.7	1.1	57.1	17	28.5	11	7.7
Deroceras		1.1				1.1	2.7		0.5
Discus cronkitei									
Euconulus fulvus									0.5
Fossaria modicella									
Fossaria parva		5.6		18		4.6			
Gastrocopta pellucida									
G. tappaniana				68.5		0.4	3.7		
Gyraulus parvus	17.6	3.5		2.2			2.7		1.9
G. circumstriatus		2.1		1.1		41.9	5.9	5.2	49
Hawaiia sp.									
Oxyloma sp.									
Physa gyrina									
Physa sp.							0.5		
P. virgata									
Pisidium casertanum	9.8	2.1			21.4	3.1			
P. rotundatum	52.9	9.1				0.4			
Pupilla hebes									
P. muscorum		6.7	50	1.1		20.8	15.2	2.1	1.4
Pupoides sp.									
Pyrgulopsis av.									
Pyrgulopsis mi.									
Pyrgulopsis sp.		2.1							
Stagnicola caperata							26.9	2.1	29.3
S. elodes									4.8
S. montanensis									
S. pilsbryi		3.5							
Succinea									
Tryonia v.									
Vallonia cyclophorella						4.6	7.5	8.9	1.4
V. gracilicosta								11	
Vallonia sp.								58.6	
Vertigo berryi	9.8	23.7	33.3	7.9	21.4	6.2	6.4	1.2	3.4

mollusks/kilogram sediment

Mollusk Samples

sample #

Species	SVF87-11	SVF87-13	SVF87-14	SVF87-17	SVF87-2	SVF87-22	SVF87-23	SVF87-24	SVF87-28
Asaminea sp.									
Catinellidae	19.8	33.3	38.2	22.7	1.5	60.1	31.4	31.6	27.2
Deroceras				2			2.8		
Discus cronkhitei									
Euconulus fulvus	2.9			1				0.7	
Fossaria modicella			4.3	3		1			
Fossaria parva	9		4.9	5	11.9	3.4	1.1	13.6	3.7
Gastrocopta pellucida									
G. tappaniana	3.3		1.2	3.5		1.5	2		7.6
Gyraulus parvus	1.7	33.3	22.8	13.6	13.4	1		4.3	1.6
G. circumstriatus	3.3		6.2	7.1	1.5		17.6	9.3	7.6
Hawaiia sp.									
Oxyloma sp.	0.4				1.5	1.1			
Physa gyrina									
P. virgata				0.5	4.5	0.5		1.4	
Pisidium casertanum	19.8	33.3	8	5.6	34.3		7.4	5	2.8
P. rotundatum				4.5	10.4	1		1.4	0.9
Pupilla hebes									
P. muscorum	17.7		1.9	4		10.8	10.2	17.2	19.6
Pupoides sp.									
Pyrgulopsis sv.									
Pyrgulopsis mi.									
Pyrgulopsis sp.	3.3				11.9				
Stagnicola caperata									
S. elodes									
S. montanensis									
S. pilsbryi						2		0.7	
Succinea									
Tryonia v.									
Vallonia cyclophorella	0.4								
V. gracilicosta						2	1.1	6.5	1.6
Vallonia sp.									
Vertigo berryi	18.5		12.3	27.3	4.5	16.7	25.2	8.5	27.5
mollusks/kilogram sediment									

.lusk Samples

Species	Sample # Pah. Mol. 1	Pah. Mol. 2	Pah. Mol. 3	Pah. Mol. 4	Pah. Mol. 5	Pah. Mol. 6	Pah. Mol. 7	Pah. Mol. 9	Pah. Mol. 17
Asaminea sp.									
Cathelliidae									
Deroceras									
Discus cronkitei		7.7		7.1					
Euconulus fulvus									
Ferrissia californica			1.2	2.4					
Fossaria modicella									
Fossaria parva	6.7		6.1					7.4	
Gastrocopta pellucida									
G. tappaniana			1.2					13.1	
Gyraulus parvus									
G. circumstriatus			4.9	2.4	56.5	56.1	44	0.6	93.6
Hawaiia sp.				2.4				28.6	
Oxyloma sp.									
Physa gyrina			2.4						
P. virgata									
Pisidium casertanum	53.3	23.1	19.5	16.7	6.5		36	20.6	
P. rotundatum									
Pupilla hebes									
P. muscorum									
Pupoides sp.									
Pyrgulopsis av.									
Pyrgulopsis mi.									
Pyrgulopsis sp.	13.3	61.4	58.5	42.7		2.4		2.9	
Stagnicola caperata				11.9	27.4	31.7	16		
S. elodes									
S. montanensis									
S. pilsbryi									
Succinea	26.7	7.7	2.4	4.8	8.1	7.3	4	4.6	6.5
Tryonia r.									
Vallonia cyclophorella				4.8					
V. gracilicosta			1.2	4.8				15.4	
Vallonia sp.									
Vertigo berryi			2.4		1.6	2.4		6.9	

mollusks/kilogram sediment

TABLE 2 AMINO ACID RATIOS ON SOUTHERN NEVADA MOLLUSKS

SAMPLE #	GENUS	AMINO ACID RATIOS FREE	TOTAL HYDROLYSATE
CS85Mol.20	*Gyraulus*	0.188	0.133
CS85Mol.5	*Gyraulus*	0.189	0.131
CSF87-17	*Gyraulus*	0.202	0.114
CSF87-15	*Gyraulus*	0.23	0.175
CSF87-22	*Gyraulus*	0.241	0.172
CSF87-27	*Gyraulus*	0.169	0.107
CSF87-33	*Gyraulus*	0.326	0.257
Pah. Mol.5	*Gyraulus*	0.191	0.112
PY Mol. 31	*Gyraulus*	0.267	0.195
Piute Valley 87-1	*Gyraulus*	0.367	0.256
CY Mol. 2	*Gyraulus*	0.338	0.214
SYF87-22	*Gyraulus*	0.198	0.118
SYF87-16	*Gyraulus*	0.191	0.111
YWF87-5	*Gyraulus*	0.291	0.183
YWF87-9	*Gyraulus*	0.295	0.197
CS85-17	*Pisidium*	0.212	0.156
CS85Mol.5	*Pisidium*	0.227	0.154
CS85Mol. 20	*Pisidium*	0.21	0.146
CSF87-15	*Pisidium*	0.266	0.179
CSF87-22	*Pisidium*	0.296	0.196
CSF87-27	*Pisidium*	0.156	0.128
CSF87-33	*Pisidium*	0.378	0.274
CSF87-79	*Pisidium*	0.236	0.158
CY Mol. 1a	*Pisidium*	0.422	0.318
CY Mol. 2	*Pisidium*	0.409	0.277
PY Mol. 29	*Pisidium*	0.264	0.214
PY Mol. 66	*Pisidium*	0.177	0.134
PY Mol. 81	*Pisidium*	0.243	0.178
PY Mol. 31	*Pisidium*	0.375	0.293
SYF87-16	*Pisidium*	0.229	0.183
SYF87-22	*Pisidium*	0.207	0.166

INCOMPLETE OR NON-LINEAR RESULTS

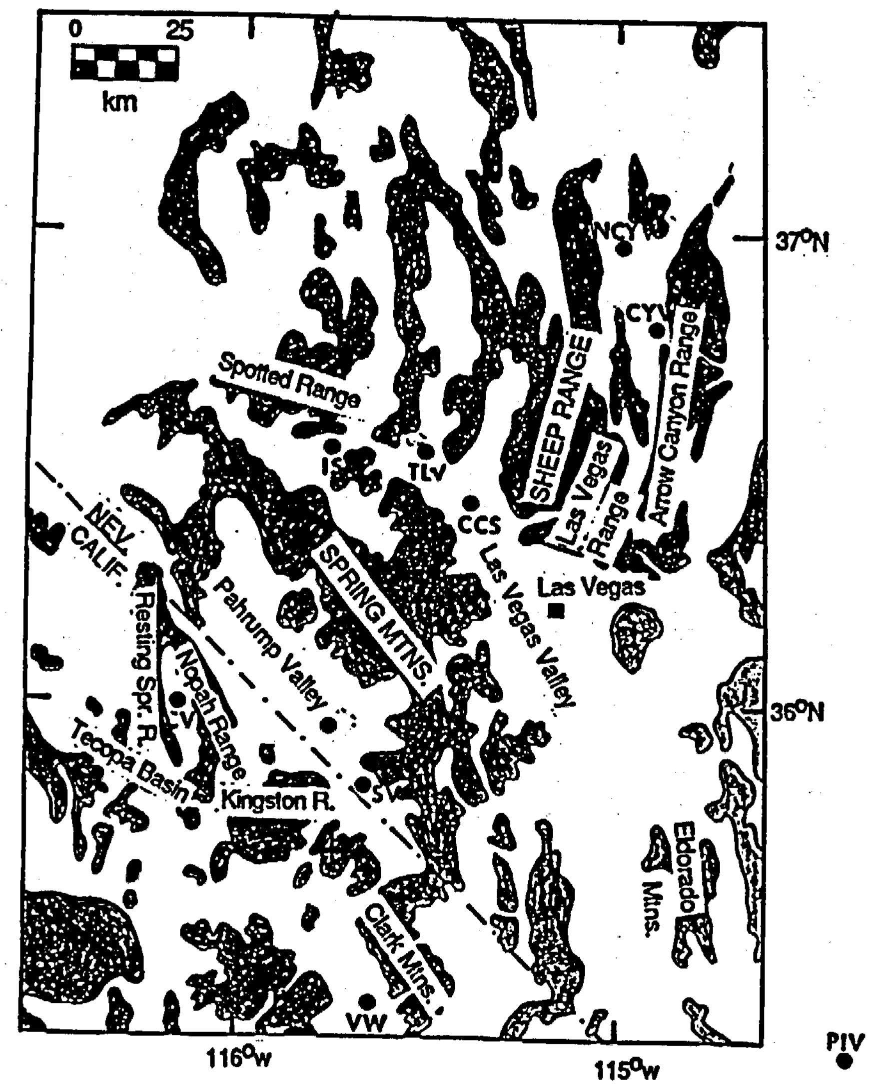
SAMPLE #	GENUS	FREE	TOTAL HYDROLYSATE
SAY. Mol. 2	*Pisidium*	0.271	0.193
Pah. 85 Mol. 16	*Gyraulus*	0.292	0.19
SYF87-14	*Pisidium*		0.215
SYF87-14	*Gyraulus*		0.147

Note: CS = Corn Creek Flat; SY = SAY = Sandy Valley; PY = Pah. = Pahrump Valley; CY = Chicago Valley; YW = Valley Wells

Radiocarbon Results

A-Number	Sample Description	Conventional Date	Del C-13
4859	Pah.85 Carb.23a - charcoal	880 +/- 50	-24.6
4860	SYC 87-4a	1300 +/- 50	-24.4
4861	CS81 Carb. 6b -humates from organic mat	9220 +/- 180	-17.4
4862	CSC87-28 - carbonized wood	11,570 +/- 240	-22.8
4897	Pah. Carb 29 (follow-up) -carbonized wood	(very small sample)	
4898	YWF87-1 - Organic mat	10,250 +/- 160	-25
4899	CSC87-25 - Shell	(result expected soon)	
4900	PYC87- 42 -carbonized wood	(only 300 mg. carbon)	
4901	CSC87-8 -carbonized wood	11,870 +/- 200	-28.2
4606	PY86-Carb.35b -Organic matter with carbonized wood	9120 +/- 110	-24.3
4607	PY86-Carb.26b - Organic matter	10,090 +/- 100	-26.3
4608	PY86-Carb.10b - Carbonized wood	8510 +/-190	-26.8
4609	PY86-Carb.39b - Carbonized wood	10,920 +/- 160	-25.1
4590	PY86-Carb.15 - Stump Spring	8570 +/- 170	-25.7
4591	PY86-Carb37 - Hidden Valley Ranch	8480 +/- 160	-26.4
4592	PY86 Carb 31b - Hidden Valley Ranch	11,190 +/- 210	-26.6
4593	PY86 Carb 33 - Hidden Valley Ranch	10,940 +/- 390	-25
4594	PY86 Carb11b - Stump Springs	10,380 +/- 380	-21.4
4595	PY86 Carb 34	8600 +/- 170	-25.6
4537	CS81 Carb. 13b -Corn Creek Spring Black organic mat	10,220 +/- 210	-26.1
4538	PYCarb.29a - Charcoal	8610 +/- 150	-28.8
4539	PYCarb. 7b - Carbonized wood	10,090 +/- 200	-28.5
4540	PYCarb. 21b - Pure humates from carbonized wood, after pretreatment	8120 +/- 210	-25.4

TABLE 3



0
25
km
37°N
36°N
116°W
115°W
Spotted Range
SHEEP RANGE
Arrow Canyon Range
Las Vegas Range
NCY
CYV
IS
TLV
CCS
NEV.
CALIF.
SPRING MTNS.
Las Vegas Valley
Las Vegas
Pahrump Valley
Resting Spr. R.
Nopah Range
Tecopa Basin
Kingston R.
Clark Mtns.
Eldorado Mtns.
VW
PIV

Appendix B-VI

Late Wisconsin Ground-Water Discharge Environments of the Southwestern Indian Springs Valley, Southern Nevada by J. Quade and W. L. Pratt.

LATE WISCONSIN GROUND-WATER DISCHARGE ENVIRONMENTS OF THE SOUTHWESTERN INDIAN SPRINGS VALLEY, SOUTHERN NEVADA

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ABSTRACT

Badland exposures in the southern Indian Springs Valley, southern Nevada contain evidence of widespread spring and seep discharge at and before about 9400 yr B.P. The stratigraphic position and appearance of most of these deposits suggests correlation with late Wisconsin (30,000 to ca. 10,000 yr B.P.) marsh deposits up to 60 km to the southwest in the Las Vegas Valley, at Tule Springs and on Corn Creek Flat. Sedimentologic and faunal evidence indicate that during the late Wisconsin, a fine-grained subaerial flat probably vegetated by phreatophytes surrounded areas of moist grassland or "wet meadow" containing at least one perennial pond and creek. This reconstruction was facilitated by comparison with active analog environments in Steptoe Valley in northeast Nevada. Elsewhere in Indian Springs Valley, such as around Indian Springs itself and on the playa below, poor exposure has prevented characterization of the late Wisconsin environment.

INTRODUCTION

Dissected fine-grained deposits blanket much of the Las Vegas Valley bottom from the urban areas of Las Vegas in the southeastern valley to Indian Springs, about 70 km northwest of Las Vegas (Fig. 1). This large expanse of mainly late Wisconsin sediments, in places underlain by genetically similar sedimentary sequences of greater age, has long been of paleontological and archeological interest (Spurr, 1903; Harrington and Simpson, 1961; Shutler and Shutler, 1962). Up to the mid-sixties, the deposits were interpreted as "lakebeds". As with geologists and nongeologists alike, the lakebed interpretation is often applied indiscriminately to any continental basin deposit that is fine grained, light colored, and that contains aquatic mollusks. This has been the case with late Pleistocene deposits in the Las Vegas Valley (Hubbs and Miller, 1948; Maxey and Jameson, 1948; Snyder *et al*, 1964; Longwell *et al*, 1966). Haynes (1967) was the first to describe the deposits in detail with his work at the Tule Springs archeological site 12 km north of Las Vegas (Fig. 1), and in adjacent spring areas. Haynes recognized the stratigraphic record as dominantly fluvial, while he also established the presence of a shallow, tule-fringed lake or marsh --'Pluvial Lake Las Vegas'-- at the archeological site during the full-glacial (Unit D). Although Haynes's Unit D interpretation was locally correct, the shallow lacustrine setting has not proved representative of most Unit D age fine-grained deposits studied since then. Mifflin and Wheat (1979) first suggested that deposition of Unit D was largely related to vigorous ground-water discharge, and not to a valley-wide lacustrine setting. Detailed stratigraphic studies of Quade (1986) lent strong support to this interpretation, and extended it to late Wisconsin deposits along the length of the upper Las Vegas valley. However, interpretation of many sedimentologic features in Unit D recognized by that study remained uncertain. This report presents the results of a comparative study between the sedimentologic and faunal evidence from late Wisconsin sediments in the Indian Springs Valley, 70 km northwest of Las Vegas, and existing ground-water discharge environments of the Steptoe and Butte Valleys in northeastern Nevada.

In particular, the analog as a model addresses several curious features of the late Wisconsin fine-grained deposits which taken together set them apart from lacustrine deposits:

(1) the presence of a sharp coarse-to-fine (gravel to sandy silt) transition on the valley flank, as described by Quade (1986)..This textural transition, although previously interpreted as possibly shoreline related, sedimentologically shows no typical shoreline features. Also, the transition does not follow elevation contours in a bathtub-ring fashion, but rather parallels the gentle slope of the valley axis.

(2) the presence of a kilometer-wide (or less) subaerial sand flat which separates gravels higher on the alluvial fan from marsh deposits in the basin center.

(3) the presence of white to green clayey sediments containing terrestrial, semi-aquatic, and aquatic mollusks in close association.

(4) the presence of sediments deposited in apparent standing water in settings with significant slopes, often within basins with little or no hydrographic closure.

Methods

Mapping was conducted on a 1:24,000 black-and-white aerial photographic base.

Organic matter sampled for dating was subjected to standard acid (6N HCl) and base (2% NaOH) pretreatment. The base soluble (humate) fraction was then precipitated by acidification with HCl, and collected over silica filter paper. This portion was dated, and results appear in the text. Base insoluble residue, largely devoid of organics after base treatment, was discarded.

Each faunal sample was collected from a single exposure within a single sedimentary unit. The amount of sediment collected was determined by the abundance of shell material, but generally averaged one to two kilograms. Mollusks were sieved and dried over mesh screens The presence or absence of ostracodes was also noted. Well-indurated samples were in some cases boiled in water mixed with Calgon and Na_2CO_3 to facilitate disaggregation. The shells were then sorted into species lots under a dissecting microscope, and the lots were identified, counted, and stored individual vials.

The basic references used for mollusk identification are Pilsbry (1939-1948) for land snails, Burch (1982) for the aquatic snails, and Burch (1972) for bivalves. Baker (1928), Bequaert and Miller (1973), Harrington (1962), and Hibbard and Taylor (1960) are supplementary sources for some taxa. Taylor (1975) proved useful as an entry to the literature on particular problem species.

Very little has been published regarding habitat selection by Great Basin mollusks *per se*, but most of the species involved are widespread, and habitat data are available from a variety of sources, including the authors' personal studies. Important among published studies are Bequaert and Miller (1973), Chamberlin and Jones (1929), Henderson (1924, 1929, 1936a, 1936b), Hibbard and Taylor (1960), Hubricht (1985), and Russell (1971).

MODERN SPRING DISCHARGE ENVIRONMENTS

Steptoe Valley is located about 450 km north-northeast of Indian Springs Valley. It receives roughly twice as much annual precipitation (23 cm) as the Indian Springs Valley, while mean annual temperature is about 10°C lower (Eakin *et al*, 1967). The shallow phreatic zone and ground-water discharge environments present in Steptoe Valley are thought to be a reasonable analog to late Wisconsin conditions in southern Nevada. This valley was also selected because no pluvial lake was present during the late Pleistocene due to lack of hydrographic closure (Mifflin and Wheat, 1979). The surface geology is therefore uncomplicated by exposures of older lacustrine deposits. Spring discharge areas in adjacent Butte Valley were also briefly surveyed and sampled. In a later section of the report, the surface sedimentologic and faunal patterns in these active ground-water discharge environments are compared to those in late Wisconsin deposits in the Indian Springs Valley.

Steptoe Valley (northeast Nevada)

The area of study encompasses the west side of the northern Steptoe valley between about Indian Ranch and Murphy Ranch (Fig. 2). Goshute Lake occupies the bottom of this portion of the valley. Although generally a playa and intermittant playa lake, in the recent high runoff years Goshute Lake has not dried completely during the warm months. When full the lake is about 8 km long and 1 to 3 km wide.

The northern Steptoe Valley is bordered on the west side by the Cherry Creek Range. The range exceeds 3000 m in elevation in places, and serves as the principal recharge source to this segment of the valley. Over seventy piedmont springs and seeps are present in this portion of the valley on the west side. The east side of the valley is bordered by only several small ranges. As a result, no springs are present on that side between the range fronts and Goshute Lake.

Little surface runoff from the ranges appears to reach the lake most of the year, probably because the range is dominated by permeable carbonate rocks. In this respect, the ranges are analogous to those in southern Nevada. Goshute Creek is the only perennial creek in the area. In late July of 1985, flow in the creek was comparable to only that of a single medium-sized spring on the west side.

In this area the valley axis slopes gently to the north, except along the playa where the gradient is nearly flat. The elevation of the highest piedmont springs also decreases to the north, although adjacent the playa the gradient is as little as 0.2 m/km (Eakin et al, 1967). Thus the elevations of springs vary in general as function of the intersection of the water table with the gentle south-to-north sloping valley gradient. In places, small faults localize spring discharge.

Three distinct vegetation zones occur in the valley lowlands. Because these zones exercise significant control on grain size of valley alluvium, vegetation was mapped on a reconnaissance level, as described below.

Big sage - greasewood - rabbitbush zone

A sharp lineament is visible on aerial photographs that runs most of the length of the west side of the valley just above the highest piedmont springs. The lineament marks the sharp vegetation transition between drought-tolerant black sage (*Artemisia tridentata nova*) and shadscale (*Atriplex convertifolia*) upslope, and big sage (*Artemisia tridentata tridentata*), greasewood (*Sarcobatus vermiculatus*), and rabbitbush (*Chrysothamnus nauseous*) below the lineament (Fig. 2). The elevation of this transition decreases downvalley (south to north), like the elevation of the highest piedmont springs. This correlation suggests that the transition marks plant root's first penetration of the capillary fringe as it approaches the ground surface above and between springs (Miller et al, 1982).

On aerial photographs, the trend and position of this vegetation lineament, and the coarse-to-fine facies transition in late Pleistocene sediments fringing valleys in southern Nevada are remarkably similar. The reason for this similarity can be seen in the impact of the vegetation changes on surface sedimentology. Above the transition, the vegetation is small and widely spaced, and the alluvium is gravelly. In contrast, below the transition, live plants and deadfall are much denser. Hydraulic roughness is evidently sufficiently increased by these factors to cause unconfined surface flow to drop most of its coarse load about 50 to 100 m downslope of the transition. Thus, most of the big sage-greasewood- rabbitbush zone is underlain by sandy silt alluvium.

Springs and wet meadows

Over seventy springs and seeps discharge on the piedmont zone of the west side of this portion of the valley. Depending on local gradient and discharge rate, either a marshy seep or a small flowing stream form at the point of discharge. If the springs are closely spaced, as in the case of the clusters around Cordano and Murphy Ranches, then a more continuous marshy area forms as spring discharge coaleses downslope. Where the springs are widely spaced, then big sage and rabbitbush cover intervening areas. Thus the big sage zone is not continuous in that springs intersperse the entire zone. The transition of this zone to the coalescing wet meadows below is also irregular, depending on the extent of local discharge (Fig. 2).

A detailed look at the morphology of spring disharge areas and associated wet meadows is instructive in that it offers an explanation for the mixed terrestrial/aquatic mollusk assemblages so common in the southern valleys in the Pleistocene. Where the gradient is high, a flowing stream issues from the point of spring discharge. *Pyrgulopsis*(*Fontelicella* of Quade, 1983, 1986, and previous authors) was observed everywhere in watercress in the margins of the clear, oxygenated flowing water(Table 1). A band of marsh vegetation composed mostly of blade and wire grasses as well as several types of wild flowers often fringes the stream. This area can be saturated, depending on the time of year. But by July, efflorescent salt gives the dried surface a white appearance on aerial photographs.

Where gradients are lower, a marshy seep or "wet meadow" instead of a stream forms at the point of discharge. One such typical seep covered 300 m by about 75 m. Most of the area was covered by tufts of grass interspersed with standing water 20 to 40 cm deep. Two small ponds were also present. Water was deeper and sediment sandier where spring water was roiling from the ground in several hollows. Mollusks were collected from each of the environments (Table 1). The small ponds and sluggish flowing water are dominated by *Gyraulus parvus* and *Pisidium casertanum* (Table 1, SV-3 and other unlisted samples).The grass tuft areas contained various terrestrial mollusks like *Vallonia gracilicosta* and *Pupilla muscorum*. Sediment samples (SV-4 and 5) from the small streams feeding out of the base of the seep area contained most of the forms found alive in the seep area, as well as *Fossaria parva*, a semiaquatic snail, *Pyrgulopsis*, and several additional terrestrial forms (*Vertigo ovata, Catinella* sp.).

The seep sediment is largely composed of strongly reduced clay. Local subaerial exposure turned the sediment white (10 YR 8/1- dry), but pockets remained black perhaps due to lack of oxidation locally. The small streams produced well-sorted sand where flow was strong but mostly poorly sorted clay, angular pebbles, and sand.

Downgradient the spring seeps coalesce into flowing streams, or where discharge is large, into continuous wet meadow with local ponds. Both scenarios occur in the Steptoe Valley. It is important to note that clay-dominated environments produced by springs on the valley flanks may or may not grade into marshy sediments below. In the case of the north end of the valley, large areas below the elevation of the marshy seeps are subaerially exposed sand and silt covered by big sage and rabbitbush.

Discharge from most major springs reaches the playa margin (or Goshute Lake in the case of the 1985 study). Seasonal contraction was visible on the lake margins in July, 1985. No permanent marsh vegetation, such is present in the Ruby Marsh in the Ruby Valley, was visible in this ephemeral lake. No mollusks were found in water on the margins of the lake.

Butte Valley (northeast Nevada)

Two sediment samples (Table 1, BV-2 and 3) containing mollusks were collected along a small perennial creek at the north end of the valley. The creek drains a large (several km^2) wet meadow. The meadow is fed by several large springs about a kilometer from the sample sites. The mollusks samples constitute thanatocenoeses accumulated in muddy channel sediment..

Both samples contain a mix of aquatic and terrestrial mollusks that reflect quite faithfully the local stream setting borbered by marshy banks and wet meadow. Interestingly, *Pyrgulopsis* is present in nearby springs tributary to the stream, but is scarce or absent in the channel sediment samples. Moreover, mollusks favoring a seasonal moisture regime are absent. Evidently, mollusks undergo little transport after death in the spring-wet meadow setting.

STRATIGRAPHY AND SEDIMENTOLOGY OF LATE WISCONSIN DEPOSITS IN S. NEVADA

Indian Springs and Cactus Springs lie in the south end of the Indian Springs Valley, located 70 km northwest of Las Vegas (Fig. 1). The valley is the highest of a series of sub-basins connected by one continuous northwest-southeast trending structural basin (Las Vegas Shear Zone) that includes Las Vegas Valley along its southern extent. The hydrographic sub-basins were created by encroachment of large alluvial fans from adjacent ranges across the valley axis. Both Indian Springs Valley and adjacent Three Lakes Valley lie in closed sub-basins divided by low sills. Southeast into the Las Vegas valley, Corn Creek Flat and Tule Springs Flat (just north of Las Vegas) are tributary to the Colorado River.

Fine-grained, late Quaternary deposits are nearly continuously exposed from Las Vegas northwest to Indian Springs Valley. Haynes (1967) established the basic stratigraphic framework for these deposits in his work at the Tule Springs archeological site near Las Vegas. Quade (1983,1986) extended most of that stratigraphy to Corn Creek Flat, between the site and Indian Springs. Similar appearing deposits are also exposed around Three Lakes Valley, which have not been studied.

The Indian Springs Valley has a backwards "L" shape. A playa occupies the longer, north-south portion valley, while Indian and Cactus Springs, and a wash that feeds into the extensive playa to the north, occupy the east-west trending foot of the valley. The origin of fine-grained deposits exposed along that wash and around the springs is the main topic of this report. The playa and surrounding bajada are undissected.

The use at Indian Springs of Haynes's stratigraphic nomenclature from the archeological site is loose: three radiocarbon dates, stratigraphic position, and lithologic similarity are the basis of correlation between the two areas. Briefly, Haynes recognized two principle marsh phases at Tule Springs: Unit B_2, which fell beyond the range of ^{14}C dating, and the more widespread Unit D (30,000 to 15,000 yr B.P.). A period of marsh contraction (Unit E_1-E_2) following 15,000 yr B.P. ended by about 7000 yr B.P. with the attainment of near modern effective moisture conditions. After 7000 yr B.P., widespread dissection of fine-grained deposits began, and this continues today.

The fine-grained deposits of the Indian Springs Valley range in age from modern to probably beyond the range of ^{14}C dating. The emphasis in this paper is on Unit D and Unit E, the two units spanning the last pluvial period (30,000 to ca. 7000 yr B.P.). The rest of the column will be dealt with only briefly below.

Pre-Unit B

Several areas are covered by pre-Unit B age fine-grained deposits. Most important are some prominent white bluffs cropping out upslope from Cactus Springs. The bluffs sediments are well-indurated and are capped by up to 75 cm of dense caliche, a degree of development much greater than that characteristic of Unit B orD. The exposed section is largely fluvial (Fig. 3), but contains several thin horizons with a mix of terrestrial and aquatic mollusks similar to those of later periods described below.

Units B and C and Soil S_3

North of Cactus Springs, deep dissection has exposed horizons older than the pale-green mudstones belonging to Unit D-E. The older horizon is entirely brown fluvial silt (Fig. 3, Unit B-C) capped by a well-developed soil (Soil S_3), and then by Unit D-E. Haynes recognized two entirely fluvial units (Unit B_3 and Unit C) at Tule Springs underlying full-glacial Unit D. Soil S_3 occurred on top of Unit B_3. Similar physical appearance and stratigraphic position were there- fore the basis for correlating the brown silts at Cactus Springs with Unit B or C, and the soil above it with Soil S_3.

Stratigraphic relations are best exposed in the central portion of the badlands (Fig. 4, Section 25). Unit B-C is not confined to that one area, but poor exposure prevents mapping its complete extent with confidence. This uncertainty is expressed on the geologic map by designating several areas as Unit B to lower Unit D undifferentiated (Fig. 5).

Unit D and E

Age

Pale green clay and mudstone mixed with secondary carbonate occur just below the top of the fine-grained valley fill over broad areas around Indian and Cactus Springs. This is also the stratigraphic position and basic composition of Unit D (30,000 to 15,000 yr B.P.) and Unit E_1 (14,000 to 11,800 yr B.P.) in the lower Las Vegas Valley, and thus a correlation with one or both is strongly suggested. Furthermore, a similar appearing thin brown alluvial unit caps the clays in both areas. In the lower Las Vegas Valley, the brown alluvium generally correlates with all or part of upper Unit E_2 (ca. 10,000 to 7200 yr B.P.).

Pale green clay crops out within 30 m downslope of the caliche-capped bluffs above Cactus Springs. The clays are inferred to be inset into the older caliche-capped sediments (pre-Unit B) although no outcrop actually exposes this relationship. The clays are much less indurated and are greener (5 Y 6/2 dry) than the older sediments (10 YR 8/1-8/2 dry). The exposure shown in Figure 6 summarizes the stratigraphic succession in the younger green clays around Cactus Springs, and also shows the position of two radiocarbon-dated samples.

USGS-2211 is disseminated carbonized wood from the green clays (Fig. 6). Carbonized wood is charcoal-like in appearance. But unlike typical charcoal, it is soluble in basic (2% NaOH) solution. Its field occurrence and chemical behavior led Haynes (1967) to conclude it was probably nonpyrolized wood. Both Haynes (1967) and Quade (1983) concluded that the material yielded reliable radiocarbon dates.

USGS-2211 yielded a date of $42,600^{+1600}_{-1300}$ (Table 2). This age on the clays is probably too old since the wood occurs about a meter below two early Holocene organic layers (see below). No disconformities are evident between the samples, and the clays and organic layers are similarly indurated. The wood is therefore tentatively concluded to be redeposited. Haynes (1967, p. 73) encountered similar anomalies at Tule Springs in the vicinity of paleospring orifices. More radiocarbon samples are being sought in the clays.

One and in places two dark gray (10 YR 4/1.5 dry), organic-rich layers overlie the green clay in most exposures around Cactus Springs. The humate fraction from two separate samples of the organic layer yielded 9680±100 yr B.P. (Table 2, USGS-2212) and 9460±70 yr B.P. (Table 2, USGS-2213). The humate fraction date should reflect a mean residence time for the organics in the layer. Pieces of a mammoth molar were discovered eroding from the top of the underlying green clays. This position relative to the organic layers is consistent with a late Rancholabrean age for the molar.

Lithology and distribution

Similar to observations at Corn Creek Flat and Tule Springs Flat (Quade, 1986), Unit D undergoes regular sedimentologic and faunal changes from valley margin to center. Gravels of the surrounding bajada surfaces grade abruptly (<100 m) to brown silty alluvium, which downslope grades to the white and pale green clay and mudstone already mentioned (Fig. 4 and Fig. 7). Fine-grained deposits below the textural transition are generally devoid of gravel. As seen elsewhere, the coarse-to-fine transition gently increases in elevation westward parallel to the length of the valley, such that the highest fine-grained deposits at the west end of the valley are about 120 m above the playa (elev. 919 m). Moreover, within the east-west "foot" or extension of the valley, the coarse-to-fine transition averages 30 m higher in elevation on the Spring Mountain (south) side than the Spotted Range (north) side.

Figure 8 shows the distribution of the three facies of Unit D-E mapped in the Cactus Springs area. They are best seen in the extreme west end of the 'foot' of the valley. Briefly, the facies from valley center to margin are:

(1) *green clays* -- pale green (5 Y 7/2 dry) very hard clay to silty clay; very sticky, very plastic; strong, medium to coarse prismatic structure; calcareous with dispersed to continuous layers of nodular secondary carbonate; locally mixed with angular pebbles; MnO_2 and FeO coatings in certain horizons; generally lacking in sedimentary structures; mollusks common.

(2) *white silty clays* -- white (10 YR 8/1 dry) hard to very hard; sticky, plastic;

weak, coarse prismatic structure; secondary carbonate as nodules or as massive ledges; MnO_2 stains and mollusks common.

(3) *sand - silts* --pale brown (10 YR 7/2-7/4 dry) interbedded sand and silt showing well-preserved planar and cross-ripple laminations; slightly hard; slightly sticky, slightly plastic; weak crumb structure to silts; rare gravel lenses; cicada and other insect burrows; rare mollusks; rare secondary carbonate; large bone fragments.

The facies scheme above is similar to that used at Corn Creek Flat (Quade, 1986). The differences are that a calcareous sand-silt facies mapped at Corn Creek is poorly preserved or exposed at Indian Springs and has therefore been lumped into the sand-silt facies. Also, the white silty clay facies was combined with the calcareous green clays at Corn Creek for mapping purposes.

There is some uncertainty in correlating of green clays over such a large area. Around Cactus Springs, where the clays underlie the dated earliest Holocene organic layers, they are moderately to strongly prismatic, and very hard when dry. Identically appearing green clays crop out in the extensive exposures west of Cactus Springs along the main valley wash. No organic layers are present in that area, but the overlying pale-brown sand and gravel is just as at the Cactus Springs exposures. These similarities make correlation between undated sequences reasonable.

The nature of late Pleistocene deposition on Indian Springs playa remains unknown due to lack of exposure. The presence of the described marshy deposits on the valley flanks suggests that possibly more than ephemeral surface runoff reached the playa at that time. However, as pointed out by Mifflin and Wheat (1979), lack of paleostrandlines rules out the existence of "Pluvial Indian Springs Lake" of Hubbs and Miller (1948).

Faunal Distribution

Eighteen mollusk/ostracode samples were collected from the area (Table 3); locations are given in Figure 9. By combining data sets, the relationship between facies and fauna can be summarized as follows:

(1) All the green clays contain ostracodes. Most aquatic mollusks present favor standing water that experiences seasonal drying (e.g. *Stagnicola caperata, Stagnicola montanensis, Gyraulus circumstriatus*). *Fossaria parva,* a semi-aquatic snail, lives in moist areas bordering permanent water. Only two samples (Table 3, CACSPR-10 and -17) contain *Gyraulus parvus,* which requires permanent standing water. These two samples are also the only ones from the area which contain less than about 20% terrestrial mollusks, although they are still represented. It is doubtful that the terrestrial forms were washed from a distance into the sample locality since there are no indication that the clays were reworked.

(2) The white silty clays lack ostracodes, but locally can contain mollusks. Terrestrial mollusks such as *Pupilla muscorum, Catinella* sp., and others dominate (Table 3, CACSPR-1 and CACSPR-9). *Fossaria parva, Gyraulus circumstriatus,* and *Pisidium casertanum* are also present in CACSPR-1. They are semiaquatic to aquatic but none require permanent water to survive.

(3) The sand-silt facies lacks ostracodes and mollusks except for occasional terrestrial forms (*Vallonidae*). Mammal bones, and borrowing produced by cicadas (*Cicadidae*), a terrestrial insect, are common.

Depositional Setting

Although the fauna collected from the Indian Springs Valley indicate that standing water was present, the sedimentologic and faunal pattern is not typical of a lacustrine setting. As Figures 4 and 8 show, green clays occur upslope from at least one area of white silty clays, the reverse of that expected were standing water to extend over the area continuously. Continuous standing water can be dismissed by physical constraints alone, since the highest clays rest nearly 120 m above the basin threshold. Furthermore, all but one of the mollusk assemblages contains terrestrial forms, suggesting a close proximity to unsubmerged ground.

The pattern of sedimentation and the types of mollusks are sufficiently similar between the Steptoe Valley and Pleistocene strata in the Indian Springs Valley to allow the reconstruction given in Figure 10. This figure was constructed by cross-referencing sediment type with fauna composition in the Pleistocene sediments, and based on the analog setting in northeastern Nevada, assigning an environment.

The coarse-to-fine (gravel to sand-silt) transition in Unit D-E probably resulted from the surface hydraulic effects of the nonphreatophyte to phreatophyte transition, as is visible in Steptoe Valley today. Below this transition, sandy silts were entrapped by dense, phreatophytic vegetation on slopes between 0.3 and 0.8 degrees, as is occurring in Steptoe Valley now. Cicades, whose burrows are common in this facies, are known to favor unsaturated, sagebrush-covered environments in the northern Great Basin (Hughie and Passie, 1963). The former presence of sagebrush in the valley is attested to by pollen spectra from the archeological site (Mehringer, 1967), and by pack-rat midden evidence (Spaulding, 1983). Spaulding also found rabbitbush in a nearby hillslope midden (Point of Rocks #2) dated at 14,800 yr B.P. The presence of large mammal bones, particularly where this facies grades into the white silty clay facies, suggests proximity to but not inundation by water. Paucity of gravels in the sand-silt facies indicates that little perennial surface flow was reaching the valley bottom from the surrounding upper fans and ranges. This phreatophyte zone surrounded all of the Indian Springs Valley wet meadows, as well as those on Corn Creek Flat (see Fig.4 in Quade, 1986) and on Tule Springs Flat.

The white silty clay facies downslope from the sand-silts probably coincides with moist grassland and typically is dominated by terrestrial mollusks (Table 3, CACSPR-1 and 9). *F. parva* and *G. circumstriatus* are also sometimes present, implying marshiness and local seasonal stands of water.

Pale green clays containing a mix of terrestrial and semi-aquatic mollusks were probably produced in the more continuously saturated seep areas, which combines subaerial (grass tufts) and shallow subaqueous microenvironments over broad areas. However, seasonal drying is impled by those assemblages dominated by the various *Stagnicola* (except *S. eloides*) and *G. circumstriatus*. These types are notably absent from the Steptoe Valley assemblages. Perhaps they were actually present in the area but were not sampled because by July seasonal water has dried and such mollusks would be dormant in muds of the unsampled wet meadows. Pale-green clays containing *G. parvus* are interpreted to represent those portions of the wet meadow environment that didn't experience seasonal drying, such as the ponds, springs, and perennial channels. *Pyrgulopsis* is notably lacking in the Cactus Springs samples while it is common at Tule Springs and Corn Creek. Fast flowing (stream or spring), well-oxygenated waters that *Pyrgulopsis* favors were evidently not widely present in the area during Unit D time. Deeper, permanent water mollusks (e.g. *Lymnaea stagnalis, Planorbella subcrenata, Stagnicola elodes,* etc.,) found in modern Ruby Marsh (unpub. data), and in Unit D on lower Corn Creek Flat (Quade, 1986) and at Tule Springs (Taylor, 1967) are not present in any of the Cactus Springs samples.

The overall setting was therefore: spring or seep discharge along gentle slopes on the valley flanks, an intervening dry area crossed by perhaps a sluggish, perennial stream immediately below the springs, and finally emergence of wet meadows and ponds at lower elevation. This pattern is not uncommon in the Steptoe Valley. Wet meadow stood higher in the valley on the Spring Range side (south) than the Spotted Range (north) side, as seen on a larger scale in Steptoe Valley.

Poor exposure and/or preservation in several areas hampers reconstruction of all potential discharge areas of the Indian Springs Valley during the late Pleistocene. Pale green clays are present in a few outcrops around Indian Springs, as well as sandy silts. But urban development has destroyed most evidence of Pleistocene discharge in that area. A few isolated outcrops of fine-grained sediments are visible on the Spotted Range side of the valley, but they remain uninvestigated. A playa or intermittant playa lake, permanent marsh, or combination of the three environments were all possibly present during the late Pleistocene in the area now occupied by Indian Springs playa, judging from modern analogs in northeast Nevada.

Unit E_2 and Soil 5

Upper Unit E_2 rests directly atop the organic layer at Cactus Springs (Fig. 6), although the organic layer is not present in the more extensive badland exposures to the west. The unit is largely pale-brown (10 YR 7/3 dry) silt with local mixed sand and gravel. It averages 1.5 to 2 m in thickness. One weak soil (Soil 5a) sometimes occurs within Unit E_2, while a stronger one is usually found on top(Soil 5b)(Figs. 3 and 6). A tightly packed desert pavement with darkly varnished clasts (10 YR 3/2) mantles the surface. Cicada burrows are common in upper Unit E_2. Their presence indicates persistance of moist, sagebrush-covered steppe in the area after 9400 yr B.P. (Hughie and Passie, 1963; Quade, 1986). The thickness of upper Unit E_2 and the weak development of Soil 5a suggests that dissection of the fine-grained deposits began within a few thousand years after 9400 yr B.P. Similar dissection began to the southeast in Las Vegas Valley at about 8000 to7000 yr B.P. (Haynes, 1967: Quade, 1986).

Unit FG

Following dissection of older fine-grained deposits beginning around 8000 to7000 yr B.P., gravelly alluvium flooded into the valley bottom. Several distinct geomorphic surfaces and deposits inset into the fine-grained deposits are visible, but no attempt will be made to discuss them here. For mapping purposes, these deposits were lumped under Unit FG (Fig. 5).

CONCLUSIONS

The stratigraphic column first established by Haynes (1967) at Tule Springs has been shown to apply to Corn Creek Flat (Quade, 1986), and is herein extended to the Indian Springs Valley. Limited radiocarbon dating and physical similarity of units support the correlations. Continuity of stratigraphy between these areas is noteworthy as the Indian Springs and Tule Springs areas are over 60 km apart and lie within hydrographically separate sub-basins. Shared climatic controls on paleohydrology and associated depositional and erosional events best explain the apparent uniformity of the stratigraphy.

Detailed examination of active phreatic discharge environments in northeast Nevada has allowed reconstruction of similar late Wisconsin environments in southern Nevada. In all, the sedimentology and fauna of the two areas have proved, with few exceptions, to be remarkably similar. It is unlikely that basin depositional environments were lacustrine in southern Nevada during the late Wisconsin as has been suggested by some previous workers. Instead, fine-grained deposits at Indian Springs and in the Las Vegas Valley were deposited in a complex mosaic of hydrologic environments. Of the valleys adjacent to the Spring Mountains studied thus far, the Indian Springs area manifests the least valley discharge. Wet meadows with only a few perennial pools characterize the area. Downvalley on Corn Creek Flat, greater discharge is in evidence in the form of widespread wet meadows and a small perennial marsh at the lower end of the valley (Quade, 1986). The Tule Springs area shows the largest discharge with the development of a shallow, tule-fringed marsh in the area (Haynes, 1967). Sedimentologic evidence from all areas suggests that water reached the valley primarily through springs, not as surface runoff.

The most southerly pluvial lakes in the Great Basin identified by Mifflin and Wheat (1979)(excluding those supported by runoff from the Sierra Nevadas and the San Gabriel Mountains) are Kawich and Groom Lakes, located 100 km north of Indian Springs. South of these former lakes, localized occurrences fine-grained deposits very similar to those described in this report are now under study outside the Las Vegas Valley. Valleys which include similar deposits are include Coyote Springs (Nevada), Pahrump and Mesquite (Nevada-California), and Chicago and Shadow Valleys (California). Recently, Hay *et al* (1986) reported on a similar ground-water discharge origin to Plio-Pleistocene fine-grained deposits in the southern Amargosa Desert, 60 km west of Indian Springs. The apparent extent of these fluvio-paludal deposits in the southern Great Basin suggests that vigorous spring discharge resulting in local marshy areas was the principal surface hydrologic expression of increased recharge associated with the last pluvial period.

ACKNOWLEDGMENTS

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TABLE 1 COMPOSITION (IN %) OF MOLLUSK SAMPLES FROM STEPTOE AND BUTTE VALLEYS, NORTHEAST NEVADA

TAXON	Sample No. SV-5	SV-4	SV-3	BV-2	BV-3
Aquatic clams					
Pisidium casertanum	14	48	2	2	9
Pisidium rotundatum				51	34
Aquatic snails					
Valvata humeralis		0.5			
Pyrgulopsis	84	8	2		1
Fossaria parva	0.5	2		2	3
Fossaria modicella			4		
Gyraulus parvus	2	0.5	92	19	37
Land snails					
Vallonia gracilicosta		6		15	5
Pupilla muscorum		11		7	10
Vertigo ovata		18		3	
Catinella sp.		6		1	1
Deroceras sp.		0.5			
Total number of mollusks in sample	216	176	51	239	131

Note: SV = Steptoe Valley, see Fig. 2 for locations; BV = Butte Valley, in main creek at north end of valley

TABLE 2 RADIOCARBON DATES FROM THE CACTUS SPRINGS AREA

Sample no.	Date (^{14}C years B.P.)	Material	Comments
USGS-2211b	$42,600 {}^{+1600}_{-1300}$	carbonized wood, humate fraction	probably redeposited
USGS-2212b	9680±100	organic layer, humate fraction	
USGS-2213b	9460±60	organic layer, humate fraction	same layer as USGS-2212b, but taken 200 meters laterally

TABLE 3 COMPOSITION (IN %) OF MOLLUSK SAMPLES FROM LATE WISCONSIN DEPOSITS IN THE CACTUS SPRINGS AREA, SOUTHERN NEVADA

TAXON	Sample No. (CACSPR-)										
	1	4	5	7	8	9	10	11	15	17	18
Aquatic clams											
Pisidium casertanum	3	3	5	4	41		70	15	9	44	14
Pisidium rotundatum										15	
Aquatic and semi-aquatic snails											
Fossaria parva	6	3	9	3	3	6	6	8			6
Stagnicola caperata									10	10	
Stagnicola montanenesis							5				
Stagnicola pilsbryi				0.5	1						
Gyraulus parvus			0.5				3			15	
Gyraulus circumstriatus	29			13	24		15	14	63	2	17
Land Snails											
Vallonia cyclophorella										1	
Vallonia gracilicosta		22	9	0.5		17		6			3
Gastrocopta tappaniana	6		20		1	0.5		7			3
Pupilla muscorum	10	50	9	38	3	54		12		2	
Vertigo berryi	16		26	23	17		1	11	12	0.5	9
Catinella sp.	26	22	21	14	10	21	2	20	6	10	11
Euconulus fulvus	3		2	4				1			
Deroceras sp.			0.5		- -						37

Total mollusks in sample	31	32	305	193	242	321	87	260	163	181	35

Note: see Figures 4 and 9 for sample locations.

List of Figures

Fig. 8 Distribution of lithologic facies for Unit D-E. in the Cactus Springs area. See Figure 5 for the full map key.

Fig. 9 Locations of fossil fauna, and their surface hydrologic implications, Cactus Springs area. See Figure 5 for the full map key.

Fig. 10 Late Wisconsin depositional environments in the Cactus Springs area. See Figure 5 for the full map key.

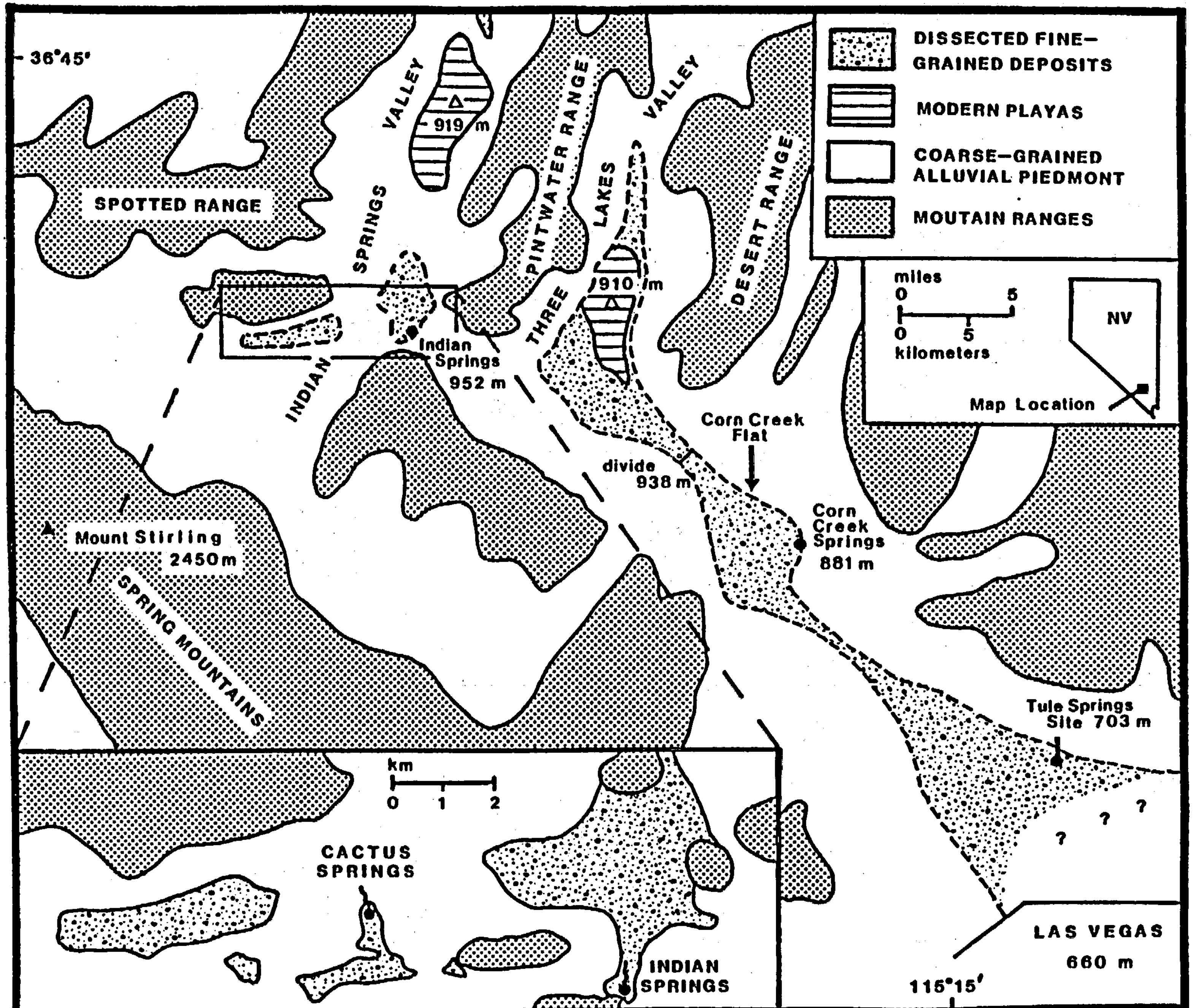
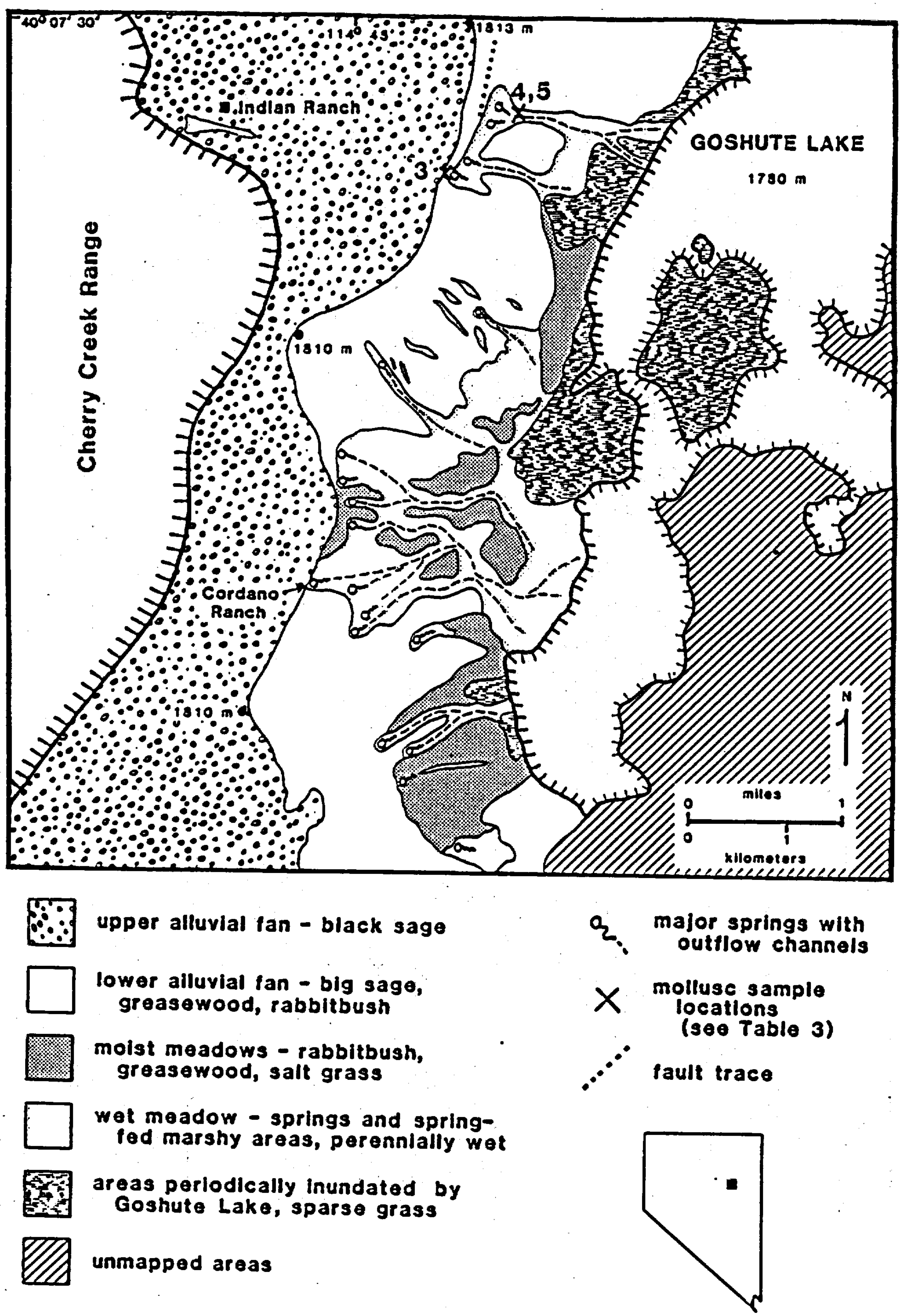
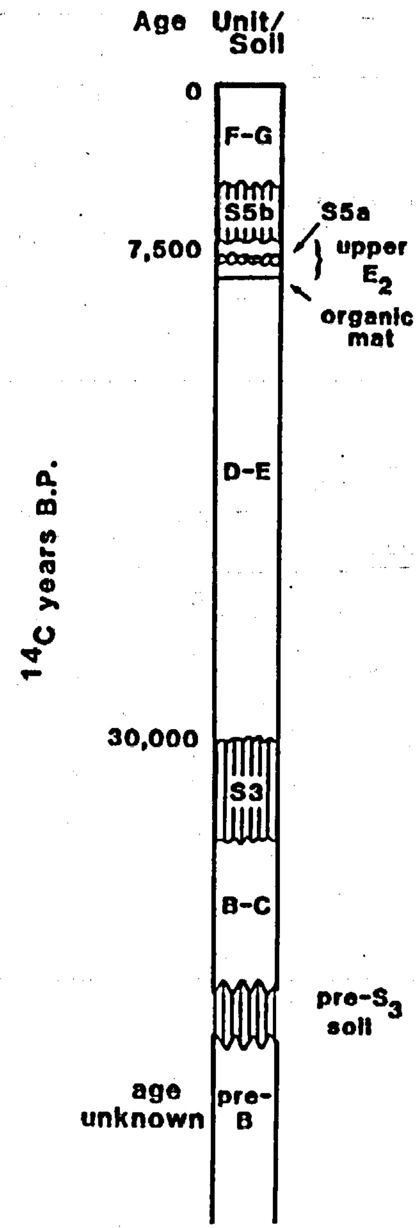

36°45'
DISSECTED FINE-GRAINED DEPOSITS
MODERN PLAYAS
COARSE-GRAINED ALLUVIAL PIEDMONT
MOUTAIN RANGES
miles
0 5
0 5
kilometers
NV
Map Location
VALLEY
919 m
PINTWATER RANGE
VALLEY
LAKES
THREE
DESERT RANGE
SPOTTED RANGE
SPRINGS
INDIAN
910 m
Indian Springs
952 m
Corn Creek Flat
divide
938 m
Corn Creek Springs
881 m
Mount Stirling
2450m
SPRING MOUNTAINS
Tule Springs Site 703 m
km
0 1 2
CACTUS SPRINGS
INDIAN SPRINGS
LAS VEGAS
660 m
115°15'

Fig. 1



40° 07' 30"
114° 45'
1813 m
4,5
Indian Ranch
GOSHUTE LAKE
1780 m
3
Cherry Creek Range
1810 m
Cordano Ranch
1810 m
N
miles
0
1
0
1
kilometers
upper alluvial fan - black sage
lower alluvial fan - big sage, greasewood, rabbitbush
moist meadows - rabbitbush, greasewood, salt grass
wet meadow - springs and spring-fed marshy areas, perennially wet
areas periodically inundated by Goshute Lake, sparse grass
unmapped areas
major springs with outflow channels
mollusc sample locations (see Table 3)
fault trace

Fig. 2



Description

<u>Unit F-G</u>: Sand and gravel, mainly limestone cobbles but some reworked secondary carbonate; mainly inset into older units as alluvial sheets and terraces.

<u>Soil S_{5b}</u>: weak cambic horizon (10 YR 7/4d, 5/4m) at base of vesicular horizon; weak Stage II calcic horizon in gravelly alluvium; generally relict, with tightly packed, well-varnished pavement capping erosionally inverted Pleistocene sediments.

<u>Upper Unit E_2</u>: Alluvial silt pale brown (10 YR 7/3d) at base, separated by weak soil (5a) from overlying gravel and sand. The silt is soft, lacks molluscs or secondary carbonate, and is bioturbated by cicadas.

<u>Soil S_{5a}</u>: mostly eroded, truncated cicada burrows, dispersed carbonate coatings on rootlet molds.

<u>Unit D-E</u>: Locally capped by dark gray (10 YR 4/1.5 dry) organic layer(s) containing dispersed molluscs.

<u>Three facies</u>:

(1) <u>sand-silt facies</u>: soft, pale brown (10 YR 7/3 dry); local gravel lenses, no molluscs or secondary carbonate.

(2) <u>white silty clay facies</u>: slightly hard to hard, white (10 YR 8/1 dry); silt to silty clay, bioturbated secondary nodular carbonate, terrestrial and semi-aquatic molluscs, common vertebrate remains.

(3) <u>pale green clay facies</u>: hard to very hard, pale green (5 Y 7/1 dry); strong prismatic structure, bioturbated, sparse to abundant secondary carbonate, terrestrial and aquatic molluscs.

<u>Soil S_3</u>: generally buried, strong cambic horizon (10 YR 6/4 dry); strong, medium prismatic; Stage II calcic horizon in fine-grained alluvium.

<u>Unit B-C</u>: Silt, pale brown (10 YR 7/3d); very hard, weakly prismatic; locally sandy, dispersed secondary carbonate nodules, MnO_2 as coatings on rootlet molds.

<u>Pre-S_3 soil</u>: relict, 50-75 cm of dense caliche, more dispersed downwards; no extant B horizon.

<u>Pre-Unit B</u>: Silt to clayey silt, pale brown (10 YR 7/2-7/3 dry); very hard, coarsely prismatic; local gravelly sand layers; several possible weak soils; strong MnO_2, FeO stains, secondary carbonate; dispersed terrestrial molluscs.

Fig. 3

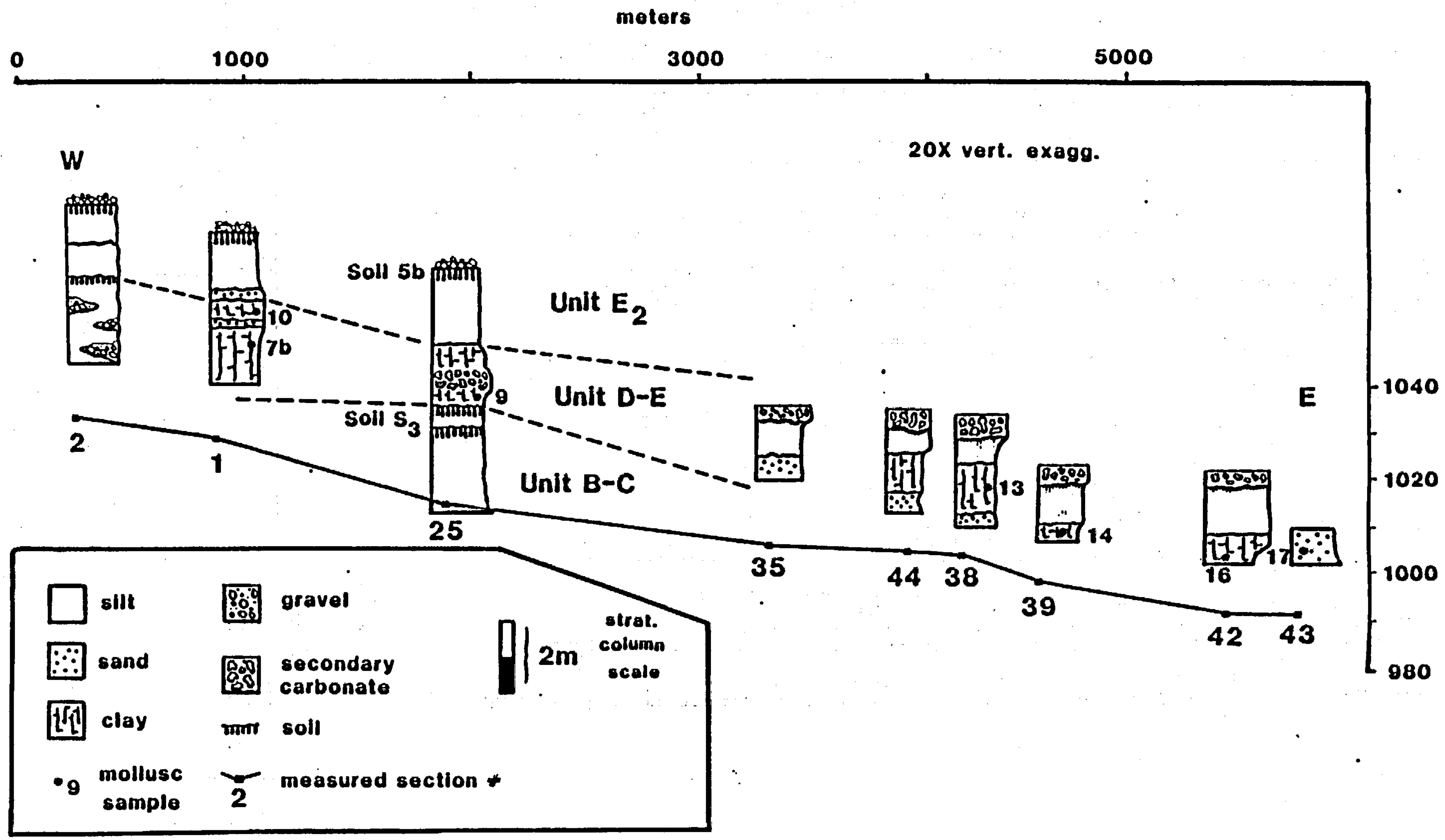
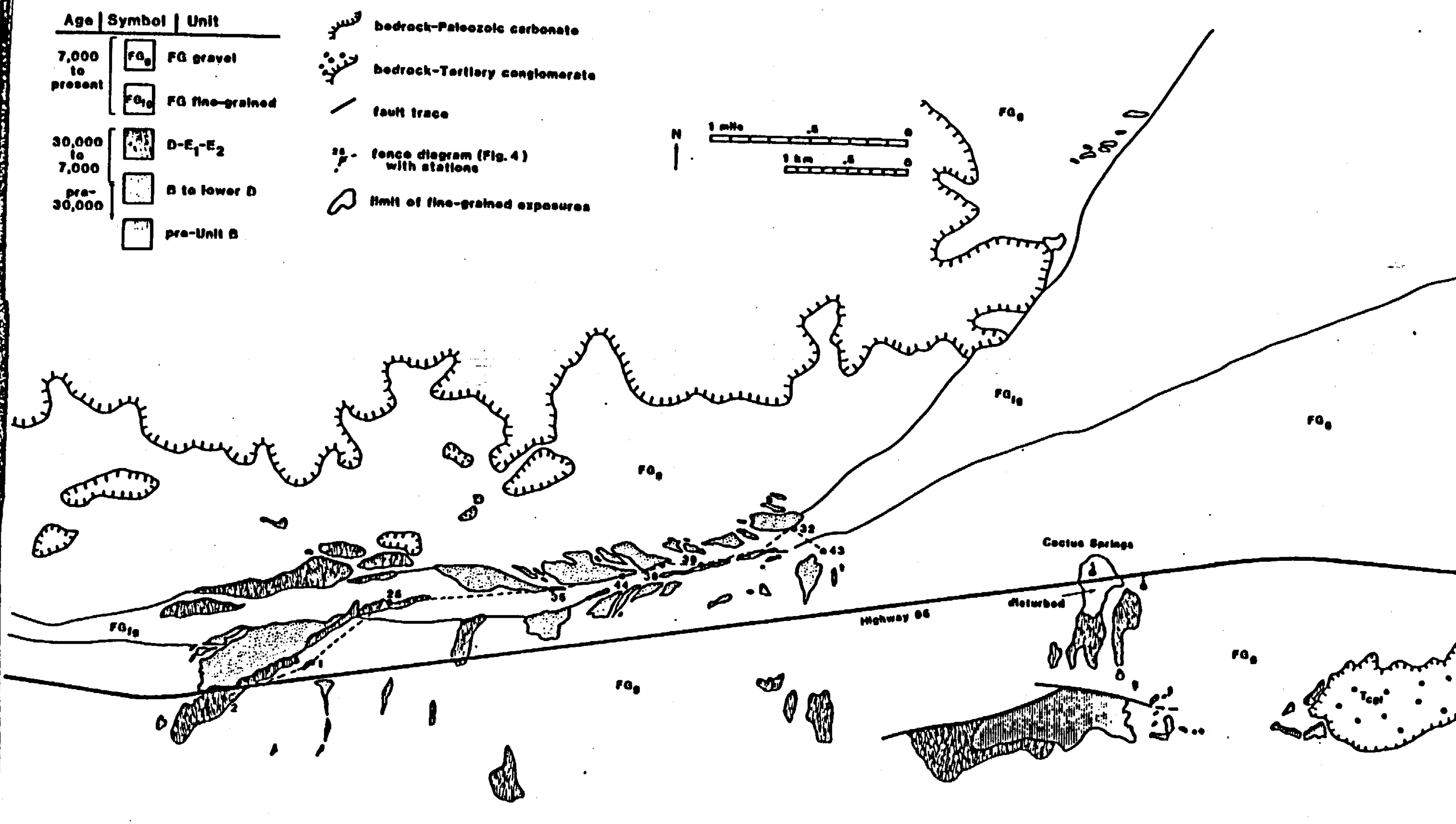

meters
0
1000
3000
5000
20X vert. exagg.
W
E
Soil 5b
Unit E2
10
7b
9
Unit D-E
Soil S3
Unit B-C
13
14
16
17
2
1
25
35
44
38
39
42
43
1040
1020
1000
980
meters
silt
sand
clay
mollusc sample
gravel
secondary carbonate
soil
measured section #
2m
strat. column scale

Fig. 4



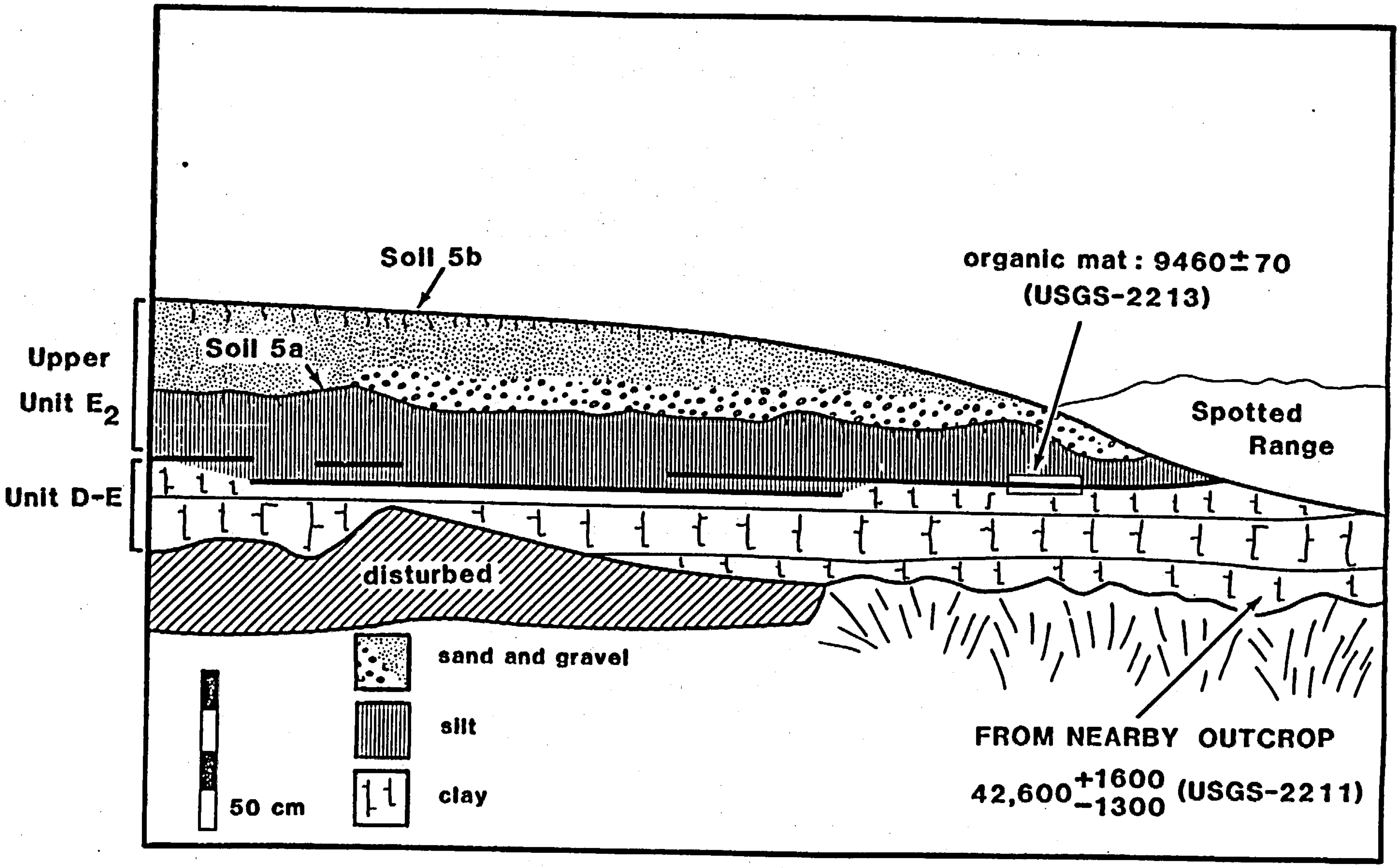
Age | Symbol | Unit
7,000 to present
FG gravel
FG fine-grained
30,000 to 7,000
D-E1-E2
pre-30,000
B to lower D
pre-Unit B
bedrock-Paleozoic carbonate
bedrock-Tertiary conglomerate
fault trace
fence diagram (Fig. 4) with stations
limit of fine-grained exposures
N
1 mile .5 0
1 km .5 0
Cactus Springs
disturbed
Highway 95
Tcgl
32
43
39
38
44
35
25
1
2

Fig. 5

Fig. 6 ----- Line drawing and photograph

photograph

line drawing



Soil 5b
organic mat : 9460±70
(USGS-2213)
Upper
Unit E2
Soil 5a
Spotted
Range
Unit D-E
disturbed
sand and gravel
silt
clay
50 cm
FROM NEARBY OUTCROP
42,600 +1600 −1300 (USGS-2211)

Fig. 6 Part 1.

Fig. 6 Part 2

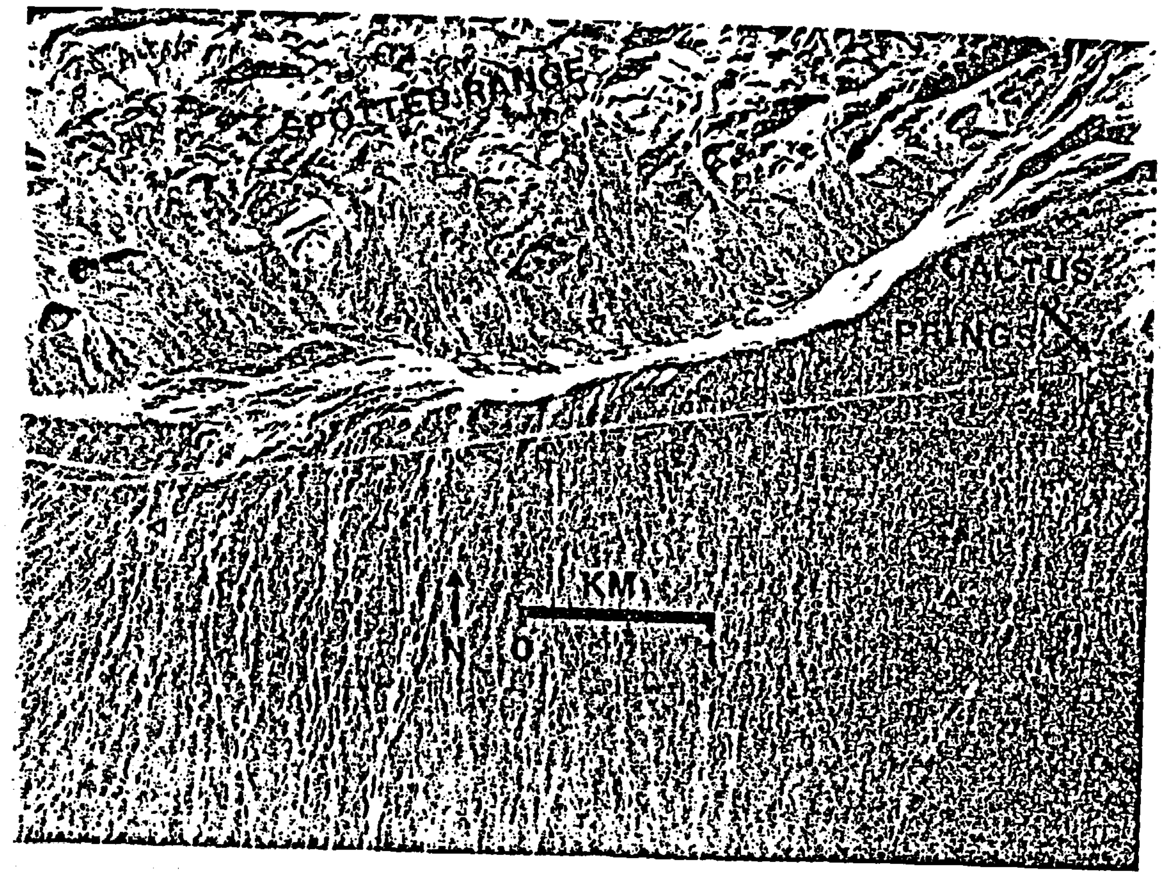
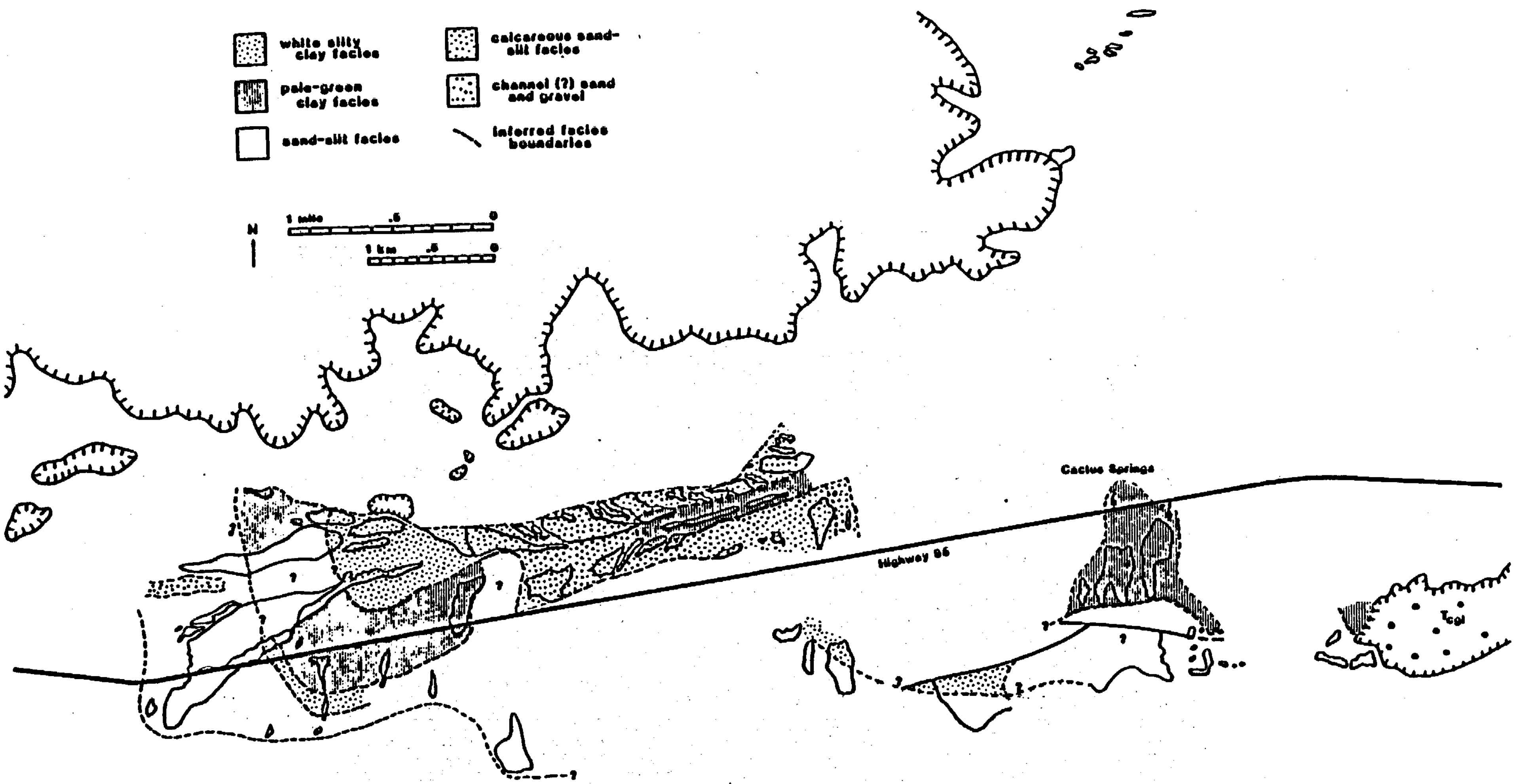


Fig. 7


white silty clay facies
pale-green clay facies
sand-silt facies
calcareous sand-silt facies
channel (?) sand and gravel
inferred facies boundaries
N
1 mile .5 0
1 km .5 0
Cactus Springs
Highway 95
Tcgl

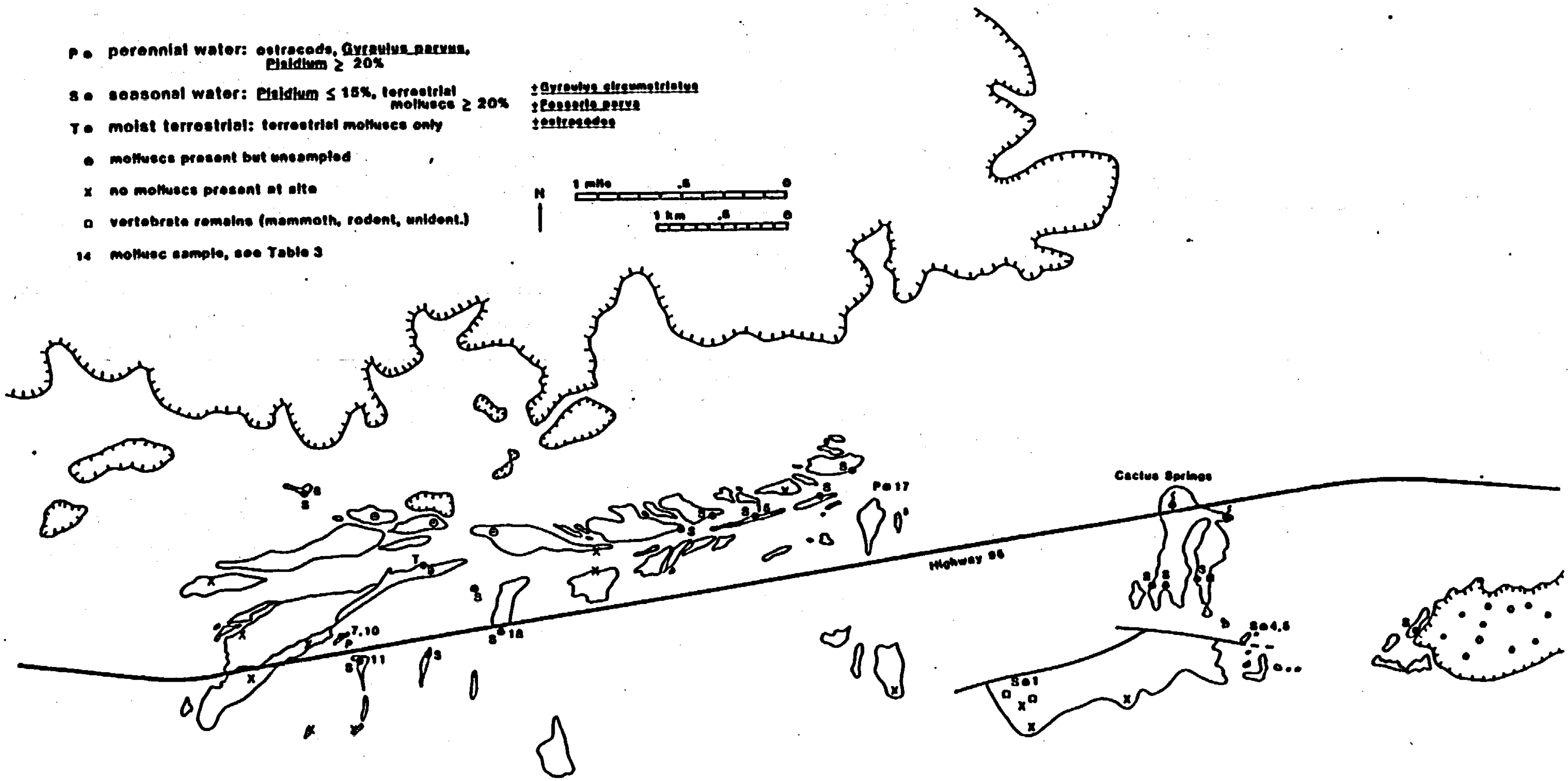

P ● perennial water: ostracods, Gyraulus parvus, Pisidium ≥ 20%
S ● seasonal water: Pisidium ≤ 15%, terrestrial molluscs ≥ 20%
T ● moist terrestrial: terrestrial molluscs only
● molluscs present but unsampled
x no molluscs present at site
□ vertebrate remains (mammoth, rodent, unident.)
14 mollusc sample, see Table 3
+Gyraulus circumstriatus
+Fossaria parva
+ostracodes
N
1 mile .5 0
1 km .5 0
Cactus Springs
Highway 95

Fig. 9

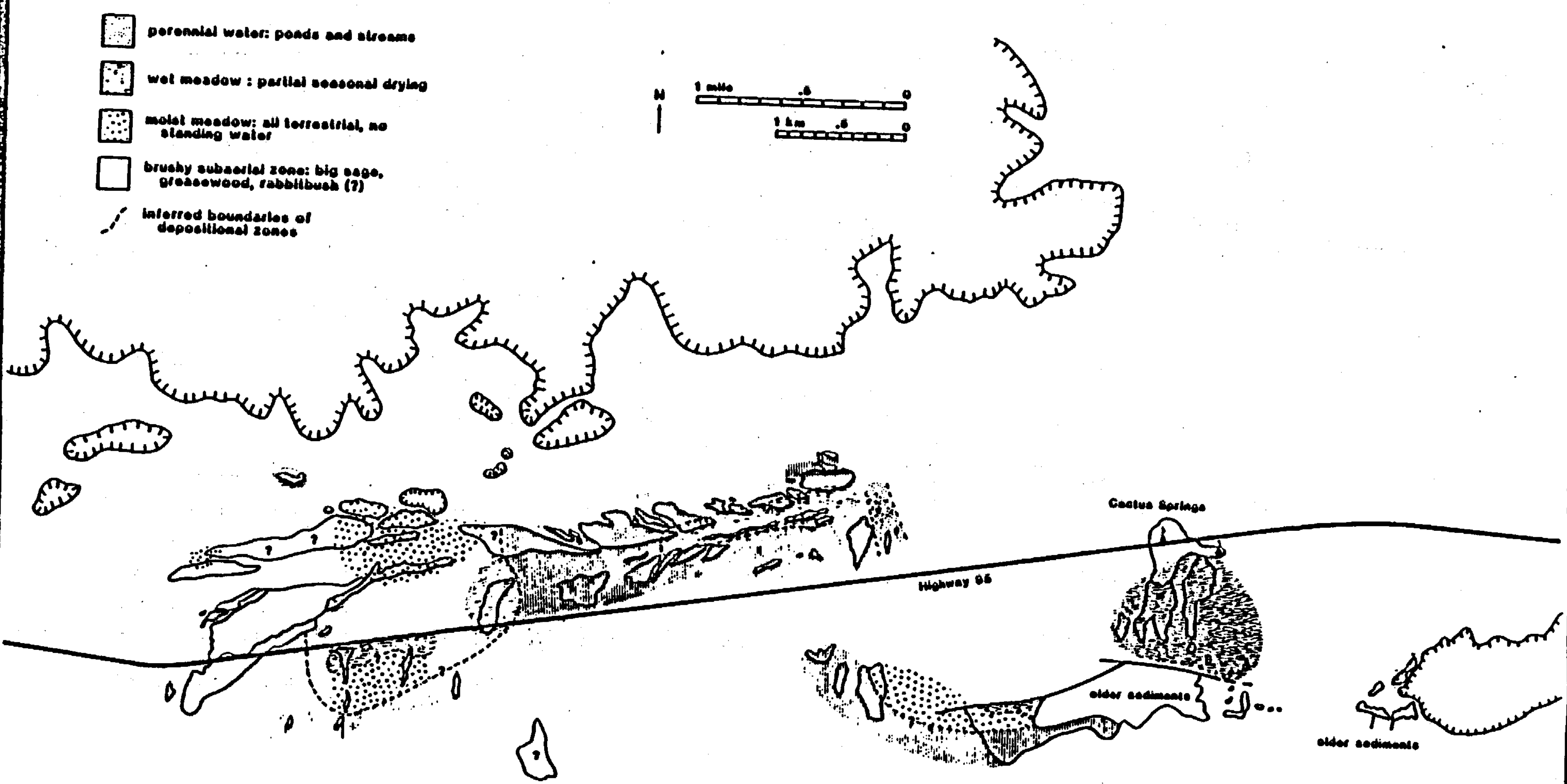

perennial water: ponds and streams
wet meadow : partial seasonal drying
moist meadow: all terrestrial, no standing water
brushy subaerial zone: big sage, greasewood, rabbitbush (?)
inferred boundaries of depositional zones
N
1 mile .5 0
1 km .5 0
Cactus Springs
Highway 95
older sediments
older sediments

Fig 18

Appendix B-VII

Systematic variations in del^{13}C and del^{18}O of soil carbonate along elevation transects in the southern Great Basin, USA by J. Quade and T. Cerling.

Systematic variations in $\delta^{13}C$ and $\delta^{18}O$ of soil carbonate along elevation transects in the southern Great Basin, USA

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ABSTRACT

Stable carbon and oxygen isotope variations in recent soil carbonates were examined along several elevation transects in the southern Great Basin, USA. Our intent was to study the relationship between the stable isotopic composition of soil carbonates and climate, ecological variations, differences in parent material, and soil depth. $\delta^{13}C$ varies by about 12 per mil over a 2440 meter elevation change, being enriched in ^{13}C at the lowest elevations. The slope of $\delta^{13}C$ versus elevation is very similar for soils developed on carbonate and on non-carbonate parent materials, being depleted by 4.6 per mil per 1000 meters increase in altitude between 300 to 2740 meters above mean sea level for the localities studied. This similarity indicates that little if any carbon in soil carbonates is inherited from the dissolution of limestone. $\delta^{18}O$ values are also higher at lower elevations, due in part to the more positive $\delta^{18}O$ values for meteoric waters at lower elevations.

$\delta^{13}C$ of soil carbonate decreases with soil depth, reflecting a decrease in the ratio of atmospheric to plant-derived CO_2 downprofile. $\delta^{18}O$ is heaviest shallow in the soil, probably due to evaporative enrichment.

INTRODUCTION

Pedogenic carbonate is an important component in many soils, yet relatively little is known about the systematics of its stable isotopic geochemistry. Although the isotopic composition of soil carbonate has been used to estimate the degree of recrystallization of carbonate in soils (e.g., Magaritz and Amiel, 1980, 1981; Amundson and Lund, 1987) and to study paleoclimatology and paleoecology (Margaritz *et al*, 1981; Cerling, 1984; Schlesinger, 1985; Cerling and Hay, 1986), few systematic studies of isotopic variations in modern soils have been made.

It has been suggested previously that the isotopic composition of soil CO_2 is controlled by the proportion of surface plant biomass using the C-3 or C-4 photosynthetic pathway (Cerling, 1984), which have average organic carbon $\delta^{13}C$ values of about -27 per mil and -13 per mil, respectively (Deines, 1980; Cerling, 1984). Considerations of typical carbonate dissolution reactions show that inherited carbon from parent material is significant in the dissolution step of carbonates (Salomons, 1986):

$$CaCO_3 + CO_2 + H_2O = Ca^{++} + 2\,HCO_3^-$$

Because the rate of new soil carbonate accumulation is small (10^{-7} to 10^{-6} $mole \cdot cm^{-2} \cdot yr^{-1}$) compared to the CO_2 respired flux (10^{-3} to 10^{-5} $mole \cdot cm^{-2} \cdot yr^{-1}$), Cerling (1984) suggested that the isotopic composition of soil carbonate will be controlled by the isotopic composition of soil CO_2 and that the inherited carbon from any dissolved carbonates would be insignificant. In this paper we compare soil carbonates formed on parent materials approaching pure limestone with soil carbonates formed on a parent material with little to no detrital carbonate. Comparison of the carbon isotopic composition of soil carbonates formed from the two different parent materials should show if any carbon is inherited from the dissolution of detrital limestone clasts.

Soil carbonates were studied along elevation transects because it was expected that large changes in the $\delta^{13}C$ value of soil carbonates should occur over several thousand meters elevation change as a function of changes in the type of plant cover at various sites. At low elevations, the $\delta^{13}C$ values should be highest. This is because they are most likely to have a high proportion of C-4 biomass, since plant utilizing the C-4 photosynthetic pathway are adapted to conditions of high water stress. In addition, low elevation sites are likely to have lower net respiration rates than higher elevation sites. Therefore, low elevation sites are more likely to have a significant atmospheric component, which happens to have an isotopic value very similar to that expected for a pure C-4 biomass (+4 per mil and + 2 per mil for soil carbonate produced from a pure atmospheric and pure C-4 component, respectively, using the three component model of Cerling, 1984). For comparison, soil carbonate formed from a pure C-3 biomass with an insignificant atmospheric component should have a $\delta^{13}C$ value of about -12 per mil. This should allow us to assess the affect of inheritance of ^{13}C from the dissolution of carbonates. In addition, these transects allow us the study the $\delta^{18}O$ variations of soil carbonates as a function of altitude, since the $\delta^{18}O$ value for meteoric water is progressively depleted with increase in elevation (Dansgaard, 1964 ; Smith *et al*, 1979).

METHODS

The sites studied were from the Spring Mountains facing the Las Vegas Valley, Titus Canyon, and from the nearby Grapevine, Panamint, and Pine Valley Mountain Ranges, all in the southern Great Basin (Fig. 1). In order to insure that sampled soils were post-early Holocene in age, we selected terraces immediately adjacent to and therefore recently abandoned by active washes. Quade (1986) has shown that such terraces in the Las Vegas Valley are younger than 7000 B.P. We also confined ourselves to terrace settings because significant vegetation changes occur between the active channels and the nearby ridge tops, the latter being much drier with a more xeric vegetation.

We sampled seven sites in the Spring Mountains and in Titus Canyon (Fig. 1) where the parent material was composed almost entirely of limestone clasts. These sites varied from 300 to 2740 meters above mean sea level. For comparison with non-calcareous parent material, seven sites were selected in the Grapevine, Panamint, and Pine Valley Ranges. For the Grapevine and Pine Valley sites, Tertiary volcanic rocks entirely compose the alluvium; at the Panamint Range site, alluvium is dominated by non-calcareous metamorphic clasts (schists, phyllite and quartzite). In all soils, a small amount of carbonate could be present due to the deposition of aeolian dust, particularly in vesicular horizons found in soils at lower elevations in the region (McFadden et al., 1987).

We sampled two or three separate profiles at each site. All the samples used to construct the transects are from 50±10 cm depth, unless otherwise noted. We chose this depth since Cerling (1984) showed that significant variations in the isotopic composition of soil CO_2 are expected shallow in soil profiles. To examine this depth dependency, we sampled one profile in detail in which soil carbonate was present at all levels. All carbonates sampled show weak to mature Stage 1 morphology (Gile *et al.*, 1966). Relatively pure encrustations of soil carbonate were scraped from alluvial clasts under a binocular microscope, taking care not to include any carbonate from the host clast itself, or from older carbonate cement.

Soil carbonates were baked under vacuum at 450 °C for one hour prior to reaction with 100% phosphoric acid. Results are reported in the δ (per mil) notation where:

$$\delta \text{ (per mil)} = \left(\frac{R_{sample}}{R_{standard}} - 1 \right) 1000$$

and R_{sample} and $R_{standard}$ refer to the $^{13}C/^{12}C$ or $^{18}O/^{16}O$ ratios in a sample or standard, respectively.

Climate varies considerably along these transects. For example, Las Vegas, Nevada, with an elevation of 640 m, has a mean annual temperature of 19.5°C and mean annual precipitation of 10 cm/yr. Based on temperature (0.54°C/100 m) and precipitation (12 mm/100m) lapse rates calculated by Barbour (?) for the Spring Range, the highest soil station on the transect has a mean annual temperature of 8.5°C and mean annual precipitation of about 33 cm /yr. Broadly, five vegetation zones are recognizable along these climatic gradients. They are: creosote-burrobush, blackbush, sage, pinyon-juniper-sage, and fir-pine. Vegetation lists were compiled at each locality in April, 1987 although additional observations were made in August, 1986, and January, 1987. Plant density and species diversity was measured along 60-meter long line transects.

RESULTS AND DISCUSSION

The $\delta^{13}C$ value for soil carbonates (Table 1) decreases systematically with elevation (Fig. 2) for soils formed on carbonate or non-carbonate parent materials. Both suites of samples decrease by 4.6 per mil per 1000 meters increase in elevation, although the best fit lines are offset by about 1.7 per mil. The $\delta^{13}C$ relationship to elevation for the two transects are:

$\delta^{13}C = 3.59 - 4.60 \times 10^{-3} \times Z$ for the carbonate transect ($r^2 = 0.93$)

$\delta^{13}C = 1.86 - 4.61 \times 10^{-3} \times Z$ for the non-carbonate transect ($r^2 = 0.86$)

where Z is the elevation above mean sea level in meters.

Inheritance of carbon from the dissolution step

The isotopic composition of soil CO_2, dissolved HCO_3^-, and newly precipitated soil carbonate are related by the fractionation factors between these species and the kinetics of exchange and precipitation. The CO_2 composition of soil gas can be described by diffusion equations that include a term for the production of CO_2 in soil (Kirkham and Powers, 1972). Cerling (1984) previously suggested that the isotopic composition of soil gas can be described by applying diffusion equations to account for $^{12}CO_2$ and $^{13}CO_2$ produced by soil respiration in the soil and mixing with atmospheric $^{12}CO_2$ and $^{13}CO_2$. That model estimated endmember soil carbonate in equilibrium with C-3, C-4, and the atmospheric components to be about -12, +2, and +4 per mil, respectively. Marine limestone has an isotopic composition of about 0 per mil. Thus, any inheritance of carbon derived from dissolution of marine limestone should result in a mixing line between the marine value and one of the other endmembers. The dissolution equation given above shows that half of the carbon in the dissolution step of carbonate is derived from pre-existing carbonate. Therefore, if total exchange with soil CO_2 does not occur, carbonates with very negative $\delta^{13}C$ values (high C-3 component) would be shifted more than those with a high $\delta^{13}C$ value (high C-4 or atmospheric component). The similarity of the slopes for soil carbonate formed in a carbonate-rich parent material compared to a non-carbonate parent material (Fig. 2) suggests that virtually no carbon is inherited by the newly precipitated soil carbonate. This implies virtually complete exchange of soil CO_2 with the soil solution containing dissolved HCO_3^- prior to soil carbonate precipitation.

Complete exchange with soil CO_2 means that the carbon isotopic composition of soil carbonates is related to the isotopic composition of soil CO_2, which in turn is related to the proportion of C-3 and C-4 biomass present as well as the total soil CO_2 respiration rate with resultant mixing of atmospheric CO_2 (see discussion below). This has important implications for ^{14}C studies of soil carbonate because it implies that no "dead" carbon appears to be inherited from the dissolution of limestone. The limitations of ^{14}C studies of soil carbonate are more likely to be with detrital contamination and sample size. Those problems will be greatly reduced by using very small sample sizes, which can be achieved by measuring ^{14}C with accelerator mass spectrometry.

Origin of the decrease in δ13C of soil carbonate as a function of elevation

The precise $\delta^{13}C$ value of soil carbonate in the transects is also of interest. Modern vegetation in the region has a considerable fraction of C-4 biomass (Table 2). A higher abundance of C-4 plants is observed at lower elevations. However, the fraction of C-4 biomass in the modern vegetation is not sufficient to explain the high $\delta^{13}C$ values observed for soil carbonate. There are two possible explanations for this: 1] that the modern vegetation is not in isotopic equilibrium with the soil carbonate, and 2] that the soil carbonates have a significant atmospheric component due to low soil respiration rates. The first is very likely to be the case because considerable vegetation changes due to overgrazing are evident at the lower elevations. Overgrazing can select against desert C-4 plants, particularly shrubs like saltbush (*Atriplex canescens* and *A. convertifolia*). In grasslands, overgrazing often selects against C-4 grasses in particular (Madson, 1982). In addition, our survey of vegetation shows that numerous non-indigenous plants such as Brome grasses (*Bromus rubens*, *Bromus tectorum*), storksbill (?), and various mustards have invaded the area. This makes modern vegetation surveys of dubious value in estimating the proportion of C-4 biomass for pre-settlement times. In any case, such surveys are further complicated because grasses and forbs are not woody and may be underrepresented by above ground plant surveys. Dorn and DeNiro (1985) and Dorn *et al* (1987) have shown that the most recent period of desert varnish formation in the lower elevations of the Mohave is dominated by C-4 organic material, although the modern vegetation is not dominantly C-4. This provides evidence that post-settlement vegetation changes have taken place in the region.

It is also possible that soil carbonates formed in these desert soils formed under conditions of very low soil respiration. Cerling (1984) showed that soil CO_2 at relatively low pCO_2 (lower than $10^{-2.5}$) has a significant atmospheric component. Low pCO_2 in soils occurs when the soil respiration rate is relatively low; in the Great Basin, such low respiration rates are to be expected even during the height of the growing season (e.g., Parker *et al*, 1983; Quade, unpublished data). Soil carbonate precipitated in isotopic equilibrium under such conditions will have a high atmospheric component, which would result in $\delta^{13}C$ values more positive than expected for CO_2 derived only from soil respiration.

We suspect that both causes contribute to the lack of correlation between the $\delta^{13}C$ value for soil carbonates and the fraction of C-4 biomass. It is certain that the modern vegetation differs from that present more than 150 years ago in the region, and it is likely that some C-4 plants have been selectively grazed out. Also, low CO_2 respiration rates of desert soils make it probable that significant CO_2 invasion from the atmosphere occurs. This causes an increase in the isotopic composition of soil CO_2 and the soil carbonate precipitated in isotopic equilibrium with it. It is thus possible that some of the trend observed in this study is due to a respiration gradient as well as a change in the isotopic composition of the soil respired CO_2 (and hence the fraction of C-4 biomass). Unfortunately, high proportions of C-4 plants and low soil CO_2 respiration rates both result in high $\delta^{13}C$ values for soil CO_2. Therefore, both of these processes, which are related to high moisture stress conditions, could result in higher $\delta^{13}C$ values for soil carbonates we have observed.

The slight offset observed between the two trends is probably due to a systematic shift in the vegetation and soil respiration that results from the suites of samples having different parent materials. Soils at the same elevation but developed on the two parent materials display slight systematic differences in soil texture, moisture, or nutrients.

Relationship between the oxygen isotopic composition of soil carbonate and elevation

The oxygen isotopic composition of soil carbonate decreases markedly with increasing elevation in both suites of samples (Fig. 3), although there is more scatter in the data than was observed for carbon. The relationship between $\delta^{18}O$ and elevation is:

$$\delta^{18}O = -3.78 - 3.4\times10^{-3} \times Z \qquad (r^2 = 0.74)$$

where Z is the elevation in meters. The relationship of meteoric water to elevation is complicated in the Great Basin and Mojave Desert region by rain shadow effects of the Sierra Nevada and other mountain ranges. However, Smith *et al.* (1979) have found that in the Mojave Desert and the adjacent Sierras the isotopic composition of δD decreases by 33 per mil/ 1000 m, which would be equivalent to a change of 4.3 per mil for $\delta^{18}O$ per 1000 m. This gradient is similar but not identical to that observed in this study.

$\delta^{18}O$ values for soil carbonate show more scatter (r^2=0.74) than for $\delta^{13}C$ (r^2=0.96 and 0.84). We suggest three possible explanations for this. First, in areas of high plant density where most water loss is through evapotranspiration it is possible that little isotopic enrichment of the soil water occurs. However, Allison *et al.* (1984) have shown that isotopic enrichment is large when bare soil is present. Thus, it is possible that soil water at our soil sites, which all have some bare ground (Table 2), have undergone isotopic enrichment with respect to oxygen as a result of evaporation. A second possible explanation is that $\delta^{18}O$ values for storms have been observed to vary substantially both individually and seasonally (Smith *et al*, 1979; Jack Hess, 1987, pers. comm.). This isotopic heterogeneity might result in variable $\delta^{18}O$ values of soil carbonate such as we observe. Finally, because all of the sites studied are in or near active channels, it is ~~likely~~ possible that some of the water infiltrating at each site originally fell at a higher elevation where precipitation was isotopically lighter.

Isotopic gradients as a function of soil depth

Cerling (1984) modeled the variation of $\delta^{13}C$ of soil CO_2 versus soil depth as a function of different soil respiration rates. As has been described, the

$\delta^{13}C$ of soil CO_2 should reflect the admixture of two sources: atmospheric CO_2 at the top of the profile, and increasing plant-derived CO_2 with depth. Atmospheric CO_2 is heavier (-7 per mil) than plant-derived CO_2 (C-3 plants= -22 per mil and C-4 plants = -8 per mil). Therefore, the model predicted an exponential decrease with depth in the $\delta^{13}C$ of soil CO_2, from -7 per mil at the surface to some lighter value more reflective of the C-4/C-3 plant ratio at the site. In turn, carbonate precipitated at the soil surface in equilibrium with atmospheric CO_2 should average about +3 per mil, and should decrease with depth. The rate and extent of that decrease depends on (1) the soil respiration rate, and (2) the proportion of C-4 to C-3 plants at the site.

In order to test Cerling's model, we sampled soil carbonate with depth at one site on the Spring Mountain transect (Site SM-2, elevation 1550 m). $\delta^{13}C$ of soil carbonate does in fact decrease exponentially with depth (Fig.4). Carbonate from the first 5 cm of the profile averaged + 3.7 per mil, reflecting isotopic equilibrium with atmospheric CO_2 as predicted by Cerling (1984). Values decrease evenly with depth and appear to level off below 30 cm at about -7 per mil. As already discussed, this value may reflect a C-4 to C-3 plant proportion no longer present at the site due to overgrazing, or an admixture of atmospheric CO_2 with plant-derived CO_2 throughout the profile, or both. The depth dependency of $\delta^{13}C$ of soil carbonate suggests that values useful for intra-site comparison in ecologic reconstruction must be taken below 30 cm, as was done in this study.

$\delta^{18}O$ of soil carbonate also decreases systematically with depth (Fig. 5). We interprete this to be the result of evaporative enrichment of near surface soil solution. The lighter isotopic values evident with depth probably represent precipitation in equilibrium with larger, more deeply penetrating (and therefore less evaporated) rainfall/runoff events. If true, the values below 30 cm should be most representative of the average annual $\delta^{18}O$ compostion of rainfall at the site. We conclude that depth dependency should be kept in mind when interpreting the ecological meaning of both the $\delta^{13}C$ and $\delta^{18}O$ composition of soil carbonate.

CONCLUSIONS

Measurements of the carbon and oxygen isotopic composition of post early-Holocene soil carbonates from the Great Basin and Mojave Desert show a strong dependence on elevation. Comparison of the carbon isotopic composition of soil carbonates on carbonate and non-carbonate parent materials suggest that virtually no carbon is inherited from the parent carbonate. This suggests that complete isotopic exchange of soil CO_2 with the dissolved bicarbonate in the soil solution occurs prior to soil carbonate formation. This in turn implies that the carbon isotopic composition of soil carbonates is directly related to the isotopic composition of soil CO_2, which itself is controlled by the fraction of C-3 and C-4 biomass present and soil CO_2 respiration rates. If this isotopic signal is preserved in paleosol carbonates, the $\delta^{13}C$ value of paleosol carbonates could prove to be a valuable tool in paleoecologic studies. Furthermore, complete exchange means that ^{14}C dates on soil carbonate should reflect true ages of carbonate precipitation, assuming that only short intervals are sampled, and that there is no detrital contamination present.

Comparison of the $\delta^{13}C$ value of soil carbonates in this study with that expected from the observed modern vegetation implies that major ecologic changes have recently taken place as a result of post-settlement grazing and related activities. Many of the observed species present at lower elevations are not native to the region, and we have reason to expect that C-4 plants are selected against by grazing. It is also probable that there is a significant amount of invasion of atmospheric CO_2 by diffusion resulting from low soil CO_2 respiration rates. The latter is not unexpected since mathematical modeling of the isotopic composition of soil CO_2 shows that atmospheric invasion is likely at low soil CO_2 respiration rates (Cerling, 1984).

$\delta^{18}O$ shows a systematic decrease in the soil carbonates with increasing elevation. This results from the changes in the average annual isotopic composition of meteoric water with elevation. Within-site variability in $\delta^{18}O$ may be due to differential evaporation of soil water, to short-term isotopic variation in rainfall, or to runoff from higher elevation sites. Preservation of the oxygen isotopic value in paleosol carbonates may make them a useful paleoenvironmental indicator, as well.

Finally, the strong depth dependency of both the $\delta^{13}C$ and $\delta^{18}O$ composition of soil carbonate must be kept in mind in interpreting the ecological implications of isotope results.

ACKNOWLEDGEMENTS

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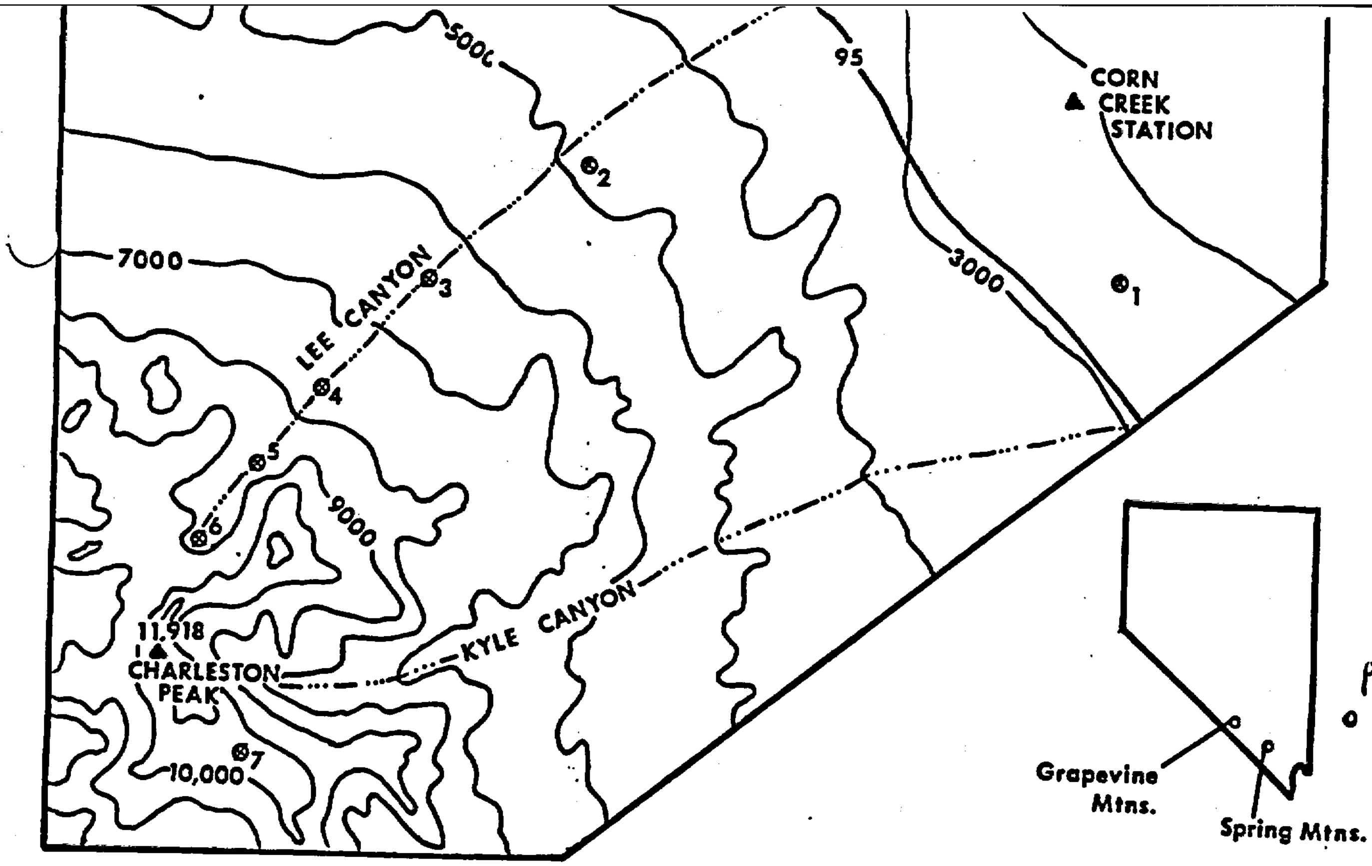
List of Figures



Pine Mts

Figure 1a. Map of the Spring Mountains showing soil sample sites

⊗ = sample sites

0 5 10 miles

C.I. = 1000'

Also need Pine Mt site location map.

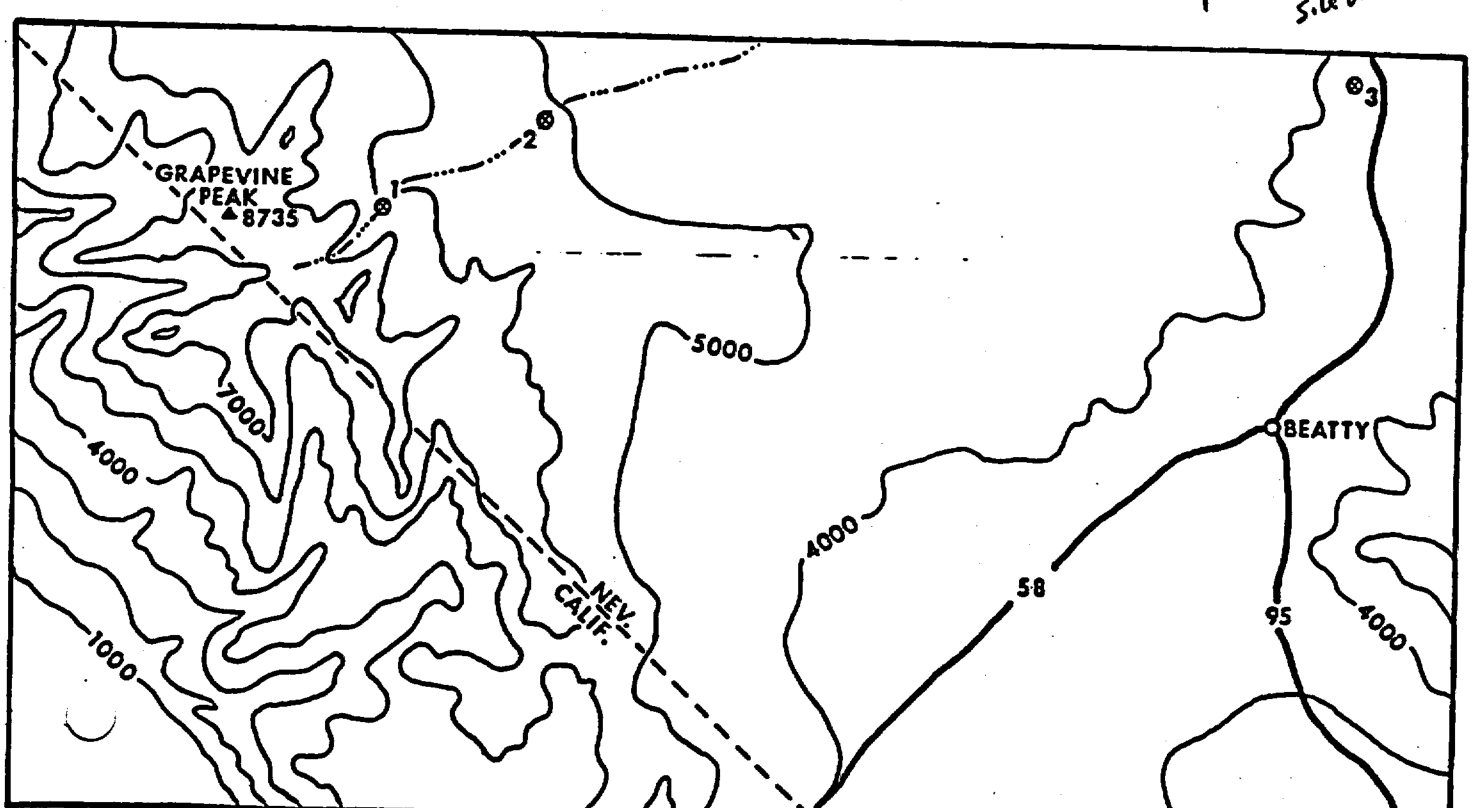
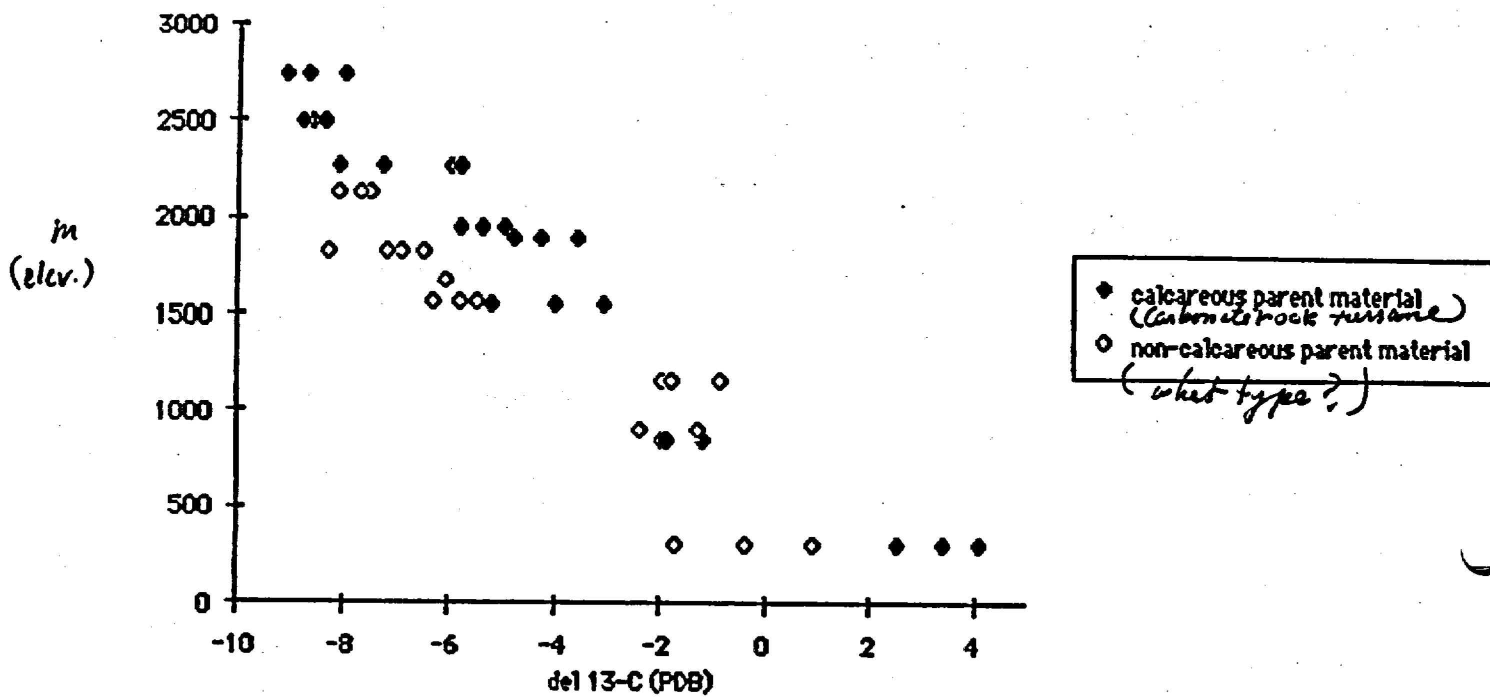


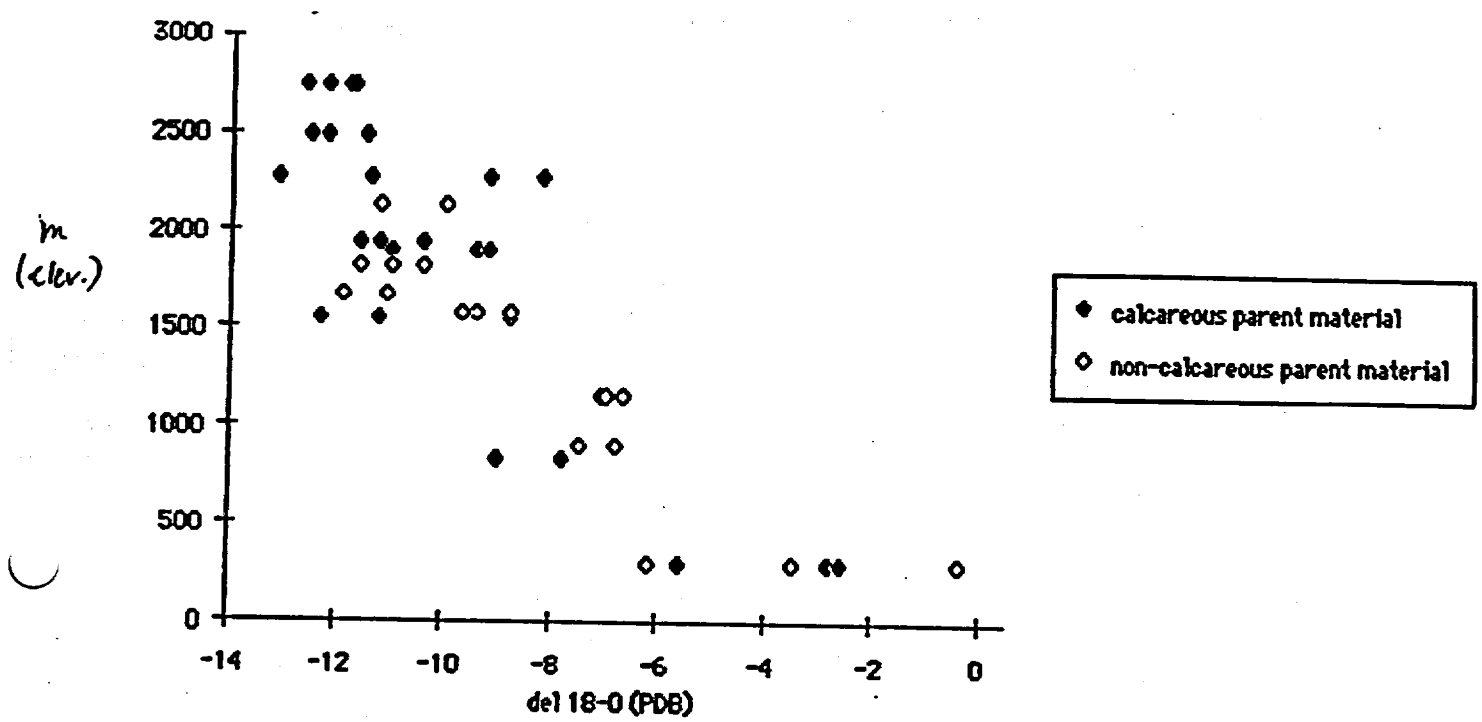
Figure 1b. Map of the Grapevine Mountains showing soil sample sites.

Figure 2



m
(elev.)
3000
2500
2000
1500
1000
500
0
-10
-8
-6
-4
-2
0
2
4
del 13-C (PDB)
calcareous parent material
non-calcareous parent material
(what type?)

Figure 3



3000
2500
2000
1500
1000
500
0
m (elev.)
-14
-12
-10
-8
-6
-4
-2
0
del 18-O (PDB)
calcareous parent material
non-calcareous parent material

Fig. 4

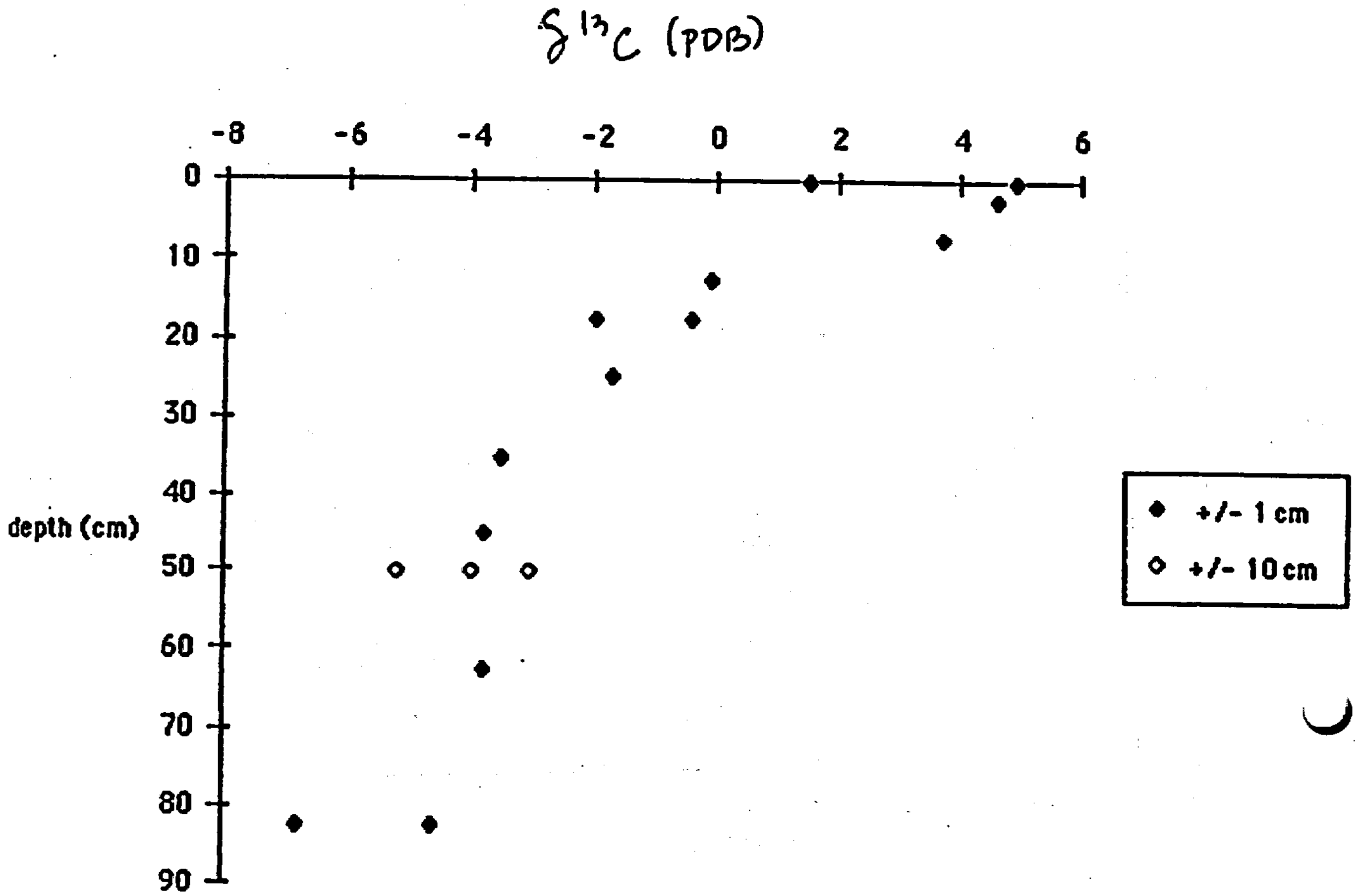
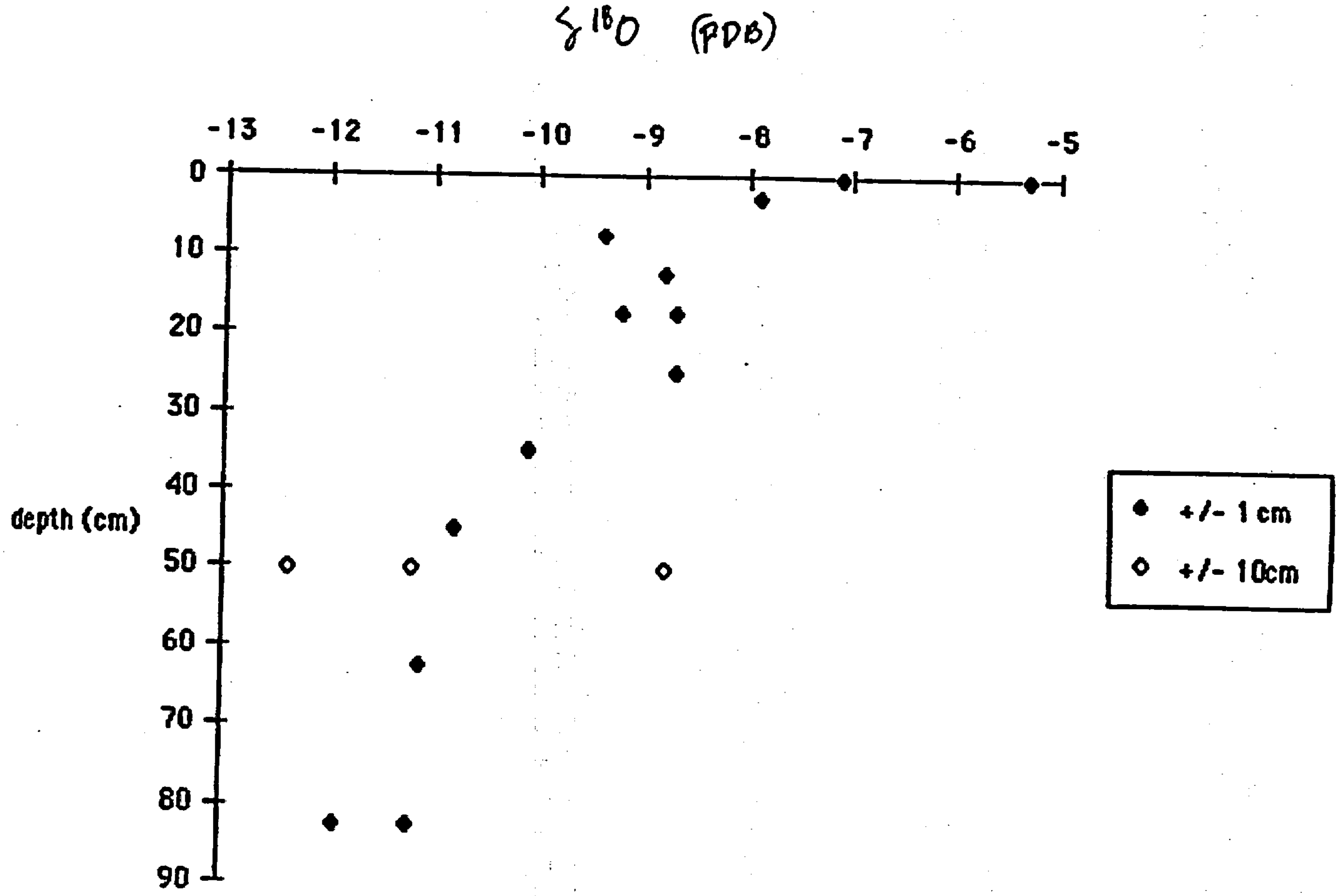


Fig. 5



δ18O (PDB)
-13
-12
-11
-10
-9
-8
-7
-6
-5
0
10
20
30
40
50
60
70
80
90
depth (cm)
+/- 1 cm
+/- 10cm

Table 1 Isotopic data from southern Great Basin soil sites

sample no.	elevation (m)	del 13-C (PDB)	del 18-O (PDB)
SM-1a	840	-2	-9
SM-1b	840	-1.9	-7.8
SM-1c	840	-1.2	-7.8
SM-2b	1550	-3.1	-8.8
SM-2b	1550	-4	-11.2
SM-2c	1550	-5.2	-12.3
SM-3a	1950	-5.4	-11.2
SM-3b	1950	-5	-11.6
SM-3c	1950	-5.8	-10.4
SM-3(B)a	1900	-4.3	-11
SM-3(B)b	1900	-3.6	-9.4
SM-3(B)c	1900	-4.8	-9.2
SM-4a	2270	-8.1	-13.1
SM-4b	2270	-6	-8.2
SM-4c	2270	-5.8	-9.2
SM-4d	2270	-7.3	-11.4
SM-5a	2490	-8.62	-12.2
SM-5b	2490	-8.4	-12.2
SM-5b-rerun	2490	-8.4	-12.5
SM-5c	2490	-8.8	-11.5
SM-6a	2740	-9.11	-12.2
SM-6b-1	2740	-8.08	-11.8
SM-6b--2	2740	-8.7	-12.6
SM-6c	2740	-8	-11.7
TC-1a	300	3.4	-2.8
TC-1b	300	4.1	-2.6
TC-1c	300	2.5	-5.6
GM-1a	1830	-8.3	-11
GM-1a--1m	1830	-6.9	-11.6
GM-1c	1830	-6.5	-10.4
GM-1d	1830	-7.2	-11
GM-2a-90 cm	1575	-6.3	-9.4
GM-2b	1575	-5.8	-8.8
GM-2c	1575	-5.5	-9.7
GM-3a	1160	-2	-6.7
GM-3b	1160	-0.9	-7.1
GM-3c	1160	-1.8	-7
GM-4a	900	-2.4	-6.8
GM-4b	900	-1.3	-7.5
PaM-1a	300	-1.7	-0.4
PaM-1b	300	-0.4	-3.5
PaM-1c	300	0.9	-6.2
PiVM-1a	1675	-6.1	-11.1
PiVM-1d	1675	-6.1	-11.9
PiVM-2a	2130	-8.1	-11.2
PiVM-2b	2130	-7.5	-10
PiVM-2c	2130	-7.7	-11.2

Table 1 Isotopic data from southern Great Basin soil sites

profile	depth (cm)	del 13-C (PDB)	del 18-0 (PDB)
SM-2p(surf. 1)	0	1.5	-7.1
SM-2p(surf. 2)	0	4.9	-5.3
SM-2p(0-5a)	2.5	4.6	-7.9
SM-2p(5-10a)	7.5	3.7	-9.4
SM-2p(10-15a)	12.5	-0.1	-8.8
SM-2p(15-20a)	17.5	-2	-9.2
SM-2p(15-20b)	17.5	-0.4	-8.7
SM-2p(20-30a)	25	-1.7	-8.7
SM-2p(30-40a)	35	-3.5	-10.1
SM-2p(40-50a)	45	-3.8	-10.8
SM-2p(50-75a)	62.5	-3.8	-11.1
SM-2p(75-100a)	82.5	-4.6	-11.9
SM-2p(75-100b)	82.5	-6.8	-11.2

Note: Sample numbers indicate locations as follows:

SM = Spring Mountains
GM = Grapevine Mountains
PaM = Panamint Mountains
PiVM= Pine Valley Mountains
TC= Titus Canyon

Two to three carbonate samples were collected from separate profiles at each transect site; individual profiles are denoted by a letter in the sample number designations (e.g. profile 'a', 'b', etc.). All samples come from 50 cm +/- 10 cm depth unless otherwise designated in the sample number. Small letters in profile sample numbers denote individual pebbles from a given depth interval.

Appendix B-VIII

Paleohydrology and Paleoclimate of the Yucca Mountain Area by W. G. Spaulding.

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QUATERNARY RESEARCH CENTER
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SEATTLE, WASHINGTON 98195

ANNUAL REPORT TO: Mifflin and Associates
Suite B-13, 2700 E. Sunset
Las Vegas, NV 89120

DATE: 6 JANUARY, 1988

SUBJECT: Paleohydrology and Paleoclimates of The Yucca Mountain Area

FOR PERIOD: June, 1987 though December, 1987

SUBMITTED BY: W. Geoffrey Spaulding
Quaternary Research Center &
Department of Botany
University of Washington

Note: This is a description of research in progress and does not constitute an actual report of research results.

Endorsement: W. G. Spaulding Date: 6 January, 1988

RESULTS TO DATE

Research is focussed on the plant macrofossil and pollen records from three localities in southern Nevada; Fortymile Canyon Locality D, Sandy Valley, and Double Canyon. The first and last are located near major drainages that are now ephemeral, but that might have had a perennial water flow during the last pluvial episode(s). The Sandy Valley locality is near paleospring deposits that are evidence of former increased discharge, presumably during former plúvials. Thus, the research questions addressed are slightly different for the paleoecological records from the two canyon localities. In their case, it is necessary to prove that there was ever perennial water in those channels. Of course, the absence of such evidence would not mean that they were dry, but positive evidence is required to demonstrate that perennially wet conditions actually existed. For all three localities, paleoecological research is designed to test for the former extent of phreatophytic habitat through the plant macrofossil and pollen records. Important data are also gained on general paleoenvironmental conditions that can be compared to prior paleoclimatic reconstructions for the Candidate Area.

Table 1 presents a summary of the midden sites located and selected for study, and Table 2 provide a list of samples selected for detailed analyses. In Table 1, "distance from target habitat" refers to the distance from the midden site to the edge of the main course of Fortymile or Double Canyons in the case of those two localities, and to the closest evident paleospring deposit in the case of the Sandy Valley locality. These values are important in that the foraging range assigned by most workers to the packrat (Neotoma spp.) is 30 m, although values of 50 m and 100 m have also been used. In several cases, macrofossils of phreatophytes have been recovered from sites that are at least 100 m from the target habitat. For example, at the Fortymile Canyon-7 site the edge of the wash is ca. 110 m distant, at the bottom of a steep 70 m slope.

The macrofossils of wet-soil plants in this assemblage indicate that the packrats were either exceeding their nominal foraging range by a considerable amount, or phreatophyte habitat was more widely distributed and(or) closer to the site. The final pollen data will provide information on which case may apply to these sites. They are not discussed in detail here because, unlike the presence-absence data provided by macrofossils, interpretation of pollen data relies on relative percentages and comparisons with modern pollen samples, and such subjective interpretations should not be hazarded until the data are final.

Fortymile Canyon Locality D

The first three packrat midden localities studied in this drainage system were sites developed in Quaternary alluvium in the lower reaches of Fortymile Canyon (950 to 1100 m). All yielded middens of late Holocene age (<1900 yr B.P.), and provided no records of phreatophytic plant taxa. However, substantial retreat of the upper limit of creosote bush occurred as a result of more mesic climatic episodes during the late Holocene, and an increase in flood frequency has been inferred from the remains of disturbance adapted species where they do not occur today (Spaulding, 1987a, b).

A different set of macrofossil records has been obtained from the higher elevation (1250 to 1310 m) sites of Fortymile Canyon locality D. At this elevation the course of the canyon is more constricted as bedrock walls confine its course. The slopes of Tertiary volcanic rocks weather in such a fashion as to afford numerous rock shelters and cavities. Middens in these cavities evidently persist for millennia longer than those in the Quaternary alluvium of localities A through C. Some assemblages (FMC-8A, FMC-11) provide vegetational records of glacial-age woodland or woodland-steppe mosaic characterized by the abundant pollen and macrofossils of sagebrush (Artemisia subgen. tridentatae), curl-leaf mountain mahogany (Cercocarpus ledifolius), and Utah juniper (Juniperus osteosperma)(Table 3). This is the vegetational context of the white fir record (see discussion of phreatophyte occurrences, below), and appears to be the paleovegetation zone below the subalpine-steppe vegetation type recorded at the Eleana Range-2 site (1810 m elevation). At the ER-2 site vegetation was dominated by limber pine, mountain mahogany, and steppe shrubs from at least 17,100 to 13,200 yr B.P. Steppe shrubs and mountain mahogany persist at these lower-elevation Fortymile Canyon sites, but limber pine has given way to Utah juniper. Other assemblages provide probable latest-glacial or early Holocene records of woodland in which mountain mahogany is not recorded and prickly-pear cactus (Opuntia cf. polyacantha) is abundant, sagebrush is much reduced, and pinyon pine (Pinus monophylla) is more common (FMC-7(1); FMC-10). This is similar to the pinyon-juniper-cactus assemblages dated to 11,700 and 10,600 yr B.P. at the Eleana Range-2 site (Spaulding et al., 1984), and is the paleovegetational context of the wild-rose and knotweed occurrences (see discussion of phreatophyte occurrences, below).

Sandy Valley

Middens from the low inselbergs adjacent to paleospring and wet-meadow deposits in Sandy Valley are of general paleoenvironmental interest because the sites were evidently below the lower limit of glacial-age woodland. Desert scrub is recorded by the Sandy Valley assemblages, albeit a different type of desert scrub than that which occupies the sites today. The warm-temperate species that currently dominate the sites are absent. Instead, the vegetation was characterized by a combination of Great Basin shrubs (Chrysothamnus nauseosus, Atriplex confertifolia) and more mesophytic northern Mojave taxa (Buddleja utahensis, Ephedra spp., _Lycium_ sp., _Lepidium montanum_-type) (Table 4). This is the vegetational context of the net-leaf hackberry record (see discussion of phreatophyte occurrences, below) and can be compared to the Pleistocene-age desertscrub records from higher elevations in the Amargosa Desert (Spaulding, 1983, 1987a, b). There had been some apparent vegetation change before the deposition of SaV-3(1), the midden deposit containing the remains of mesquite (_Prosopis juliflora_; Table 4; see discussion of phreatophyte occurrences, below). The most mesic upland taxa (e.g. _Symphoricarpos_), are not recorded in this assemblage and thermophiles appear, including rock-nettle (_Eucnide urens_) and tidestromia (_Tidestromia oblongifolia_). The inferred younger age for this assemblage is being tested by radiocarbon dating, but is consistent with the presence of mesquite. Today mesquite reaches its northern limit in the Candidate Area, and it would not be expected during times when winter minimum temperatures were appreciably lower (>1.5°C) than those of today. Its presumed immigration into the region during the latest glacial or early Holocene can provide important paleoclimatic information on minimum temperatures, as well as on the presence of artesian water.

Double Canyon

The Double Canyon midden records more closely resemble the paleovegetation records from the lower Grand Canyon (Phillips, 1977; Mead and Phillips, 1981) than they do those from the Nevada Test Site area. Key taxa that are rare or absent from the glacial-age vegetational records of the Sheep Range and areas northwest include Whipple cholla (_Opuntia whipplei_) and single-leaf ash (_Fraxinus anomala_)(Table 5), species well-represented in the lower Grand Canyon fossil record. This suggests an appreciable east-west gradient of effective moisture during the last pluvial episode(s), perhaps greater than that of today.

PHREATOPHYTIC SPECIES ENCOUNTERED TO DATE AS MACROFOSSILS

Wild rose (Rosa woodsii): thorned twigs. seeds. Recovered from both Wisconsin-age assemblages from Fortymile Canyon-7. the habitat of the species as described by Beatley (1976. p. 251) is "in seepage areas or usually in washes below springs." This characterization is consistent with field observations of this author...wild rose is a facultative phreatophyte and, in the Great Basin climatic regime, it is restricted to perennially wet areas. It was likely growing at the foot of the cliff below the site, on the margins of Fortymile Canyon Wash. The present distance to the edge of the wash from the site is estimated at 110 m. It is unlikely that wild rose was growing on the exposed slopes any closer to the site

White fir (Abies concolor); a single needle. Recovered from the Wisconsin-age Fortymile Canyon-11A(1) assemblage. A possible product of long-distance transport from elsewhere in the vicinity. A single needle is not sufficient evidence that the tree was growing at the site. Eolian transport of pine needles has been observed to carry them as much as 500 m from the nearest tree in the Toquima Range of central Nevada (author's field notes, vol. 11). However, at such a low elevation (1310 m), this montane tree was probably a phreatophyte wherever it occurred in this area. At present its lower limit in a mesic canyon in the Sheep Range is ca. 2070 m elevation; the lowest Wisconsin-age record prior to this find is from a midden in the Sheep Range, at 1570 m elevation. This was also in mesic setting, but in a smaller canyon (the Willow Wash locality; Spaulding, 1981). White fir was not recovered from any of the Eleana Range midden samples; although the ER sites are at a higher elevation (1810 m), they occupy a xeric south slope, and white fir was not detected in the stadial-age limber pine-steppe shrub assemblages (ER-2), or in the interstadial-age woodland assemblages (ER-3; Spaulding et al., 1984; Spaulding, 1985). As such, this is a new and paleoclimatologically significant record for the Yucca Mountain area. Assuming its water requirements were met, its occurrence at this elevational range would have been limited by summer temperature only. This makes certain calculations of summer temperature decline possible (Table 6).

Knot-weed (Polygonum lapathifolium-type); seeds. Recovered from the Wisconsin-age Fortymile Canyon-7(1) assemblage. Only one Polygonum species (P. douglasii) is recorded as being native to the Nevada Test Site area (Beatley, 1976), and its seeds are shaped differently from those of this fossil taxon. These are lenticular and without angles, and their morphology conforms with taxa such as P. pennsylvanicum and P. lapathifolium. This taxonomic assignment is significant because P. douglasii may grow in mesic settings away from water, while those taxa included in P. lapathifolium-type occupy the moist, disturbed soils of wet meadows and stream-sides (Munz, 1968). Like wild-rose, it was likely growing below the site,on the margins of Fortymile Canyon Wash.

Mesquite (Prosopis juliflora): pod fragments and leaflets. Recovered from the latest Wisconsin or early Holocene-age Sandy Valley-3(1) assemblage. The presence of both leaflets and seeds indicates that the species may have been growing within 30 m of the site. In the Candidate Area today it occurs only on perennially moist ground, or in dunes along fault lineaments where it is probably also reliant on artesian water (Quade, pers. comm., 1987)

Net-leaf hackberry (Celtis reticulata): a single seed. Recovered from the Wisconsin-age Sandy Valley 2(3)3 assemblage. The remains of hackberry are rare in the southern Great Basin macrofossil record. The tree is an obligate phreatophye throughout its range in the Great Basin and adjacent areas (Benson and Darrow, 1981). Even in an area such as the Grand Canyon, which receives more average annual and summer precipitation than does the Candidate Area, net-leaf hackberry is restricted to perennially moist sites (Phillips et al., 1987). Like the white fir needle discussed above, this macrofossil represents probable long-distance transport. However, because the seed is encased in a berry, it could have been transported a considerable distance in the gut of an animal, to be excreted near the site and then the feces incorporated into the midden. Such is the presumed manner of origin of all other Celtis records in the Candidate Area, with the exception of the Deadman Canyon- 2 site (see below).

Prior Records of Phreatophytic or Hydrophyllic Species in The Candidate Area

Skeleton Hills- 2(2): Ondatra sp. (muskrat); A single tooth identified by C.A. Repenning, U.S.G.S., Denver. Likely from a carnivor scat or raptor "pellet". it is associated with a radiocarbon date of 8710 ± 100 yr B.P. (Spaulding, 1987a, b).

Skeleton Hills- 1B(2): Celtis reticulata; A single seed from this site, at 910 m elevation in the Amargosa Desert, is associated with a radiocarbon date of 9160 ± 140 yr B.P. (Spaulding, 1987a, b).

Deadman- 2: Celtis reticulata; Abundant seeds indicating the presence of this tree at 2075 m near the mouth of Deadman Canyon, presently an ephemeral drainage on the west side of the Sheep Range. The seeds yielded a radiocarbon date of 9560 ± 180 yr B.P. (Spaulding, 1981).

Flaherty Shelter: Celtis reticulata; A single seed from stratified sediments in a rockshelter at 1650 m elevation on the east site of the Sheep Range. Designated "early Holocene" (10,000 to 8000 yr B.P.) on the basis of an overlying radiocarbon date of 6950 ± 320 yr B.P. (Spaulding, 1974).

CONCLUDING COMMENTS

The radiocarbon samples have been submitted for dating and all midden samples have been processed for analyses. While some conjecture as to the age of certain assemblages has been made for the heuristic sake of testing prior paleovegetational reconstructions through inferences based upon them, the results of dating tests are not desired until the macrofossil and pollen analyses are completed. In this manner we may avoid any interpretational bias introduced by knowing the age of a particular series of samples before its macrofossil and pollen flora is completely analyzed.

An additonal benefit from these studies will be the records of climatically sensitive plant taxa near what was their lower (or upper) elevation limit during the last glacial age. By applying estimated elevation depression values and lapse rates, we may derive a more secure notion of what the climatic parameters of the Candidate Area are during a pluvial episode. Coupled with specific information on the near-surface hydrologic impact of those climatic events, this research is developing a broad-based understanding of the climatic causes and hydrologic effects of paleoenvironmental change in the area.

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Table 1. Packrat midden sites included in this research project.

Site name and no.	N. lat.	W. long.	Elev. (m)	Dist. (m) from target habitat	Substrate	Site's primary habitat			Secondary habitat			Tertiary habitat		
						Type	Orientation	Area	Type	Orientation	Area	Type	Orientation	Area
FORTYMILE CANYON, NEVADA TEST SITE, NYE COUNTY														
Fortymile Canyon-7	36°56'41"	116°22'21"	1250	110	Tfv	lj,tc	260°	60%	rtp	-	30%	cl	260°-300°	10%
Fortymile Canyon-8	36°56'49"	116°22'46"	1240	100	Tfv	stc	38°	70%	lj, rtp	-	30%			
Fortymile Canyon-9	36°56'49"	116°23'01"	1280	400	Tfv	cl,lj	340°-180°	60%	ts,lj	15°-25°	40%			
Fortymile Canyon-10	36°56'57"	116°22'39"	1230	< 50	Tfv	ts	193°	40%	lj,rtp	-	30%	cl,lj	245°	30%
Fortymile Canyon-11	36°56'49"	116°23'27"	1310	500	Tfv	lj,tc	332°	70%	cl,lj	340°-180°	30%			
Fortymile Canyon-12	36°56'26"	116°22'35"	1240	100	Tfv	lj,cl	85°	50%	cl,lj	20°-60°	25%	lj,ts	90°-200°	25%
BIG SANDY (MESQUITE) VALLEY, CLARK COUNTY														
Sandy Valley-2	35°52'40"	115°42'28"	935	450	Pzc	lj,ts	45°	60%	rtp	135°	15%	stc	160°-90°	25%
Sandy Valley-3	35°52'40"	115°42'25"	885	200	Pzc	lj,tc	230°	50%	rtp,lj	-	40%	alf	190°	10%
COYOTE SPRINGS (PAHRANAGAT) WASH, DOUBLE CANYON, ARROW CANYON RANGE														
*Double Canyon-1	36°47'05"	114°53'04"	660	< 50	Pzc	ts,lj	40°-65°	80%	cl,lj,tc	45°-90°	20%			
*Double Canyon-2	36°46'50"	114°52'51"	670	150	Pzc	lj	90°-110°	65%	stc	95°	25%	stc	25°-90°	10%
*Double Canyon-4	36°46'50"	114°52'53"	690	200	Pzc	lj	95°-120°	60%	stc	80°-105°	40%			
*Double Canyon-5	36°46'23"	114°52'44"	ca. 600	270	Pzc	PROSPECT SAMPLING ONLY								

*original site name: Coyote Springs Wash

alf, alluvial fan; Cbk, Cambrian Bonanza King dolomite; cl, cliff; lj, bedrock ledges; Pzc, Paleozoic carbonate rocks; rtp, ridge top; stc, stabilized, colluvial slope, tc, rubbly talus chutes; Tfv, welded tuff, the rhyolite of Vent Pass (Orkild and O'Connor, 1970); ts, talus slopes; wa, dry wash.

Note: longitude and latitude values for the Sandy Valley sites are approximate

Table 3 Plant species from the Fortymile Canyon Locality D midden sites

	SITE	Fortymile	FMC-7	FMC-7(1)	FMC-8	FMC-8A	FMC-9	FMC-10	FMC-10A(1)	FMC-10C(2)	FMC-11	FMC-11A(1)	FMC-11A(2)	FMC-12
	ASPECT/AGE	Canyon Wash	W	> 12 KBP	NE	> 12 KBP	N to E	S to W	12>8 KBP	12>8 KBP	N	> 12 KBP	> 12 KBP	NE to S
FAMILY	GENUS AND SPECIES													
Hydrophyllaceae	Nama demissum	x												
	Phacelia mustelina										x			x
	Phacelia sp.						x							
Lamiaceae	Salazaria mexicana				2									2
	Salvia cf columbariae								1					
	I Salvia dorrii											1	2	
Malvaceae	Sphaeralcea ambigua	x	1		1		1							2
	Sphaeralcea sp.			1					1	1				
Nyctaginaceae	Mirabilis multiflora				1									
	Mirabilis sp.									1				
Papaveraceae	Argemone munita	x												
Pinaceae	I Abies concolor											••		
	I Pinus flexilis											1		
	I Pinus monophylla			3					1	•		••		
Plantaginaceae	Plantago sp								1					
Poaceae	Aristida cf. longiseta		3		1		1							x
	Bromus rubens		x		x		x	x			x			x
	Bromus tectorum	x			x		x	x			x			x
	Erioneuron pulchellum							1						
	Hilaria jamesii				1									
	Muhlenbergia porteri													
	Oryzopsis hymenoides	x		1								1		
	Poa sp.				1									
	Sitanion hystrix				x		x	x			x			
	Stipa sp.		2				x	x			x			x
	Poaceae undifferentiated					2			2	1		1		
Polemoniaceae	cf. Leptodactylon pungens		3		1		1				x			1
	Gilia sp.								1					x
Polygonaceae	Chorizanthe sp.					1								
	Eriogonum fasciculatum	x	3		2		2	4			x			3
	I Eriogonum heermannii-type			1										
	Eriogonum inflatum	x												
	Eriogonum thomasii													
	Eriogonum sp (perennial)					2					x	1		x
	Eriogonum sp (annual)	x								1				
	I Polygonum lapathifolium-type			1										
	I Polygonum sp.					1								
Polypodiaceae	Pellaea mucronata										x			
Rosaceae	I Cercocarpus ledifolius					2						3	3	
	I Chamaebatiaria millefolium			1		1						1		
	Coleogyne ramosissima				4		1							1
	I Holodiscus microphyllus					1						1		
	Purshia glandulosa	x			1		1		4	4				1
	I Rosa woodsii			1										
Rubiaceae	Galium sp.					1				1				
Rutaceae	Thamnosma montana		x											
Saxifragaceae	I Ribes cf velutinum											1		
	I Ribes sp.					1								

Table 3 Plant species from the Fortymile Canyon Locality D midden sites

FAMILY	SITE ASPECT/AGE GENUS AND SPECIES	Fortymile Canyon Wash	FMC-7 W	FMC-7(1) > 12 KBP	FMC-8 NE	FMC-8A > 12 KBP	FMC-9 N to E	FMC-10 S to W	FMC-10A(1) 12>8 KBP	FMC-10C(2) 12>8 KBP	FMC-11 N	FMC-11A(1) > 12 KBP	FMC-11A(2)1 > 12 KBP	FMC-12 NE to S
Scophulariaceae	Castilleja chromosa		1											
	Castilleja sp.					1								
	Penstemon cf. palmeri	x												
Solanaceae	Datura meteloides	x	1											
	Lycium andersonii							1						1
Ulmaceae	Celtis reticulata				1		***	2						
Zygophyllaceae	Larrea divaricata	x			**									

* in the vicinity of the sites, but more than 50 m distant
** in the vicinity, but more than 100 m from site
*** ca. 200 m distant in wash bottom
' nut shell fragments only
'' one fragment only
l extralocal taxon
x, present; 1, rare; 2, occasional; 3, common; 4, abundant; 5, very abundant.

TABLE 4. Plant species at the Sandy Valley midden sites

	Site and sample no.: SaV-	2 veg.	2 veg.	2(1)1	2(3)3	3 veg.	3(1)	3(2)
	Aspect/age	NE slope	S slope	8-12 K	> 10 K		8-12 K	> 10 K
Family	Genus and species							
Agavaceae	Yucca brevifolia	*	*		1	*	1	
	Yucca schidigera	**	**			**		
Amaranthaceae	Tidestromia oblongifolia						1	
Asteraceae	Ambrosia dumosa	x	3	'		2		
	Amphipappus fremontii	x	1					
	Brickellia arguta	x				2		
	B. microphylla	1						
	Brickellia sp.				2			
	! Chrysothamnus nauseosus				3			1
	Cirsium sp.						1	
	Encelia farinosa	x						
	Encelia sp.			1			1	1
	Gutierrezia microcephala	x			1	3		2
	Peucephyllum schottii	x						
	Pleurocoronis pluriseta					1		
	Stephanomeria sp.					1		
Boraginaceae	Amsinckia sp.			1	1			1
	Cryptantha racemosa	x						
	Cryptantha sp.					x		
Brassicaceae	Lepidium montanum-type			1			3	2
	! Lepidium cf. fremontii				1			
Cactaceae	Coryphantha vivipara	x						
	Echinocactus polycephalus		1		1	1		
	Mammilaria microcarpa						1	
	! Opuntia sp.			1	1		1	1
Caprifoliaceae	! Symphoricarpos cf. longiflorus							3
	! Symphoricarpos sp.			1				
Caryophyllaceae	Scopulophila rixfordii	x		5	4			
Chenopodiaceae	! Atriplex canescens				1			
	Atriplex hymenelytra	**	**			**		
	Atriplex confertifolia		1					
	Atriplex confertifolia-type			1				4
	! Ceratoides lanata							1
Ephedraceae	Ephedra funerea					2		
	Ephedra nevadensis-type							2
	! E. torreyana-type			3				
	Ephedra sp.				2		1	
Fabaceae	Prosopis juliflora						1	
Hydrophyllaceae	Phacelia sp.		x					
Krameriaceae	Krameria parvifolia		2			1		
Hydrophyllaceae	Phacelia sp.			1				
Lamiaceae	Salazaria mexicana	**	**			**		
Loasaceae	Eucnide urens	x					1	1
	Loasaceae undet.							1
Loganiaceae	Buddleja utahensis			3	2	2		3

TABLE 4. Plant species at the Sandy Valley midden sites

Family	Site and sample no.: SaV- / Aspect/age	2 veg. NE slope	2 veg. S slope	2(1)1 8-12 K	2(3)3 > 10 K	3 veg.	3(1) 8-12 K	3(2) > 10 K
Nyctaginaceae	Boerhaavia sp.			1				
	Mirabilis sp.							1
Plantaginaceae	Plantago sp.		x	2			1	1
Poaceae	Aristida adscencionis	x				x		
	Bromus rubens					x		
	Erioneuron pulchellum		x	1		x	1	
	Hilaria rigida	x						
	Muhlenbergia porteri					x		
	Oryzopsis hymenoides							1
	Stipa sp.			1				
	Poaceae undetermined			1	1		2	3
Polemoniaceae	Gilia sp.			1	1			1
	Leptodactylon pungens	x			2	1		
Polygonaceae	Chorizanthe brevicornu	x						
	Chorizanthe brevicornu-type							1
	Chorizanthe rigida		x					
	Eriogonum heermannii	x			1	1		
	Eriogonum inflatum		x					
	Eriogonum thomasii					x		
Polypodiaceae	Cheilanthes feeii	x						
Rosaceae	! Coleogyne ramosissima			1				
Rubiaceae	Galium sp.				1			
Rutaceae	Thamnosma montana	x	1	2	1	1	1	1
Solanaceae	Lycium andersonii	x	2			2		
	Lycium pallidum					1		
	Lycium sp.			2	2		3	3
	Physalis crassifolia	x						
	Nicotiana trigonophylla	x		1		2	2	2
Ulmaceae	! Celtis reticulata				†			
Zygophyllaceae	Larrea divaricata	x	2			1		

† 1 fragment only, a possible contaminant (as with A. dumosa), or long-distance transport (C. reticulata)
* within 1 km of sites but restricted to the alluvial fan
** in the vicinity of the sites, but more than 60 m distant from either
see Table 3 for a key to relative abundance values

Table 5. Plant species from the Double Canyon midden sites

Family	Site and sample no.: Genus and species	DC-1	DC-1(1)	DC-2	DC-2(1)
Agavaceae	Yucca schidigera	1		1	
Asteraceae	Ambrosia dumosa	2		3	
	Ambrosia acanthicarpa	*			
	Artemisia subgen. tridentatae				1
	Bebbia juncea	1		1	
	Brickellia arguta	2		1	
	! Chrysothamnus nauseosus		1		
	Encelia virginensis	1		1	
	Erigeron sp.				1
	Gutierrezia microcephala	1	1	3	
	Haplopappus sp.				3
	Hymenoclea salsola	*			
	Peucephyllum schottii	1		1	
	Stephanomeria pauciflora			1	
	Xylorhiza tortifolia	1			
Bignoniaceae	Chilopsis linearis	*			
Boraginaceae	Amsinckia sp.	x			
	Cryptantha pterocarya-type		1		
	Cryptantha sp.			x	
Brassicaceae	Lepidium montanum	2		1	
Cactaceae	Echinocactus polycephalus	1			
	Ferocactus acanthodes	1		1	
	Opuntia erinacea	1	1	1	
	! Opuntia whipplei		3		
	Opuntia sp.				2
Caprifoliaceae	! Symphoricarpos cf. longiflorus		2		1
Caryophyllaceae	! Scopulophila rixfordii		2	3	
Chenopodiaceae	! Atriplex confertifolia		1		
Cupressaceae	! Juniperus osteosperma		5		4
Ephedraceae	Ephedra torreyana	1		1	
Fabaceae	Acacia greggii	*		1	
	! Astragalus sp.		1		
Krameriaceae	Krameria parvifolia	1		1	
Lamiaceae	Salazaria mexicana			1	
	! Salvia dorrii		1		
Loasaceae	Eucnide urens	1		2	

Table 5. Plant species from the Double Canyon midden sites

	Site and sample no.:	DC-1	DC-1(1)	DC-2	DC-2(1)
Family	Genus and species				
Loganiaceae	Buddleja utahensis			**	1
Malvaceae	Sphaeralcea ambigua	3			
Oleaceae	! Fraxinus anomala		1		
Plantaginaceae	Plantago sp.	x			
Poaceae	Aristida adscencionis			1	
	Bromus rubens	x		x	
	Erioneuron pulchellum	1			
	Hilaria rigida	2		1	
	Schismus arabicus	x			
	Stipa arida	1			
	Poaceae undetermined				
Polemoniaceae	Gilia sp.	x			
	Leptodactylon pungens				1
Polygonaceae	Chorizanthe rigida	x			
	Eriogonum fasciculatum	2		2	
	Eriogonum heermannii				2
	Eriogonum inflatum	x		x	
	Eriogonum sp. (annual)			x	
Plantaginaceae	Plantago sp.	x			
Rosaceae	! Prunus fasciculata		1		1
Rubiaceae	Galium stellatum	1		1	
Rutaceae	Thamnosma montana	1			
Saxifragaceae	! Ribes cf. velutinum		1		
Solanaceae	Lycium andersonii	2			
	Lycium pallidum	*			
Zygophyllaceae	Larrea divaricata	3		4	
* ca. 70 m from DC-1 site, restricted to Pahranagat Wash					
** within 100 m, but more than 30 m distant from site					

Table 6. Calculations of glacial-age departure of summer temperature in the Candidate Area assuming that the water requirements of species noted are met at their lower limit.

	current lower limit (m)	lowest fossil record (FMC)	minimum displacement (m)	calculation of summer temperature decline - ΔTs with lapse rate of ___°C/100 m				Reference
	-	-	-	0.60	0.65	0.70	0.75	
Abies concolor	2073*	1280	793	4.8	5.2	5.6	5.9	from data in progress
d.o. adjusted for Merriam effect (+200 m)	2273†	d.o.	993	6.0	6.5	7.0	7.4	from data in progress
Pinus flexilis	2439	1280	1159	7.0	7.5	8.1	8.7	from data in progress
	lower limit (m)	lowest fossil record	minimum displacement (m)					
Juniperus osteosperma	1900	700	1200	7.2	7.8	8.4	9.0	from Spaulding (1985, Table 8)
Pinus flexilis	2650	1585	1065	6.4	6.9	7.5	8.0	from Spaulding (1985, Table 8)

* lower limit in mesic canyon bottom on moderate-size mountain range (Sheep Range)

† adjustment for Merriam effect assumes that on a smaller mountain mass (Yucca Mountain) the lower limits will be higher than on a large mountain mass, such as the Sheep Range

FIELD MAP COPIES

1. Location of Fortymile Canyon Locality D and the Fortymile Canyon-7 site (immediately east of the eastern margin of the Topopah Springs NW, 1:24,000 sheet.

2. Location of the Fortymile Canyon-7 , -8, -9, -10, and -11 sites.

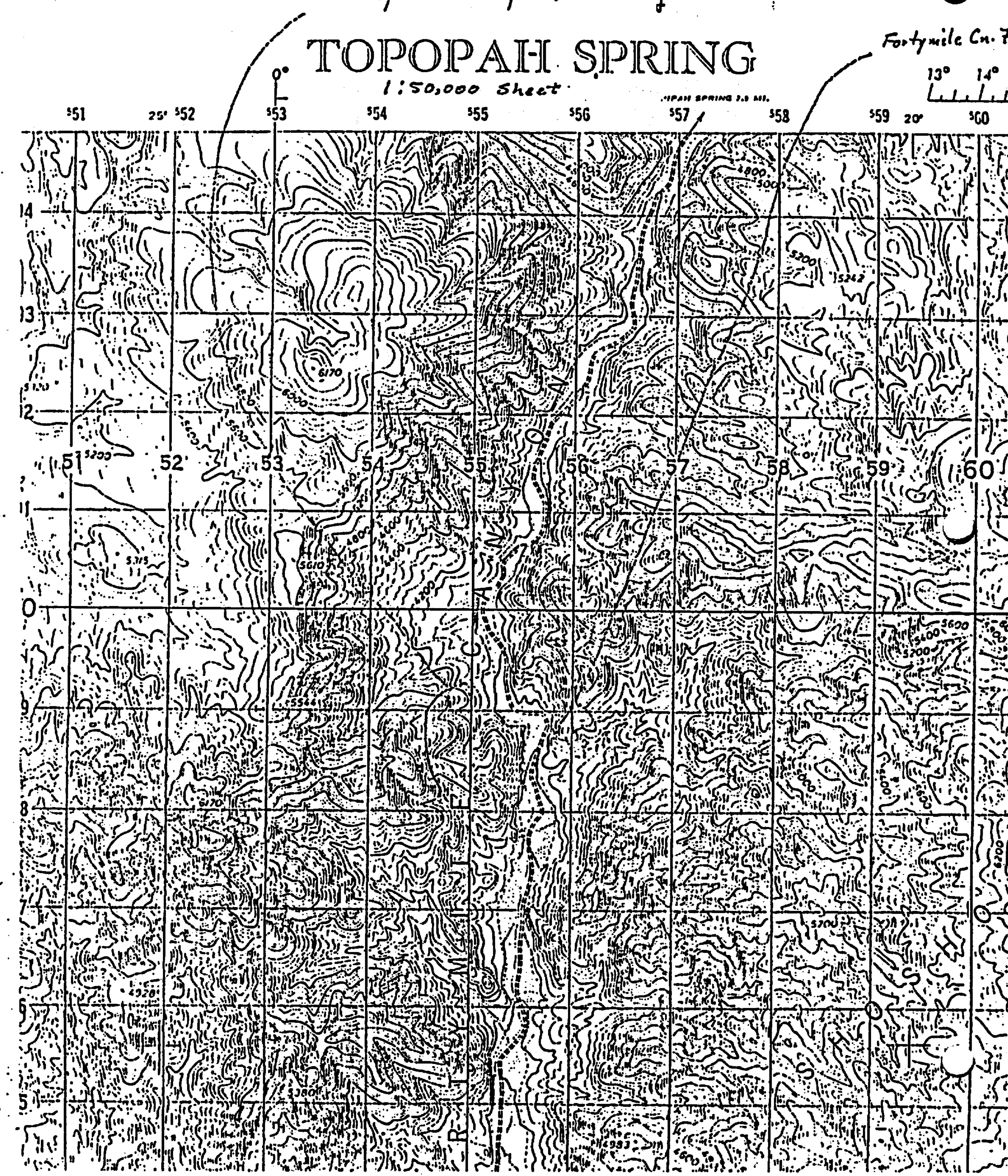
3. Location of the Sandy Valley midden sites, copy of J. Quade field map.

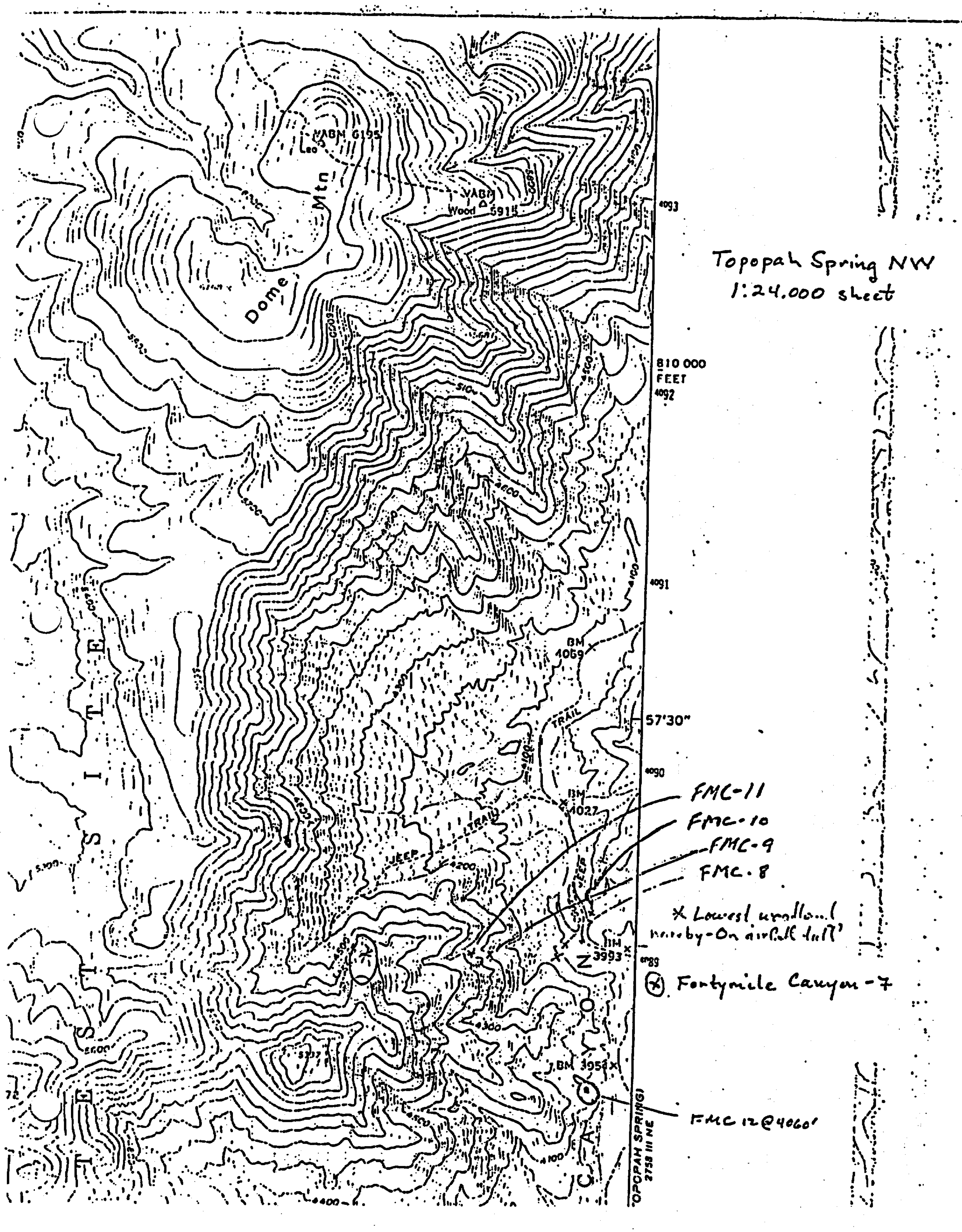
4. Location of the Double Canyon (formerly Coyote Springs Wash [CSW]) sites.

Fortymile Canyon, Locality D

TOPOPAH SPRING

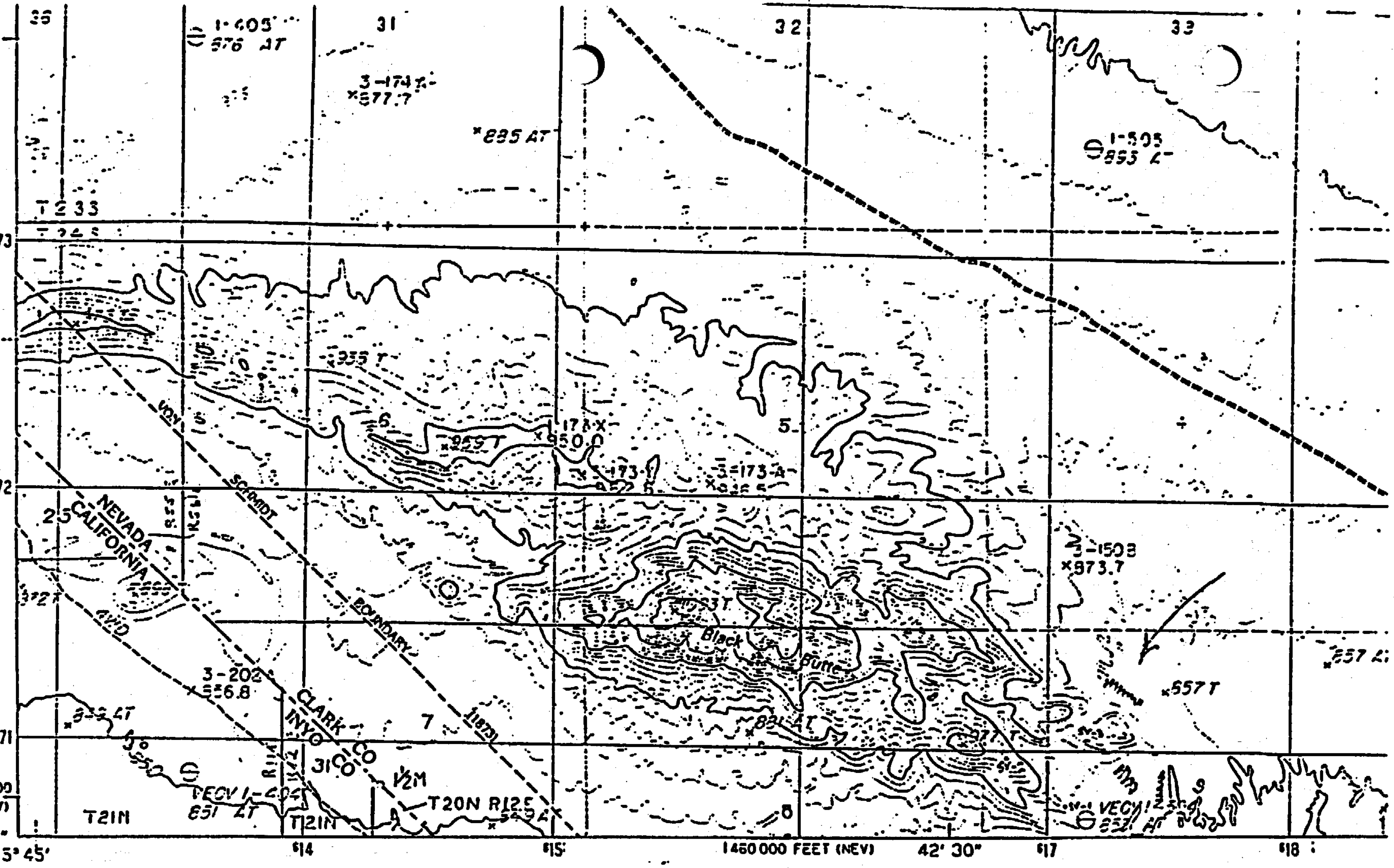
1:50,000 Sheet





Topopah Spring NW
1:24,000 sheet
VABM 6195
VABM
Wood 5915
Dome Mtn
810 000 FEET
57'30"
BM 4059
BM 4027
TRAIL
JEEP
FMC-11
FMC-10
FMC-9
FMC-8
X Lowest unwelded nearby-On airfall tuff?
3993
Fortymile Canyon-7
BM 3953
FMC 12@4060'
TOPOPAH SPRING
2758 III NE
S I T E

Sandy Valley (SaV) sites



Green Monster Mine, Nv-Cal

7.5'

PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY
CONTROL BY .... USGS, NOS/NOAA
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN .... 1976 AND 1978
FIELD CHECKED .... 1980. MAP EDITED 1984
PROJECTION .... UNIVERSAL TRANSVERSE MERCATOR
GRID: 1000-METER UNIVERSAL TRANSVERSE MERCATOR ..... ZONE 11
10 000-FOOT STATE GRID TICKS...NEV., EAST ZONE AND CALIF., ZONE 4
UTM GRID DECLINATION .... 0°46' EAST
1990 MAGNETIC NORTH DECLINATION .... 14°30' EAST
VERTICAL DATUM ... NATIONAL GEODETIC VERTICAL DATUM OF 1929
HORIZONTAL DATUM .... 1927 NORTH AMERICAN DATUM
To place on the predicted North American Datum of 1983, move the projection lines as shown by dashed corner ticks (5 meters north / 76 meters east)
There may be private inholdings within the boundaries of any Federal and State Reservations shown on this map
Certain land lines are omitted because of insufficient data

NORTH

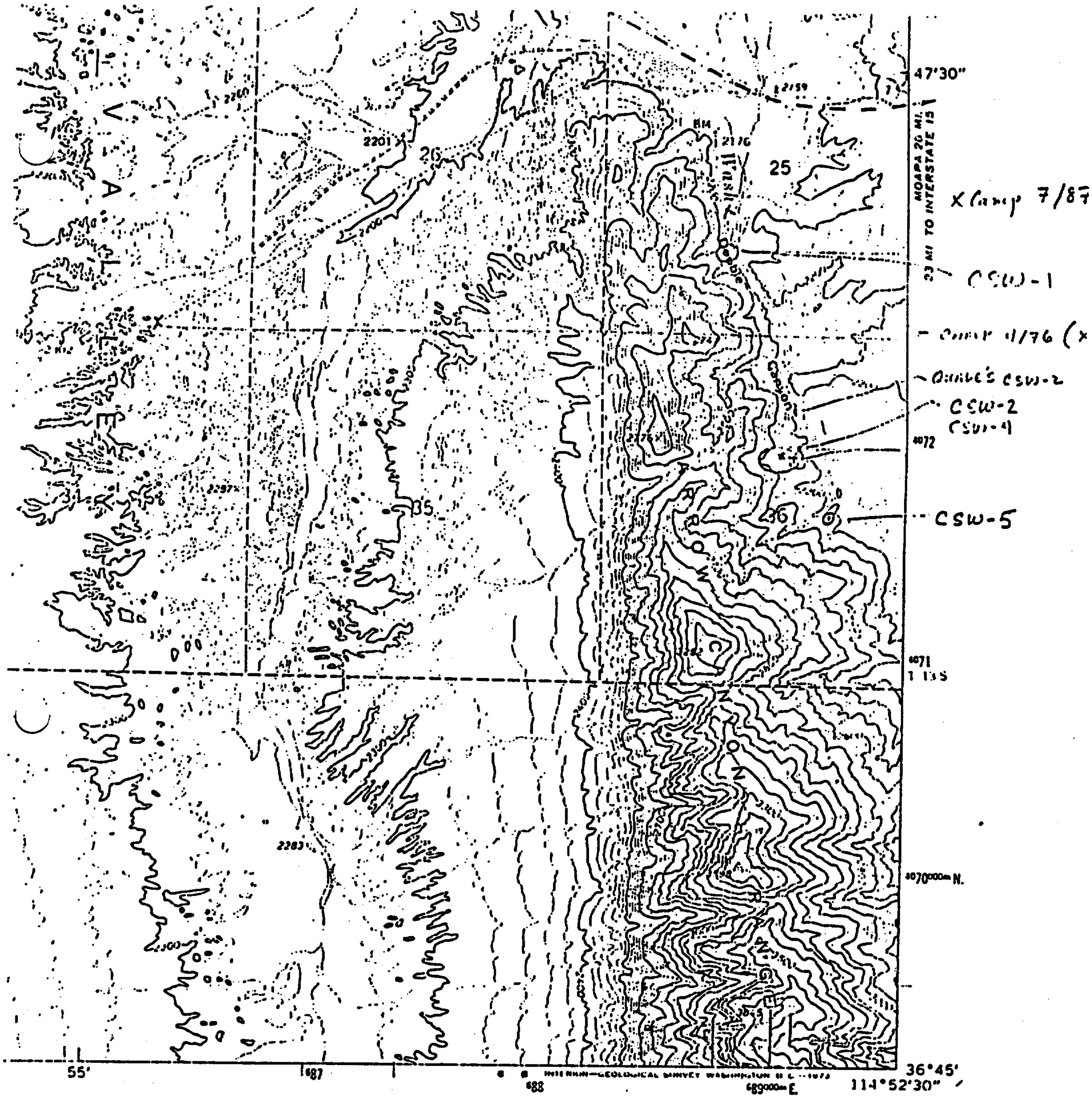
= SV-1 = ... sample
935m = SV-2 = ...
885m = SV-3 = ...

PROVISIONAL MAP
Produced from original manuscript drawings. Information shown as of date of field check. 2

SCALE
1 .5 0 KM
1000 0
1 .5
1000 0 1000 2000 3000 4000

CONTOUR INT
10 meter contours
SUPPLEMENTARY CO
CONTROL ELEVATIONS SH
OTHER ELEVATIONS SH
To convert meters
To convert feet to

THIS MAP COMPLIES WITH NAT
FOR SALE BY U.S. GEOLOGICAL SURVEY, DEN



ROAD CLASSIFICATION

Primary highway, hard surface	Light-duty road, hard or improved surface
Secondary highway, hard surface	Unimproved road

Interstate Route U. S. Route State Route

NEVADA

QUADRANGLE LOCATION

WILDCAT WASH SW, NEV.

N3645—W11452.5/7.5

1969

AMS 3057 IV SW—SERIES V896

. C. 20242

long: .1618'/cm

DOUBLE CH SITES

Appendix B-IX

The Paleohydrology and Paleoenvironments in the Vicinity of the Proposed Yucca Mountain Nuclear Waste Repository by W. G. Spaulding.

Update Report:

The Paleohydrology and Paleoenvironments in The Vicinity of The Proposed Yucca Mountain Nuclear Waste Respository

Prepared by

Arid Lands Paleoecology Laboratory, Quaternary Research Center, AK-60, University of Washington, Seattle 98195

Endorsement: ______________________ Date: 24 June 198[illegible]

W. Geoffrey Spaulding, Research Assoc. Professor
Quaternary Research Center and Department of Botany

Research on the nature of pluvial-age environments in the vicinity of the proposed Yucca Mountain Nuclear Waste Repository (here referred to as the "Candidate Area") has as its primary objective the detection of episodes of increased ground-water discharge in this presently arid region. Increased ground-water discharge in nearby valley bottoms during the Late Wisconsin (Quade, 1986, 1987) provides good reason to further investigate both low-land spring-discharge habitats, and upland drainages. This is a deliberate test of the hypothesis that during some climatic regimes there may be both increased ground-water discharge and increased discharge through presently-ephemeral desert washes. This possibility has exceptional implications for the long-term integrity of a proposed nuclear waste respository because it is resonable to anticipate that pluvial climates will occur again, within the design life of the respository (10,000 to 100,000 yr). On one hand, if no exceptional evidence of increased discharge is found, it would be considered a favorable finding from the point of view of hydrologic stability in this region. On the other hand, if evidence is found for perennial water in currently-dry drainages such as Fortymile Canyon, this would indicate that provisions for substantially increased recharge rates, ground-water travel times, and instability of drainage systems need to be made.

Other means of studying the long-term climatic and hydrolgic stability of the Candidate Area include general paleovegetation reconstructions, since the same data base can be used for both, and because former paleoenvironmental reconstructions in the region need to be related to ongoing research. This provides the basis for testing the results of former studies that found relatively dry climatic conditions prevailing through late Wisconsin time in the Candidate Area (Spaulding, 1985), and evidence for a monsoonal period during the Wisconsin-Holocene transition (Spaulding and Graumlich, 1986).

The data for these studies are derived from radiocarbon dated plant macrofossil and pollen assemblages from ancient packrat middens. The sampling strategy of this research is to collect middens at localities that, on geologic and geomorphic grounds, could have been near stream-side or spring environments. Such riparian habitats have a distinctive flora composed of plants adapted to the constant presence of near-surface water. In the rugged terrain of the Candidate Area it is possible to locate midden sites near canyon-bottoms and paleospring sites. Today these habitats are, almost without exception, dry water courses or barren valley-bottom inselbergs. However, at certain times in the past, conditions were quite different.

RESULTS OF RADIOCARBON DATING

The results of ^{14}C dating on middens collected in June of last year are generally consistent with the predicted ages of the samples (Table 1). These predictions were made on the basis of floristic composition of the macrofossil assemblages recovered from the packrat middens, and on the basis of curves that establish the tendency for ancient middens from a given geographic area to cluster in particular age ranges (Fig. 1).

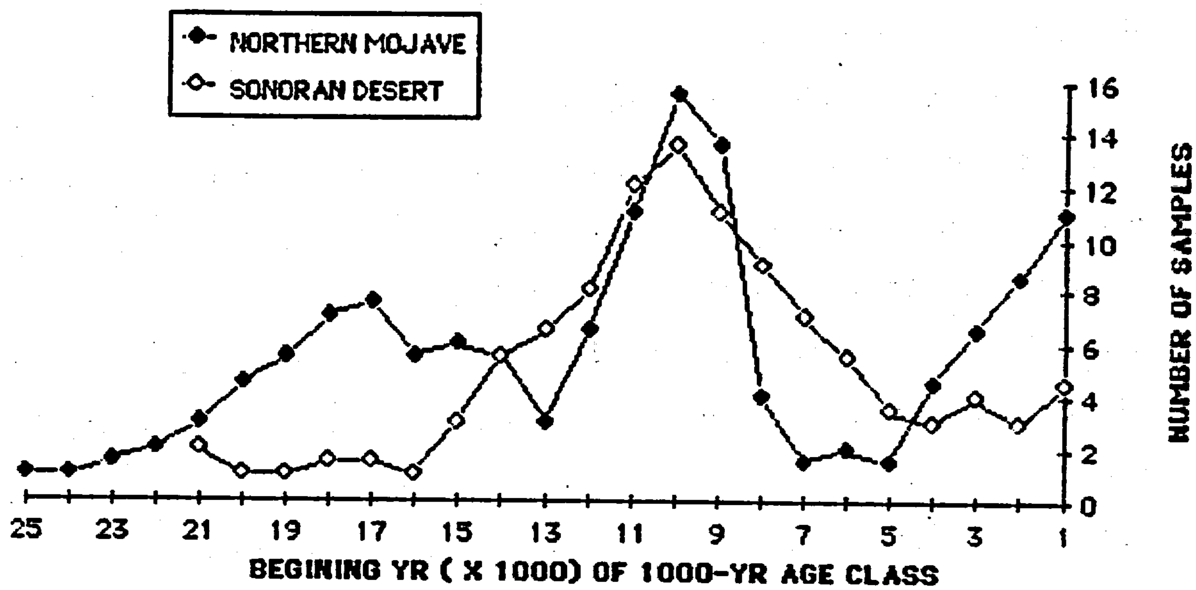


Figure 1. Age distribution of radiocarbon dates on packrat middens from two separate regions in the American southwest. Note the absence of a Wisconsin-maximum peak in sample abundance from the southerly, Sonoran region, and the bundance of samples from the terminal-Wisconsin-early Holocene (ca. 12,000 - 8,000 yr B.P.) in both regions. The data are smoothed by a two-level moving average and include all published radiocarbon dates available before July, 1987.

In the northern Mojave Desert, most middens date to the last 4,000 yr, to the period 8,000 to 12,000 yr B.P., or to the period from ca. 14,000 to 21,000 yr B.P. These new sample dates fall into those periods (Fig. 2), with the exception of two from the Fortymile Canyon- 7 site that are considerably older (Table 1). As

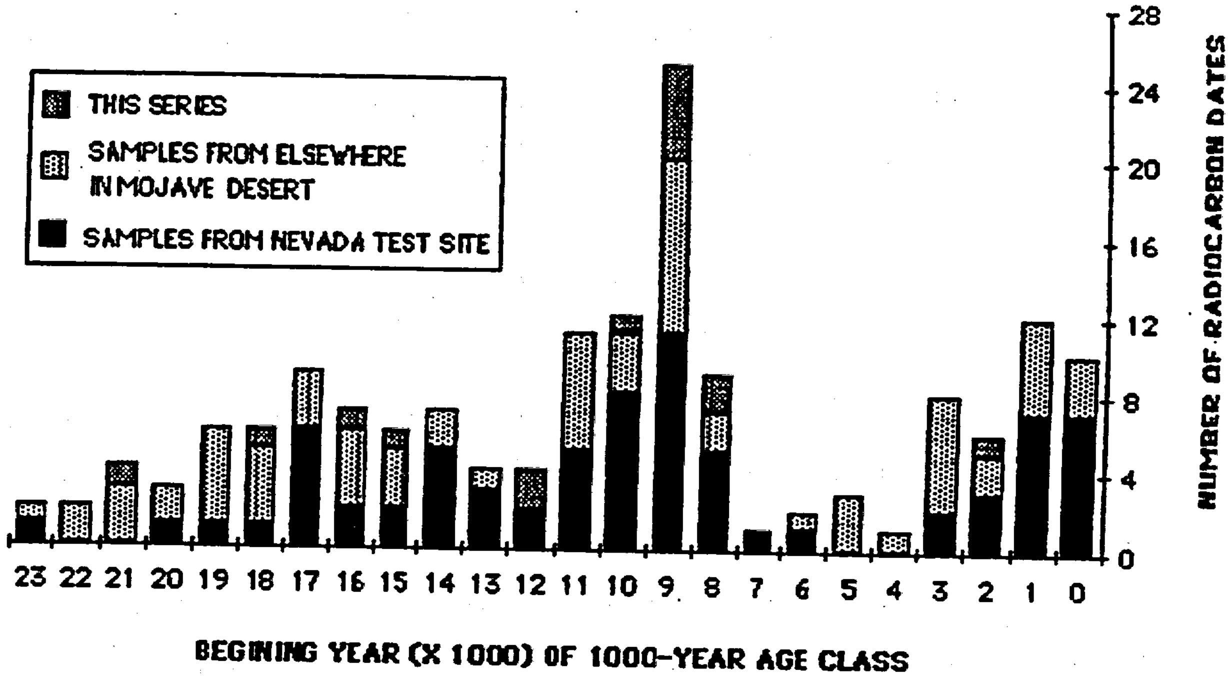


Figure 2. Age-distribution of radiocarbon dates on packrat middens from the northern Mojave Desert, including the new series discussed in this report (Table 1).

discussed in prior reports, there is reason to believe that (1) midden accumulation rates are higher during periods of increased effective moisture and (2) middens deposited during the full-glacial may, in some areas, have been destroyed by excessive moisture during subsequent pluvial episodes. The former hypothesis is supported by the tendency for midden abundance peaks to correlate with other paleohydrologic records of increased effective moisture (Fig. 3). The latter is supported, at least circumstantially, by the general absence of full-glacial records from the Sonoran Desert; a region that may have been characterized by a particularly intense, terminal-Wisconsin monsoonal pluvial (Spaulding and Graumlich, 1986). This idea is relevant in assessing the dating results from the most southerly locality in Big Sandy (Mesquite) Valley.

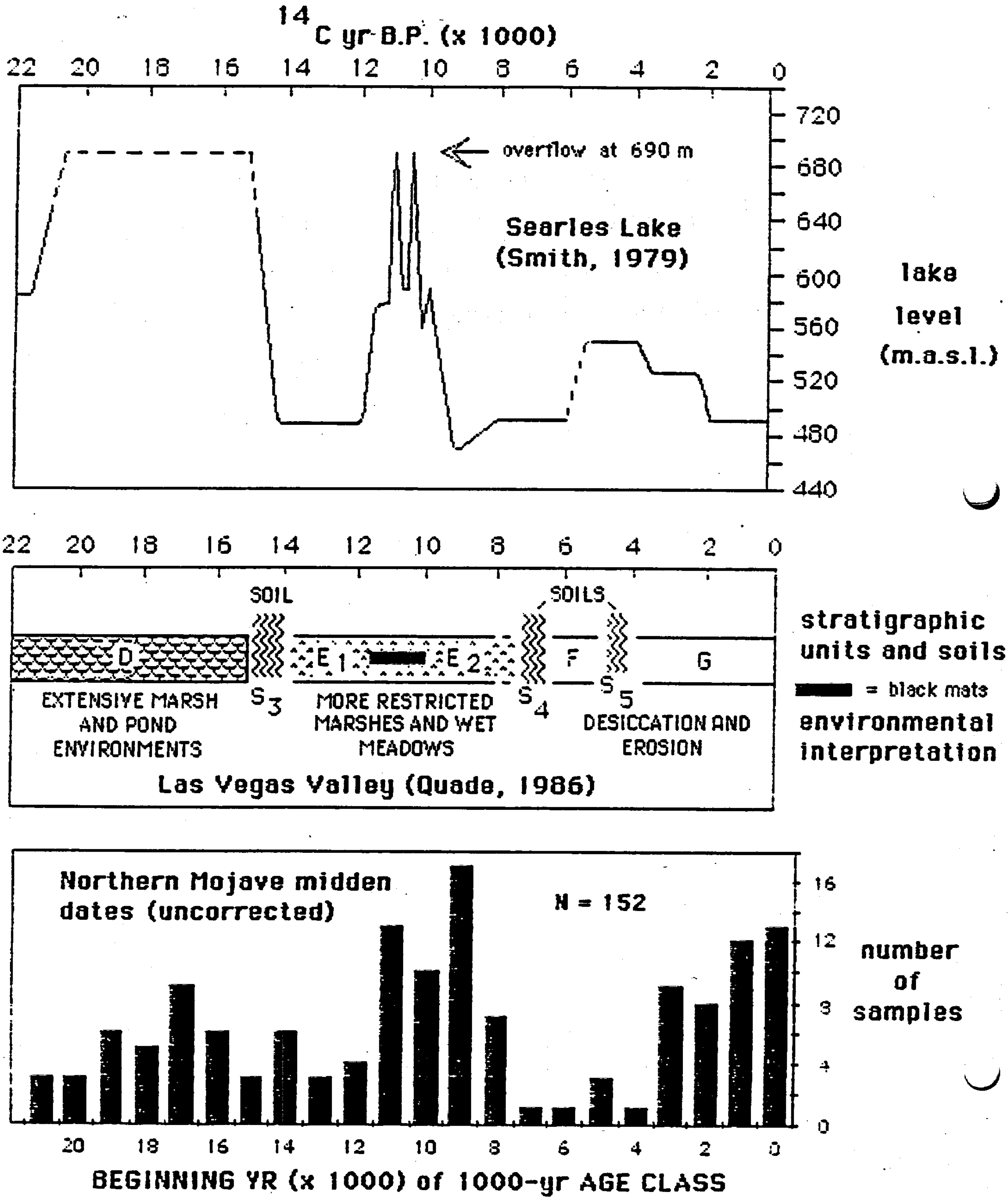
Age of The Big Sandy Valley Middens

Inselbergs of Paleozoic carbonate rocks occur in the vicinity of paleospring deposits in Big Sandy Valley, and these rocks contain abundant shelters and small caves ideal for the preservation of ancient packrat middens. In the search for middens from this locality, emphasis was placed on collecting those deposits which appeared to be of the greatest age, and therefore offered the best chance of yielding fossil evidence of pluvial climatic conditions.

Despite the ideal setting and the scores of individual cavities that were checked, only two middens of any great antiquity were discovered. A large midden deposit, Sandy Valley- 2 (SaV-2), contained multiple units that appear to have been deposited within a millennium, from ca. 9400 to ca. 8800 yr B.P. (Table 1). A

Figure 3 (following). Comparison of age-frequency distribution of radiocarbon dates on packrat middens from the northern Mojave Desert and two independent sources of evidence for variations in effective moisture in the region.

LATE WISCONSIN AND HOLOCENE



smaller deposit from a separate shelter, SaV-3, also dates to the early Holocene (ca. 8500 and 9400 yr B.P.). Due to the thoroughness of the field search and emphasis on the oldest assmeblages recovered, the absence of full-glacial middens from this locality appears not to be an artifact of sampling procedure. The Sandy Valley locality is not in the northern Mojave bioclimatic region. At 35°53' N lat., it is closer to the Sonoran Desert (Rowlands et al., 1982). The fact that dating results indicate a clustering of samples during the early Holocene suggests that whatever mechanism served to obliterate full-glacial records in the Sonoran Desert (Fig. 1) may have also operated here. In other words, there is the possibility that a particularly strong south-north gradient of decreasing effective moisture existed in this region during the latest Wisconsin and early Holocene.

Age of The Fortymile Canyon Middens

Farther north near the current northern limit of the Mojave Desert, at 36°53' N lat., rock shelters from the bedrock narrows of Fortymile Canyon do yield middens of full-glacial age, as well as those that date to the early Holocene (Table 1). Also recovered was a deposit of Middle Wisconsin age, the Fortymile Canyon- 7 midden (FMC- 7), with ^{14}C dates on the top and bottom units of 47,200 ± 3000 yr B.P. and >52,000 yr B.P., respectively. Of the five other midden samples judged to be older than 12,000 yr B.P., four yielded dates ranging from 21,830 ± 110 to 15,870 ± 70 yr B.P., satisfying the prediction based on the age-frequency curves (Fig. 1) that there is an abundance of full-glacial deposits in the region. A fifth sample, from the FMC-11B(1) midden, yielded an age of 12,870 ± 50 yr B.P. This falls near or in the apparent "dead zone" between full-glacial and latest glacial midden abundance, and will provide valuable clues to the nature of climate during this period.

The general chronology of vegetation change during the Late Wisconsin in the vicinity of Yucca Mountain is well enough known that macrofossil assemblages of terminal Wisconsin or early Holocene age could be identified from their component plant species. Samples from the FMC-10 site fall into this category. Two separate middens from this rock shelter yielded similar radiocarbon ages of 9470 ± 40 and 9390 ± 40 yr B.P. A final sample, thought to be younger than 4000 yr B.P., yielded a radiocarbon date of 2770 ± 30 yr B.P. (Table 1).

Age of The Pahranagat Wash Middens

Pahranagat Wash Locality A is at the north end of the Arrow Canyon Range, where the wash has incised a narrow canyon into Paleozoic carbonate rocks. Preliminary dating of two of the best deposits, from the Double Canyon-1 and -4 sites (DC-1, DC-4) revealed that both were of terminal Wisconsin age. The sample from DC-1, dated at 12,060 ± 70 yr B.P. falls close to the northern Mojave hiatus of ca. 15,000 to 12,000 yr B.P.(Figs. 1-3). Many more middens dating from ca. 14,000 to 12,000 yr B.P. have been recovered from the Lower Grand Canyon (Fig. 4; Phillips, 1977), less than 100 km east of this locality, than have been recovered from the Candidate Area. Although these samples are receiving full analysis, a subsequent field trip to this drainage has been made to collect middens that are more likely to be of full glacial age, and that lie closer to the floor of Pahranagat Wash.

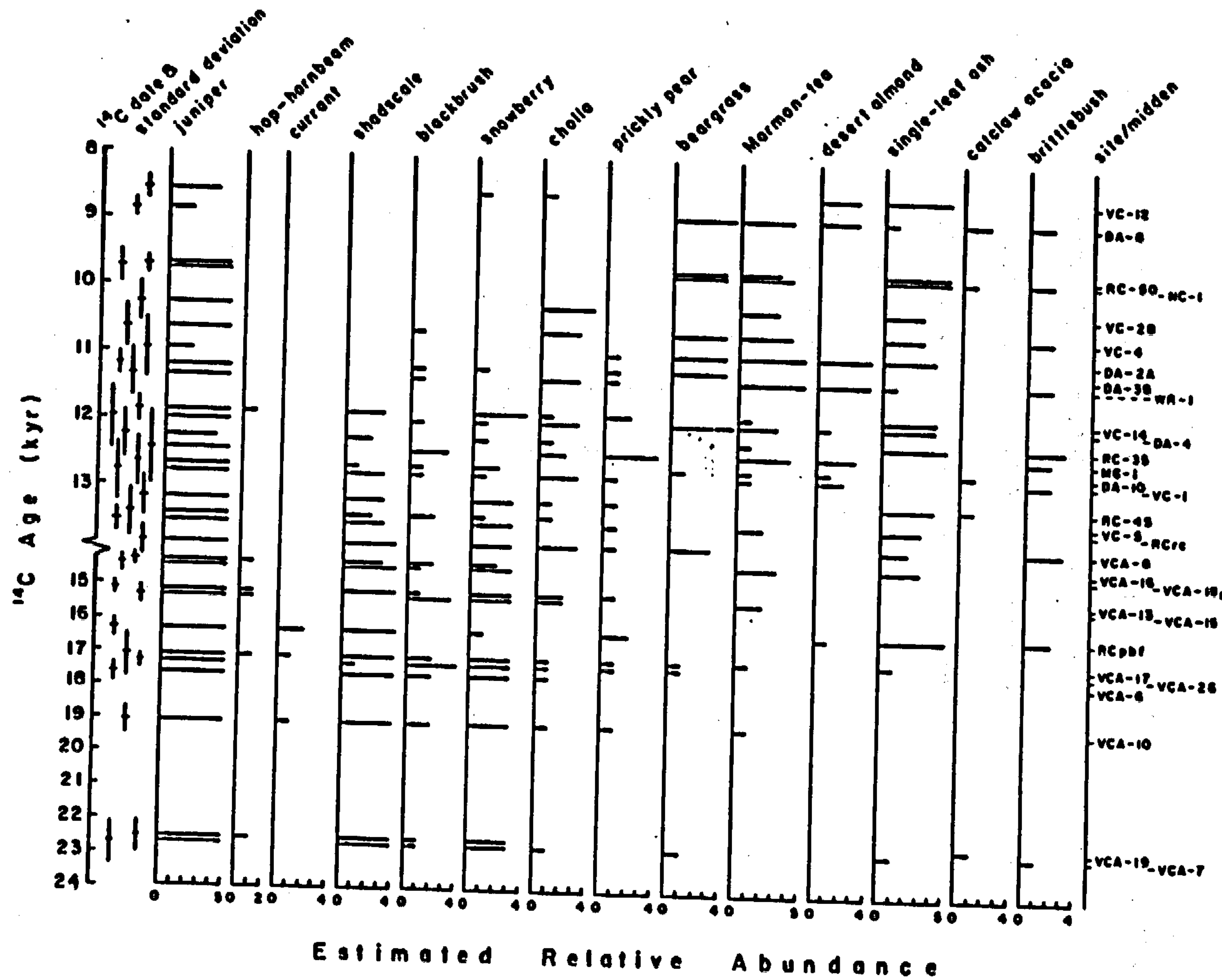
PALEOENVIRONMENTS OF FORTYMILE CANYON

The six midden sites from the middle reaches of Fortymile Canyon provide plant macrofossil and pollen data that allow relatively detailed reconstructions of glacial and early Holocene conditions. All macrofossil assemblages dated to these periods reflect Utah juniper (Juniperus osteosperma) woodland, but with substantial changes in associated dominants and secondary components, depending on age and site characteristics.

Wisconsin-age Records

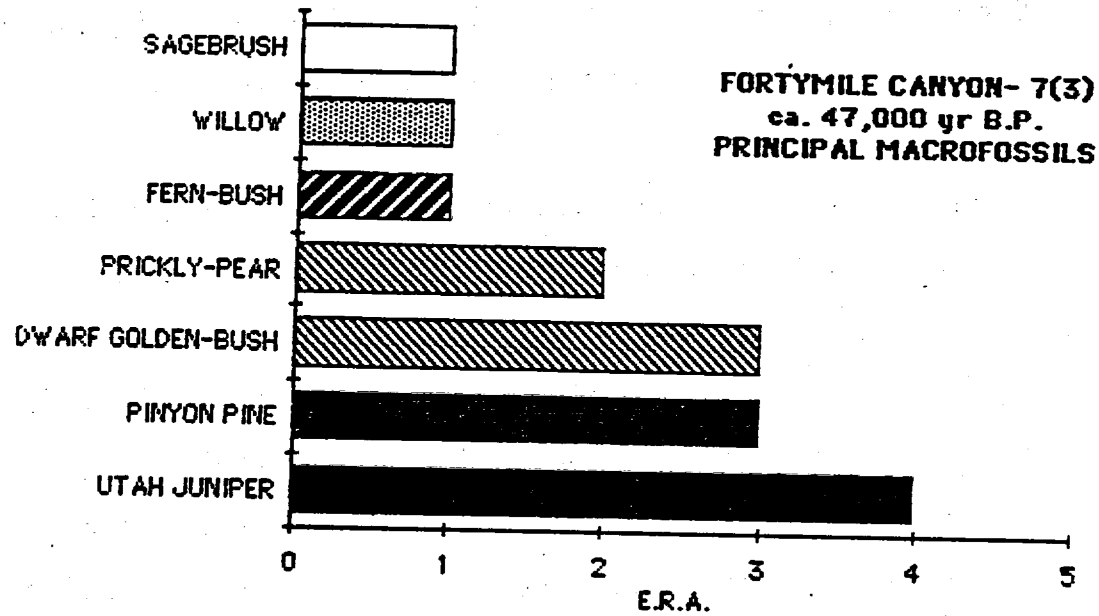
The Fortymile Canyon -7(1) [FMC-7 (1)] midden sample, dated at 47,200 ± 3000 yr B.P., is the only assemblage containing common pinyon pine (Pinus monophylla)(Fig. 5). Plains prickly-pear (Opuntia cf. polyacantha) and dwarf goldenbush (Haplopappus nanus) are other important components of this assemblage; today both are

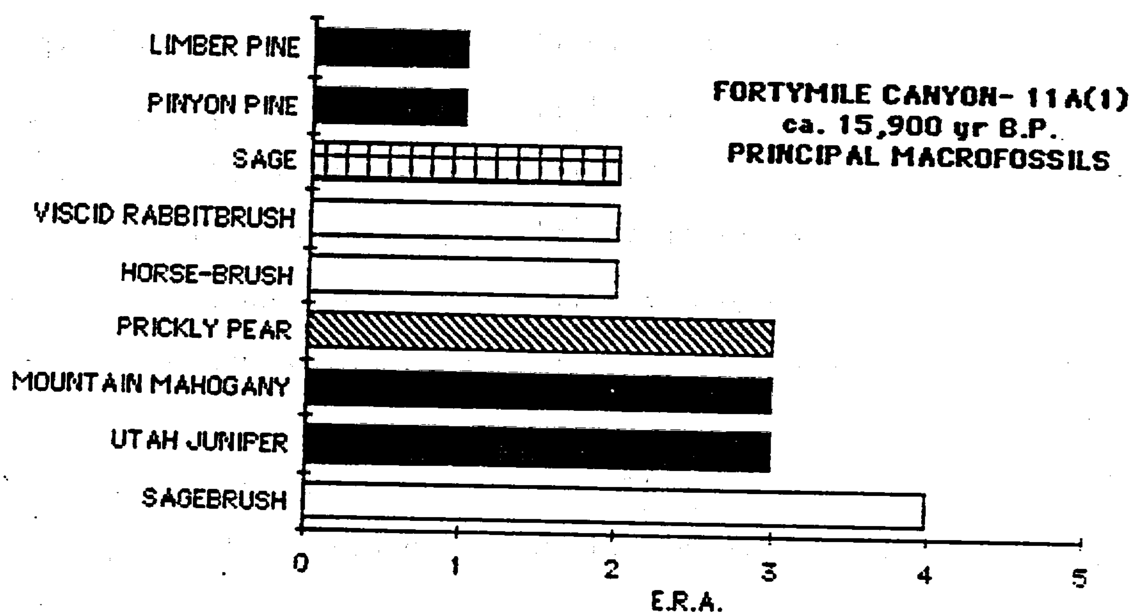
Figure 4 (following). The estimated relative abundance of selected plant taxa in Late Wisconsin and early Holocene middens from the Lower Grand Canyon, Arizona. Site abbreviations are : DA, Desert Almond; MG, Muav Gate; NC, Needle-eye Canyon; RC, Rampart Cave; VC, Vulture Canyon; VCA, Vulture Cave; WR, Window Rock. Data from Phillips (1977), Mead and Phillips (1981). Figure from Spaulding (1988).



14C date & standard deviation
juniper
hop-hornbeam
currant
shadscale
blackbrush
snowberry
cholla
prickly pear
beargrass
Mormon-tea
desert almond
single-leaf ash
catclaw acacia
brittlebush
site/midden
14C Age (kyr)
Estimated Relative Abundance

Figure 5 (following). Summary macrofossil diagrams for the Fortymile Canyon-7(1) and Fortymile Canyon-11A(1) packrat midden samples. E.R.A., estimated relative abundance where: 1, present but rare; 2, occasional; 3, common; 4, abundant; 5, very abundant.


SAGEBRUSH
WILLOW
FERN-BUSH
PRICKLY-PEAR
DWARF GOLDEN-BUSH
PINYON PINE
UTAH JUNIPER
FORTYMILE CANYON- 7(3)
ca. 47,000 yr B.P.
PRINCIPAL MACROFOSSILS
0
1
2
3
4
5
E.R.A.

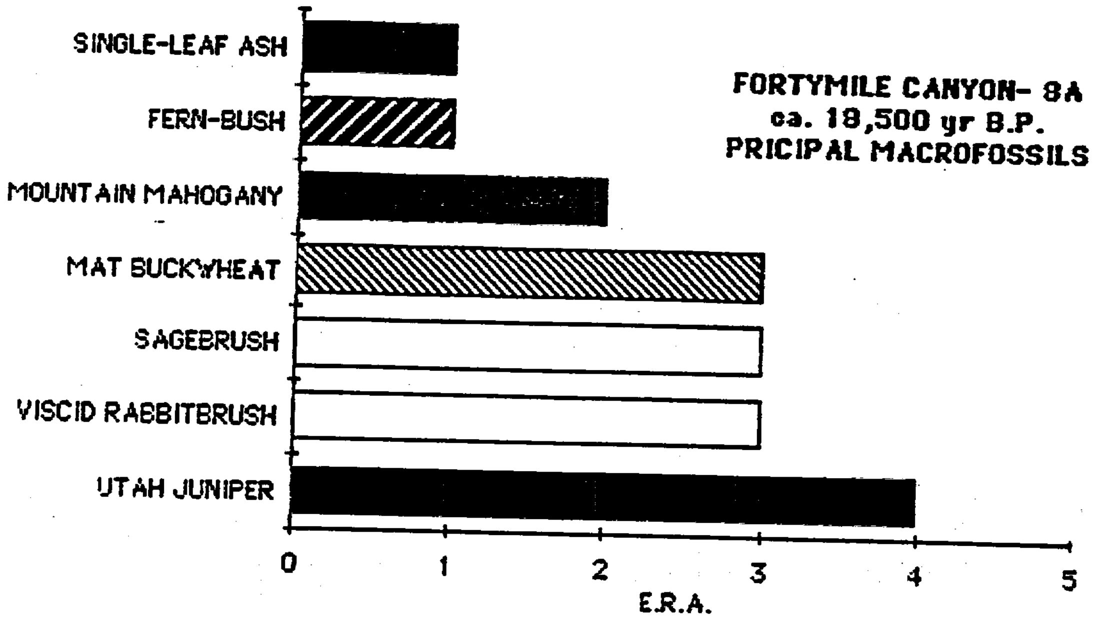

LIMBER PINE
PINYON PINE
SAGE
VISCID RABBITBRUSH
HORSE-BRUSH
PRICKLY PEAR
MOUNTAIN MAHOGANY
UTAH JUNIPER
SAGEBRUSH
FORTYMILE CANYON- 11A(1)
ca. 15,900 yr B.P.
PRINCIPAL MACROFOSSILS
0
1
2
3
4
5
E.R.A.

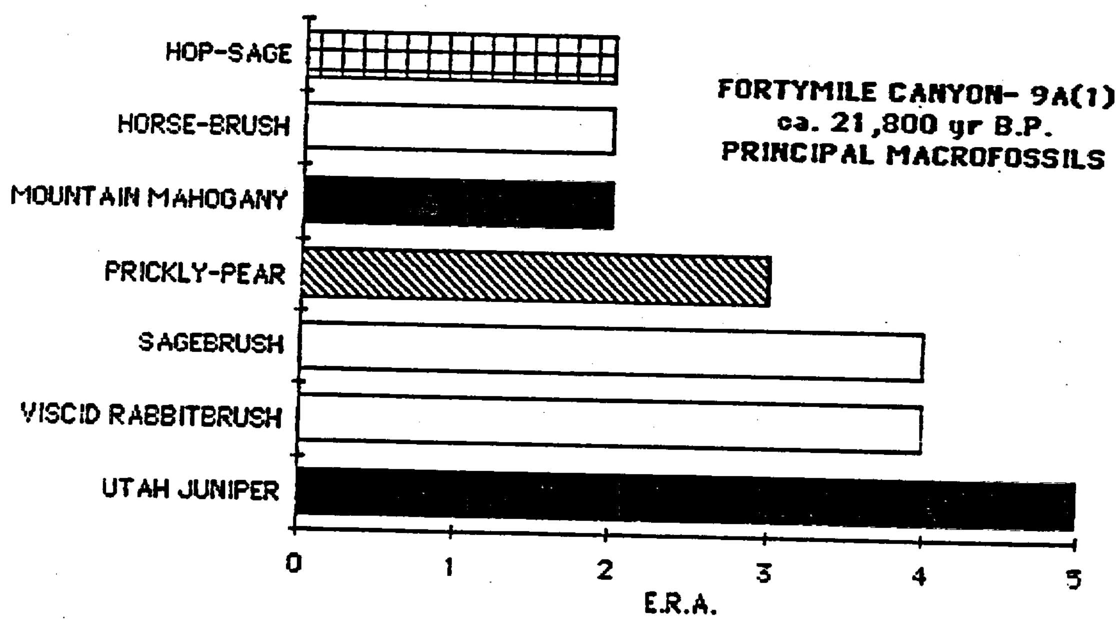
associated with open woodland habitats. Fern-bush (Chamaebatiaria millefolium), however, occurs in more mesic woodland and montane settings. Willow (Salix sp.) is present in this assemblage, although the distance from the FMC-7 site to the bottom of Fortymile Canyon is greater than 100m. Sagebrush (Artemisia subgen. tridentatae) is but rare, in contrast to those assemblages of full-glacial age.

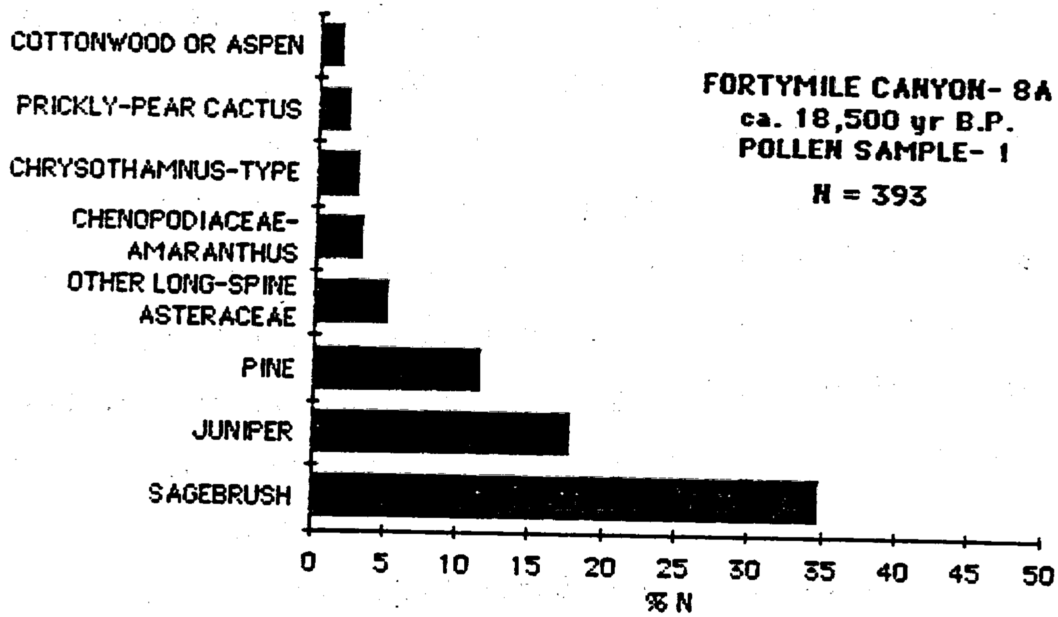
Macrofossil assemblages that date to about the full-glacial contain abundant Utah juniper and, moreover, common to abundant steppe shrubs (sagebrush, viscid rabbitbrush [Chrsothamnus viscidiflorus], horsebrush [Tetradymia canescens-type]; Figs. 5, 6). The association of woodland plants (juniper, fern-bush, mountain mahogany [Cercocarpus ledifolius]) with shrubs typical of Great Basin steppe is a common feature of stadial-age vegetation in southern Nevada (Spaulding et al., 1983). The importance of sagebrush, relative to juniper, in these samples suggests considerable open habitat. Sagebrush is a heliophile and its abundant pollen (Fig. 7) is consistent with the interpretation of an open woodland. The climatic implications of such woodland-steppe shrub associations have been discussed by Spaulding (1985). They conform to the interpretation of a semi-arid climate with winter temperatures $\geq$ 6°C lower than present, strong winter-seasonality of precipitation, and only a modest increase ($\leq$ 40%) in average annual precipitation.

Macrofossil assemblages from the Fortymile Canyon-8, -9, and -11 sites, dating from ca. 21,800 to 15,900 yr B.P. (Table 1), show

Figure 6 (following). Summary macrofossil diagrams for the Fortymile Canyon-8A and Fortymile Canyon-9A(1) packrat midden samples. E.R.A., estimated relative abundance where: 1, present but rare; 2, occasional; 3, common; 4, abundant; 5, very abundant.


FORTYMILE CANYON- 8A
ca. 18,500 yr B.P.
PRICIPAL MACROFOSSILS
SINGLE-LEAF ASH
FERN-BUSH
MOUNTAIN MAHOGANY
MAT BUCKWHEAT
SAGEBRUSH
VISCID RABBITBRUSH
UTAH JUNIPER
0
1
2
3
4
5
E.R.A.


FORTYMILE CANYON- 9A(1)
ca. 21,800 yr B.P.
PRINCIPAL MACROFOSSILS
HOP-SAGE
HORSE-BRUSH
MOUNTAIN MAHOGANY
PRICKLY-PEAR
SAGEBRUSH
VISCID RABBITBRUSH
UTAH JUNIPER
0
1
2
3
4
5
E.R.A.



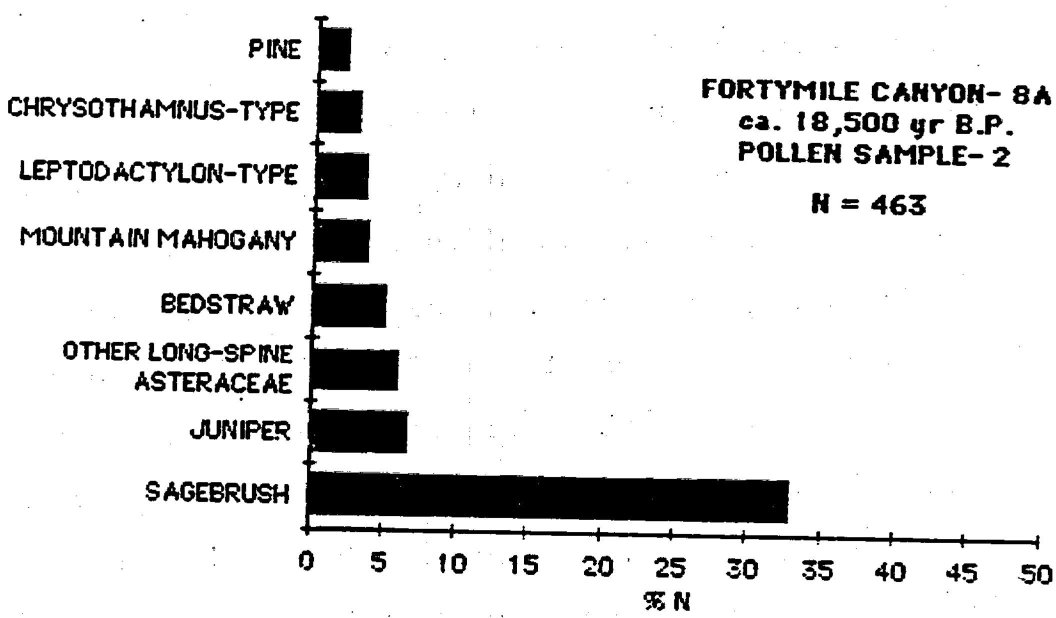


Figure 7. Summary pollen diagrams for samples from the FMC-8A packrat midden sample. N, total number of pollen grains encountered.

variations in composition that may be attributable to local variations in effective moisture. Of interest in this regard is the occurence of hop-sage (Grayia spinosa) in FMC-9A(1)(Fig. 6). A desert shrub in the Chenopodiaceae family, its presence here suggests relatively xeric conditions at this exposed site. The occurence of limber pine (Pinus flexilis) in FMC-11A(1) is consistent with the fact that this midden was from a mesic, north-facing alcove near a stream bed. At ca. 1310 m, this subalpine conifer was likely near its lower elevational limit at this site during the full glacial. Limber pine is the principal arboreal component of a higher elevation (1810 m) vegetation sequence in the Eleana Range (Spaulding et al., 1984), showing that the full-glacial vegetation zonation in the vicinity of Yucca Mountain was from higher elevation subalpine-steppe shrub communities to juniper-steppe shrub vegetation at lower elevations.

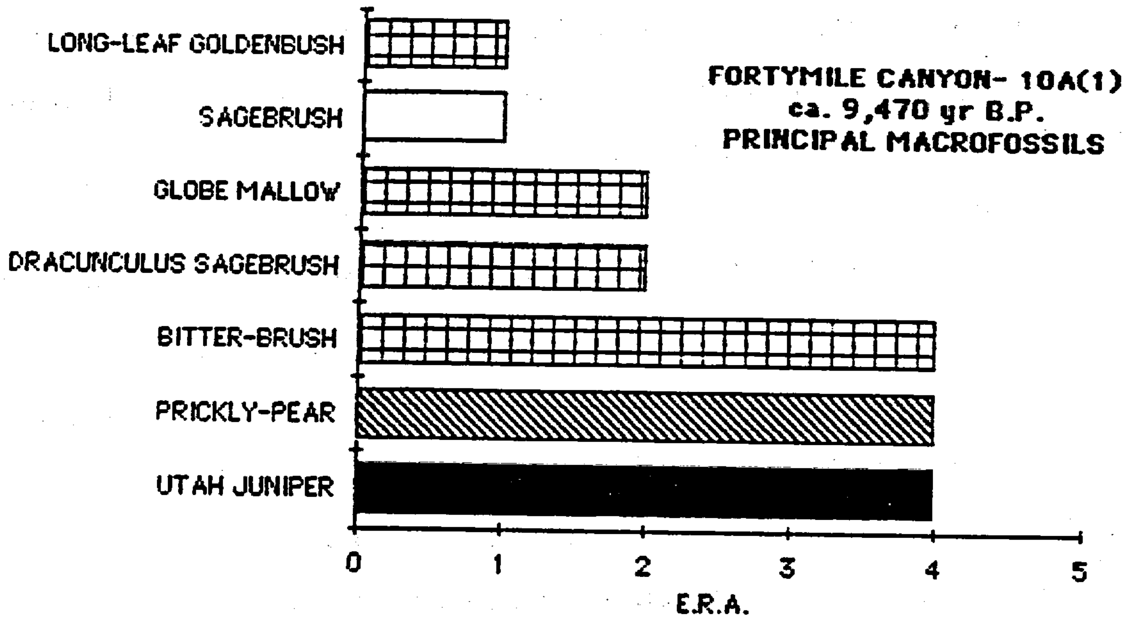
The occurence of single-leaf ash (Fraxinus anomala) in several full-glacial samples from this locality is of biogeographic significance (e.g. Fig. 6; Table 2). Known from only a few localities in the Mojave Desert today (Grapevine Mountains, Panamint Range), it is a shrub common in lower-elevation woodlands in the Colorado Plateau. Like limber pine and several other plant species discovered in these middens (Table 2), it is not known to occur today anywhere in the Yucca Mountain-Pahute Mesa-Belted Range highland complex (Beatley, 1976).

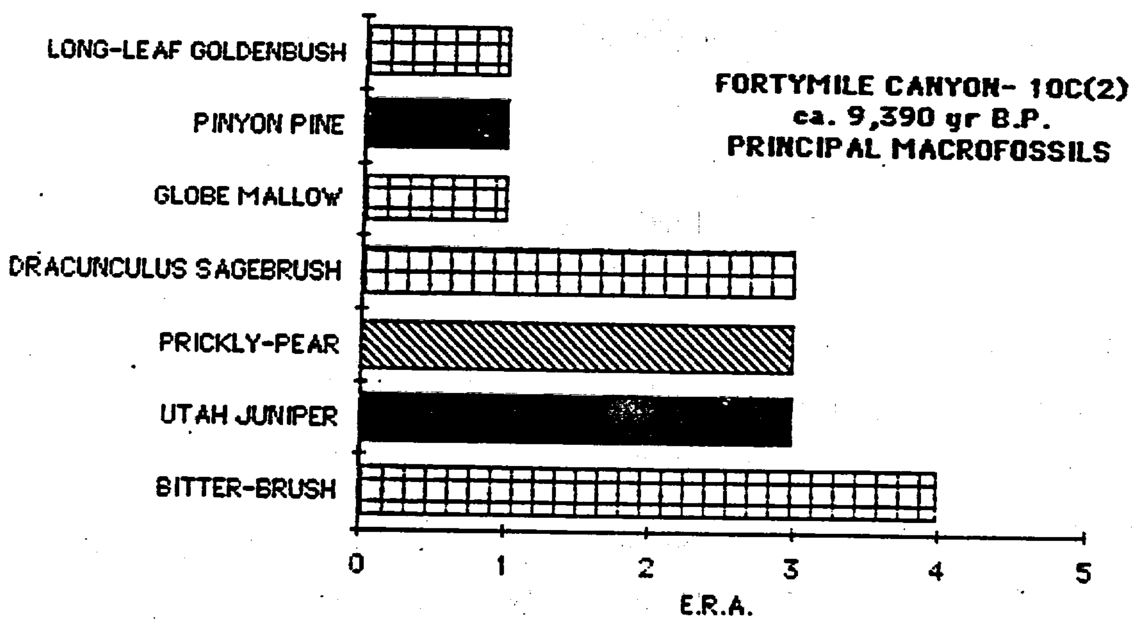
Early Holocene Records and Contrasts With Wisconsin-age Conditions

While juniper woodland evidently persisted into the early Holocene, as it did in many mid-elevation localities in the region (Van Devender, 1977), macrofossil assemblages from the FMC-10 middens show substantial differences with Wisconsin-age samples. Shrubs important in current desertscrub at the loaclity are well-represented for the first time; species such as globe mallow (Sphaeralcea ambigua), bitter-brush (Purshia glandulosa), and dracunculus sagebrush (Artemisia dracunculus)(Fig.8) Steppe shrubs are rare or absent, consistent with a change to warmer winters and decreased importance of winter precipitation (Spaulding and Graumlich, 1986).

Values of Nts (number of tree, shrub, and succulent taxa) for these early Holocene samples (11 and 13) are lower than those for the Wisconsin-age assemblages (15 to 18). The younger FMC-10 assemblages also contain 25% and 32% extralocal (not occurring within the area) or extralimital (not occurring in the Yucca Mountain-Pahute Mesa-Belted Range highland complex) taxa, as opposed to values between 41% and 63% for glacial-age samples (Table 2). The apparent reduction in shrub and tree species in the early Holocene therefore appears to have been due to the extinctions of taxa that today occur farther north, at higher

Figure 8 (following). Summary macrofossil diagrams for samples from the Fortymile Canyon-10A and Fortymile Canyon-10C packrat middens, located in the same rock shelter. E.R.A., estimated relative abundance where: 1, present but rare; 2, occasional; 3, common; 4, abundant; 5, very abundant.


FORTYMILE CANYON- 10A(1)
ca. 9,470 yr B.P.
PRINCIPAL MACROFOSSILS
LONG-LEAF GOLDENBUSH
SAGEBRUSH
GLOBE MALLOW
DRACUNCULUS SAGEBRUSH
BITTER-BRUSH
PRICKLY-PEAR
UTAH JUNIPER
0
1
2
3
4
5
E.R.A.


FORTYMILE CANYON- 10C(2)
ca. 9,390 yr B.P.
PRINCIPAL MACROFOSSILS
LONG-LEAF GOLDENBUSH
PINYON PINE
GLOBE MALLOW
DRACUNCULUS SAGEBRUSH
PRICKLY-PEAR
UTAH JUNIPER
BITTER-BRUSH
0
1
2
3
4
5
E.R.A.

elevations, or in wetter habitats. This and the failure of some modern elements to immigrate to the site by the beginning early Holocene led to lower species richness values, in a manner predicted by Cole's (1985) model of vegetational inertia. The immigration of many modern, thermophilous taxa was delayed for millennia, resulting in depressed species richness values following terminal-Wisconsin climatic change.

With this idea in mind, it is interesting to examine species-richness values for herbaceous plants and grasses. They appear to display a behavior inverse to that of the woody taxa, being more abundant in the early Holocene samples (54% of N in both assemblages), compared to the glacial-age middens (21% to 41%; Table 2). Part of this appears to be due to the appearance of annual species larely dependent on late spring and summer rains, such as pig-weed (*Amaranthus* sp.), lambs-quarters (*Chenopodium* sp.), spurge (*Euphorbia* cf. *serpyllifolia*), six-weeks gramma (*Bouteloua barbata*), and spectacle-pod (*Thysanocarpus curvipes*; Table 2).

Paleohydroligic Implications

Plant species useful in paleohydrologic reconstructions can be placed in four classes, with abbreviations as used in Table 2:

1) The obligate hydrophiles, or phreatophyes (H). These include such species as willow, cottonwood (*Populus* sp.), and cat-tail (*Typha* sp.).

2) The facultative phreatophyes (h). Species restricted to spring margins and the banks of perennial streams in the Great Basin, but that occur over a broader range of habitats elsewhere in the western United States. Examples include wild rose (Rosa woodsii) and hackberry (Celtis reticulata). Also included here are plants usually restricted to perennially-moist habitats near their lower elevational limits, such as white fir (Abies concolor).

3) Plants associated with riparian habitats in the Nevada Test Site area by Beatley (1976)(aH). These are forbs such as dock (Rumex cf. salicifolius) and Scouler's heliotrope (Plagiobothrys cf. scouleri) collected in perenially moist habitats but not necessarily dependent on constant moisture.

4) Desert riparian plant species (DR). Riparian desertscrub is a distinctive community type typical of ephemeral drainages (Bradely and Deacon, 1967), and there are plant taxa that are found only in these communities. These are desert shrubs well-adapted to habitats characterized by episodic floods and sandy, poorly developed soils.

Only one macrofossil assemblage analyzed to date contains unequivoval evidence of a riparian habitat, FMC-7(1), dated at 47,000 ± 3000 yr B.P. Four hydrophilic taxa and two desert-riparian species were encountered in this sample. Plants such as willow, wild rose, and knotweed (Polygonum lapathifolium-type) indicate perennial water within packrat foraging distance of the site. The remains of arroyo bursage (Ambrosia cf. acanthicarpa) and dock (Table 2) suggest that the canyon-bottom habitat was accessible from the FMC-7 site, and the vegetation sampled by the packrat was probably not that of a perennial seep on the canyon-side. The question of whether the packrat(s) were collecting plants from the bottom of Fortymile Canyon or from a seep somewhere nearer the site is an important one because, at present, the site is ca. 110 m from the canyon bottom. However, if there was more alluvium in Fortymile Canyon, its bed would be elevated and the canyon-bottom habitat would be closer to the site. In other words, it is possible that the canyon was not as deeply incised during the Middle Wisconsin, and the hydrophilic and riparian species present in FMC-7(1) are there because they occurred within the packrat's normal foraging distance of 30 to 50m. This would imply that incision of Fortymile Canyon has occurred in latest Quaternary times.

In contrast to this assemblage, those from other middens collected thus far have yielded few macrofossils of riparian plants. The possible remains of velvet ash (cf. Fraxinus velutina) in FMC-9A, a single white fir needle in FMC-11A(1), and the seeds of Scouler's heliotrope in FMC-11A(2) are all equivocal indicators of perennial water from ca. 21,800 to 15,900 yr B.P. (Table 2). The macrofossils of hydrophilic taxa have not been identified in the early Holocene FMC-10 assemblages, despite the proximity to the margin of Fortymile Canyon Wash (<50 m), and the occurrence of the desert-riparian shrub scale-broom (_Lepidospartum latisquamum_) in both assemblages (Table 2). Scale-broom indicates that packrats did forage down to the wash, and that the absence of riparian species in the FMC-10 assemblages would be consistent with the absence of perennially moist ground near this site.

CURRENT ACTIVITIES

This research represents a new approach to paleoenvironmental reconstruction using ancient packrat middens, and the particular aspects of research activities that affect the quality and reliability of these results have been identified. The taxonomic diversity of the macrofossil assemblages under study represents one challenge. Unidentified macrofossil types may represent riparian plant taxa seldom encountered in the normal course of field work in the southern Great Basin. Pains must be taken to identify these because, in some cases, they are indeed important paleoenvironmental indicators. The identification of willow in FMC-7(1) and Scouler's heliotrope in FMC-11A(2) represents one man-day of work for the Principal Investigator, and verifications of those identifications at the University of Washington Herbarium will require a minimum 2 hours of additional work.

The diversity of pollen types and tendency for packrat-midden pollen assemblages to be swamped by endogenous pollen (pollen originating from the flowers transported to the midden by the packrat) represents another challenge. Just as thousands of plant macrofossils must be sorted in a single plant macrofossil assemblage, pollen tallies must be high in order to assure that the pollen of such plants as willow or cat-tail are not important components of, say, the full-glacial pollen rain.

These then are current activities at the Quaternary Research Center's Laboratory of Arid Lands Paleoecology:

(1) The final validation of the taxonomic status of the plant macrofossil types that comprise the radiocarbon dated assemblages from Fortymile Canyon, Big Sandy Valley, and Pahranagat Wash.

(2) The continuing analysis of pollen samples from those middens in order to have individual pollen counts that exceed 400 identified grains per sample, and the assessment of intersample variability of pollen spectra in key midden samples.

(3) The continuing analysis of new samples from Pahranagat Wash in order to gain better understanding of paleohydrologic conditions on the eastern boundary of the Candidate Area.

Table 1. Results of radiocarbon dates on packrat midden samples from Fortymile Canyon, Coyote Springs Valley, and Double Canyon (first batch)

Site name and no	N. lat.	W. long.	Elev. (m)	SAMPLE NO.	Predicted age (yr B.P.)	14-C date (yr B.P.)	Standard deviation (s)	Laboratory number (QL-)	wt (g)	MATERIAL
FORTYMILE CANYON, NEVADA TEST SITE, NYE COUNTY										
Fortymile Canyon- 7	36°56'42"	116°22'21"	1250	FMC-7(1)	> 12,000	47,200	3,000	4,218	8.6	Neotoma pellets and Utah juniper twigs and seeds
				FMC-7(3)	> 12,000	>52,000	-	4,233	11.5	Neotoma pellets and Utah juniper twigs and seeds
Fortymile Canyon- 8	36°56'49"	116°22'45"	1240	FMC-8A	> 12,000	18,536	80	4,219	15.9	Neotoma pellets and sagebrush wood
Fortymile Canyon- 9	36°56'49"	116°23'01"	1280	FMC-9A(1)2	> 12,000	21,830	110	4,220	16.2	Neotoma pellets
Fortymile Canyon- 10	36°58'57"	116°22'39"	1230	FMC-10A(1)	12,000 > 8,000	9,470	40	4,221	16.4	Neotoma pellets
				FMC-10C(2)	12,000 > 8,000	9,390	40	4,222	16	Neotoma pellets
Fortymile Canyon- 11	36°56'49"	116°23'27"	1310	FMC-11A(1)	> 12,000	15,870	70	4,223	16.2	Neotoma pellets
				FMC-11A(2)1	> 12,000	16,410	70	4,234	16.3	Neotoma pellets
				FMC-11B(1)1	> 12,000	12,870	50	4,224	16.1	Neotoma pellets
Fortymile Canyon- 12	36°56'26"	116°22'35"	1240	FMC-12B	< 4,000	2,770	30	4,225	16.7	Neotoma pellets
BIG SANDY (MESQUITE) VALLEY, CLARK COUNTY										
Sandy Valley- 2	35°52'40"	115°42'20"	935	SAV-2(1)1	12,000 > 8,000	8,790	80	4,226	7.6	Neotoma pellets and undifferentiated twigs
				SAV-2(3)2	12,000 > 8,000	9,250	60	4,235	12.7	Neotoma pellets and undifferentiated twigs
				SaV-2(3)3	> 10,000	9,400	90	4,227	16	Neotoma pellets
Sandy Valley- 3	35°52'40"	115°42'25"	885	SAV-3(1)	12,000 > 8,000	8,490	120	4,236	8.5	Undifferentiated midden debris
				SaV-3(2)	> 10,000	9,430	60	4,237	4.1	Undifferentiated midden debris
COYOTE SPRINGS (PAHRANAGAT) WASH, DOUBLE CANYON, ARROW CANYON RANGE										
Double Canyon-1	36°47'05"	114°53'04"	660	DC-1(1)	> 10,000	12,060	70	4,228	11.8	Neotoma pellets and undifferentiated twigs
Double Canyon-4	36°46'50"	114°52'53"	690	DC-4(2)	> 10,000	10,400	60	4,238	8.7	Undifferentiated midden debris

Table 2 Significant macrofossil records from the Fortymile Canyon packrat middens. These are only species of special environmental or biogeographic significance. See Appendix I for complete species lists for these assemblages.

FAMILY	GENUS AND SPECIES	AFFINITY	FMC-7(1) 47,200	FMC-8A 18,530	FMC-9A(1) 21,830	FMC-10A(1) 9,470	FMC-10C(2) 9,390	FMC-11A(1) 15,870	FMC-11A(2)I 16,410
	SITE AND SAMPLE: APPROXIMATE 14-C AGE:								
TREES, SHRUBS, SUBSHRUBS, AND SUCCULENTS									
Asteraceae	Ambrosia cf. acanthicarpa	DR							
	Brickellia californica	I	1						
	Chrysothamnus albidus-type	I			1		1		
	Chrysothamnus nauseosus	I					1		
	Chrysothamnus paniculatus	DR	1						1
	Chrysothamnus cf. parryi	I							
	Lepidospartum latisquamum	I, DR							1
	Tetradymia canescens-type	I				1	1		
Cactaceae	Opuntia cf. polyacantha	I	1	1	2			1	2
Caprifoliaceae	Symphoricarpos sp.	I	2	1	3	4	3	1	3
Cupressaceae	Juniperus osteosperma	I	1						
Elaeagnaceae	cf. Shepherdia argentea	II, M/S	4	4	5	4**	3	4	3
Fabaceae	Lupinus argenteus-type	I, mW		1					
Lamiaceae	cf. Monardella	I, M/S		1				2	1
	Salvia dorrii	I							1
Oleaceae	Fraxinus anomala	II	1					1	2
	cf. Fraxinus velutina	I, H		1					
Pinaceae	Abies concolor	II, h, M/S			1				
	Pinus flexilis	II, M/S						**	
	Pinus monophylla	I						1	1
Polygonaceae	Eriogonum heermannii	I	3		1	**	1	1	1
Rosaceae	Cercocarpus ledifolius	I	1		1				
	Chamaebatiaria millefolium	I, M/S		2	2			3	3
	Holodiscus microphyllus	I, M/S	1	1	1			1	1
	cf. Rubus sp.	II, M/S		1	1			1	1
	Rosa woodsii	I, H	1						
Salicaceae	Salix sp.	I, H	1						
Saxifragaceae	Ribes velutinum	I	1						
	Ribes sp.	I						1	
Solanaceae	cf. Nicotiana attenuata	I	1	1					
				1					

Table 2 (continued)

FAMILY	SITE AND SAMPLE: APPROXIMATE 14-C AGE: GENUS AND SPECIES	AFFINITY	CHARACTER	FLOWERING	FMC- 7(1) 47,200	FMC-8A 18,530	FMC-9A(1) 21,830	FMC-10A(1) 9,470	FMC-10C(2) 9,390	FMC-11A(1) 15,870	FMC-11A(2)1 16,410
HERBS, FORBS, AND GRASSES											
Amaranthaceae	Amaranthus sp.		an.	June - Nov.							
Boraginaceae	Cryptantha barbigera-type	I	winter an.	May - June				1	1		
	Plagiobothrys cf. scouleri	H, aH	an.	June				1	1		
Brassicaceae	cf. Athysanus pusillus	I	-	-						1	1
	Thysanocarpus curvipes	TI	an.	Apr. - May				1			
Chenopodiaceae	Chenopodium sp.		an.	May - Oct.				2	2		
Euphorbiaceae	Euphorbia cf. serpyllifolia		summer an.	Sept. (July-Oct.)			1				
Hydrophyllaceae	Phacelia hastata-type	TI	peren.	I. May - July				1	1		
Loasaceae	Mentzelia veatchiana-type	TI	winter an.		1	1	1			1	1
Papaveraceae	Argemone munita	DR	peren.	I. May - Aug.							
Poaceae	Bouteloua barbata	TI	summer an.	Aug. - Sept.							
	Bromus carinatus	DR	peren.	May - July					1		
Polygonaceae	Polygonum lapathifolium-type	I, H			1				1		
	Rumex cf. salicifolius	DR, aH	peren.	I. Apr. - Sept.	1						
OTHER REMAINS											
	Ochotona fecal pellets (tally)	I, M/S									2
SUMMARY DATA											
	Mts (tree, shrub, and succulent taxa)				10	17	16	11	13	15	17
	N- Mts (herb, forb, and grass taxa)				8	12	9	13	15	4	7
	(N- Mts) as % of N				33%	41%	36%	54%	54%	21%	29%
	N (total number of taxa)				27	29	25	24	28	19	24
	Extralocals and extralimitals				15	12	11	6	9	11	15
	Extralocals/limitals as % of N				56%	41%	44%	25%	32%	58%	63%
	Hydrophilic taxa				4	0	1	0	0	1	1
	Desert riparian taxa				2	0	0	1	1	0	0

Key to occurrence symbols:

- * in the vicinity of the sites, but more than 50 m distant
- ** in the vicinity, but more than 100 m from site
- *** ca. 200 m distant in wash bottom
- ' nut shell fragments only
- '' one fragment only
- ''' two species
- +' observed in fecal pellets

Key to affinity symbols:

- DR- desert-riparian taxon
- H- obligate hydrophile or phreatophyte
- h- facultative hydrophile or phreatophyte
- aH- Noted by Beatley (1976) as occurring in wet meadows or stream-side habitats
- M/S- montane or subalpine taxon
- mW- mesic woodland taxon
- I- extralocal species
- TI- probable extralocal species
- II- extralimital species