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Revision Number 0

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STUDY PLAN

for

STUDY 8.3.1.5.1.2

PALEOCLIMATE STUDY: LAKE, PLAYA, MARSH DEPOSITS

Rev 0

October 25, 1991

U. S. GEOLOGICAL SURVEY

PREFACE

This study plan summarizes and extends the discussion of Study 8.3.1.5.1.2 in the Site Characterization Plan (SCP). Sections 1, 4, and 5, which show the study in the context of the total site characterization program, are drawn principally from the SCP and related Yucca Mountain Project documents. Sections 2 and 3 discuss the rationales and selected methods for the different activities, and present details of the planned tests beyond those described in the SCP.

J. P. Bradbury, R. M. Forester, and R. S. Thompson are the principal authors of the study plan. F. R. Singer prepared input for sections 1, 4, and 5.

ABSTRACT

Study 8.3.1.5.1.2 will establish the nature, timing, duration, and amplitude of paleoclimate changes in the Yucca Mountain area, based on paleontologic, geochemical, stratigraphic, sedimentologic, and geochronologic data obtained from lacustrine, playa, and marsh deposits. Study and analysis of the paleoclimate record will be directed toward qualitative, semiquantitative, and quantitative estimates of past changes in precipitation, temperature, moisture balance, and other climate parameters.

The documented record of paleoclimatic changes provides a basis for predicting the possible range of future climate conditions in the Yucca Mountain area. The data will therefore assist in evaluating the effects of future climate changes on surface water, unsaturated zone, and saturated zone hydrology, which is essential to address the objective of limiting radionuclide releases to the accessible environment. The resulting data also contribute to the resolution of other performance and design issues, and to other studies in the site characterization program.

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STUDY 8.3.1.5.1.2
PALEOCLIMATE STUDY: LAKE, PLAYA, MARSH DEPOSITS

Study 8.3.1.5.1.2 consists of four activities:

- 8.3.1.5.1.2.1 - Paleontologic analyses
- 8.3.1.5.1.2.2 - Analysis of the stratigraphy-sedimentology of marsh, lacustrine, and playa deposits
- 8.3.1.5.1.2.3 - Geochemical analyses of lake, marsh and playa deposits
- 8.3.1.5.1.2.4 - Chronologic analyses of lake, playa, and marsh deposits

The study is part of the climate program (8.3.1.5); it is one of a series of studies designed to collect data that will contribute to interpretations of past, present, and future climatic conditions and to determinations of the effects of climate change on surface, unsaturated zone, and saturated zone hydrology (fig. 1-1).

1. PURPOSE AND OBJECTIVES OF THE STUDY

1.1 Information to be obtained and how that information will be used

Climate change, particularly with regard to an increase in effective moisture within the next 10,000 to 100,000 yr in the Yucca Mountain area, is of critical importance to site characterization. Increased effective moisture causes infiltration rates and effective permeability of the unsaturated zone to rise, and would elevate the water table and the rate of ground-water flow that potentially transports radionuclides to the saturated zone and hastens their appearance in surface water environments. Knowledge of the history of climate change is critical to this problem because the magnitude and timing of past natural climate variability provides one method for predicting and evaluating future changes. Paleolimnological and paleohydrological stratigraphic records from specific sites in the Yucca Mountain area and the surrounding region provide direct physical evidence of past climate change in terms of hydrologic processes. These site specific studies are needed to validate climate models and document real paleohydrologic environments in space and time that are likely to characterize the southern Great Basin in the future. Possible anthropogenic causes, also a factor in considering climatic change, are not considered in the present study.

This study, in combination with other studies (e.g., Study 8.3.1.5.1.3, Climatic implications of terrestrial paleoecology), will help to establish the nature, timing, duration, and amplitude of paleoclimate changes based on analyses and dating of paleontologic, geochemical, and stratigraphic-sedimentologic data obtained from lake, playa, and marsh deposits in southern Nevada and adjacent parts of southeastern

California. The geographical scope will be broadened (e.g., farther north into central Nevada) if necessary to achieve the objectives of the study. Study and analysis of the aquatic paleoclimatic record will be directed towards obtaining qualitative, semiquantitative, and quantitative estimates of past changes in precipitation, temperature, moisture balance, and other climatic parameters. These estimates, when integrated regionally for particular climatic episodes, will aid in identifying the particular pattern of atmospheric circulation (air-mass interactions) responsible for the observed variations. These estimates will also provide the basic data utilized for analyses of past climatic periodicity and for validating climate models.

Because climate variability may significantly affect the hydrologic system, especially in terms of recharge and discharge, the results of this study will also be central to the paleohydrological studies of the area. The degree to which past climatic and past hydrologic changes are linked will provide a basis for comparing or linking the outputs of models that predict future climatic variability.

1.2 Rationale and justification for the information to be obtained: why the information is needed

Data obtained through Study 8.3.1.5.1.2 will provide a documented record of past climatic changes in the Yucca Mountain area and provide a basis for validation or rejection of various atmospheric circulation models. These data will ultimately be integrated into Study 8.3.1.5.2.2 (Characterization of the future regional hydrology due to climate changes), to assist in evaluating the effects of future climate on surface water, unsaturated zone, and saturated zone hydrology (fig. 1-2). Such evaluations are required by certain performance and design issues, and also contribute significantly to other site characterization programs (fig. 1-3). More specifically, information to be supplied by analysis of paleoclimate is necessary to address the objective of limiting radionuclide releases to the accessible environment as required by 10 CFR Part 60 and CFR 191.13, and as embodied in Issue 1.1. One of the stated performance parameters and associated tentative goals involved in the resolution of Issue 1.1, for example, is that the expected magnitude of change in water-table level owing to climatic change over the next 10,000 yr is less than 100 meters. This same limitation in water-table altitude change applies in the resolution of Issue 1.9b, wherein the time period involved is 100,000 yr. Confidence levels in both these parameters need to be improved from their current low status to a high category. Information on future climatic conditions that is needed to satisfy Issues 1.1 and 1.9b is also sufficient to assist in resolving the other issues shown on figure 1-3.

2. RATIONALE FOR SELECTING THE STUDY

Because there are no direct climate records beyond the historic records, knowledge about climate in pre-historic times must come from data that indirectly record past climatic conditions. Lake, playa, and marsh deposits contain a continuous or semi-continuous record of sedimentological and biological information that can serve as a proxy record of climate once the interactions between climatic and lacustrine, marsh, and playa processes are understood. Study 8.3.1.5.1.2 involves paleontologic, stratigraphic, sedimentologic, geochemical, and chronological analyses of these deposits to provide the data necessary to interpret past climatic conditions. Such data record and date changes in the physical and chemical properties of water. Water temperature and solute composition are most easily linked to climate, although records of nutrient dynamics, water depth, transparency, seasonality, and length of lake circulation can also be linked to subtle climatic changes. However, processes which are not climatically modulated (e.g., input of brines from deep aquifers and/or diversion of feeder rivers due to tectonic processes) should be considered when interpreting the stratigraphic record as a product of climatic change.

The four activities discussed below represent reliable approaches to extracting paleoenvironmental and paleoclimatic information from the lake, playa, and marsh deposits common to southern Nevada. Alternative methods such as dating high-stand shorelines, which can be applied to lakes in central and northern Nevada and parts of southeastern California, are not applicable to southern Nevada because high-stand shoreline deposits are either only poorly preserved or are not present. (Mifflin and Wheat, 1979).

2.1 Rationale for the types of tests selected

2.1.1 Activity 8.3.1.5.1.2.1 - Paleontologic analyses

Paleontological analysis involves examining sediment samples from outcrops and sediment cores that represent lake, playa, and marsh deposits in southern Nevada. The principal organisms to be studied are ostracodes, diatoms, and the seeds and pollen of aquatic plants. Other taxa such as fish, chrysomonad cysts, branchiopods, mollusks, and charophytes are known to exist in southern Nevada deposits and may prove useful in some records. The particular merits of various fossils for reconstructing past climate are examined in section 3.

In general, the annual and seasonal character and variability of the physical and chemical environment define a microhabitat within which some organisms can occur and others cannot. Their productivity (inferred from the abundance of fossils in the sediment record) is a measure of their success and hence of the persistence of optimal chemical, physical, and nutrient conditions relevant to that species. Such autecological information coupled with the fossil abundance in a sediment sample provides a proxy record of the physical and chemical conditions that existed in the past when the organism was living.

These conditions are typically under strict climatic control, and because diatoms and ostracodes and other aquatic organisms thrive only during comparatively short periods of time, their paleontologic record can be used to interpret details of climate history that are unavailable through other kinds of analyses.

2.1.2 Activity 8.3.1.5.1.2.2 - Analysis of the stratigraphy- sedimentology of marsh, lacustrine, and playa deposits

Sedimentologic and stratigraphic analysis involves examining the clastic and chemical sediments from cores and outcrops. This activity will characterize sediments on a detailed stratigraphic level and then integrate this information to determine the overall depositional history of a particular basin. Stratigraphic analysis will involve all common aspects of sedimentology including, but not limited to, texture, grain size, composition, sorting, bedforms, bed morphometry, nature of contacts and other properties of the sedimentary units. This information, when integrated vertically and laterally throughout the basin and combined with paleontologic and geochemical data (Activities 8.3.1.5.1.2.1 and 8.3.1.5.1.2.3), provides both general climatic information and a framework by which sediments can be sampled for paleontologic and geochemical analyses. The sum total of the physical and chemical properties provides climatic information because those properties may be related to the general physical and chemical properties of the water from which the sediments were deposited. The character of the sediments may also indicate their transport and depositional history. Sediment characteristics usually do not provide information about water temperature nor details of water chemistry and thus cannot provide the same kind of information available from paleontology or geochemistry. Sedimentology does, however, provide the kinds of details needed to create a general climate interpretation and a framework within which the more detailed sorts of information can be associated. Moreover, sediment characteristics provide the vital information needed to direct sampling strategies for more detailed studies.

2.1.3 Activity 8.3.1.5.1.2.3 - Geochemical analyses of lake, marsh and playa deposits

Geochemical (elemental and mineralogic) analyses of lake, playa, and marsh sediments provide detailed insights into the depositional environment of both clastic and chemical sediments. Their value in paleoclimatic interpretation varies according to the specific record under investigation. For example, in clastic depositional regimes the Na content of feldspars in bulk lake sediments relative to the Na content of the feldspars in the source area can be related to weathering intensity in the drainage area, a function of precipitation and vegetation cover. Other elements can provide information about the source of clastic sediments in a basin. Calcium content of the sediment typically is related to either biogenic productivity of calcareous organisms or to concentration and precipitation of carbonate minerals in climates of high evaporation. Similarly, the amount of Sr and Mg in ostracode shells is a function of the salinity and temperature, respectively, of the water in which these animals grew.

Endogenic mineral species (e.g. halite, gypsum, borates) are most diverse in waters with salinities above about 100 parts per thousand (ppt). Carbonate minerals (calcite, aragonite) and some clay minerals are important exceptions to this generalization. Carbonate minerals commonly precipitate from fresh to very saline water and provide mineralogic, trace metal, and isotopic records of the chemical environment from which they precipitated.

Isotopic records of carbon and oxygen, generally from carbonate shells of ostracodes and snails, can be used to evaluate past sources and temperatures of chemical precipitation, salinity, water temperature and other kinds of paleoenvironmental information.

2.1.4 Activity 8.3.1.5.1.2.4 - Chronologic analyses of lake, playa, and marsh deposits

All of the paleoenvironmental, paleolimnologic and paleoclimatic histories derived from the analysis and interpretation of lake, playa, and marsh deposits must be placed within a detailed temporal framework. The chronology activity is intended to cover this aspect of the study. The types of geochronologic dating techniques relevant for this region and for the kinds of lacustrine deposits present include radiometric dating (potassium-argon, U-trend, radiocarbon, etc.), paleomagnetic, tephrochronologic, amino acid, and thermoluminescene techniques. The applicability of any of these dating techniques will depend on specific site and sediment characteristics, the level of accuracy required, and the age of the record.

2.2 Rationale for selecting the number, location, duration, and timing of tests

2.2.1 Number of tests

Sites containing paleolimnological/paleoclimatic records are numerous (e.g., Benson, et al, 1990; Snyder, et al, 1964) in southern Nevada and southeastern California (fig. 2-1). The records vary in the length of time covered, the temporal/stratigraphic detail of coverage, and the sensitivity with which climatic change is recorded. In addition, the region is climatically heterogeneous; the variable elevations, drainage areas, aspects, and distances within the Sierra Nevadan rain shadow gradient mean that different sites record different microclimatic conditions. These distinct records must be studied and correlated so that subregional or mesoscale climatic generalizations can be extracted.

An adequate program to investigate climate change in the area of interest must work from an array of several sites that encompass the range of variability in the area and span the time intervals of interest in appropriate levels of detail. The longest and most continuous records will have the highest priority for study (e.g., Owens Lake, Death Valley) because they will provide a general framework into which shorter records from other areas can be patched. Records from moister environments at higher elevations will likely contain continuous documentation of the late Pleistocene-Holocene climate change. This time interval is of great importance in developing an understanding of modern climate variability. Playa records from low elevations will record climatic changes irregularly, but such records are closest to Yucca Mountain and, therefore, must receive special attention.

The following classes of sites (some examples are given below) will be studied to provide the required paleoclimatic data:

- Long, continuous records: Owens-China Lake, Walker Lake, Soda-Silver Playa
- Now dry, Pleistocene lake systems: Mud Lake, Kawich Playa, Columbus Salt Marsh
- High elevation sites with present lakes: Deep Springs Lake; may also include lakes in Ruby Mountains and Spring Mountains
- Low elevation dry playas: Yucca Flat, Desert Dry Playa, Frenchman Flat

About four cores from each site class will be obtained and applied to the study.

2.2.2 Location of sites

Sites to be investigated (see above) are located both in the Yucca Mountain area and in the surrounding region at distances that are governed largely by the presence of suitable basins with extractable paleolimnologic/paleoclimatic records (fig. 2-1). Areal coverage is essential to document climate change at regional level. Duplicate sites (similar sites close to one another and in the same environmental setting), or duplicate cores at single sites may be required to document constancy of the paleoclimatic record and the spatial scale at which regional climate variation can be expected.

2.2.3 Duration of tests

The tests must be of sufficient analytical duration to allow careful biostratigraphic, sedimentologic, and geochemical work to be accomplished for key paleolimnologic/paleoclimate records surrounding Yucca Mountain. The stratigraphic/temporal duration of some records should be of sufficient dimension to establish paleoclimatic variations back to several hundred thousand years. For example, a 600,000-yr record from Owens Lake requires a core about 300 m long (Smith and Pratt, 1957). Similarly long records from dry playas may be found at shallower depths, but continuity of sedimentation is dubious in such cases.

2.2.4 Timing

This study requires considerable reconnaissance testing to select the best records for detailed study. Timing of the tests must be organized in such a way that a maximal number of sites are cored or otherwise collected early in the program of investigation. The results from the reconnaissance investigations will be applied to detailed coring and collection of the most favorable sites. Sites will be designated as favorable both on the basis of the continuity, length, and sensitivity of their records, and on their geographic location relative to Yucca Mountain and to larger scale climate systems operative in southern Nevada.

Timing of this activity must ensure that the results produced are available for use by interrelated activities such as climate modeling, paleohydrology, hydrological modeling, Yucca Mountain paleoenvironmental studies, and various synthesis activities.

2.3 Constraints

The choice of tests for this study was unaffected by their impacts on the site, simulation of repository conditions, or interference with other tests or the exploratory shaft design and construction. With regard to the limits, capability, scale, and applicability of the planned tests, the resulting documentation of mineralogic and geochemical constituents, sedimentological characteristics, chronological relationships, and kinds and abundances of fossils will conform to standard levels of accuracy and precision. Such documentation is expected to result in reliable interpretations regarding the former presence of lakes, playas, and marshes and their size, chemical characteristics, and duration in sufficient detail for use in climate and hydrologic modeling for the site characterization program for Yucca Mountain. The planned work should be completed before the final climate and hydrologic modeling is scheduled.

3. DESCRIPTION OF TESTS AND ANALYSES

3.1 Activity 8.3.1.5.1.2.1 - Paleontologic analyses

The objective of this activity is to assemble and interpret, in paleoclimatic terms, detailed records of ostracodes, diatoms, and pollen, along with other types of fossils as warranted by specific paleoclimatic questions.

3.1.1 General approach

This activity involves the collection, identification, enumeration, and interpretation of paleontologic data that will emphasize the past 50,000 yr in great detail, the past 200,000 yr in moderate detail and the past 1,000,000 yr in some detail,(Bradbury, et al, 1989). Calcareous fossils will also be collected for geochemical and age analyses of their carbonate content. The areas where collections will be made in southern Nevada will be selected from those shown in figure 2-1.

Ostracodes

Ostracodes are small crustacea with bivalved calcite carapaces that can be identified to the generic or specific levels. They are largely benthic animals, living at or just below the sediment-water interface. Ostracode life-cycles range from about three weeks to well over a year, and their ecology is governed by annual or seasonal climatic and hydrologic phenomena. Ostracodes live in virtually all oxic waterbodies that persist for more than about a month. They attain their highest population densities in quiet or gently flowing water and are most commonly preserved in circumneutral to alkaline water.

Nonmarine ostracodes are divided into two major ecologic groups: those that live in surface waters (epigean), and those that live in ground water (hypogean). Epigean taxa may be further divided ecologically into those living in ground-water discharge environments and those that live in lacustrine environments. Both ground-water discharge and lacustrine taxa may be further subdivided into groups of taxa that only live in very particular environments such as continuously cold water (cryobionts) or continuously warm water (thermobionts), or water that is warm for at least a given period during the year (thermophilic). Ostracodes are very sensitive to water chemistry, with the distribution of some taxa determined by the major dissolved ion content of the water. Other parameters, such as turbidity, oxygen levels, or biotic factors appear to influence ostracode productivity.

Most ostracode species have well defined biogeographic ranges that appear to be limited by seasonal variations in water temperature and chemistry. Ostracodes are capable of entering new environments through the transport of adult ostracodes or eggs by birds, insects, or wind. Similarly, as environments change, some species will no longer be able to survive and will become locally extinct. Thus, ostracodes may rapidly expand or contract their geographic ranges in response to changing hydroenvironmental and climatic conditions.

Diatoms

Diatoms are single-celled algae that produce an opaline silica frustule, which provides precise taxonomic information. Various species of diatoms cover a range of aquatic habitats from the sediment-water interface to the open-water epilimnion. Diatoms are rapidly reproducing organisms and, therefore, can respond by increasing species abundance to environmental phenomena operating on weekly time scales. Particular species are known from all aquatic environments within the photic zone. Some are especially sensitive to water quality, including parameters such as solute composition, salinity, and pH. They are also extremely sensitive to the availability of nutrients such as nitrogen, phosphorous, silica, and dissolved organic compounds. Diatoms have an excellent fossil record, and, unlike ostracodes, they are commonly preserved in acidic environments or any environment low in HCO_3 activity. Where both groups of organisms are preserved, the diatoms may provide useful information on short term (seasonal) environmental phenomena related to nutrient cycling and climatically induced factors that govern lake circulation.

Pollen

The pollen record of emergent and submergent macrophytes and the remains of certain non-siliceous algae provide important information about the chemical and, to a lesser extent, thermal properties of the water in which they lived. The development of aquatic plants in aquatic environments relates primarily to salinity, depth and permanence of the lake, pond or marsh system. For example, emergent plants such as cattail require the local water level to remain within a specified range, otherwise they will drown from rising water levels or desiccate from falling levels. Knowledge about the stability of a water body on a seasonal to annual scale is an important hydrologic and climatic property. It should be noted that pollen from terrestrial plants will be studied as part of Study 8.3.1.5.1.3 (Climatic implications of terrestrial paleoecology).

Other fossils

Other fossils, ranging from terrestrial vertebrates to aquatic chrysophyte cysts and branchiopods, may prove vital to understanding the nature of a particular climate record (e.g., Quade, 1986). The way in which climate interpretations would be made from other kinds of fossils generally follows the format given above for ostracodes, diatoms, and pollen. Other types of fossils can be used to evaluate and refine the climatic interpretations derived from the principal organisms and may offer information not available from these organisms. For example, the occurrence of branchiopod fossils together with ostracodes implies a wet-playa hydrology whereas the presence of branchiopods without ostracodes implies a dry-playa hydrology. The recognition of a wet and dry playa record from cores in the modern day dry playas near Yucca Mountain would have climatic importance.

3.1.2 Test methods and procedures

Fossil diatoms, ostracodes and pollen will be extracted from the sediment of lake cores and outcrops of lacustrine deposits according to techniques established by the relevant technical procedures (table 3-1). The fossils will be enumerated at each level tested, and the data will be drafted as fossil abundance vs. depth and time silhouettes.

The changing abundances of fossils through the stratigraphic section represents the primary data from which paleolimnologic/paleoclimatic changes are interpreted.

The ecology of diatoms, ostracodes, and other aquatic organisms is necessarily related to the properties of the water in which they live. In order to extract climatic information from the fossil record of aquatic organisms, the relationship between limnological conditions and climate must be established.

Shallow wet-playa lakes, marsh ponds, and spring pools from shallow aquifers are surface water features that are common today and were common in the past in southern Nevada. The water columns in each of these environments is thermally coupled to the daily or weekly changes in air temperature over the water body (Forester, 1987). Furthermore, the water temperature of spring vents from shallow aquifers provide good estimates of mean annual air temperature. The seasonal variability in water temperature of standing bodies or the constant value of spring vents provides a thermal habitat that relates occurrence and abundance of all aquatic organisms, especially ostracodes. New taxa appear as the thermal habitat changes with changing climate, while others become locally extinct. Thus, knowledge about the thermal ecology and biogeography of aquatic taxa provides direct information about water temperature which may then be interpreted in terms of air temperature. These interpretations may be qualitative, based on empirical observations; semiquantitative, based on multivariate analyses techniques; or quantitative, based on statistical analyses and organism physiology.

The temperature regime of large lake systems is a major factor in determining lake circulation and nutrient dynamics. Different diatom species are adapted to prosper under different, temperature-circulation dependent nutrient fluxes, and the abundance of these diatom species in paleolimnologic records can thereby be interpreted in terms of seasonal temperature variability in the past.

Climate may play an important role in determining water chemistry when water with a given input composition is evaporatively coupled to the atmosphere over the basin. Wet periods result in dilution or flushing of dissolved salts from the basin. Dry periods result in concentration and solute evolution due to selective mineral precipitation and other processes. The chemistry of the surface water body is thus coupled to the atmospheric moisture balance over the water body. The chemical character of the water establishes a chemical habitat that determines organism occurrence and abundance. As the chemical habitat changes with changing climate new taxa appear and old taxa become locally extinct and thus provide a record of paleohydrochemistry that may be interpreted in terms of moisture balance. As with paleotemperature, these interpretations may be qualitative, semiquantitative, or quantitative.

3.1.3 QA level assignment

Quality Assurance requirements will be specified in a Yucca Mountain Project QA Grading Report which will be issued as a separate document.

3.1.4 Required tolerances, accuracy and precision

No explicit requirements for tolerance, accuracy or precision have been specified for this activity. The planned methods, however, should result in the following limits of accuracy:

- Concentrations and percentages of microfossils--established with an accuracy of 5%
- Paleolimnological interpretations--not directly testable, but expected to be reasonable and accurate with respect to moisture sources and balance (+ or -), and to seasonal and annual temperatures
- Hydrochemistry--total dissolved solids within 10%, with reasonable ion character and concentration
- Lake depth--correct to within 10% of total depth

3.1.5 Range of expected results

Previous studies in southern Nevada (e.g., Quade, 1986) and southeastern California (e.g., Smith, et al, 1983) suggest that (1) during the last episode of pluvial (substantially wetter than present) conditions, mean annual air temperature was about 6°C cooler than present; (2) moisture balances were positive on an annual basis with substantial amounts of precipitation arriving in the winter time; (3) large lakes formed as a result of the positive moisture balance and under the influence of substantially increased runoff from the Sierra Nevada Mountains in California and other water sources in northern Nevada and Utah (perennial marshes and shallow lakes occupied basins as close as 40 km north of Yucca Mountain); and (5) shallow aquifer-supported marshes fringing the Spring Mountains existed within the same distance southeast of Yucca Mountain. At the peak of this moist episode, marshes and lakes were essentially fresh although before and after they were often alkaline and moderately to highly saline.

3.1.6 Equipment

The equipment needed for extraction, identification, and enumeration of microfossils is conventional and readily available. The major items are:

- Laboratory with sinks, sieves, centrifuge, fume hood, and necessary glassware and chemicals for breaking down sediments to extract diatoms, ostracodes and pollen and ostracodes.
- Compound and stereoscopic microscopes capable of 1000 and 200 x magnifications, respectively.
- Counters, computers and other means for tabulating data and drafting results.

Equipment needed for coring lake sediments (mechanical and hand-operated drilling devices) is also conventional. Sampling cores and outcrops requires standard laboratory and field equipment such as spatulas, bags, markers, notebooks and so forth.

3.1.7 Data-reduction techniques

Standard data-reduction techniques will be used to organize, compile, and display paleontologic data (e.g., sample location maps, fossil lists, and charts showing ranges of different fossil species). Sediment volume and (or) weights are measured, microfossils are enumerated in aliquots of the sample, and concentration of microfossils per unit of sample volume or weight are determined by manipulation of counts, aliquots, and original sample volumes. Percentages of microfossils are determined as fractions of the sum of counted microfossils in given ecological categories.

3.1.8 Representativeness of results

Although the specific paleolimnological histories of the several sites to be investigated are expected to differ in detail, the general paleoclimate information obtained in this activity is expected to be representative of Quaternary lacustrine and marsh stratigraphic sequences in the area because representative basins will be sampled either in reconnaissance or in detail. Gaps in the stratigraphic record of some basins may preclude full documentation of their Quaternary paleolimnological histories, but this information will itself become valuable in assessing the developmental extent of lacustrine environments and the climates responsible for them in southern Nevada.

3.1.9 Relations to performance goals and confidence levels

See sections 1.2, 4, and 5.

3.2 Activity 8.3.1.5.1.2.2 - Analysis of the stratigraphy-sedimentology of marsh, lacustrine, and playa deposits

The objectives of this activity are to:

- Identify and characterize the general physical and chemical properties of sedimentary units from outcrops, shore deposits, and cores; this information will provide a physical and relative temporal framework within which various paleoenvironmental studies will be made

- Determine the specific environment of deposition for the sedimentary units using the principles of clastic and chemical sedimentology

3.2.1 General approach

The planned work for this activity primarily involves field and laboratory investigations designed to provide sedimentological information bearing specifically on environments of deposition and paleoclimatic conditions. In its early stages, these investigations will focus on collecting the kinds of information required to construct a preliminary physical and stratigraphic framework of lacustrine, playa, and marsh deposits in each of the sites within the region surrounding Yucca Mountain where it is believed that representative stratigraphic sequences will be found. This initial work will include studies of deposits from both the interior and the shoreline zones of the lake, playa, or marsh in order to determine which sites hold the most promise for having the best and most complete records of paleoenvironmental conditions preserved in their particular sedimentary sequence. It is also anticipated that seismic techniques -- primarily shallow reflection (Mini-sosie) and refraction (Bison) surveys -- will be employed in selected areas to assist in defining depocenters and hence, to provide information as to where the thickest sequences are located for the siting of boreholes. Studies will entail (1) mapping, measuring, describing, and sampling the various deposits; (2) coring (and trenching, as necessary) of unexposed sequences; (3) correlation of stratigraphic units and analyses of sedimentary facies; and (4) measurements of physical properties of sediments, such as grain size, density, and magnetic susceptibility. On the basis of preliminary findings, certain sites will subsequently be selected for more detailed studies and additional sampling that will provide the most complete stratigraphic/sedimentological framework from which to interpret paleoclimate. For long records (300m$\pm$) the sampling interval is expected to be about 25 cm; for short records (10 m$\pm$), the interval is expected to be about 10 cm. These sampling intervals are based on the general relationship that in a short record ($\pm$10 cm) each 10 cm represents about 100 years, during which time vegetation variations will likely be reflected in the stratigraphic record. For long records ($\pm$300 m), representing about 3 million yr (1 m$\doteq$ 10,000 yr), the sampling interval of 25 cm is selected so as to define broader climatic changes (e.g., Quaternary climatic conditions vs Holocene climatic conditions). This approach should minimize the number of samples and field observations needed to achieve the objectives of the activity. Following hand-sample descriptions in the field and physical properties measurements in the laboratory, the collected materials will be made available for geochemical analysis to be conducted in Activity 8.3.1.5.1.2.3 (see secs. 3.3.1 and 3.3.2).

3.2.2 Test methods and procedures

Methods and technical procedures for this activity are listed in table 3-1. Lithostratigraphic studies will involve general physical and compositional characterization of sedimentary units in order to define the different units and to place them in space and time. Investigations will describe sediment thickness, color, grain size, texture, bedding, magnetic susceptibility, and other properties deemed necessary for accomplishing this task.

Clastic and chemical sedimentology involves more precisely identifying and describing the physical nature of the sedimentary units identified by the lithostratigraphic studies in order to define the physical and chemical nature of the depositional environment. Properties such as grain size, composition, bedforms, nature of contacts between sediment units, or other properties that will aid in interpreting depositional environment will be studied. Sedimentologic data provides general paleoclimatic information together with general environmental boundary conditions for other studies.

3.2.3 QA level assignment

Quality Assurance requirements will be specified in a Yucca Mountain Project QA Grading Report which will be issued as a separate document.

3.2.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy or precision have been specified for the tests in this activity. However, the goals of the activity require that distinctive and diagnostic sedimentary units be characterized as fully and accurately as necessary to establish their environmental origin with reasonable confidence and with the recognition that more detailed, accurate, and precise analysis would not significantly improve or expand the paleoenvironmental interpretation of the unit.

3.2.5 Range of expected results

The most likely sedimentary units to be encountered in lake, playa, and marsh deposits of Quaternary age in and around Yucca Mountain include carbonate tufa deposits on shorelines of ancient lakes, beds of lake clays, marls, peats, diatomites, evaporites, lacustrine sands, conglomerates, and related deposits associated with shallow-water, near-shore lacustrine environments.

3.2.6 Equipment

Picks, shovels, augers and related hand sampling devices are required for sampling outcrops and non-surface lacustrine deposits. Hand-samples will be described through use of hand lens, grain-size comparators, and color charts. Collection of cores requires both hand and mechanized coring devices. Specialized items of equipment for conducting seismic surveys and measuring physical rock properties are, or will be listed in the technical procedures cited in table 3-1.

3.2.7 Data-reduction techniques

Standard data-reduction techniques will be used to synthesize and compile field observations. Observations made on the ground surface and in natural exposures will be transferred to scale-stable maps of the basin under study. Where appropriate, cross sections documenting facies changes and stratigraphic relationships will be prepared. Stratigraphic and sedimentological descriptions of cores will be compiled on lithostratigraphic core logs.

3.2.8 Representativeness of results

The results are expected to be representative only for the individual basins under study. Different basins will have different stratigraphic sequences and sediment components because of differences in drainage areas, basin dimensions, geological terrains, climatic and hydrologic conditions, and other characteristics.

3.2.9 Relations to performance goals and to confidence levels

See sections 1.2, 4, and 5.

3.3 Activity 8.3.1.5.1.2.3 - Geochemical analyses of lake, marsh, and playa deposits

The objective of this activity is to provide a geochemical and mineralogical characterization of lacustrine, marsh, and playa deposits to generate information about paleohydrochemistry, sediment provenance, weathering rates, and sediment-water interface environments in ancient lakes. Parameters include (1) elemental analyses of bulk sediments, (2) carbonate and noncarbonate mineralogy, and (3) stable isotope analyses.

3.3.1 General approach

The planned tests for this activity involve studies of the chemical processes--endogenic and diagenetic--operating within the lacustrine environment as well as processes (allogenic) that contribute materials from the surrounding region. These types of data are essential for characterizing past climate because the endogenic-authigenic processes provide information about water chemistry that may be related to moisture balance whereas the allogenic record provides information about stream input and other factors that may characterize wet periods. Many of the samples required for analyses will be collected during the field investigations being conducted in Activity 8.3.1.5.1.2.2.

Endogenic carbonate mineralogy is related to the Mg/Ca ratio of the water from which the carbonate precipitates. As lake water evaporates or freshens, the Mg/Ca ratio increases or decreases respectively, thereby controlling the precipitation of different carbonate minerals. The expected mineral sequence from dilute water to concentrated water is low-Mg calcite, high-Mg calcite, aragonite (or dolomite), and monohydrocalcite. The stratigraphic sequence of these carbonate minerals in a core may provide evidence for wet and dry cycles. Moreover, biogenic carbonate, principally the shells of ostracodes or snails, may provide information about the temperature and salinity of the water in which the carbonate was precipitated. The Mg/Ca ratio of biogenic calcite is known to be closely related to the temperature at which the carbonate precipitated (Chivas, et al, 1983), whereas the Sr/Ca ratio appears to be related to the salinity of the water (Chivas, et al, 1985). Temperature and salinity are important climate indicators in climatically sensitive aquatic environments.

Noncarbonate minerals such as salts and silica minerals (opals and clays) will be identified and studied to provide information about the composition of the parent body of water (and moisture balance) and (or) about the post-depositional environment, the latter being an indication of the degree of alteration of the sedimentary unit(s).

Analyses of stable isotopes, principally oxygen and carbon, but also strontium, sulfur, deuterium/hydrogen, will be conducted to provide information about the source/temperature of precipitation, water salinity, water temperature, and other forms of environmental information. This information, as with aquatic microfossils, provides a means of evaluating the moisture balance or temperature of the atmosphere over the water body. Other types of geochemical analyses may prove necessary in some situations. Marsh sediments, for example, may be especially rich in organic compounds or other components not common to playas.

3.3.2 Test methods and procedures

Methods and technical procedures for this activity are listed in table 3-1. Element analyses of bulk sediments involve determining the quantity of elements present in sediment samples taken as a time series from a core or outcrop. Conventional analytical techniques for bulk element analysis include atomic absorption, plasma-coupled neutron activation, x-ray fluorescence, and assorted wet chemical techniques. Mineral determinations will be made by semi-quantitative x-ray diffraction techniques.

3.3.3 QA level assignment

Quality Assurance requirements will be specified in a Yucca Mountain Project QA Grading Report which will be issued as a separate document.

3.3.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy or precision have been specified for the tests in this activity. However, the laboratory procedures being followed for the planned analyses will result in standard levels of accuracy as will be described in the technical procedures listed in table 3-1.

3.3.5 Range of expected results

Previous mineralogical and geochemical studies in lacustrine deposits of the Great Basin (e.g., Benson, 1988) indicate that the entire suite of carbonate mineralogy can be expected as precipitates and diagenetic alterations in sediments of alkaline, saline lakes. However, much of the sediment load of these lakes comes from clastic sources, and geochemical/mineralogical tests will effectively document river input and autochthonous sediment production for ancient lake systems. Isotope tests on lake cores show the effects of lake-water dilution by river inflow and lake concentration by evaporation.

3.3.6 Equipment

All of the planned analyses involve conventional, off-the-shelf items of equipment as listed in technical procedures (table 3-1).

3.3.7 Data-reduction techniques

Standard data-reduction techniques will be used for organizing and compiling geochemical, mineralogical, and isotopic data from cores and outcrops of lake sediments. Time (depth) vs concentration or percent silhouettes will be used to present these data.

3.3.8 Representativeness of results

The results of geochemical, isotopic, and mineralogical analyses are expected to be representative only of the section or core from which they are taken. Different cores or sections will record different geochemical, isotopic and mineralogical signals because they represent slightly different lacustrine environments. Similarly, geochemical studies from different basins will differ. With regard to isotopic analyses of shell materials, prior knowledge of such parameters as water temperature, evaporation effects, and the oxygen isotopic content of the water should be carefully considered before interpretations of paleoenvironmental conditions are made. Commonly, these parameters are poorly known and can only be inferred.

3.3.9 Relations to performance goals and confidence levels

See sections 1.2, 4, and 5.

3.4 Activity 8.3.1.5.1.2.4 - Chronologic analyses of lake, playa, and marsh deposits

The objective of chronologic analyses is to obtain an accurate chronologic framework for the paleoclimatic information acquired in this study. All age information should, whenever possible, be tested with other techniques to reduce uncertainties. The parameters are the ages of biostratigraphic indicators and sediments as determined through use of the following techniques: carbon-14, amino acid, thermoluminescence, uranium-series, uranium-trend, paleomagnetism, tephrochronology, fossils, and others. All of these Quaternary dating techniques, as well as the special factors and limitations involved in their use, are summarized in a table prepared by Colman and Pierce (in press). The following discussions are based largely on data presented in that table.

3.4.1 General approach

Radiocarbon analyses will be conducted on organic-rich sediments, on terrestrial organic matter deposited in aquatic sediments, or on biogenic carbonate using conventional or tandem accelerator methodologies. Radiocarbon can provide age information from the modern to 40,000 yr B.P. age range, but is subject to various geochemical problems that may lead to errors.

Amino acid analyses may be applied to well-preserved mollusc or ostracode shells. Particular amino acids are known to change from one state to another as a function of time and temperature. Thus, when temperature is known to have been relatively constant, amino acid analyses may provide age, but when thermal histories are variable, amino acid data may be used only for relative age determinations or as a correlation tool.

Thermolumninescence is in the experimental stage at this time, but may prove useful for dating aquatic sediments in the age range of 2,000 to 250,000 yr B.P.

U-Series analyses are conducted largely on inorganic or biogenic carbonates. Errors with this method are usually due to the materials being part of an open system. Age range is from about 5,000 to more than 300,000 yr B.P.

U-Trend analyses will be conducted largely on surface sediments such as marsh outcrops or soil sequences. It may be applicable under some circumstances to playa cores. This method relies on the material being dated to be part of a geochemically open system.

Paleomagnetic analyses will be applied to core and trench sediments to establish the remanent magnetism (NRM). Except for geologically short intervals, the past 700,000 yr have exhibited normal polarity. In most instances the discovery of reversed-polarity sediments indicates they were deposited before this date.

Tephrochronology method involves the comparison of the chemical and physical characteristics of volcanic ashes with those of ashes of known ages.

The geologic history of some terrestrial and aquatic organisms are sufficiently well known so that the occurrence of these organisms provides an age range for the sediment. In addition, the timing of the expansion or contraction of biogeographic ranges for microtine rodents is also sufficiently well known so that the occurrence of such a taxon in a particular area offers a more refined age than the geologic range of the species.

Other techniques such as stratigraphic position, sediment accumulation rates, soil development, or degree of weathering may offer needed age estimates. Also, tree-ring data may be useful in interpreting climatic fluctuations for the past 1,000 years.

3.4.2 Test methods and procedures

The test methods and procedures for this activity are listed in table 3-1.

3.4.3 QA level assignment

Quality Assurance requirements will be specified in a Yucca Mountain Project QA Grading Report which will be issued as a separate document.

3.4.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this activity. All of the planned tests are designed to provide standard levels of accuracy for the particular technique being used. No dating technique, however, is perfect; hence, alternative dating systems will be employed where possible to cross check results.

3.4.5 Range of expected results

Geochronological studies in Great Basin lake deposits indicate that the full range of Cenozoic ages may be expected (e.g., Stewart and Carlson, 1976). Lake deposits in southern Nevada range from Miocene through Holocene times and have been effectively dated by radiometric, tephrochronologic, vertebrate paleontological, and paleomagnetic techniques. Quaternary lake sediments vary in age from greater than 600,000 yr to less than 18,000 yr. Detailed magnetostratigraphy of selected cores and outcrops may reveal datable magnetic excursions.

3.4.6 Equipment

Highly specialized equipment in well-equipped laboratories is required for the radiometric/geochemical dating techniques. Lists of equipment are included in the technical procedures listed in table 3-1.

3.4.7 Data-reduction techniques

Conventional data-reduction techniques will be employed to organize, compile, and present geochronological data for core and outcrop studies. Standard deviations of radiometric dates will be listed and illustrated in all graphs and tables.

3.4.8 Representativeness of results

Previous studies in the Great Basin have shown that all geochronological dating techniques give representative, generally reasonable results (e.g. Benson, et al, 1990). There are exceptions, and anomalous dates are difficult to predict and to explain. It is not uncommon for radiocarbon dates on different materials to vary, and accurate determination of paleolimnologic/paleoclimatic changes within short time intervals during the last 30,000 yr often requires extreme care in sample selection and preparation.

3.4.9 Relations to performance goals and confidence levels

This component of the paleolimnology/paleoclimate study has a critical relation to performance goals and confidence levels. To be useful for documenting paleoclimate change and for extrapolating such changes into the future, the records must be reliably dated. However, in most cases absolute accuracy is not required to obtain a general picture of Quaternary lake and climate change, and the planned dating techniques are capable of providing the necessary accuracy for this purpose. See sections 1.2, 4, and 5 for additional discussions.

4. APPLICATIONS OF RESULTS

This discussion is summarized from information detailed in Chapter 8 of the SCP. Related discussions in section 1.2 consider the uses of information from the study in the context of issue resolution and performance goals.

Information from this study will be used to cross-check and supplement the terrestrial paleoecological record to establish mutual compatibility as well as disparities in the paleoclimate-paleoenvironmental data (Activities 8.3.1.5.1.3.2, 8.3.1.5.1.3.3, 8.3.1.5.1.4.3, and 8.3.1.5.1.5.1; see table 4-1).

Paleoclimate data will ultimately be integrated into a paleoclimate-paleoenvironmental synthesis study (Activity 8.3.1.5.1.5.1). The study will provide a large portion of the data required for evaluating and validating numerical regional and global scale climate models (Study 8.3.1.5.1.6). Finally, information from this study will indirectly assist in the evaluation of the impacts due to potential future climate changes on the regional hydrologic system (Study 8.3.1.5.2.2).

5. SCHEDULE AND MILESTONES

Figure 5-1 shows the principal milestones for this study and all direct scheduling ties to other studies. This information is abstracted from the most current and complete project schedule network.

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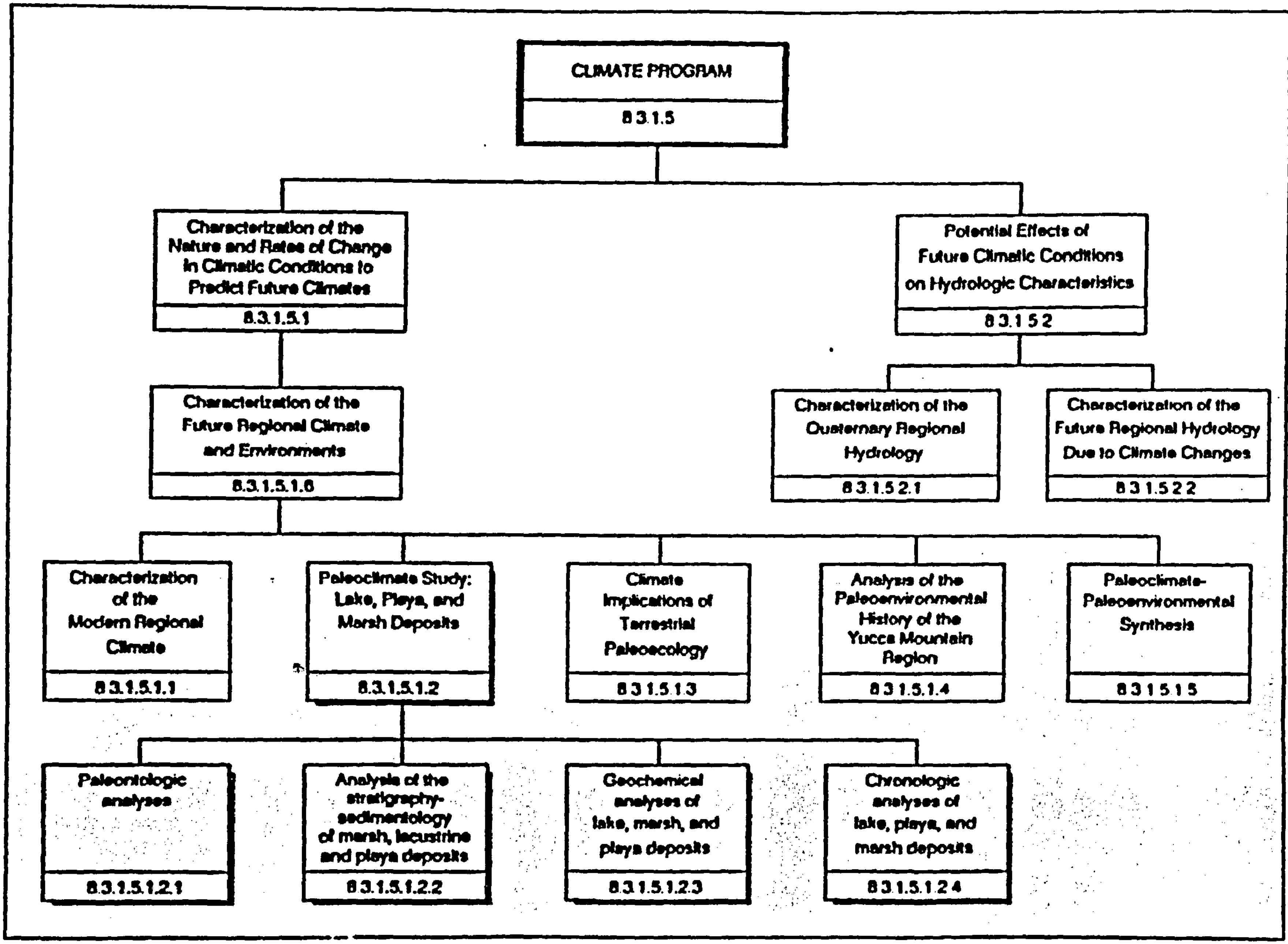


Figure 1-1. Relation of Study 8.3.1.5.1.2 to the climate program.

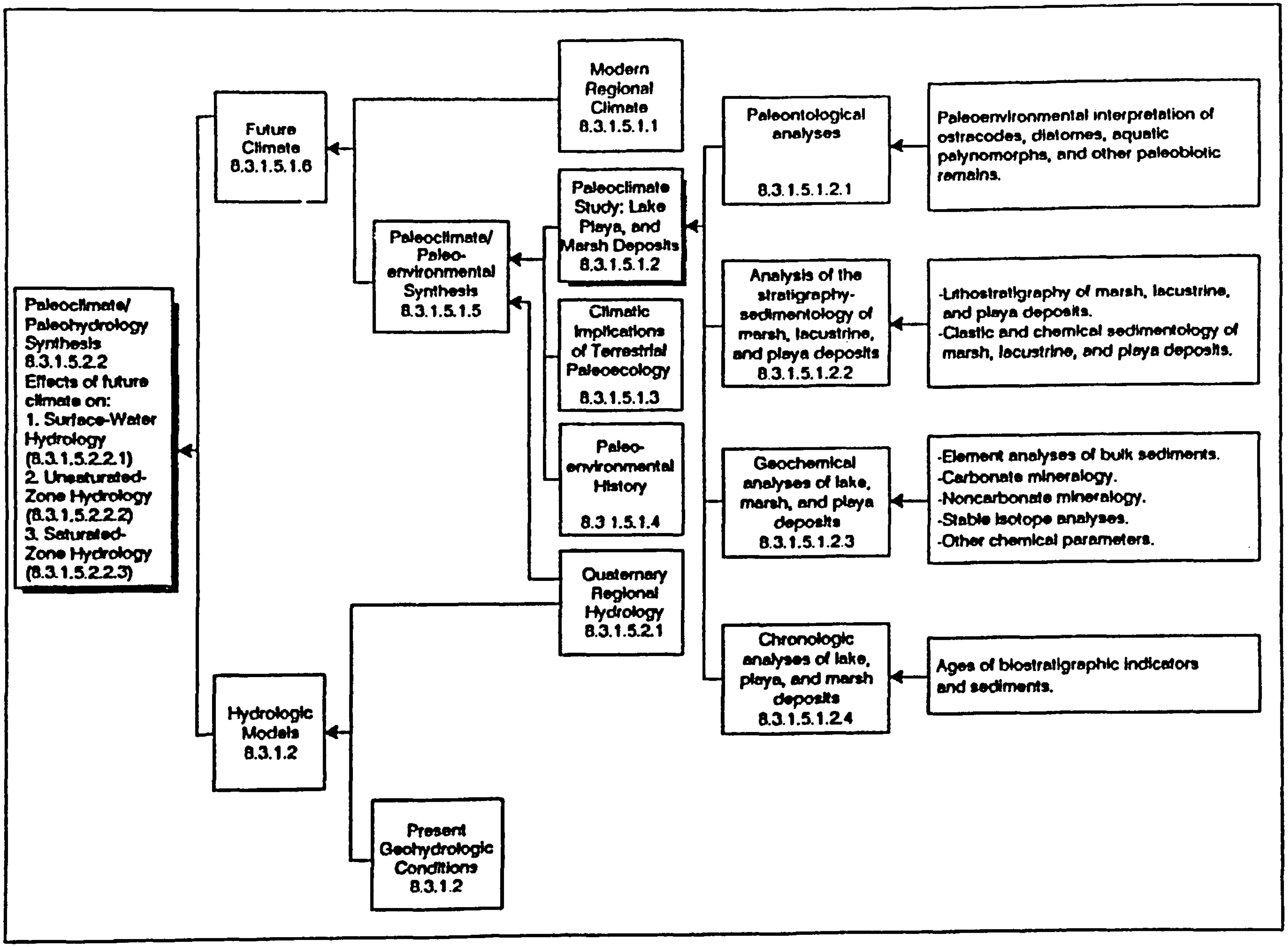


Figure 1-2. Logic diagram showing site characterization parameters of Study 8.3.1.5.1.2 in relation to the climate program.

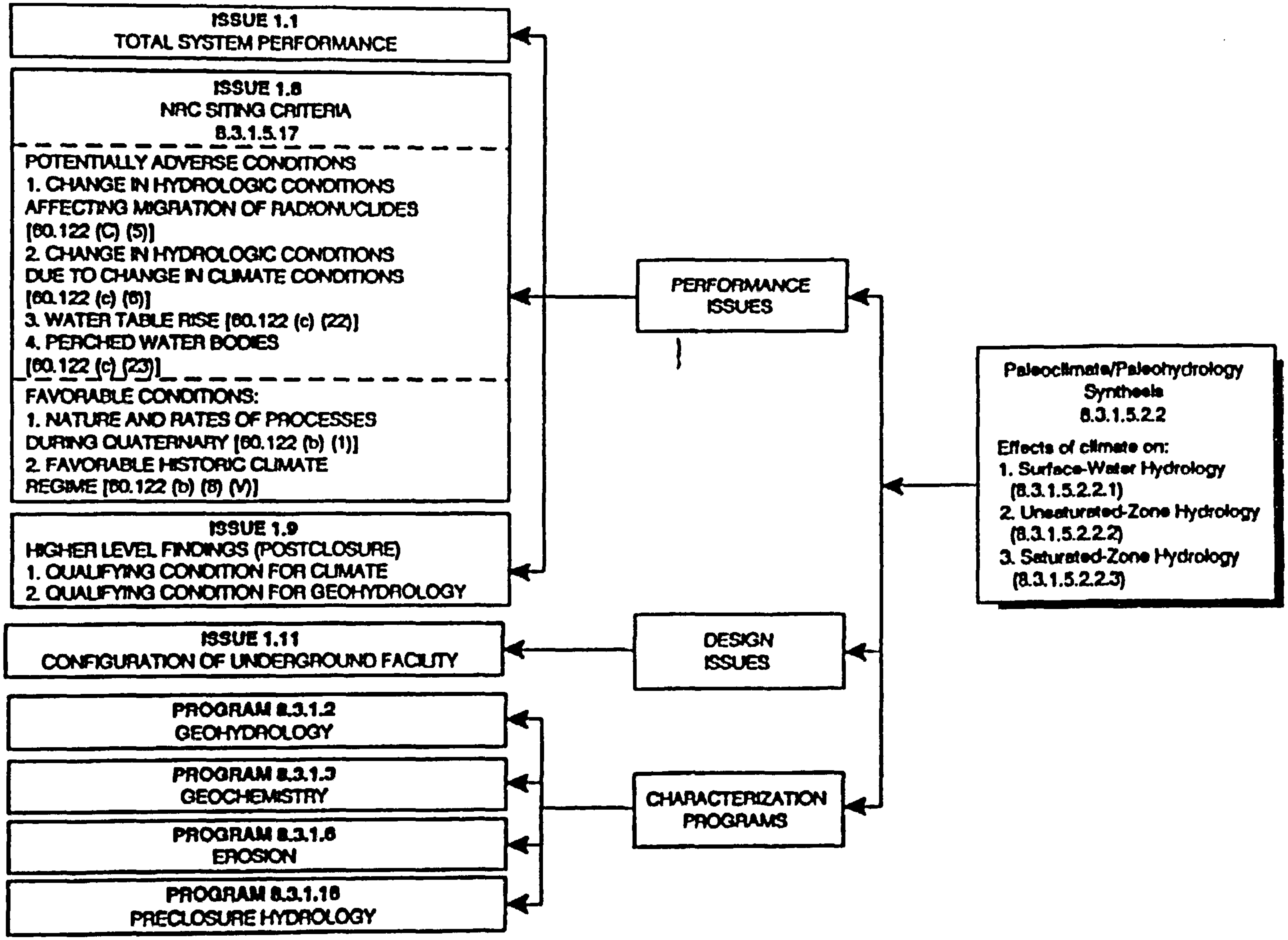


Figure 1-3. Interfaces of study 8.3.1.5.1.2 with YMP performance and design Issues and other site-characterization programs.

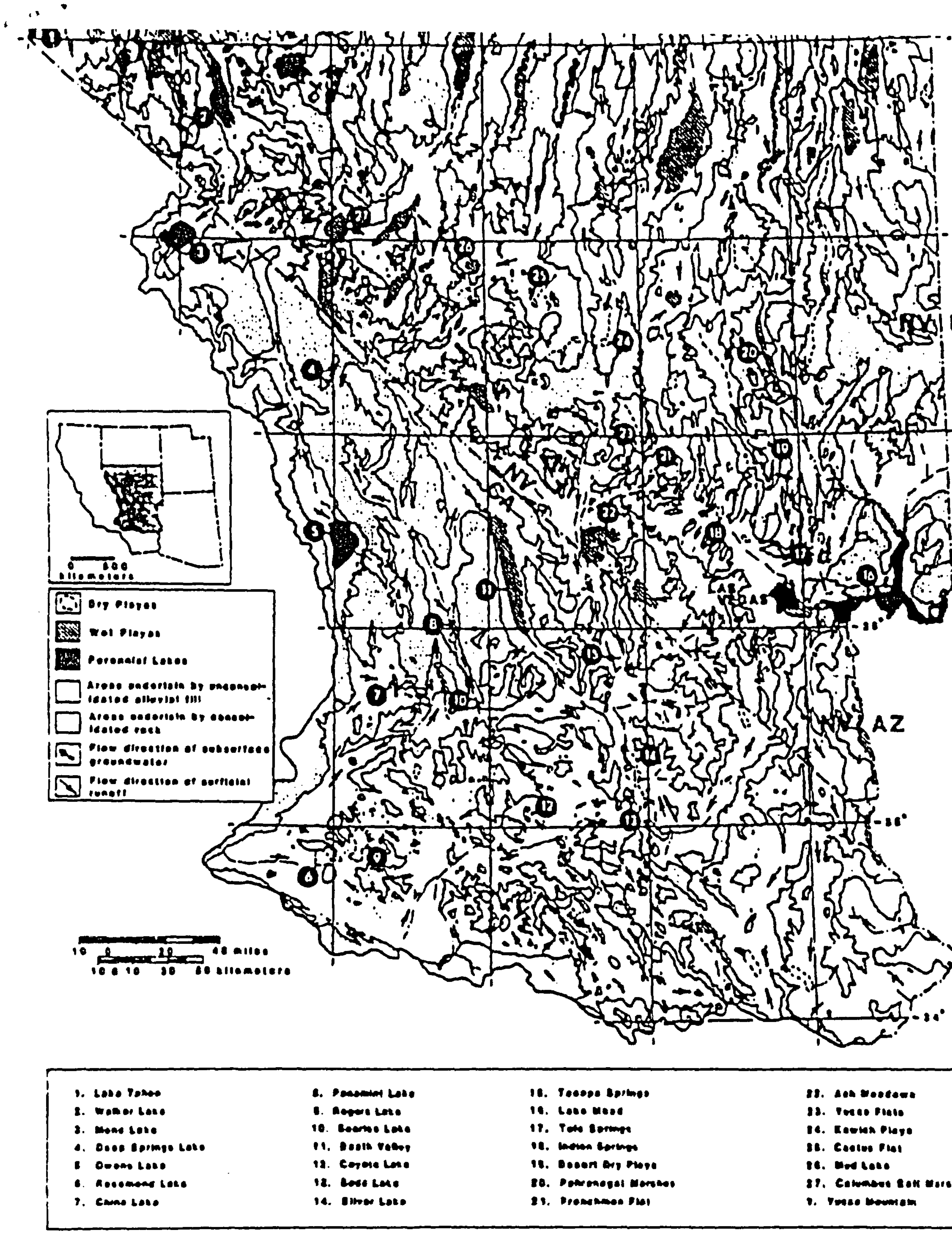
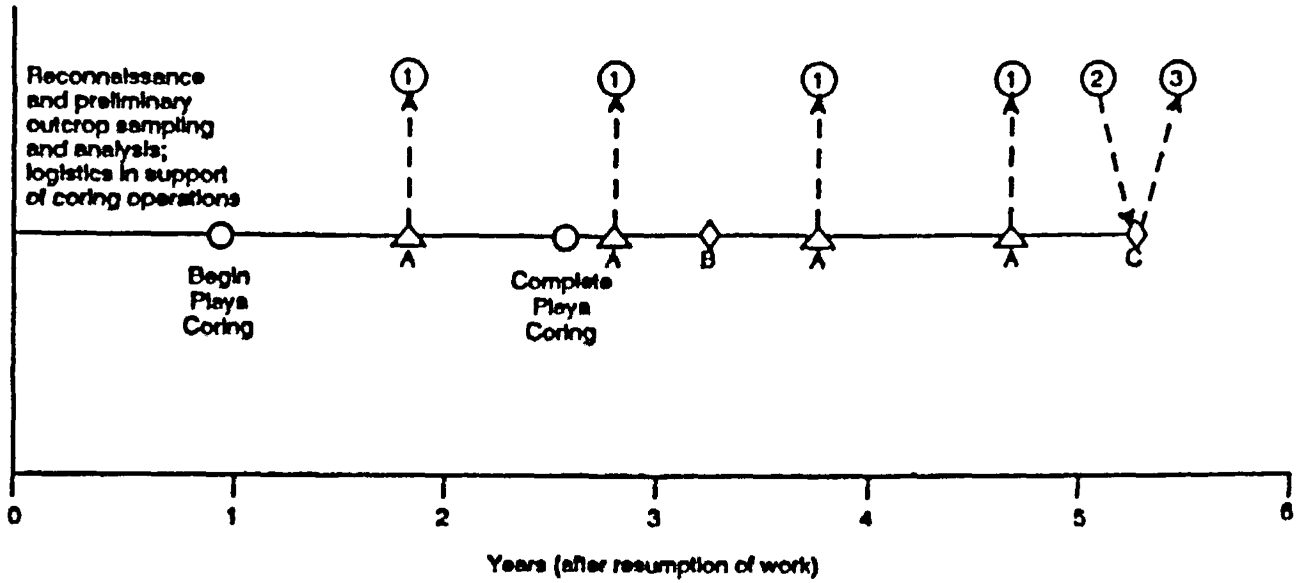


Figure 2-1. Index map showing location of lakes and playas in southern Nevada and southeastern California (from Bedinger et al., 1984).



Explanation

- Level 2 milestones
- Level 3 milestones
- Scheduled input or output of data
- Test duration
- A Milestone description
- A Open File Report: Paleoclimatic implications of lake, playa, and marsh deposits.
- B Preliminary Report: Paleoclimatic implications of lake, playa, and marsh deposits.
- C Final Report: Paleoclimatic implications of lake, playa, and marsh deposits.

1 Output:
to Activity 8.3.1.5.1.3.2 (Analysis of pollen samples)
to Activity 8.3.1.5.1.3.3 (Determination of vegetation-climate relationships)
to Activity 8.3.1.5.1.4.3 (Eolian history of the Yucca Mountain region)

2 Input:
from Activity 8.3.1.5.1.1.1 (Synoptic characterization of regional climate)

3 Output:
to Activity 8.3.1.5.1.5.1 (Paleoclimate-paleoenvironmental synthesis)
to Study 8.3.1.5.1.6 (Characterization of future regional climate and environments)

Figure 5-1. Summary schedule for Study 8.3.1.5.1.2

Table 3-1. Technical procedures for Study 8.3.1.5.1.2

Activity	Method	Technical Procedure Number	Technical Procedure Title
		(NWM-USGS-)	
8.3.1.5.1.2.1	Palynological and paleoecological analyses	HP-76	Diatom enumeration studies
		HP-78	Nonmarine calcareous-microfossil sample preparation and data acquisition procedures
		HP-79	Analysis of fossil pollen from lake sediments
		TBD*	Ostracode sample collection procedures for modern and fossil materials
8.3.1.5.1.2.2	Coring, trenching, and sampling of lake, playa and marsh sediments	GCP-02	Labeling, identification, and control of samples for geochemistry and isotope geology
		GP-07	Geologic mapping
		GP-02	Subsurface investigations
		GP-03	Stratigraphic studies
		GP-07	Geologic trenching studies
		HP-37	Preliminary procedure for drilling and coring of wet- and dry-lake sediments
		TBD*	Procedures for sedimentologic description of sediment cores
		TBD	Description and interpretation of sedimentary features
		TBD	Seismic refraction surveys
		SP-14	Shallow seismic reflection profiling (Mini-Sosie)

Table 3-1. Technical procedures for Study 8.3.1.5.1.2 (cont.)

		Technical Procedure	
Activity	Method	Number	Title
		(NWM-USGS-)	
8.3.1.5.1.2.3	Carbonate mineral analysis	TBD*	Quantitative x-ray diffraction analysis of carbonate minerals and quartz
	Analyses of organics in lake, playa, and marsh sediments	TBD	Procedure to characterize and quanitify organic matter bio-marker contents of lake sediment samples
	Mineralogic analyses	TBD	Element analyses of bulk sediments
	—	TBD	Mineral analyses of bulk sediment samples
		TBD	Stable oxygen and carbon isotope analyses of organic and biogenic carbonate
		TBD	Trace metal analyses of inorganic and biogenic carbonate
8.3.1.5.1.2.4	Dating of lake, playa, and marsh deposits	GCP-01	Radiometric-age data bank
		GCP-02	Labeling, identification and control of samples for geochemistry and isotope geology
		GCP-03	Uranium-series dating
		GCP-05	Radium, equivalent uranium, thorium, and potassium analysis by gamma-ray spectrometry
		GCP-06	Potassium-argon dating

Table 3-1. Technical procedures for Study 8.3.1.5.1.2 (cont.)

Activity	Method	Technical Procedure Number	Technical Procedure Title
		(NWM-USGS-)	
8.3.1.5.1.2.4 (cont.)	Dating of lake, playa, and marsh deposits (cont.)	GP-08	Correlation of tephra by means of chemical analyses
		GCP-04	Uranium-trend dating
		TBD*	Amino acid analysis
		TBD	Radiocarbon dating conventional and tandem accelerator methods
		TBD	Thermoluminescence dating
		TBD	Paleomagnetic analyses
		TBD	Biostratigraphic and bio-chronologic analyses

*TBD - to be determined

Table 4-1.--Information to be provided to other studies by Study 8.3.1.5.1.2

Information to be obtained from this study	Where information will be used'	How information will be used
Lake sediment samples from cores.	8.3.1.5.1.3.2	To provide a source of data to be used in pollen analyses.
Nature, timing, duration, and amplitude of paleoclimate changes based on analyses of paleontologic, geochemical, and stratigraphic data for the southern Great Basin. Estimates of past changes in precipitation, temperature, relative moisture balance, and other climatic parameters.	8.3.1.5.1.3.3, 8.3.1.5.1.4.3, and 8.3.1.5.1.5.1	To be used as a tool to cross-check and supplement the terrestrial paleoecological record in light of paleoclimatic information (i.e., to establish mutual compatibility as well as disparities in the paleoclimate-paleoenvironmental data).
	8.3.1.5.1.5.1	To be integrated with other studies into formats that can be utilized by investigations of future climatic changes and paleohydrology.
	8.3.1.5.1.6*	To analyze past climatic periodicity and for validating numerical and empirical climate models.
	8.3.1.5.2.2*	To assist in the characterization of the potential effects of future climatic conditions on the regional hydrologic system at Yucca Mountain.

Table 4-1. (Continued)

Studies or activities in which information will be used:

8.3.1.5.1.3.2: Analysis of pollen samples.
8.3.1.5.1.3.3: Determination of vegetation-climate relationships.
8.3.1.5.1.4.3: Eolian history of the Yucca Mountain region.
8.3.1.5.1.5.1: Paleoclimate-paleoenvironmental synthesis.
8.3.1.5.1.5.6: Characterization of the future regional climate environments.
8.3.1.5.2.2: Characterization of the future regional hydrology due to ılimate changes.

* Information from Study 8.3.1.5.1.2 will be used indirectly.