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PREFACE

This study plan summarizes and extends the discussion of Study 8.3.1.5.1.3 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 generally beyond those described in the SCP.

R. S. Thompson is the principal author of the study plan. F. R. Singer prepared input for sections 1, 4, and 5. W. R. Keefer assisted in the preparation and review of the plan.

ABSTRACT

Study 8.3.1.5.1.3 is designed to provide qualitative and quantitative data bearing on climatic changes during late Quaternary time in the Yucca Mountain and surrounding regions of the southern Great Basin. Based primarily on the collection and analysis of plant macrofossils from pack rat middens and fossil pollen assemblages from lake, playa, and marsh deposits, these data will be used to: (1) relate past regional climatic changes with global climate variations; (2) validate numerical models of climate; (3) establish the relationships between past climatic changes and hydrologic responses; and (4) predict future climatic fluctuations.

The results of the study will assist in evaluating the effects of future climate changes in surface water, unsaturated zone, and saturated zone hydrology, which is essential to address the objective of limiting release of radionuclides 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 8.3.1.5.1.3

CLIMATIC INTERPRETATIONS OF TERRESTRIAL PALEOECOLOGY

This study plan summarizes and supplements the discussion of section 8.3.1.5.1.3 of the Site Characterization Plan (SCP). It describes plans for estimating climatic changes in the southern Great Basin during the last 200,000 years based on three activities:

- 8.3.1.5.1.3.1 -- Analysis of pack rat middens.
- 8.3.1.5.1.3.2 -- Analysis of pollen samples.
- 8.3.1.5.1.3.3 -- Determination of vegetation-climate relationships.

The study is part of the Climate Program (8.3.1.5); it is one of three planned studies to gather data bearing on the paleoclimate of the region surrounding Yucca Mountain. Figure 1-1 shows the relation of the study to other studies in the climate program.

1 PURPOSE AND OBJECTIVES OF THE STUDY

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

The arid climate of the southern Great Basin is one of several factors making Yucca Mountain potentially attractive for the long-term disposal and isolation of radioactive waste. The persistence of arid conditions (and of an accompanying thick unsaturated zone) in the region through the postclosure period would be advantageous to waste isolation. However, paleoclimatic studies in the surrounding region indicate that the modern degree of aridity is atypical of the past few hundreds of thousands of years. Shallow ground-water recharge occurred in southern Nevada between 20,000 and 10,000 years ago (Claassen, 1985), when major climatic changes created vast lakes in many of the valleys of Nevada, Utah, and eastern California (see SCP section 5.2). Although such high magnitude events may be quasi-periodic on a time scale of 100,000 years, most of the intervening periods appear to have been wetter than today (Smith, 1984).

To provide both qualitative and quantitative estimates of changes in climatic parameters (precipitation, temperature, seasonality, etc.) for late Quaternary time in the southern Great Basin, this study will collect and analyze data on (1) plant macrofossils from pack rat middens; (2) fossil pollen assemblages from lake, marsh, and playa deposits; (3) radiocarbon age determinations on paleo-vegetational assemblages; (4) vegetation-climate and

(or) pollen-climate response surfaces; and (5) pollen-climate transfer functions. This information will be used to relate past regional climatic changes with global climate variations, to validate numerical models of climate, to establish the relationships between past climatic changes and hydrologic responses, and to predict future climatic fluctuations. These results, in turn, will be used to predict future changes in the hydrologic regime at Yucca Mountain.

The specific information to be obtained in each activity is discussed in sections 3.1.1, 3.2.1, and 3.3.1. Specific uses of the information for measuring repository performance against goals for performance measures are discussed in sections 1.2 and 3.3.9; uses of the information for supporting other studies are discussed in section 4.

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

Information from the study is needed as a basis for evaluating the nature and rates of change in climatic conditions to predict future climates. As noted in sections 1.1 and 4, the information is needed mainly as input into future climate studies and paleohydrologic studies. Information from this study is not intended to directly satisfy design and performance goals for design and performance issues; the SCP does not identify any site characterization parameters needed from this study to satisfy data requirements of design and performance parameters (necessary to determine if the issues performance goals can be met). Specifically, the information will be used to derive a model of future climatic change. This model is needed to predict potential future climatic changes that could (through the hydrologic regime) alter the long-term waste isolation capability of the Yucca Mountain site.

As shown in SCP Table 8.3.1.5-2, information from this study will be used to support Performance Issue 1.1 (Section 8.3.5.13), the system performance objective for limiting radionuclide releases to the accessible environment as required by 10CFR60.112 and 40CFR191.13 and Performance Issue 1.9b (Section 8.3.5.18), the comparative evaluation required by 10CFR960.3-1-5 over the next 100,000 years (SCP Table 8.3.1.5-2).

For the 10,000-year period, it has been determined that information needed to satisfy Issue 1.1 will be sufficient to address Issues 1.8, 1.9a, 1.10, 1.11, and 1.12. Information from the study will indirectly address:

- the potentially adverse condition for climate (Issue 1.8, section 8.3.1.17), namely "potential for changes in hydrologic conditions resulting from reasonably foreseeable climatic changes" (10CFR60.122(c)(6)).

- the qualifying condition for geohydrology (Issue 1.9a, section 8.3.5.18): "The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation" (10CFR960.4-2-1).

- information on post emplacement near-field waste package environment (Issue 1.10, section 8.3.4.2).

- characteristics and configuration of the repository-engineered barriers (Issue 1.11, section 8.3.2.2)

- seal characteristics (Issue 1.12, section 8.3.2.2)

This study will also provide data on past, present, and future climatic conditions needed to address:

- the favorable condition for climate (Issue 1.8, section 8.3.5.17): "A climatic regime in which the average annual historic precipitation is a small percentage of the annual potential evapotranspiration" (1-CFR60.122(b)(7)(v)).

- the qualifying condition for climate (Issue 1.9a, section 8.3.5.18); "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" (10CFR960.4-2-4).

Figure 1-2 (after SCP figure 8.3.1.5-2) shows how the parameters measured in this study contribute to modeling and synthesis activities that result in a determination of the effects of future climate on surface-water, and unsaturated-zone and saturated-zone hydrology. Ultimately, this information will be used to satisfy the performance and design issues (and other characterization programs) shown in figure 1-3 (after SCP figure 8.3.1.5-1).

2 RATIONALE FOR SELECTING THE STUDY

When viewed on a scale of hundreds to thousands of years, climate is constantly changing, and future climatic fluctuations may significantly affect the hydrologic regime and erosion rates at Yucca Mountain. Thus, climate change must be considered when evaluating the suitability of the potential repository site. Over the last 200,000 years, the climate of the Northern Hemisphere has been both considerably warmer and colder than today, ranging from "interstadial glacial" to "full-glacial" conditions, to conditions warmer than today (Isotope stage 5e and the middle Holocene), and to modern conditions. This period thus offers examples of different configurations of global climatic boundary conditions, and the effects of these changes in southern Nevada must be studied in detail. Available techniques for dating paleoclimatic changes are also most precise over this period and "synoptic snapshots" of paleoclimatic conditions at appropriate times in southern Nevada can be constructed for numerical model validation.

The global climates of the next 10,000 to 100,000 years may include a period of much warmer than modern conditions (i.e., a "greenhouse" world), as well as glacial conditions. To understand the ramifications of this change, the last 200,000 years must be studied in moderate detail to provide examples of the climatic effects of such global changes on the Yucca Mountain region. Because climatic conditions have varied enough to allow boreal small mammals such as the bog-lemming to live in wet seeps in the Yucca Mountain region over the last 500,000 to 1,000,000 years, some knowledge of these seemingly very different conditions is also required to predict the possible magnitudes of future wet episodes at Yucca Mountain. Moreover, data from even farther back in time may ultimately be needed to provide evidence on regional conditions under much warmer than modern global climates.

Climate is operative on a regional scale, and no single station or paleoclimatic site can provide an adequate record of past variability or be representative of the climate over the entire recharge area. The same characteristic applies to paleoclimatic records, and paleoclimatic data on a regional scale are necessary to provide a check on the continuity of the local records and thereby reduce the uncertainty involved in identifying major past periods of high effective moisture. Regional records, especially palynological data from extant lakes and marshes, should provide more complete stratigraphic sections and greater temporal resolution for dating past periods of major recharge. The potential for missing portions of the record through deflation, etc., will be minimized by studying permanently wet sites. Regional scale data are also necessary for describing variations in past storm track positions, for the validation of climatic models, and for testing hypotheses on temporal and spatial patterns of climatic change. These aspects would require a spatial network of sites for key time-periods in the past. The sources of paleoclimatic proxy data that are available on a regional scale are the same as on the local scale, with the notable addition of permanent lakes as sources of micropaleontological data.

Paleoclimatic studies at Yucca Mountain will attempt to determine the past frequency and timing of past climatic circulation patterns that led to high levels of effective moisture. Future climatic studies of future climate will attempt to estimate the probability of these occurrences over the next 10,000 to 100,000 years.

Other types of terrestrial paleoecological data have been considered, including small vertebrates and insects. While these alternative data-sources will be used to provide important supporting information, they are not as well distributed in time and space as the vegetation data.

2.1 Rationale for the types of tests selected

2.1.1 Activity 8.3.1.5.1.3.1 Analysis of pack rat middens

A single test -- collection, analysis, and radiocarbon dating of pack rat midden macrofossil assemblages -- will be conducted to provide data for use in determining past vegetation changes in the Yucca Mountain area. Rodents of the genus Neotoma (pack rats, wood rats, or trade rats) gather plants from the immediate area (30-50m) surrounding their middens, and deposit such materials in these rock cavities. The plant remains can usually be identified to the species level, and the preserved assemblages in ancient middens are thus a direct indication of (1) the kinds of plants growing at that locality during a particular period of time, and (2) the climatic conditions that existed during growth. Macrofossil plant assemblages less than 20,000 years old can commonly be dated to within a few hundred years by radiocarbon dating methods. Middens are known as far back as approximately 50,000 years, but radiocarbon dates become less precise with increasing age (Colman and Pierce, in press).

2.1.2 Activity 8.3.1.5.1.3.2 Analysis of pollen samples

The test for this activity involves the collection and analysis of pollen deposited in lake and other sediments. Studies of fossil pollen in stratified deposits have been used extensively in the eastern United States and Europe to reconstruct fluctuations in temperature and precipitation over the last 20,000 years. The applicability of the method has been limited in the western United Sates by the relative scarcity of bogs and small lakes. However, paleoclimatological insights have been gained from studies of fossil pollen contained in sediments deposited in pluvial and alpine lakes, caves, rock shelters, and alluvium.

Pack rat middens also contain pollen, particularly from the local vegetation surrounding the midden site, and its analysis can be helpful in determining the nature of the pollen rain in areas where lakes and marshes are not prevalent.

Pollen records, in general, provide quasi-continuous records of regional vegetational change. Although most pollen studies are restricted to the Holocene, palynological studies

of pluvial lake, marsh, and playa sediments also provide information over a period of ten to several hundreds of thousands of years ago. Studies of pollen from cores collected from these kinds and ages of sediments will be conducted as part of Study 8.3.1.5.1.2 (Paleoclimate study: lake, playa, marsh deposits), and the resulting data applied in this activity.

2.1.3 Activity 8.3.1.5.1.3.3 Determination of vegetation-climate relationships

In this activity, the data resulting from the pack rat midden (Activity 8.3.1.5.1.3.1) and palynological studies (Activity 8.3.1.5.1.3.2) will be analyzed to provide a regional network of time series of vegetational change spanning the past few tens of thousands of years. Much of the evidence for past climatic variations comes from such paleoecological records for past vegetation. In addition, tree-ring data that have been collected in central and western Nevada (La Marche, 1974) may be interpreted to determine relationships between tree-ring widths and seasonal fluctuations in climate on the scale of 10 to 1,000 years. The analysis will be conducted in conjunction with similar analyses in Activity 8.3.1.5.1.2.4 (Chronologic analyses of lake, playa, and marsh deposits).

Interpretations of past vegetation-climate relationships are necessary for constructing the simulation models of past climatic conditions that are being planned for Study 8.3.15.1.6 (Characterization of the future regional climate and environments). To judge the ability of a given model to correctly simulate past climate, information bearing on modern vegetation-climate relationships is used to transform model simulations of past climates into estimates of past vegetation. These estimates can then be compared with the observed fossil record to make quantitative estimates of past climate variables, which is the primary objective of this activity.

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

The number and location of data points for pack rat midden studies and pollen analyses will depend in large part on the requirements of the validation exercises being planned for the numerical modeling of climatic and paleohydrologic changes in Activity 8.3.1.5.1.6.2 (Regional climate modeling), inasmuch as the estimation of past climatic variables by numerical methods is based on networks of both modern calibration data and fossil data. Although the requirements for the fossil data (from Study 8.3.1.5.1.3) have not yet been determined, it is anticipated that middens will be sampled and studied at as many as several hundred sites throughout the southern Great Basin and adjacent regions (fig. 2-1). The sites will be selected so as to (1) substantiate and supplement the extensive amounts of data published previously on pack rat middens in the southern Great Basin (e.g., Betancourt, et al, 1990); and (2) ensure that a representative range of paleoclimate data (precipitation, temperature, evaporation) is obtained throughout the recharge area surrounding Yucca Mountain. Sampling localities for pollen will be dictated in part by the localities selected for study in Study 8.3.1.5.1.2. The sampling network is expected to provide the information necessary for (1) understanding synoptic-scale climatic variations, and (2)

validating numerical climate models. Such regional information is also necessary for describing variations in storm-track positions and for testing hypotheses on temporal and spatial patterns. The work being planned for Activity 8.3.1.5.1.3.3 is dependent upon the number and location of the study sites selected for Activities 8.3.1.5.1.3.1 and 8.3.1.5.1.3.2.

With regard to duration and timing, data collection and analysis for Activities 8.3.1.5.1.3.1 and 8.3.1.5.1.3.2 will take approximately four years, and should precede the bulk of the work being planned for the numerical analyses of the fossil data in Activity 8.3.1.5.1.3.3. The latter activity is expected to be completed about 6 months after the completion of work for the first two activities.

2.3 Constraints

The choice of tests for this study was unaffected by their impacts on the site, simulation of repository conditions, timing, or interference with other tests or the design and construction of the exploratory study facilities. Other factors related to test selection are as follows:

1. Required accuracy and precision: none specified in SCP, but tests selected so as to provide specific data that will help to identify temperature and precipitation extremes for numerical modeling of climatic and hydrologic systems.

2. Limits of analytical methods:

   (a) In most cases, fossil plant remains in pack rat middens can be identified to the species level, although some fossils (such as grass culms) may only be identifiable at the genus or family level.
   (b) Most fossil pollen grains can be identified to the generic level, although some can only be assigned to plant family or group of families. Pollen can only rarely be resolved to the specifies level.

3. Capability of analytical methods: the planned vegetation studies are designed primarily to provide data for numerical models of hydrologic and climatic conditions which require estimates of past precipitation, temperature, and seasonality.

4. Scale and applicability of selected tests:

   (a) Analyses of pack rat midden macrofossil plant assemblages will provide paleoclimatic estimates from a sample area extending about 50 m outward from the midden site, with an approximate temporal resolution of ±200 years for the past 20,000 years and up to a few thousand years as the limit for radiocarbon dating resolution is approached.

(b) Analyses of fossil pollen samples will provide data for time-series of paleoclimatic estimates potentially covering the last million or more years. These data differ from those from pack rat middens in that: 1) they provide quasi-continuous records of change, 2) they have coarser taxonomic resolution (and thus provide coarser paleoclimatic estimates), 3) an individual pollen spectrum usually integrates information from a wider geographic region than does a midden assemblage, 4) they are more readily quantified and subjected to statistical analyses, and 5) they are available for much longer periods of time (i.e., for hundreds-of-thousands to millions of years versus tens-of-thousands of years). This latter factor is particularly important in that fossil pollen data may provide information on previous climatic episodes that resemble the expected future "greenhouse" climate of the next few hundred years.

3 DESCRIPTION OF TESTS AND ANALYSES

3.1 Activity 8.3.1.5.1.3.1 Analysis of pack rat middens

The objective of this activity is to determine the nature, timing, duration, and magnitude of past vegetation change as recorded in plant macrofossil assemblages preserved in pack rat middens. The parameters include (1) macrofossil assemblages collected from pack rat middens in the southern Great Basin and surrounding region, (2) radiocarbon age determinations, and (3) collection of related data, such as vertebrate, insects, and isotopic data ($\delta^{18}O$, $\delta^{13}C$, δD). The activity will be carried out in conjunction with Activity 8.3.1.5.2.1.4 (Analog recharge studies). The analog recharge studies are based largely on prior midden studies (see e.g., Spaulding, 1985).

3.1.1 General approach

Pack rat midden analysis is restricted to the semiarid and arid deserts of western North America, whereas pollen studies (discussed below) are generally carried out in permanently wet environments. In this activity, past vegetation is reconstructed from plant remains preserved in middens deposited in rock cavities by rodents of the genus Neotoma (pack rats, wood rats, or trade rats). The plant remains can often be identified to the species level, and the assemblages are believed, based on the contents of modern middens, to represent biota living within a radius of 30 to 50 m of the midden at the time of accumulation. Studies of ancient pack rat middens provide radiocarbon-dated inventories of plants, vertebrates, and insects that lived near the collection site in the past. This information can be converted into estimates of precipitation, temperature, and seasonal conditions by quantitative methods that are based on the modern climatic tolerances of these taxa. Figure 2-1 shows the area within the southern Great Basin and surrounding regions where numerous sites will be collected for pack rat midden and palynological data.

3.1.2 Test methods and procedures

Pack rat middens are collected by extracting 0.5 and 1 kilogram-sized samples of material from different levels of the deposit. Where the midden is constructed of multiple deposits, those of particular interest (all or parts of the entire midden) will be samples (see Spaulding, et al, 1990). The samples are soaked in water to dissolve the cementing material (urea) and sieved to concentrate the plant remains (stems, needles, leaves, seeds, etc.). When dry, the plant material is sorted and counted or weighed to produce a quantified record of the different plant taxa present.

Selected plant macrofossils or other materials from each midden are dated by radiocarbon analysis (Donahue, et al, 1983; Linick, et al, 1986). This dating method provides an estimate of the age of the midden assemblage, accurate to within a few hundred years. Where more precision in dating is required, multiple samples from the

same midden are submitted for radiocarbon dating. The paleobotanical data from the individual midden assemblages are compiled to create time series of vegetational change from a given area and vegetational setting. Replication of pack rat chronologies from sites with similar settings ensures that site-specific phenomena do not introduce bias into the interpretation of the data set.

In addition to plant macrofossils, pack rat middens are rich sources of vertebrate and insect remains, pollen, and cellulose for isotopic investigations ($\delta^{18}O$, $\delta^{13}C$, δD). The data may be analyzed to elucidate certain paleoclimatic signals, such as the past seasonal distribution of precipitation or the annual range of temperatures (see, e.g., Long, et al, 1990; Epstein, et al, 1977; and Edwards and Fritz, 1986).

3.1.3 QA level assignment

Quality Assurance (QA) requirements for this activity will be specified in a Yucca Mountain Project QA Grading Report, which will be issued as a separate document. All procedures applicable to this activity will be identified on the basis of the findings in the Grading Report and will be prepared in accordance with applicable QA requirements.

3.1.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this activity. Radiocarbon analysis provides an estimate of the age of the midden assemblage, accurate to within a few hundred years for materials as old as 40,000 years (Colman and Pierce, in press). Where more precision is required, multiple samples from the same midden are submitted for dating. Plant remains from midden macrofossil assemblages should be identified to the species level, if possible.

3.1.5 Range of expected results

From previous studies (e.g., Betancourt, et al, 1990), it is expected that the vegetation in the southern Great Basin over the past 40,000 years has included desert, steppe, woodland, and subalpine forest assemblages. Few data are available to indicate what the longer term variations have been or what the conditions were during previous much-warmer-than-present episodes (Smith, 1974).

3.1.6 Equipment

This activity uses standard field and laboratory equipment (Donahue, et al, 1983; Linick, et al, 1986). Field reconnaissance and sampling equipment includes rock hammers, chisels, flashlights, sample bags, sample labels, marking pens and tape, field notebooks, maps, compasses, and cameras. Laboratory equipment includes notebook, plastic buckets, soil-sieves, drying oven, triple-beam balance, tweezers, and a dissecting microscope. A microcomputer and database program are used to organize the data.

3.1.7 Data-reduction techniques

The paleobotanical data from the individual midden assemblages are compiled to create time series of vegetational change from a given area and vegetational setting. Pack rat middens of equivalent age from several sites will be compiled to produce maps of vegetation for selected time slices.

3.1.8 Representativeness of results

Replication of studies of pack rat middens from sites with similar settings ensures that interpretations based on site-specific information will not introduce bias into the interpretations to be made from the entire data set. The results of the activity are therefore expected to be representative of the region covered in the investigation.

3.1.9 Relations to performance goals and confidence levels

See sections 1.2 and 3.3.8.

3.2 Activity 8.3.1.5.1.3.2 Analysis of pollen samples

The objective of this activity is to determine the nature, timing, duration, and magnitude of past vegetation change as recorded in the stratigraphic record of fossil pollen grains. The parameters are: (1) pollen assemblages collected from lacustrine, marsh, and playa sediments (and other sedimentary deposits) in the southern Great Basin, and (2) radiocarbon dates, tephrochronology, and other chronological markers.

3.2.1 General approach

Fossil pollen data are available from sediments deposited in standing or very-slow moving water in lakes and marshes. These data provide information on the terrestrial vegetation growing near the collection site, as well as in the general region. The sedimentary deposits can be dated through radiocarbon analysis (conventional; AMS, as appropriate) and (or) other techniques (such as thermoluminescence and tephrochronology) and the pollen data analyzed numerically to provide time-series of paleoclimatic estimates.

3.2.2 Test methods and procedures

Pollen is extracted from samples by dissolving unwanted mineral and organic matter with strong acids and bases (see Technical Procedure HP-79, Analysis of fossil pollen from lake sediments). The pollen is comparatively resistant and will remain and become concentrated after dissolution of extraneous materials in the sediment sample. The pollen may be stained to enhance its microstructural detail, and mounted on microscope slides for examination. Pollen grains of known plant taxa are identified, tabulated, and plotted stratigraphically according to absolute concentration (per gram or cubic centimeter of

sediment) or relative percentages. The stratigraphic plots are interpreted in terms of increasing or decreasing amounts of plant taxa responsible for the various pollen types, taking into account the relative pollen production of individual plant groups, the ease by which pollen is distributed, and the processes by which it is incorporated into the sediment and preserved. Methods and techniques for radiocarbon dating are discussed by Donahue, et al (1983) and Linick, et al (1986). Other methods for dating Quaternary materials are given by Colman and Pierce (in press).

In some cases pollen studies will be conducted at the same sites as those for paleolacustrine investigations (Study 8.3.1.5.1.2), because lake sediments may contain well-preserved pollen and represent more or less continuous deposition. However, because of exposure and oxidation, playa deposits may be unsuitable for pollen analysis. Pack rat middens also contain pollen, particularly from the local vegetation surrounding the midden site, and its analysis can be helpful in determining the nature of the pollen rain (the pollen coming from and falling on any region) in areas where lakes and marshes are few.

3.2.3 QA level assignment

Quality Assurance (QA) requirements for this activity will be specified in a Yucca Mountain Project QA Grading Report which will be issued as a separate document. All procedures applicable to this activity will be identified on the basis of the findings in the Grading Report and will be prepared in accordance with applicable QA requirements.

3.2.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified in the SCP for this activity. Radiocarbon analyses (conventional or AMS) provide an estimate of the ages of pack rat middens accurate to within a few hundred to a few thousand years. Pollen stratigraphic profiles are dated with radiometric techniques (radiocarbon, U series, K/Ar, Ar/Ar, or others as appropriate) through tephrochronology, paleomagnetics, fossil correlation, or other techniques as appropriate, with the accuracy being dependent on the method (see Colman and Pierce, in press).

3.2.5 Range of expected results

The discussion in section 3.1.5 is applicable to this section when sediment accumulations is rapid. If sediment accumulation is low (centuries or millennia) pollen grains are often not preserved. If they are preserved, their value for paleoclimatic interpretations are greatly diminished.

3.2.6 Equipment

Items of equipment required for radiometric dating are given in Donahue, et al (1983) and Linick, et al (1986). Items utilized for field work for this activity are: coring devices,

flotation devices, sample bags, sample labels, marking pens, and tape. Items used to record the position, geographic location, and setting of pollen cores or samples include field notebooks, maps, compasses, and cameras. In the laboratory the following equipment is used to record sample information, extract the pollen from the sediment matrix, transfer the sample residue to vials, and identify the microfossils: laboratory notebook, fume hood, centrifuge, centrifuge tubes, hot-water bath, chemical reagents, and an electronic balance. Following these steps, the pollen and other microfossils are identified (using a compound microscope), counted, and recorded on a microcomputer. An IBM PC-compatible with database program will be used to organize the pollen data. No additional major equipment is required, but maintenance and repair of existing equipment may be necessary.

3.2.7 Data reduction techniques

The pollen spectra from a given deposit will be compiled to form time-series of paleobotanical changes from the collection site. Pollen records of equivalent age from several sites will be compiled to produce maps of vegetation for selected time slices.

3.2.8 Representativeness of results

The discussion in section 3.1.8 is applicable to this section, except that the reference should be to the results of pollen studies.

3.2.9 Relations to performance goals and confidence levels

See sections 1.2 and 3.3.8.

3.3 Activity 8.3.1.5.1.3.3 Determination of vegetation-climate relationships

3.3.1 Purpose of analysis

The purpose of this analysis is to translate the vegetational records provided by pack rat midden and palynological activities in the present study, and from available dendroclimatological data, into quantitative estimates of past climatic variables in support of the paleoclimatic-paleoenvironmental synthesis of Study 8.3.1.5.1.5.

3.3.2 Methods of analysis

Numerical methods for quantitative analyses of paleo-vegetation data will be selected from among numerous previous studies (e.g., Webb, et al, 1987) as data produced in Activities 8.3.1.5.1.3.1 and 8.3.1.5.1.3.2 become available. The interpretation of these paleoecological records in climatic terms requires information on the modern relationships between vegetation and climate. Paleoclimatic conditions are inferred from fossil vegetation by extrapolation from the relations between modern vegetation and climate. It is expected that the two related approaches for constructing statistical relationships between

modern vegetation and climate data will be used in this activity: (1) a transfer function approach in which individual climate variables are expressed as a function of several vegetation predictor variables (e.g., the percentages of different pollen types); and (2) a response function approach in which the presence/absence and (or) relative abundances of individual taxa are expressed as nonlinear functions of one or more environmental variables.

The transfer function approach usually makes use of a multiple regression analysis to construct a relationship between a particular climate variable and a number of predictor variables, which are generally the percentages of individual pollen types in the modern world. In practice, a data set of paired observations of modern surface pollen samples and climate is required for calibration of the transfer function equation. The resulting equation is then applied to fossil pollen data to interpret them in paleoclimatic terms.

In the response function approach, the relative abundance of probability of occurrence of different taxa is expressed as a nonlinear (usually polynomial) function of one or more environmental (usually climatic) variables. The resulting functions are usually displayed as "response surfaces" that show how the abundance or probabilities vary in the space defined by the environmental variables. For relative abundance data, the response functions are fit using linear regression, while for presence/absence of data, the surfaces are fit using logistic regression. The same set of modern climate and vegetation data required for the calibration of these is the same as that for the calibration of transfer functions.

Because response functions illustrate the environmental preferences of different taxa, they can provide guidance in the qualitative interpretation of fossil data in climatic terms. Quantitative reconstruction is possible as well, using response functions of several taxa to determine the environmental conditions necessary to give rise to a particular fossil assemblage.

Application of response functions for climate model validation is relatively straightforward. The relative abundance or presence/absence of different taxa can be simulated by applying response functions to the values of climate variables simulated by climate models. The simulated vegetation variables can then be compared with the observed. In a typical example, the climate model would be set up to simulate some specific paleoclimate, and the simulated vegetation would be compared with the observed fossil record.

Another approach for reconstructing past climatic variations makes use of the method of modern analogs. In this approach, a set of modern pollen or vegetation samples is searched in order to find a close analog for a particular fossil assemblage. The climate values associated with the best match(es) then become the climate reconstructions. This approach may be limited by a lack of good modern analogs for the fossil assemblages at particular times.

3.3.3 Technical procedures to be followed

Tentative technical procedures include (1) transfer functions and response surfaces, and (2) preparation of "synoptic snapshots" of climate extremes. Completion schedules have not yet been established for these procedures.

3.3.4 QA level assignments

Quality Assurance (QA) requirements for this activity will be specified in a Yucca Mountain Project QA Grading Report which will be issued as a separate document. All procedures applicable to this activity will be identified on the basis of the findings in the Grading Report and will be prepared in accordance with applicable QA requirements.

3.3.5 Data to be analyzed

Data that will be analyzed include: 1) modern climatic data (e.g., temperature, precipitation, evaporation, wind velocity) from standard sources; 2) modern vegetation data from published sources; 3) modern pollen surface samples, generated by this study and from published sources; 4) vegetation data from modern pack rat middens; 5) fossil pollen data in cores from lakes and bogs; 6) macrofossil data from fossil pack rat middens; and 7) model output from climate simulation models.

3.3.6 Expected output and accuracy

The combination of data on modern and past vegetation as listed above should lead to specific conclusions regarding the nature of the climatic variations responsible for the vegetation changes recorded by the fossil evidence. The accuracy of the findings depends upon the levels of accuracy achieved in the dating and correlation of deposits and materials that are being collected and analyzed in this study (see secs. 3.1.4 and 3.2.4).

3.3.7 Representativeness of results

Palynological and pack rat midden studies together provide a regional network of time series of vegetational change spanning the last few tens of thousands of years. The combination of these two methods should ensure that the range of past regional climate fluctuations over the past 40,000 years will be represented in this study. Study of fossil pollen from land plants recovered from cores of lacustrine sediments is expected to provide similar data for the past 200,000 years.

3.3.8 Relations to performance goals and confidence levels

The conversion of paleo-vegetation data into quantitative estimates of past climatic variations is essential to the modeling of future climatic changes and to determining the effects of these changes on the hydrologic regime that could alter the long-term waste

isolation capability of the potential Yucca Mountain site. Accordingly, the results provide supporting data in addressing several design and performance goals and issues as discussed in section 1.2.

4 APPLICATION OF RESULTS

As summarized from information presented in chapter 8 of the SCP and shown on table 4-1, information from this study, in conjunction with other data gathering activities (Activity 8.3.1.5.1.1.1, Synoptic characterization of regional climate, and Study 8.3.1.5.1.2, Paleoclimate study: lake, playa, and marsh deposits), will form the basis for the paleoclimate-paleoenvironmental synthesis study (Study 8.3.1.5.1.5). 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).

Related discussions in section 1.2 consider the uses of information from the study in the context of issue resolution and performance goals.

5 SCHEDULES 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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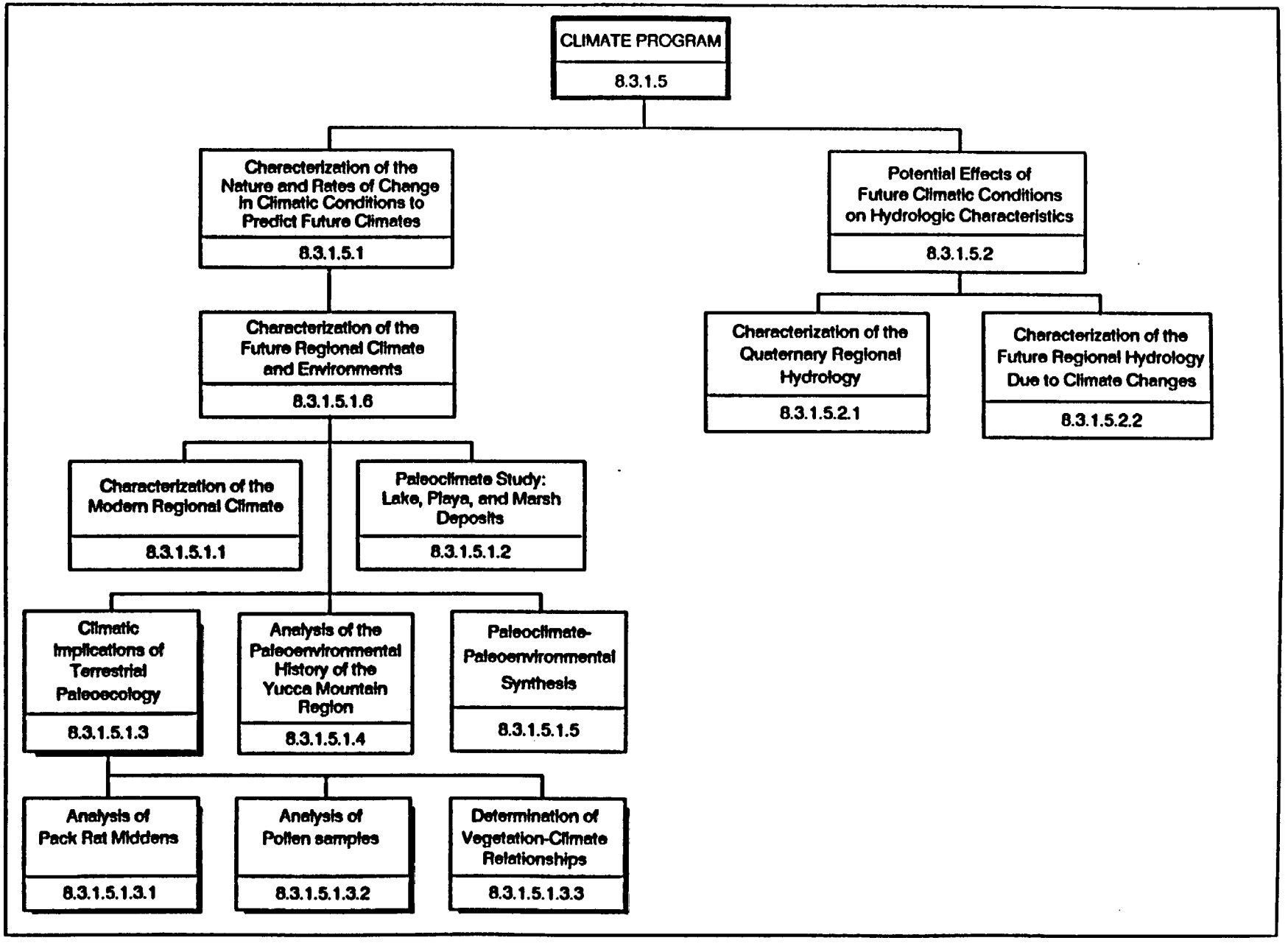


Figure 1-1. Location of the study within the future climate program.

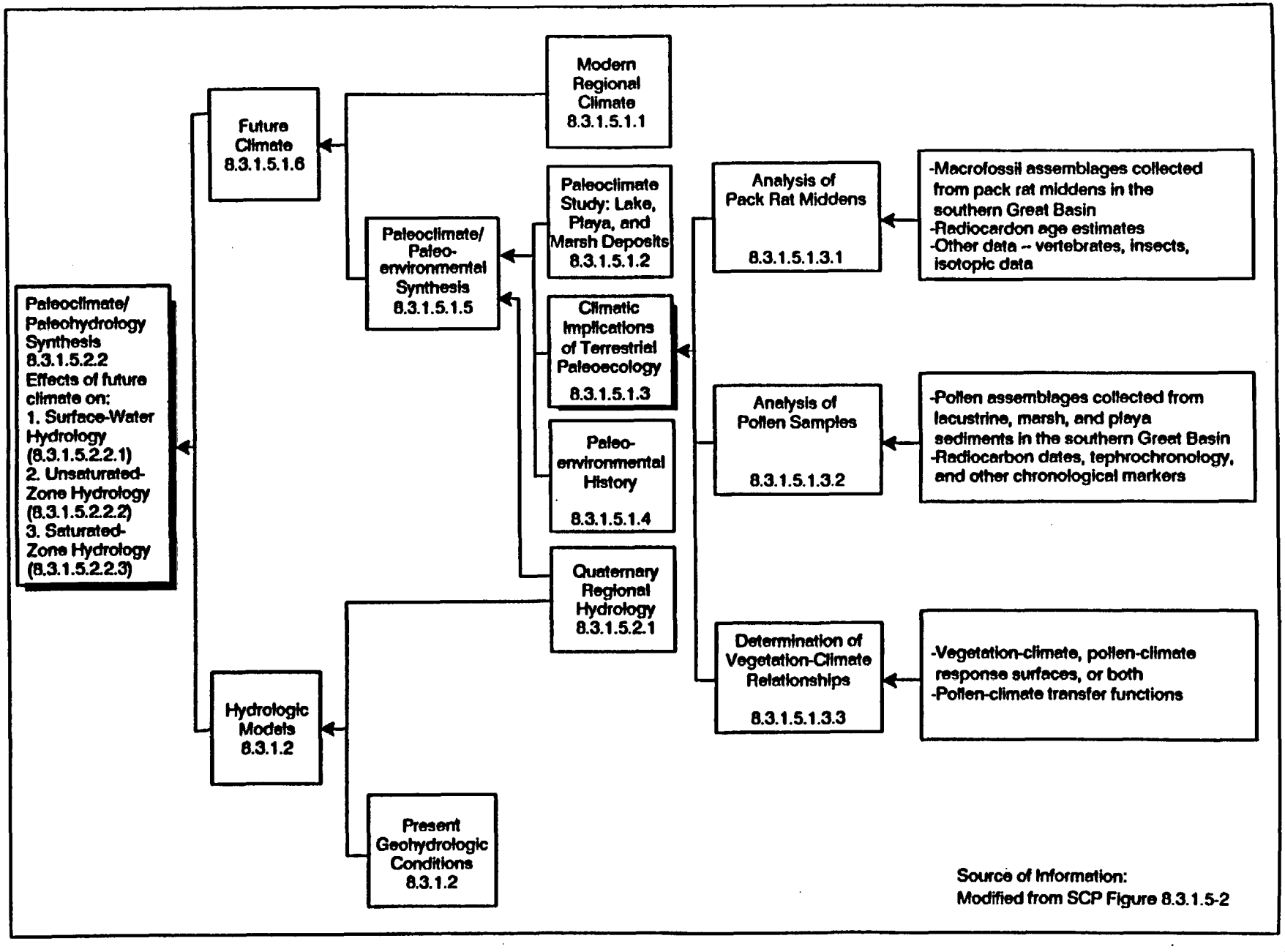


Figure 1-2. Logic diagram showing site characterization parameters of Study 8.3.1.5.1.3 in relation to the climate program.

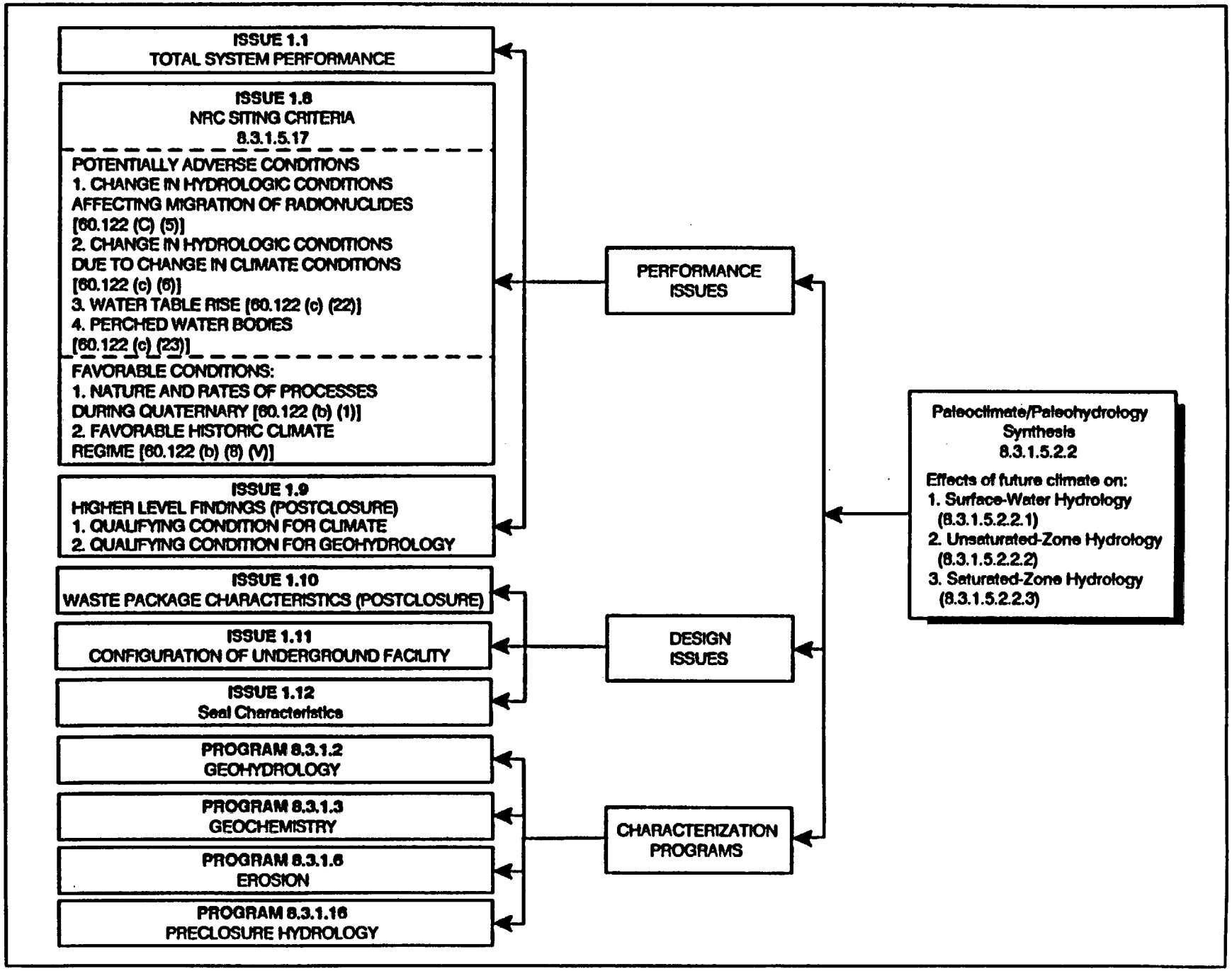


Figure 1-3. Interfaces of study 8.3.1.5.1.3 with YMP performance and design issues and other site-characterization programs.

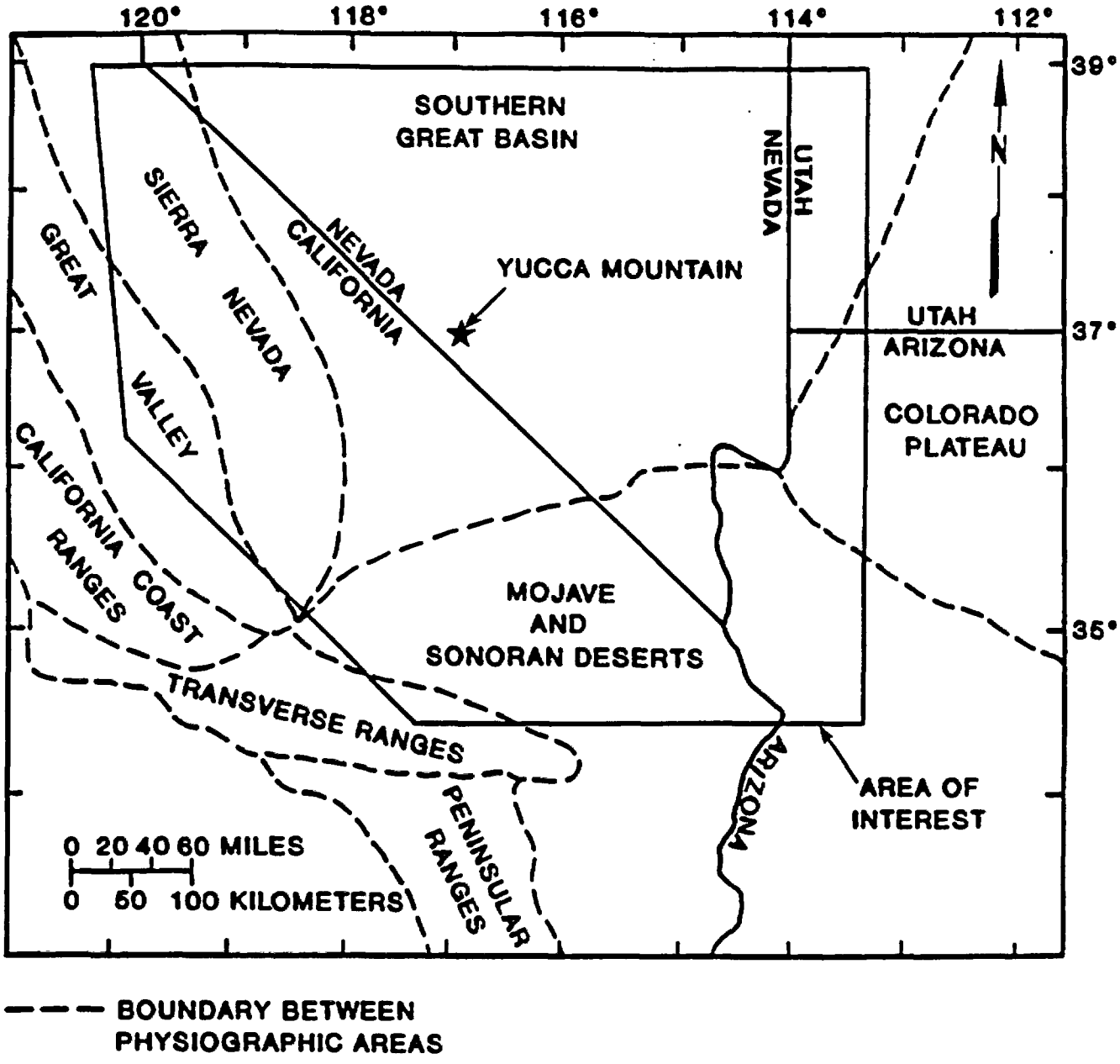
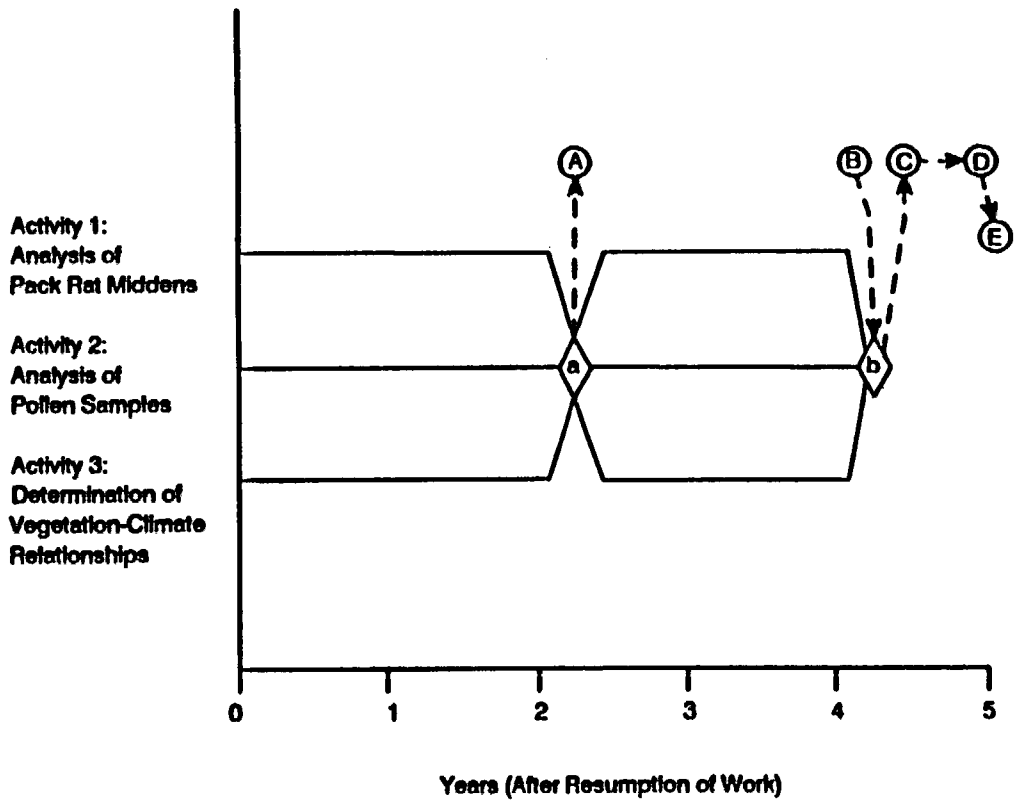


Figure 2-1. Map showing area in southern Nevada and adjacent parts of Utah, Arizona, and California in which sites will be selected for collection and analysis of pack rat and palynological data. (Physiographic boundaries from U.S. Geological Survey, 1984, fig. 7.)



Explanation

◇ Level 2 milestone
a - Interpretive Report: Terrestrial Paleocology
b - Final Report: Terrestrial Paleocology

○ Scheduled input or output

—— Test duration

(A) Output: Study 8.3.1.5.1.5 (paleoclimate-paleoenvironmental synthesis)

(B) Input: Activity 8.3.1.5.1.1.1 (synoptic characterization of regional climate) and Study 8.3.1.5.1.2 (paleoclimate study: lake, playa, and marsh deposits)

(C) Output: Define Quaternary climate of Yucca Mountain (Study 8.3.1.5.1.5 - paleoclimate-paleoenvironmental synthesis)

(D) Output: Simulate future climates (Activity 8.3.1.5.1.6.3 - linked global-regional climate modeling)

(E) Output: Hydrology due to climate (Activity 8.3.1.5.2.2.1 - analysis of future surface hydrology due to climate changes) Input to UZ hydrology for license application (Activity 8.3.1.2.2.9.5 - Site UZ integration and synthesis)

Figure 5-1. Schedule for Study 8.3.1.5.1.3.

Table 4-1.--Information to be provided to other studies by Study 8.3.1.5.1.3

Information to be obtained from this study	Where information will be used[1]	How information will be used
Estimates of changes of climatic variables (e.g., precipitation, temperature) for the southern Great Basin.	8.3.1.5.1.5, 8.3.1.5.1.6*	To provide a baseline and background for investigations of future climatic changes and paleohydrology.
Reconstruction of past climates.		To provide a regional network of time series (chronologies) of vegetational change spanning approximately the last 200,000 years.
Reconstruction of vegetation change near Yucca Mountain and vicinity.		To contribute to synoptic snapshots of climatic conditions during key periods in the past.
		To provide a basis for estimating magnitude, timing, and duration of major past periods of high effective moisture.
		To provide input into future climate conditions to evaluate/validate numerical and empirical models.
		To establish the relationships between past periods of high effective moisture in southern Nevada and global climate states.
		To provide boundary conditions for regional and global climate modeling.
	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.

[1]Studies in which information will be used:

8.3.1.5.1.5:	Paleoclimate-paleoenvironmental synthesis
8.3.1.5.1.6:	Characterization of the future regional climate and environments
8.3.1.5.2.2:	Characterization of the future regional hydrology due to climate changes

* Information from Study 8.3.1.5.1.3 will be used indirectly in this study.

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