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Revision Number 0

Prepared by: U.S. Geological Survey

Date: 9/15/92

J. Timothy Sullivan for 11/6/92
Director, Regulatory and Site Evaluation Division / Date

Catherine Hampton for 10-21-92
Director, Quality Assurance Division / Date

9212240074 921217
PDR WASTE
WM-11 PDR

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STUDY PLAN

FOR

STUDY 8.3.1.9.2.1
NATURAL RESOURCE ASSESSMENT OF
YUCCA MOUNTAIN, NYE COUNTY, NEVADA

Rev 0
September 15, 1992

U.S. Geological Survey

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PREFACE

This study plan summarizes and extends the discussions of Study 8.3.1.9.2.1 in the Site Characterization Plan (SCP). Sections 1, 4, and 5 are drawn from the statutory SCP and from related Yucca Mountain Project documents; those sections show the study in the context of the SCP. Section 2 discusses the rationales for the planned studies, and Section 3 describes the selected tests and analyses generally in greater detail than the descriptions given in the SCP.

Sections 1, 4, and 5 of this plan were prepared mainly by Frances R. Singer. Principal authors for Sections 2 and 3 include J.R. Bergquist, C.E. Barker, J.D. Bliss, J.A. Grow, D.B. Hoover, W.R. Keefer, V.E. Langenheim, R.F. Mast, H.W. Oliver, J.A. Peterson, W.I. Ridley, and K.H. Wohletz.

ABSTRACT

Study 8.3.1.9.2.1 will collect information for the purpose of identifying the mineral and energy resources of the Yucca Mountain area. Four activities comprise the principal data-gathering elements of the study; these include (1) a geochemical assessment based on a detailed sampling and analytical program, (2) an appraisal of the mineral resource potential based on geological and geophysical data, (3) study and assessment of potential geothermal resources, and (4) study and evaluation of potential hydrocarbon resources. A fifth activity will synthesize the data from the other four activities and conduct modeling and analog studies to make a comprehensive evaluation of the mineral and energy resource potential of the repository area.

The information resulting from this study will provide the basis for probabilistic calculations for determining inadvertent human interference and intrusion of the repository itself. In general, the data are needed to meet the performance objectives for containment requirements of the site, and for future performance of the disposal system, by addressing questions concerning the attractiveness of the site relative to the possible presence of mineral and energy resources and the potential for future exploration in the form of drilling or other disruptions at Yucca Mountain in the postclosure period.

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STUDY 8.3.1.9.2.1
NATURAL RESOURCE ASSESSMENT OF YUCCA MOUNTAIN, NYE COUNTY, NEVADA

Study 8.3.1.9.2.1 consists of five activities:

■ 8.3.1.9.2.1.1 - Geochemical assessment of Yucca Mountain in relation to the potential for mineralization;

■ 8.3.1.9.2.1.2 - Geophysical/geologic appraisal of the site relative to mineral resources;

■ 8.3.1.9.2.1.3 - Assessment of the potential for geothermal energy at Yucca Mountain, Nevada;

■ 8.3.1.9.2.1.4 - Assessment of hydrocarbon resources at or near the site; and

■ 8.3.1.9.2.1.5 - Mineral and energy assessment of the site, comparison to known mineralized areas, and the potential for undiscovered resources and future exploration.

This study is part of the postclosure human interference program (8.3.1.9) and is one of two studies in Investigation 8.3.1.9.2 (Studies to provide the information required on present and future value of energy, mineral, land, and ground water resources) which gather data and evaluate the geochemical, geophysical, geological, and hydrologic characteristics of the site and the potential for mineral, geothermal, ground water, and hydrocarbon resources (fig. 1-1).

1. PURPOSE AND OBJECTIVES OF THE STUDY

This study will identify and assess the mineral and energy resource potential of the Yucca Mountain area. Such an assessment is essential in evaluating the possibility of human intrusion at the proposed repository site. The higher the mineral or energy resource potential of the area, the greater the likelihood of future human intrusion in the form of exploration and exploitation that might in some way compromise the integrity of the underground facility. Conversely, a determination of little or no mineral or energy resource potential can be considered to lessen the likelihood of future intrusion at the site.

The mineral and energy resource potential will be evaluated on the basis of existing data and on new data to be acquired during this study, including information on geology, geophysics, geochemistry, geothermal characteristics, hydrocarbons, and statistical analyses. Analogy is a valuable tool in mineral and energy resource assessments, and the geological conditions at the proposed site will be compared with nearby areas of known economic resources and with areas of similar stratigraphic sequences, structures, and tectonic settings elsewhere in the region.

Objectives specific to each activity in this study are discussed in sections 3.1, 3.2, 3.3, 3.4, and 3.5, respectively.

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

The information obtained from this study will pertain to the identification and assessment of mineral and energy resource potential at the proposed repository site, based on:

- Data from geochemical sampling and analyses of surface and subsurface materials, which will be used to evaluate the potential for precious, base and strategic metals; energy resources; and industrial mineral resources in the vicinity of Yucca Mountain.
- Geologic data from published sources and from field examinations in and around the site.
- Data from existing regional and site-specific reports (published and unpublished) on geophysical surveys, to identify any geophysical anomalies that may require additional exploration and possibly constrain any known geochemical anomalies.
- Geothermal and calculated heat flux data, as well as chemical and isotopic analyses of springs and wells, for characterizing the local geothermal regime as it might relate to the presence or perceived presence of a geothermal energy resource.
- Data on the amount of organic matter and the thermal maturation of any organic matter in Paleozoic and Tertiary rocks, to determine the potential presence of suitable hydrocarbon source rocks, and stratigraphic and structural data to identify and characterize reservoir rocks, traps and seals at or near the site.
- Application of the above data to the identification and characterization of mineral, hydrocarbon, and geothermal resources.

The combined information will provide the basis for probabilistic calculations of inadvertent human interference and intrusion (Study 8.3.1.9.3.1). Specific uses of the data for measuring repository performance against goals for performance measures are discussed in Section 1.2; 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 this study is needed to determine site suitability and to characterize the potential repository site. It is also required to predict the performance of the repository and measure the predicted performance against tentative goals associated with performance measures. In general, the data are needed to meet the performance objectives for containment requirements of the site, and for future performance of the disposal system, by addressing questions concerning the attractiveness of the site relative to the possible presence of resources (Activity 8.3.1.9.2.1.5) and the potential of future drilling or disruption (Study 8.3.1.9.3.1) at Yucca Mountain during the postclosure period.

The presence of natural resources at the site would have the potential to encourage activities that could interfere with the isolation of waste (e.g., drilling for resources). As a consequence, the guidelines of 10 CFR (60.21)(C)(13) stipulate that the Safety Analysis Report shall include:

> An identification and evaluation of the natural resources of the geologic setting, including estimates as to undiscovered deposits, the exploitation of which could affect the ability of the geologic repository to isolate radioactive wastes. Undiscovered deposits of resources characteristic of the area shall be estimated by reasonable inference based on geological and geophysical evidence. This evaluation of resources, including undiscovered deposits, shall be conducted for the site and for areas of similar size that are representative of and are within the geologic setting. For natural resources with current markets the resources shall be assessed, with estimates provided of both gross and net value. The estimate of net value shall take into account current development, extraction and marketing costs. For natural resources without current markets, but which would be marketable given credible projected changes in economic or technological factors, the resources shall be described by physical factors such as tonnage or other amount, grade, and quality.

Information from this study will specifically address the objective of limiting radionuclide releases to the accessible environment as required by 10 CFR Part 60.112 and 40 CFR 191.13, and as embodied in Issue 1.1 (SCP section 8.3.5.13; SCP tables 8.3.1.9-1 and 8.3.5.13-11) (fig. 1-2). The study supports the resolution of this issue by providing data on the expected partial performance measure for the initiating event where exploratory drilling for potential natural resources intercepts a waste package and brings nuclear waste up with core or cuttings. The goals for this partial performance measure deal with the expected density and frequency (drill holes per square kilometer per 10,000 year) that can be reasonably assumed for a repository at Yucca Mountain. This study contributes to these goals by providing information on the types, quantities, tonnages, and grades of known or inferred mineral and energy resources.

Study 8.3.1.9.2.1: Natural resource assessment of Yucca Mountain, Nye County, Nevada

Information from this study will contribute to the resolution of performance issues 1.8 and 1.9 (SCP sections 8.3.5.17, table 8.3.1.17-13 and 8.3.5.18) through its contributions to issue 1.1.

2. RATIONALE FOR SELECTED STUDY

Five activities will be conducted to identify and assess the natural resource potential at the proposed repository site. The planned tests for each of the activities were selected on the basis that they afforded the best means available for achieving the stated objectives (see secs. 3.1., 3.2, 3.3, 3.4, and 3.5) and for obtaining the required parameters. The rationales for the selected test methods are given in the following sections; the test plans themselves are described in section 3.

2.1 Activity 8.3.1.9.2.1.1 Geochemical assessment of Yucca Mountain in relation to the potential for mineralization

In order to achieve the objectives for this activity, the following tests will be conducted:

- Establish a geochemical data base through sampling and laboratory analysis of surface and subsurface geologic materials

- Evaluate geochemical data

2.1.1 Rationale and justification for the selected tests

2.1.1.1 Establish a geochemical data base through sampling and analysis of surface and subsurface geologic materials

A program for the sampling and laboratory analyses of surface samples and borehole cores is required to evaluate the potential for metallic, energy, and industrial mineral resources in the vicinity of Yucca Mountain. The principal chemical elements selected for analysis will be those representing mineral commodities that are commonly associated with silicic volcanic rocks, carbonate rocks, and (or) surficial deposits which occur in the area. Included in the sampling program are outcrops of all major rock units in and around Yucca Mountain as well as drill core, vein materials, fault breccias, alteration zones, surficial deposits, indicator plants, and water from boreholes.

Relevant activities and studies are 8.3.1.5.2.1.5 (Studies of calcite and opaline silica vein deposits), 8.3.1.3.2.1.3 (Fracture mineralogy), and 8.3.1.3.2.2 (History of mineralogic and geochemical alteration of Yucca Mountain). We intend to make full use of these studies inasmuch as they impact and can contribute to our geochemical studies. Where appropriate, we will also examine materials studied in the above cited investigations in order to promote cooperation, communication, and optimum utilization of resources.

The chemical composition of rocks provides insights into their potential for mineralization, especially when compared and contrasted with samples from surrounding areas that are known to be mineralized. Surficial sediments provide a well-mixed sampling of materials (especially heavy minerals) concentrated along stream channels and in slope wash deposits that are representative of a much larger area than rock samples alone. Some species of plants, trees, shrubs, etc., have the potential for concentrating certain elements in their roots, leaves, branches, and bark. They may therefore provide an enhanced geochemical signature beyond that provided by the substrate alone. Analyses of ground water samples for dissolved metals and hydrocarbon gases may offer valuable information related to petroleum and mineral resources.

The methods for geochemical sampling and analyses (see section 3.1.1) were selected because they represent a reliable means for obtaining the required data. An evaluation based on a review of existing geologic, geophysical, and geochemical data for Yucca Mountain and surrounding areas, is not considered sufficient to predict the presence of potential mineral deposits with any degree of accuracy or confidence.

2.1.1.2 Evaluation of geochemical data

The geochemical data resulting from the sampling and analytical program need to be examined and evaluated statistically from residual and anomaly maps, and to be compared with calculated background levels and average element values in rock types and surficial deposits in the area. A review of existing literature on similar geologic environments with known mineral occurrences, especially those near Yucca Mountain, is also necessary to fully assess the mineral potential of the site area and to determine whether the site is likely to experience active exploration in the future, taking into account anticipated changes in exploration methods and concepts.

Interpretations of the geochemical information will be based on standard, widely used data-reduction techniques and mapping methods (see section 3.1). There are no reasonable alternatives that would furnish the desired results.

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

2.1.2.1 Establish a geochemical data base through sampling and analysis of surface and subsurface geologic materials

The configuration of the surface sampling program, and the number of sample locations will be based on the geology, known and expected mineral occurrences, topography, and boundaries of the perimeter drift (fig. 2-1). A sampling system will be used that provides comprehensive coverage as determined by the spatial distribution of appropriate sample media (see section 3.1.1 for details). Biased sampling will be done where rock types and alteration zones or other geologic phenomena commonly associated with mineralization are observed. In addition, surficial deposits will be sampled in selected areas, including drainages.

The subsurface sampling program will include a sufficient number of drill hole cores selected so as to adequately cover the study area. The program is intended to include the deep holes (UE-25p#1 and proposed drill holes G-5, -6, and -7) that intersect the Paleozoic rocks beneath Yucca Mountain (fig. 2-1). Biased samples will be collected from rock types, contacts, and alteration zones that might be associated with mineralization. The sampling of cores will be coordinated with the integrated drilling program (Activity 8.3.1.4.3.1.1).

Several analytical methods are planned for the samples collected for geochemical study (see sec. 3.1.1). Numbers of individual samples to be collected and analyzed cannot be estimated accurately at present, but it is anticipated that as many as 500 surface and drill core samples, 1600 surficial deposit samples (including 200 panned concentrates), 500 plant samples, and 50 water samples will be involved in the geochemical study.

Geochemical sampling and analysis is expected to take about 3 years, but is largely dependent upon the borehole drilling activity. Completion should coincide with the scheduling requirements for the geochemical data to be integrated into the mineral and energy assessment of the site (Activity 8.3.1.9.2.1.5).

2.1.2.2 Evaluate geochemical data

Anomaly and residual maps of chemical analyses from the sampled areas will be prepared. Given the ore deposit models that are probably most appropriate for Nevada, the following element anomaly maps should adequately cover the presence of ore minerals: Au, Ag, As, Sb, Te, Se, Hg, Tl, Bi, Mo, Ca, Pb, ZN, Sr, Rb, F, Ba, Sn, Th, U, Y, Cd, Li, Be, Nb, and REE. The duration and timing of this test will be the same as discussed in the above section.

2.1.3 Constraints: factors affecting selection of tests

The selection of test methods for this activity was not affected by their potential impacts on the site, simulation of repository conditions, timing, scale of the phenomena to be measured, or interference with other tests or with the exploratory shaft facility design and construction. With regard to accuracy and precision of the parameters to be measured, and the limits and capability of the selected analytical methods, all of the planned laboratory analyses involve state-of-the-art methods designed to provide standard limits of accuracy in terms of parts per million or parts per billion, and to levels that reflect at least crustal abundance. Some of the boreholes from which cores will be studied have already been drilled, and the drilling of other boreholes in the future is the responsibility of another activity (8.3.1.4.1.1).

2.2 Activity 8.3.1.9.2.1.2 Geophysical/geologic appraisal of the site relative to mineral resources

This activity will evaluate the existing geophysical and geologic data base, as well as the additional information to be acquired in this activity, as they relate to an appraisal of the mineral resource potential of the Yucca Mountain area. Individual tests are not listed in the SCP, but the planned work will utilize information derived from a variety of other studies in the site characterization program (e.g., Investigation 9.3.1.17.4, Preclosure tectonics data collection and analysis), and will evaluate the geologic models that have been interpreted from these data. Such evaluations, combined with data obtained from the geochemical assessment in Activity 8.3.1.9.2.1.1, provide the primary basis for determining which types of ore-forming processes and models should then be considered in a more quantitative assessment of the mineral resource potential of the repository site.

2.2.1 Rationale and justification for the selected test

A comprehensive evaluation of the available geologic and geophysical information is a necessary first step in recognizing potential mineralized zones beneath Yucca Mountain. The resulting data base will then be used as a basis for comparisons with known mineralized rocks elsewhere in the region. Although a major part of the activity consists of evaluating existing geological and geophysical maps and reports, the results may indicate the need to conduct additional field studies, geochemical sampling, and geophysical surveys to more clearly define possible zones of mineralization.

The planned test described above and in sections 3.2.1 and 3.2.5 represents a standard, widely used approach to assessing mineral resource potential. There are no reasonable alternatives that would provide the necessary information.

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

Geologic and geophysical maps and reports to be evaluated in this activity provide detailed coverage of areas in the immediate vicinity of Yucca Mountain. Other published materials to be studied broaden the data base and permit an evaluation of the mineral resource potential of the repository site in a regional geologic and geophysical context.

Locations and numbers of existing surface geophysical surveys and boreholes from which geophysical logs have been acquired are shown on a series of maps presented in a recently completed report on the status of geophysical activities in the Yucca Mountain area (Oliver and others, 1990). Many of these existing geophysical records and logs will be used for the present activity. Data from new surveys and drill holes will also be utilized as they become available; the locations and the total number of these data sources will be determined primarily by other studies (e.g., 8.3.1.4.2.1, Vertical and lateral distribution of stratigraphic units within the site area; and 8.3.1.17.4.7, Subsurface geometry and concealed extensions of Quaternary faults).

With regard to duration and timing, evaluations of existing data are estimated to take 1-2 yr, depending on the data set. Completion of the planned work, however, will depend in large part on the timing of the future geophysical surveys and borehole logging and sampling being scheduled for this and other studies. The duration and timing are also subject to the requirements for this activity to provide information to other studies according to the Project Integrated Schedule (see section 4 and 5).

2.2.3 Constraints: Factors affecting selection of test

The selection of test methods for this activity was unaffected by their potential impacts on the site, simulation of repository conditions, required accuracy and precision, limits and capability of analytical methods, timing, scale of phenomena to be measured, or interference with other tests or with the exploratory shaft facility design and construction.

2.3 Activity 8.3.1.9.2.1.3 Assessment of the potential for geothermal energy at Yucca Mountain, Nevada

This activity will be undertaken in cooperation with Activity 8.3.1.8.5.2.3, Evaluation of regional ambient heat flow and local heat flow anomalies. The latter activity will focus on geothermal activity and heat flow calculations as they relate to Quaternary igneous processes or events, whereas the present activity (8.3.1.9.2.1.3) assesses the geothermal regime in terms of its energy resource potential for either hydrothermal or conductive reservoir thermal systems. Interpretations of thermal profile for both of these activities and for Study 8.3.1.15.2.2.1 (Characterization of the site ambient thermal conditions) will require compensation for the possibly significant effects of flowing ground water and consequent convective heat transport.

In order to provide a comprehensive evaluation of the geothermal energy resource potential of the site area, the following tests and analyses are planned:

- Review existing geologic, geophysical, geothermal, and hydrogeochemical data relevant to geothermal resource assessment.

- Collect and analyze new spring and well water samples as necessary to meet the requirements for a comprehensive hydrogeochemical data base.

- Compile and review information on age and location of igneous systems as possible heat sources. (Note: Activity 8.3.1.8.1.1.3, Presence of magma bodies in the vicinity of the site, is responsible for reviewing geophysical and geochemical data to assess whether there are any indications of the presence of crustal magma bodies in the vicinity of the site.)

- Assess potential of geothermal energy resources for input to Activity 8.3.1.9.2.1.5.

2.3.1 Rationale and justification for the selected tests

The first three tests listed above include the principal methods used for the exploration of geothermal energy (Edwards and others, 1982); there are no practicable or reasonable alternatives to the planned data-gathering elements of the activity. The fourth test synthesizes the information resulting from those tests to make a comprehensive evaluation of the geothermal energy resource potential in and near the Yucca Mountain area.

The model being planned to treat heat flow and thermal gradient data is called Finite Element Heat and Mass Transfer Code (FEHM) (Zyvoloski and others, 1988). It is currently being verified and validated for YMP (Zyvoloski, 1990), and is considered to be reliable for determining convective and conductive heat and mass transfer in geologic media.

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

The data-gathering elements of this activity will be concentrated primarily in an area within a 5-km radius of the proposed repository site at Yucca Mountain (fig. 2-1); resources in areas more distant are considered to have lower significant potential to affect the performance of the site vis-a-vis the expected nature of future exploration and development activities. However, the planned studies will cover a considerably broader area in somewhat lesser detail, because the hydrothermal conditions in and near Yucca Mountain are related regionally to the structural and volcanic geology of the southern Great Basin.

Some geochemical data exist for well waters near Yucca Mountain (Benson and McKinley, 1985; see fig. 3-1), but not all wells have yet been collected for water geochemistry or for stable isotope and tritium analyses. Hence, additional samples from springs and from existing as well as proposed boreholes may be required to establish a more representative data base for the site area. Tritium data are especially useful in evaluating the relative ages of different waters and the mean residence time of fluids in geothermal reservoirs (Vuataz and Goff, 1986). The requirements for new water samples and the location of specific wells and springs to be either resampled or sampled for the first time, should be coordinated as closely as possible with other studies having need for data on the chemical and isotopic constituents of ground water, such as those in the geohydrology program (SCP section 8.3.1.2) and Study 8.3.1.5.2.1 (Characterization of the Quaternary regional hydrology). The number of required samples cannot be accurately estimated at present.

The duration and timing for this activity (8.3.1.9.2.1.3) will necessarily coincide with the work being planned for Activity 8.3.1.8.5.2.3 (Heat flow at Yucca Mountain and evaluation of regional ambient heat flow and local heat flow anomalies). Although not discussed in the SCP or in section 5 of this study plan, it is anticipated that, should work completion schedules permit, Activities 8.3.1.8.1.1.3 and 8.3.1.15.2.2.1 will provide useful data to this activity. Results of the heat flow studies and subsequent evaluation of the potential geothermal energy resources should be available for integration into Activity 8.3.1.9.2.1.5, when the final assessment of the mineral and energy resources of the site area is being made (see secs 2.5, 3.5, 4, and 5).

2.3.3 Constraints: factors affecting selection of tests

The choice of test methods for this activity was unaffected by their impacts on the site, the need to simulate repository conditions, or their interference with other tests or the exploratory shaft. With regard to the capability (or limitation) and accuracy and precision of the methods planned for hydrogeochemical analyses, the laboratory procedure that will be followed (see sec. 3.3.1.2) for each suite of cations or anions was selected on the basis that it provides equal or higher levels of accuracy and precision than any of the alternative methods. The planned tests are applicable to the scale of the heat flow modeling technique that will be used in the activity (see sec. 2.3.1).

2.4 Activity 8.3.1.9.2.1.4 Assessment of hydrocarbon resources at or near the site

The SCP does not contain a specific listing of the tests for this activity, but in order to achieve the stated objectives (see sec. 3) the following tests were selected:

- Determine presence (or absence) of hydrocarbon source rocks
- Measure thermal maturity of potential source rocks
- Reconstruct thermal history of potential source rocks
- Identify potential reservoir rocks and traps and seals favorable for hydrocarbon accumulation

2.4.1 Rationale and justification for the selected tests

2.4.1.1 Determine presence (or absence) of hydrocarbon source rocks

One of the prime factors in evaluating the potential for oil and gas resources is the presence (or absence) of organic-rich rocks capable of generating hydrocarbons. Paleozoic strata, known to contain organic matter in parts of the Great Basin are exposed in areas adjacent to Yucca Mountain and underlie the area at depths generally greater than 3 km. Some of these strata have been penetrated and cored in the UE-25p#1 well, (fig. 2-2), but the sequence drilled (Lone Mountain Dolomite and Roberts Mountain Formation of Silurian age) represents only a small part of the Paleozoic section that should be sampled and analyzed for its organic content. Proposals are being advanced for the drilling of three additional boreholes to the Paleozoic as part of the integrated Drilling Program (Activity 8.3.1.4.1.1). Plans for these wells (G-5, G-6, and G-7, fig. 2-1) should include the drilling of a much larger portion of the total Paleozoic sequence in order to provide a comprehensive evaluation of potential source rocks. Exposures in adjacent areas should also be systematically sampled for this purpose.

To date, geologic investigations have not shown that lacustrine strata of Tertiary age are present within or adjacent to Yucca Mountain. However, such rocks are known to be source beds for petroleum in other areas of the Great Basin (e.g., Eagle Springs field, fig. 2-3). If subsequent drilling and (or) mapping activities should identify similar Tertiary lacustrine beds in the subsurface of the study area, they will be given the same consideration and level of study as the potential source rocks of Paleozoic age.

2.4.1.2 Measure thermal maturity of potential source rocks

Whether or not potential source rocks have been subjected to sufficiently high temperatures to generate oil and gas is a second important factor in evaluating petroleum resources. In this test, several standard and widely used methods to determine the thermal maturity of organic-rich sedimentary strata will be conducted; such methods are described in detail in secs. 3.4.2.1 and 3.4.2.2. Alternatives methods include fluid inclusion thermometry and determinations based on clay mineral diagenesis and other mineral alterations, but none of these is considered to provide as good or better quality data than the selected methods.

2.4.1.3 Reconstruct thermal history of potential source rocks

This test is designed to provide information on the timing of hydrocarbon generation, which is another important element in oil and gas resource evaluation. To reconstruct the thermal history of potential source rocks, it is necessary to determine: (1) burial history, based on stratigraphic and structural relationships converted to burial depth estimates over geologic time, and (2) burial temperatures, based on analyses of paleogeothermal gradients. Methods to be used in obtaining these kinds of data (see secs. 3.4.3.1 and 3.4.3.2) are in common use throughout the petroleum industry.

2.4.1.4 Identify potential reservoir rocks and traps and seals favorable for hydrocarbon accumulation

This test addresses the question of whether suitable reservoir rocks and traps and seals capable of accumulating oil and gas occur beneath Yucca Mountain and adjacent areas. For this purpose, it will be necessary to review the stratigraphy and geologic structure of the site area, and of areas away from the site, within the context of available and planned drill hole and geophysical data. Comparisons will also be made between the geologic relations of known petroleum occurrences elsewhere in the Great Basin region (e.g., the productive trend in the Railroad Valley area of northeastern Nye County, Nevada, fig. 2-3) with those of the Yucca Mountain area to evaluate whether similar conditions may be present.

Short of drilling strategically located wells either vertically or directionally into the Paleozoic rocks beneath Yucca Mountain, the methods employed in this test (see secs. 3.4.4.1 and 3.4.4.2) are the only available means of obtaining data on reservoir rocks and possible traps and seals in the site area.

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

2.4.2.1 Number

This section applies primarily to the first two listed tests. With regard to cores and cuttings of Paleozoic strata, only one well (UE-25p#1, fig. 2-1) has penetrated any part of these rocks and about 10 samples will be obtained for determining organic content and degree of thermal maturation of the various units encountered. Plans call for three additional wells in the Integrated Drilling Program to be drilled to depths that will penetrate Paleozoic rocks (wells GS-5, GS-6, and GS-7, fig. 2-1) in the vicinity of Yucca Mountain, but how much thickness will ultimately be drilled is as yet unknown. However, it is expected that numerous samples (cuttings and cores) will be obtained for analysis; the actual number of samples cannot now be accurately estimated. Selected samples will be used for physical properties testing to determine reservoir quality.

Outcrops of Paleozoic sedimentary units near the site area (locations discussed below) are likewise a source of samples to be analyzed for their organic content and degree of thermal maturation, and to be used for physical properties testing. A suite of about 150 samples from some exposures east of Yucca Mountain was obtained in 1974 as part of an earlier USGS program to evaluate Paleozoic source rocks throughout the Great Basin region. Some of the data have been published (Poole and Claypool, 1984), but these samples plus many more have yet to be analyzed using advanced analytical techniques developed since the earlier study. We propose to utilize as many of these existing samples as is feasible, and to obtain additional surface samples (as fresh and unweathered as possible) as is necessary to complete the planned analytical and physical properties testing program. The total number of samples will be a few hundred.

2.4.2.2 Location

The surface boundary for the detailed evaluation of oil and gas resources is defined in the SCP as the area lying within 5 km of the center of the surface projection of the perimeter drift of the repository (fig. 2-1). Because of the greater potential for impacts on waste isolation in the repository block, the area including and immediately surrounding the repository block will require more scrutiny than areas more distant. However, because of the paucity of data pertaining to oil and gas resource evaluation in the immediate vicinity of Yucca Mountain, a broader, more regional study will be required to adequately assess the hydrocarbon potential of the site.

The locations of boreholes from which cores and cuttings of Paleozoic strata will be obtained for study and analysis within and adjacent to the site area are dictated by the existence of one completed borehole (UE-25p#1) and by the sites being selected for additional boreholes as part of the Integrated Drilling Program (USW G-5, G-6, and G-7, fig. 2-1). Selected exploration holes drilled by the petroleum industry elsewhere in southern Nevada will also be evaluated to determine if information relative to the site can be obtained (fig. 3-2). Outcrop samples of Paleozoic rocks will be obtained from exposures in adjacent areas such as Bare Mountain and the Calico Hills (fig. 2-1), from the Bullfrog Hills and Mine Mountain-Syncline Ridge area which lie 40 km west and 35 km northeast of the site, respectively, and possibly from selected outcrop sites more distant from Yucca Mountain; the total number of samples cannot be accurately estimated in advance.

2.4.2.3 Duration and timing

Study of the hydrocarbon resources will necessarily coincide in part with the drilling and coring of the three proposed boreholes scheduled to penetrate potential source rocks of Paleozoic age (fig. 2-1). Accordingly, the timing and duration of the activity will depend to a large extent on the availability of cores from these wells and the time required to perform the planned organic content analyses and thermal maturity studies. Duration and timing of other aspects of the investigation, such as evaluation of petroleum reservoir rocks and the existence of possible traps and seals, also depend on the availability of cores and related drill data.

The timing and duration of this activity also depend upon the availability of geophysical data (e.g., seismic profiles) to assist in identifying geologic conditions that are favorable for oil and gas accumulation beneath the site and adjacent areas. Part of the effort discussed in the above statement will be conducted under Activity 8.3.1.9.2.1.2, wherein an early assessment will be made regarding the applicability of the available geophysical data to the interpretation of subsurface geologic structures. The assessment of the hydrocarbon resources of the Yucca Mountain area should be completed according to the schedule of work being planned for Activity 8.3.1.9.2.1.5.

2.4.3 Constraints: factors affecting selection of tests

The selection of test methods for this activity was not affected by: simulation of repository conditions, required accuracy and precision of parameters to be measured, limits and capability of analytical methods, timing, scale of phenomena to be measured, or interference with other tests or with the exploratory shaft facility design and construction. With regard to potential impacts on the site, the siting of boreholes (a responsibility of the Integrated Drilling Program) is constrained by the inadvisability of drilling within the repository block.

2.5 Activity 8.3.1.9.2.1.5 Mineral and energy assessment of the site, comparison to known mineralized areas, and the potential for undiscovered resources and future exploration

This activity is designed to integrate data obtained in the other four activities in Study 8.3.1.9.2.1. Specific tests are not listed in the SCP, but the principal tasks being planned are:

- Assemble information that is readily available from published sources and relevant to the assessment of mineral and energy resource potential

- Apply the data collected in Activities 8.3.1.9.2.1.1, 8.3.1.9.2.1.2, 8.3.1.9.2.1.3, and 8.3.1.9.2.1.4 as well as other existing site-specific data, to calculate grades, tonnages, or other amounts of commodities, mineralized rock, or ore

- Compare data on the Yucca Mountain area with (1) analog areas outside the proposed repository site, and (2) published grade-tonnage and genetic ore deposit models

- Evaluate the resource potential of any identified or undiscovered mineral and energy resources in the site area, and the potential for future exploratory activity

2.5.1 Rationale and justification for the selected tests

A synthesis of the mineral and energy resource data obtained in Study 8.3.1.9.2.1, combined with previously existing site-specific information, is required to:

- Calculate gross and net values of commodities of current and future commercial value

- Compare site-specific grades, tonnages, and amounts with the average abundances in similar rock types to determine if the site has extractable commodities of commercial value, of future commercial value, or anomalous concentrations of a commodity that might attract future exploration

The methods being planned to accomplish the above were selected on the basis that they represent the best and most practical means available for evaluating mineral resource potential. Alternatives include the drilling and coring of closely spaced holes throughout the site area, but this would be too costly and too damaging to the repository block itself.

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

The number of models selected for comparison with the geologic, geochemical, and geophysical characteristics of Yucca Mountain will be determined after the planned work for Activities 8.3.1.9.2.1.1, 8.3.1.9.2.1.2, 8.3.1.9.2.1.3, and 8.3.1.9.2.1.4 is essentially completed. The location will also depend upon the results obtained from these other activities, in terms of where mineral and energy resources may be identified within or near Yucca Mountain. In the case of geothermal and oil and gas resources, the SCP states (p. 8.3.1.9-28) that, as a first approximation, the surface boundary for the detailed assessment of these commodities is defined as within 5 km of the center of the surface projection of the perimeter drift of the repository. The SCP also states (p. 8.3.1.9-18) however, that as site characterization activities proceed and new information is provided, evaluation boundaries will be more explicitly defined.

The duration and timing will depend upon the availability of data being provided by the other four activities in the study, the availability of data from other studies, and the requirements for data input to the Human Interference program (see secs. 4 and 5).

2.5.3 Constraints: factors affecting selection of tests

This activity utilizes published information and data generated by other activities; hence the selection of tests was not affected by the following factors: impacts on the site, simulation of repository conditions, required accuracy and precision, limits or capabilities of analytical methods, timing, scale and applicability of measurements, and interference with other tests or the exploratory shaft facility design and construction.

3. DESCRIPTION OF TESTS AND ANALYSES

3.1 Activity 8.3.1.9.2.1.1 Geochemical assessment of Yucca Mountain in relation to the potential for mineralization

The primary objective of this activity is to conduct a geochemical sampling and analytical program to evaluate the potential for precious, base, and strategic metals, energy resources, and industrial mineral resources near Yucca Mountain. The SCP parameters, stated in terms of the elements that are currently considered to be important commodities, include: gold, silver, copper, lead, zinc, tin, mercury, thorium, and uranium. Pathfinder elements that may also be considered include, but are not limited to, antimony, fluorine, barium, arsenic, and yttrium. Additional parameters relate to the occurrence, abundance, and quality of industrial minerals.

3.1.1 General approach

3.1.1.1 Establish a geochemical data base through sampling and analysis of surface and subsurface geologic materials

The surface sampling program for geochemical analyses will be based on the geology of Yucca Mountain (i.e., the distribution of various rock and soil types in surface exposures), known and expected mineral occurrences, topography, and configuration of the perimeter drift and controlled area boundaries (fig. 2-1). Although the approach to a systematic sampling program will be based primarily on these factors, the normal procedure will be to collect "grab" samples of not less than 2 Kg at spacing expected to range between 250 and 750 feet within the controlled area for the first-order program. If anomalies are identified in this first-order sampling program, then a more closely-spaced sampling pattern may be necessary for a second-order program to define the boundaries of the anomaly more closely. Biased sampling will also be done where rock types and alteration zones or other geological phenomena commonly associated with mineralization are observed. In addition, sediment sampling within selected areas, including drainages, may be necessary. In this regard, pan samples will be collected where feasible to obtain heavy mineral concentrates. Information on the occurrence, abundance, and quality of industrial minerals will also be collected as sampling is performed. For example, some of the silicic tuffs in the vicinity of Yucca Mountain may be sufficiently alkaline to warrant examination of their niobium, rare earth, uranium and thorium potential.

For the subsurface sampling program, a sufficient number of drill holes will be selected so as to adequately cover the site area. The program will include the deep holes, such as UE-25p#1 (fig. 2-1), which intersect the Paleozoic rocks under Yucca Mountain. Spacing of sampling intervals within cores will range between 50 and 300 feet. Biased samples will likewise be taken from different rock types and from altered or mineralized zones. Additional, more closely spaced core samples will be collected if anomalies are identified.

The sampling program will not be restricted entirely to the controlled area. Samples will also be collected from areas surrounding Yucca Mountain, and from areas with potential or suspected mineralization, such as Calico Hills, Wahmonie-Salyer district, and from prospects and currently or previously active mines. However, a complete listing of the specific localities to be studied and sampled cannot be made at present, inasmuch as access to properties is subject to approval by the individual owners; such access will not be determined until the work is ongoing.

Analytical methods to be used in this test include, but are not limited to, emission and absorption spectroscopy, stable isotope spectroscopy, fluid inclusion studies, polarized and reflected light petrography, x-ray diffraction and fluorescence, and potassium-argon and argon-argon. In addition to the planned analyses, studies will be made of the isotopic composition of oxygen, hydrogen, and sulfur as indicators of the past potential for the movement of mineralizing fluids through rocks and sediments. Analyses of fluid inclusions in crystals will also be performed to assist in reconstructing paleohydrologic conditions and mineralizing environments, and for placing constraints on the types of deposits that might have developed.

Specific parts of certain plant species will be sampled and analyzed for selected elements that may be concentrated in their roots, leaves, twigs, or bark. Particular emphasis will be given to flora having long root systems capable of sampling a relatively large volume of the surrounding soil (Erdman and others, 1988). Ground water samples will be obtained from selected drill holes at various depths below the water table (fig. 3-1) using a double check valve bailer. The latter has been successfully employed along the Getchell gold trend in northern Nevada (Grimes and others, 1991). Ground water samples will be analyzed by standard analytical methods.

3.1.1.2 Evaluate geochemical data

Anomaly and residual maps will be prepared for each element and standard statistical analyses will be performed to characterize the background levels and spatial variability for the various elements, including averages and standard deviations of the results of the analyses. Potential relations between elements will be evaluated using multivariant techniques. A comparison of background levels found in the rock units at Yucca Mountain with identified anomalies will be made. In addition, average elemental abundances typical of the various rock types will be compared with the elemental abundances found at Yucca Mountain.

One type of map to be prepared will display single- or multi-element anomalies relative to mapped geologic units, thereby relating geochemistry to bedrock geology. Another type of analysis to be performed uses vector statistics to determine multi-element correlations that might be interpreted in terms of specific deposit models (Cox and Singer, 1986). Such constructions play a vital role in developing a mineral resource appraisal.

3.1.2 Test methods and procedures

The methods and procedures to be employed in this activity are described in numerous publications, including Baedecker (1987), Roedder (1984), and Valley, et al (1986). Pertinent technical procedures include GCP-02 (Labeling, identification, and control samples for geochemistry and isotope geology), GP-17 (Describing and sampling soils in the field), GP-19 (Procedure for the identification, handling, and disposition of drill core and cutting samples from the drill site to the core library), and GP-27 (Trench wall and natural outcrop sampling for coordinated studies).

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 controlled 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. Data collected outside the QA program will be qualified as required.

3.1.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this activity. Laboratory analyses will result in values that reflect standard limits of detection for the particular element and analytical procedure involved (see following section).

3.1.5 Range of expected results

The planned sampling and analytical procedures for this activity are expected to provide quantitative and semi-quantitative geochemical data on all the elements of interest in assessing the mineral potential of the Yucca Mountain area. Induction-coupled plasma atomic emission spectroscopy (ICP-AES) enables multi-element analysis (a standard package includes 44 elements) of geologic materials at moderate to low concentrations (Lichte and others, 1987). For many of the determined elements, the detectability using a standard multi-acid sample digestion is at crustal abundance levels, making ICP-AES ideally suited for resource appraisal studies. Precision of most determinations is 5-10 percent relative standard deviation with the optimal limit of 1-2 percent. Detection limits are shown in the table on the following page.

Detection limits in a granite for elements normally reported using an acid digestion[1] (values given in micrograms per gram, unless otherwise indicated).

Element	Limit	Element	Limit	Element	Limit	Element	Limit
Al	0.05	Ag	2	Ge	20	V	2
Fe	0.05	As	10	La	2	Y	2
Mg	0.05	Au[2]	8	Li	2	Yb	1
Ca	0.1	Be	1	Mo	2	Pr	10
K	0.1	Bi	10	nB	4	nD	20
Ti	0.01	Cd	2	Ni	2	Sn	50
P	0.01	Ce	4	Pb	4	Eu	2
		Co	1	Sc	2	Gd	10
		Cr	1	Sn	4	Tb	20
		Cu	1	Sr	2	Dy	4
		Ga	4	Th	4	Ho	4
				U	1[3]	Er	4

[1]HF, HC1, HNO_3, $HC1O_4$; Si and B are lost in this approach to sample dissolution.

[2]The polychromator in Reston does not have a fixed channel for gold. However, a 0.5-m Ebert monochromator, which is part of the inductively coupled plasma spectrometer system, enables measurements on gold and other elements not routinely determined.

[3]Based on delayed neutron activation.

The detection limit of certain elements, including Ag, As, Sb, Cd, and Bi, by ICP-AES may be further reduced using solvent extraction (Motooka, 1988). Mercury is detected at the 20 ppb level with 10 percent standard deviation precision using cold vapor atomic absorption spectroscopy (AAS). Gold may be detected at the 50 ppb level using flame AAS and at the 3 ppb level using graphite furnace AAS, both following an HBr-Br2 sample dissolution and solvent (MIBK) extraction. All of these elements are critical to the recognition of potential precious metal mineralization. Information pertinent to analyses of fluid inclusions and stable isotopes is given in Roedder (1984) and Valley, et al (1986), respectively.

3.1.6 Equipment

All equipment to be used in this activity are standard, off-the-shelf items; lists of analytical equipment are given in Baedecker (1987).

3.1.7 Data-reduction techniques

Sample collection sites will be described in field notebooks, and locations will be plotted on topographic quadrangle maps. The resulting analytical data will be tabulated and archived according to standard procedures. Single-element and element-association data will be plotted and contoured, and the resulting maps overlain on geologic maps to compare geochemistry with the geology (e.g., distribution of rock and soil units) of a given area. Map scales will generally be 1:24,000. Core data from drill holes will be plotted in vertical columns for ready display of geochemical features.

3.1.8 Representativeness of results

The geochemical sampling and analytical program is designed to provide comprehensive coverage of the area studied. However, the data are point-sources of information, and interpretive maps require interpolation between data points. Complex, but standard algorithms will be used for interpolation, and the results are expected to be representative, in terms of elemental abundance distribution, for rocks, surficial deposits, and other sampled media. Results that rely on interpolation will have a level of confidence determined by sample distribution and density and by geologic complexity.

3.1.9 Relation to performance goals and confidence levels

See sections 1.2, 3.5.9, and 4.

3.2 Activity 8.3.1.9.2.1.2 Geophysical/geologic appraisal of the site relative to mineral resources

The primary objective of this activity is to obtain the geologic and geophysical data necessary to permit a reliable assessment of mineral resources at the site. Part of the data exists (much of it published), and part will be obtained through field investigations conducted under this activity. Specifically, the combined data will be used to: (1) identify geologic conditions favorable for the formation or concentration of mineral deposits at or near the repository site; (2) interpret geophysical anomalies or signatures that may reflect zones of alteration or mineralization; and (3) provide a basis for comparison of geologic conditions at the site with analog environments of known mineralized rocks elsewhere in the region.

3.2.1 General approach

All available geological and geophysical information pertinent to a study of the mineral resource potential of the Yucca Mountain area will be synthesized in this activity. The resulting interpretations will be used to prepare maps and cross sections that display relevant data and show the type and extent of identified or inferred zones of alteration and mineralization. Major emphasis will be placed on identifying rock types, depositional environments, mineral associations, and tectonic and volcanic settings that are favorable for or indicative of the formation of mineral deposits.

The geologic investigations planned for this activity will be coordinated closely with the geochemical assessment in Activity 8.3.1.9.2.1.1. For example, geologic features such as structures, altered zones, and different lithologies identified under the Geophysics/geology activity will be used as selection criteria in obtaining samples of rock, sediment, panned concentrates, and core for geochemical analysis. Geologists and geochemists will work together in the sampling program.

Existing geophysical maps, profiles, and interpretive cross sections, as well as new data obtained from other site characterization activities (e.g., Studies 8.3.1.4.2.1, Vertical and lateral distribution of stratigraphic units within the site area, and 8.3.1.17.4.7, Subsurface geometry and concealed extensions of Quaternary faults), will be used to help assess mineral resource potential from geophysical evidence. Included in this assessment will be a review of the existing seismic, magnetic, gravity, and geoelectric data, as well as interpretations based on selected geophysical logs. Airborne gamma ray data collected by the National Uranium Resource Evaluation (NURE) project over Yucca Mountain and surrounding areas will also be examined to determine U and Th concentrations and as a guide to lithology, as

- As a correlation tool, the gamma-ray log is expected to be less effective in tuffs than in sedimentary rocks. These logs show, however, that the Topopah Spring Member of the Paintbrush Tuff is characterized by a relatively large and unvarying gamma-ray signature, and that the Prow Pass Member of the Crater Flat Tuff can be correlated between drill holes by a distinctive signature near the top of the unit. Gamma-ray spectroscopy logs of the surface and boreholes will be used in measuring concentrations of U and Th for use in the evaluation of possible U mineralization at the site.

- Electrical resistivity of the Topopah Spring Member is high, usually greater than 200 ohm-meters, not only because the unit is unsaturated but because it is densely welded with consequent restriction in pore connectivity. By contrast, both the density and resistivity of the underlying Calico Hills unit are significantly reduced. The relative differences between welded and nonwelded tuffs are evident whether measurements are made above or below the present water table, and these differences are also consistent in drill holes distributed in the northern and southern portions of the site area. The nature of alteration may also produce characteristic log responses in the various units, particularly the Calico Hills tuffs, but present understanding of this phenomenon does not permit logs to be used to characterize altered rocks.

- Extensive measurements of compressional velocity, resistivity, and induced polarization have been made on rock cores from eight drill holes at Yucca Mountain (Anderson, 1981a; 1981b; 1984). Resistivity and sonic velocity are correlated to porosity, indicating the dependence of these properties on textural rather than compositional differences (Anderson, 1982). There are significant departures from simple dependence, probably associated with effects of processes such as devitrification and zeolitization.

- Polarization measurements show that frequency effect cannot be relied upon as an indicator of clay or zeolite content. Low-porosity tuff with few conduction paths and low content of polarizable material may exhibit polarization response comparable to high-porosity tuff rich in clay minerals (Anderson, 1984). Specific capacity (or the frequency domain equivalent "metal factor") is a more reliable indicator of clay or zeolite content, but not without apparent conduction path effects.

- Aerial and ground gamma-ray surveys measure the gamma radiation emitted by radioisotopes at and near the surface of the ground. The measurements are sensitive to naturally occurring radioisotopes, primarily members of the uranium-238 decay series, thorium-232 decay series, and potassium-40, and to artificial radioisotopes such as cesium-137 and cobalt-60 that result from nuclear activities. The distribution of natural radioisotopes reflects the activities that formed them and the weathering that controlled their distribution. Concealed faults may be revealed in natural

3.2.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this activity. All maps, cross sections, and other graphic displays will be prepared at standard levels of accuracy. (See sec. 3.5.4 for additional discussion.)

3.2.5 Range of expected results

The planned synthesis of geologic and geophysical data for this activity is expected to provide input to the mineral deposit modeling efforts planned for Activity 8.3.1.9.2.1.5 (see sec. 3.5) and hence, to furnish essential information for a comprehensive assessment of the mineral resource potential of the Yucca Mountain area.

There is no known field evidence of ore mineralization at Yucca Mountain, and it is possible that, after the planned work for this activity is completed, there will be no additional evidence of ore mineralization in either the Tertiary volcanic rocks or in the Paleozoic sedimentary rocks. Among other possible results are that (1) no evidence will be found for ore mineralization in the volcanic rocks, but ore mineralization will be detected in the Paleozoic carbonate rocks beneath the volcanic rocks (pre-Tertiary mineralization), and (2) there may be no ore mineralization in either the Tertiary or Paleozoic sequences, except where localized along the contact between the two (i.e. post-deposition of the lowermost volcanic unit).

Based on past experience with geophysical surveys in and near the Yucca Mountain area, some of the expected results from a comprehensive evaluation of geophysical data are as follows:

- Induced polarization (IP) is generally considered the best geophysical method for locating metal sulfide deposits with which gold and silver are sometimes associated (Parasnis, 1966, pp. 187-207). IP has been tested in the Wahmonie area just east of Yucca Mountain where silver sulfosalts (proustite and pyrargyrite) have been reported and produced a strong response (Hoover and others, 1982b; Ponce, 1984). In addition, gold was recently discovered in the Joshua Hollow area in the northeast part of Bare Mountain just west of Yucca Mountain by test drilling a large IP anomaly (Steve Green, Gexa Gold Corp., personal commun., 1987).

- Audio magnetotelluric (AMT) measurements have not been tested in the Yucca Mountain area, but have been used extensively by the mining industry for locating gold in the western United States, particularly in combination with geochemical methods.

well as to determine locations for ground surveys if warranted. The 1-mile spaced data obtained by NURE include the area of new gold discoveries west of Yucca Mountain, and the Calico Hills-Wahmonie region to the east. The 3-km gridded data need to be reviewed and gridded to 0.5 km for better resolution.

In addition to the above, the geophysical assessment study requires new deep induced polarization (deep IP) and audio magnetotelluric (AMT) surveys of Yucca Mountain and vicinity inasmuch as these important methods for locating gold and silver sulfide deposits are not being planned by other site characterization activities. The assessment will focus on evidence for extension of previously obtained IP anomalies over Wahmonie silver deposits westward to Yucca Mountain in a manner analogous to the distribution of mineralization at the Twin Ridge pluton (Maldonado, 1981) along the axis of a mostly buried intrusion. Similarly, gold-associated IP anomalies at Bare Mountain will also be traced eastward to Yucca Mountain, particularly in the vicinity of the magnetic anomalies near the proposed repository (Bath and Jahren, 1984).

Particular attention will be given to geophysical boundaries associated with faults and lithologic variations in bedrock that may be indicative of igneous intrusions (and associated zones of sulfide mineralization), fracturing, and (or) alteration. The possible presence of faults, including detachment and thrust faults, and (or) a metamorphic core complex beneath Yucca Mountain, and their significance to ore-forming processes, will also be evaluated. Recognizing the geophysical "signatures" of known mineral deposits in similar geologic settings will be especially useful in locating areas of potential mineralization. Geophysical surveys, including seismic reflection and refraction profiles planned for Study 8.3.1.17.4.2.1 (Characterization of the vertical and lateral distribution of stratigraphic units within the site area), will be evaluated for structures and strata that bear on the evaluation of mineralized zones. Additional geophysical surveys beyond those planned for this activity may subsequently be recommended if anomalies are detected and there is a need to define them more completely.

3.2.2 Test methods and procedures

There are no required procedures for the non data-collecting aspects of this activity; standard practices will be followed in locating, depicting, and characterizing possible zones of altered and mineralized rocks, faults, and intrusions based on existing information. With regard to IP and AMT surveys, standard commonly used procedures will be employed as described in several published reports (e.g., Parasnis, 1966; Vozoff, 1972; Strangeway and others, 1973; Clarke and others 1983; Fink and others, 1990).

3.2.3 QA level assignment

The statements in section 3.1.3 are applicable to this section.

gamma-ray data by the detection of lithologic discontinuities and by anomalous radon-222 occurring at the surface. Radon emanometry may be used to aid in detecting concealed faults and possible shallow U mineralization.

- Magnetotelluric data indicate variations in the resistivity of the upper crust (2 to 5 km depth) that provide information on the distribution of sedimentary and volcanic rocks, with implications for the distribution of deep-penetrating, high-angle faults as well as low-angle faults. Indications on how such structural features can be detected are provided by Hoover and others (1982a, 1982b).

- Shallower penetrating geoelectric methods such as dipole-dipole applied at various locations in the region that includes Yucca Mountain have indicated faults, intrusive rocks, and zones of altered rocks. The reports of Hoover and others (1982a, 1982b), although pertaining to Syncline Ridge in the Wahmonie/Calico Hills areas (fig. 2-1) and not Yucca Mountain, indicate that shallower penetrating methods have uses in site characterization. Schlumberger resistivity soundings acquired at 136 locations throughout the Amargosa Desert (Greenhaus and Zablocki, 1982), have been used for mapping the depth to the Paleozoic basement. In addition to depth-to-basement interpretation, inferred differences in resistivity of the upper 75 m of alluvium were used in conjunction with driller's logs to identify areas with coarser and probably more transmissive sediments.

- A magnetic anomaly trends from the Wahmonie-Calico Hills area west to the northern part of Yucca Mountain. This has been interpreted to represent either a buried intrusion, or metamorphosed Eleana argillite that was altered by an intrusive body at greater depth (Kane and Bracken, 1983; Bath and Jahren, 1984; Baldwin and Jahren, 1982).

As indicated by the above discussion, certain types of geophysical data are believed to be especially promising for the detection of variations in rock characteristics at depth, some of which may reflect altered or mineralized zones. Until these planned studies are well under way, however, what may be expected insofar as clear evidence for the presence or absence of mineralization is concerned must remain highly speculative.

3.2.6 Equipment

Standard items of equipment will be employed in this activity, including deep induced polarization, audio-magnetotelluric, resistivity, and electromagnetic instruments; computers; software; and laser printers.

3.2.7 Data-reduction techniques

Standard data-reduction techniques will be used to synthesize, compile, and display geologic and geophysical data. Maps and data will be drawn and plotted on scale-stable base maps at standard publication scales (e.g., 1:10,000, 1:100,000, etc.). Computers will be used to manipulate geophysical and numerical data.

3.2.8 Representativeness of results

The information resulting from this activity is expected to be sufficient to permit a reliable assessment of potential mineral resources in the site area as defined by geological and geophysical data, because all known and (or) suspected mineralized sites will be studied in detail. The synthesis of data will take into account altered and mineralized rocks known to occur in nearby areas outside the site area, and the similarities and differences will be evaluated relative to the assessment of potential mineral resources within the site area.

3.2.9 Relation to performance goals and confidence levels

See sections 1.2, 3.5.9, and 4.

3.3 Activity 8.3.1.9.2.1.3 Assessment of the potential for geothermal energy at Yucca Mountain, Nevada

The primary objective of this activity is to assess the potential for a geothermal resource at Yucca Mountain. Specific objectives are to:

- Compile measured geothermal and calculated heat flow data to quantify vertical and horizontal geothermal gradients.
- Compile appropriate chemical and isotopic (oxygen and deuterium) analyses of water samples from springs and wells useful for predicting subsurface temperatures.
- Evaluate existing data on geothermometry heat flow necessary to adequately characterize the region for its geothermal resource potential.
- Recommend whether additional studies may be needed, including the collection and integration of additional geothermal data from existing or planned drill holes.
- Provide the information necessary for the final resource assessment to be performed in Activity 8.3.1.9.2.1.5.

Stated in terms of the SCP-designated parameters: (1) heat flow will be calculated using temperature gradient and thermal conductivity data from boreholes and the exploratory shaft facility; (2) geothermometry methods will be evaluated on the basis of water chemistry and isotopic (oxygen and deuterium) analyses; and (3) geothermal energy potential will be assessed using temperature of ground water from springs and wells, and from geological, hydrological, and structural data at the site and in the surrounding region.

The planned work for this activity will be coordinated closely with that of Activity 8.3.1.8.5.2.3 (Heat flow at Yucca Mountain and evaluation of regional ambient heat flow and local heat flow anomalies); both activities are aimed at characterizing the local geothermal regime as it might relate to repository performance. Whereas this activity (8.3.1.9.2.1.3) will assess geothermal activity as a potential energy resource, Activity 8.3.1.8.5.2.3 will evaluate the local ambient heat flow and local heat flow anomalies in relation to Quaternary igneous bodies.

In the following sections, the general approach topic for each of the four planned tests and analyses (see sec. 2.3) will be discussed separately, whereas the remaining topics (test methods and procedures, etc.) will be treated on an activity-wide basis.

3.3.1 General approach

3.3.1.1 Review existing geologic, geophysical, geothermal, and hydrogeochemical data relevant to geothermal resource assessment

A review of all pertinent published reference materials will be made; the list of references will be compiled through several computer searches, including Energy Data Base, National Technical Information Service (NTIS), and the Geological Reference Database (GEOREF) of the American Geological Institute. As part of this test, relevant data collected by other studies in the site characterization program will be compiled and evaluated as they become available during the course of the planned work. Included are data from Study 8.3.1.2.3.2 (Characterization of the saturated zone hydrogeochemistry) and Study 8.3.1.5.1.2.1 (Characterization of the Quaternary regional hydrology). Analyses of ground water samples obtained from drill holes as part of Activity 8.3.1.9.2.1.1 will also be utilized (see sec. 3.1.1.1).

An important part of the data evaluation will be the compilation and analysis of regional hydrothermal information regarding the location of thermal springs along faults in Nevada or in association with intrusive bodies. This information will provide a basis for predicting the development potential of a hydrothermal system on faults or igneous features near Yucca Mountain in the future. The data resulting from this test will be used to prepare a variety of maps and related reports (see sec. 3.3.7).

3.3.1.2 Collect and analyze new spring and well water samples as necessary to meet the requirements for a comprehensive hydrogeochemical data base

Depending upon the results of the compilation and analysis of data that will be carried out jointly between this activity and Activity 8.3.1.8.5.2.3 (see sec. 3.3), it may be necessary to collect and analyze additional spring and well water samples in order to establish a better and more consistent data set by which to evaluate hydrogeochemical indicators of geothermal potential. Possible collecting sources for new samples are: (1) wells currently being monitored on and around Yucca Mountain (fig. 3-1), Jackass Flat, and Crater Flat; (2) new wells in and near the site area; and (3) cold and warm springs within distances of about 50 km of Yucca Mountain. Only a few such springs are present, including Specie Spring (20 km west), springs in Oasis Valley (30-40 km northwest), Topopah Spring (20 km northeast), Cane Spring (32 km east), and springs in the Ash Meadows area (45-60 km south). Ground water data from the above sources should lead to a better understanding of the characteristics of potential geothermal systems in the vicinity of Yucca Mountain. The collection of ground water samples from wells will be closely coordinated with the geochemical sampling program planned for Activity 8.3.1.9.2.1 (sec. 3.1.1.1).

Technical procedures for hydrogeochemical sample collection and standard chemical analyses are summarized in Trujillo and others (1987) and Watson (1978). The planned analyses include:

- Cations -- Ca, Cs, B, Fe, K, Li, Mg, Na, Rb, Si, and Sr
- Anions -- Cl, F, S, HCO_3, CO_3, and SO_4
- Gases -- CO_2, H_2S, H_2, CH_4, N_2, NH_3, O_2, Ar, and He

In addition to these analyses, stable isotope data will be obtained for selected samples, including $^{18}O^{16}O$, ^{3}H, and ^{2}H-(D). In conjunction with Activity 8.3.1.8.5.2.3, the silica geothermometry methods used by Fournier and others (1979) for calculating regional heat flow will be evaluated as to their utility in corroborative heat-flow calculations for Yucca Mountain.

Along with the collection of new geochemical samples, spring water temperatures, eH, and pH will be recorded, and sample sites will be plotted on maps (1:24,000 scale) to record locations of warm and cold springs, zones of secondary mineralization, and structural elements that may have future importance in the localization of hydrothermal activity.

3.3.1.3 Compile and review information on the age and location of igneous systems as possible heat sources

Although known geothermal resources in Nevada do not depend upon the presence of igneous systems, but may be related to deep circulation of meteoric waters along fault zones in regions of high crustal heat flow, the potential of igneous systems as origins of high heat flow will be considered. This test consists primarily of compiling published information on the types, ages, and locations of igneous rocks and modeling their potential contribution to crustal heat flow in the Yucca Mountain area. Other studies contributing information to this data base include Study 8.3.1.8.5.2 (Characterization of igneous intrusive features).

The planned work includes the following steps:

- Compile, from existing maps and related reports and from new data as they become available from other site characterization studies (see above), information on the compositions, ages, and volumes of volcanic features in and near the site area.

- Infer, from the relationships exhibited by surface volcanic features, the size and location of intrusive bodies within 20 km of Yucca Mountain inasmuch as intrusive bodies within this radius can have measurable heat flow effects over time periods of millions of years. Because the most prominent volcanic features of the area are resurgent, silicic calderas (Christiansen and others, 1977), approximations as to the volumes of intrusive bodies that may be present will be based on the work of Smith and Shaw (1975) who have demonstrated that silicic calderas are underlain by magma chambers whose volumes are larger than that of their extrusive counterparts by a factor of ten. This factor is considered to reflect average intrusive equivalent volumes for all types of volcanoes, ranging from a factor of about 1 to 6 for the basaltic type and 10 or greater for the silicic type (Smith and others, 1978; Crisp, 1984; Wadge, 1982).

- Determine the depths of the inferred magma chambers from published petrologic relationships concerning pressure-sensitive phase equilibria. Warren and others (in press) suggest that the upper portions of silicic chambers around the Nevada Test Site occur at a depth of 10 km; basaltic ones occur essentially as dike-like bodies extending from the mantle through the crust (Crowe and others, 1983a; 1983b).

Based on the size, location, and age of the inferred intrusion bodies, the FEHM model (Kolstad and McGethchin, 1978; Zyvoloski, 1990) will be applied to calculate 2-D and 3-D transient heat conduction and heat and mass transfer of hydrothermal convection around intrusives. The results of the heat flow model predictions will be used in evaluating thermal gradients and temperatures with respect to measured regional and local heat flow to determine if any unexplained thermal excursion exists around Yucca Mountain. If present, the thermal excursion may be evidence of a relatively young intrusion. In this regard, it should be noted that the only positive test for the existence of an igneous body beneath Yucca Mountain is to drill a deep hole into the suspected anomaly.

3.3.1.4 Assess potential of geothermal energy resources for input to Activity 8.3.1.9.2.1.5

The results of the tests in this activity will be used in conjunction with pertinent geologic, structural, stratigraphic, and hydrologic data to perform the geochemical resource assessment. Modeling will follow standard geothermal assessments developed by White and William (1975), Muffler (1979), and Reed (1983). The following models will be considered:

(1) High and Intermediate-Temperature Hydrothermal Systems for the conventional, high-temperature (T >150 C), and intermediate-temperature (90 <T <150 C) geothermal systems exploited for electricity or industrial uses are associated either with young volcanism or young tectonism. Several such areas are being exploited and (or) developed in Nevada, which has relatively high regional heat flow. Resource assessment will include the following procedures:

   (a) Calculation of estimated equilibration (reservoir) temperatures of spring and well waters will show if convective hydrothermal systems exist (e.g., from measurements made by Na-K-Ca geothermometers).

   (b) Stable isotope and tritium data will be used to assess source areas of water recharge, possible rock-water chemical interactions in a high-temperature environment, and age of the water in possible reservoirs. (Note: Studies 8.3.1.2.3.2 and 8.3.1.5.2.1 will also be using these indicators, as well as general hydrochemistry and radiogenic isotopes (87Sr/86Sr) to assess recharge areas and flow paths.)

   (c) The above data will be combined with regional heat flow and thermal gradient data, other available geophysical data, and geologic data to produce models of possible hydrothermal circulation, if indicated by the data.

(2) Low-Temperature (<90 C) Geothermal Resources

Low-temperature geothermal resources can be divided into two types, hydrothermal convection and conduction dominated, on the basis of the major mechanism of heat transfer (see discussions in Reed, 1983). Low-temperature hydrothermal convection systems in the western United States tend to be relatively small volume and are usually associated with a hot spring at the surface or a highly anomalous well temperature. Large volume conduction-dominated resources are concentrated in the central and eastern United States where thick sequences of sedimentary rock provide adequate permeability on a regional scale.

The basis for assessing low-temperature geothermal resource potential in hydrothermal convection systems is similar to that for high- and intermediate-temperature systems, with the most useful data being measurements of spring temperatures and chemical analysis of hot-spring water samples. Geothermometer temperatures are much less certain at low temperatures, and one tends to rely more heavily on measured spring water temperatures. The assessment of low-temperature geothermal resources in conduction-dominated areas is based upon temperature measurements in wells and inferences from heat flow measurements in shallow wells.

(3) Hot Dry Rock

Hot dry rock (HDR) geothermal reservoirs are defined as deep masses of hot, crystalline, relatively unfractured rock that are exploited by literally mining the heat through a man-made fracture system (Smith, 1983). In theory, two or more wells are drilled into the deep hot rock mass, the wells are connected by hydraulic fracturing, cold surface water is pumped down one well, the water is heated as it flows through the newly created fracture system and is then extracted from the other well. Technical feasibility of this method of geothermal energy extraction was demonstrated at Fenton Hill, New Mexico, in 1978, but commercial feasibility remains to be proved (Dash and others, 1983; Brown and others, 1987). Assessment of HDR resources both nationwide and at specific sites has been described by Goff and Decker (1983); they list two areas that were evaluated in Nevada, including Desert Peak and Dixie Valley. The approach taken in assessment is to first identify areas that may be underlain by relatively unfractured blocks of crystalline rock of not less than 1 km length in any direction. Heat flow/thermal gradient data are then used to estimate the depth needed to drill to a rock temperature of geothermal interest (>200RC for most geothermal electrical applications). Most prospective sites, not adjacent to or associated with young igneous activity, require drilling to great depths in order to find suitable temperatures (Goff and Decker, 1983). Thus HDR resources are not considered commercially exploitable at this time for most parts of the United States.

3.3.2 Test methods and procedures

The SCP states that there are no methods or procedures for this activity; for the most part, existing data and data collected in support of other site characterization activities will be used. References to technical procedures for hydrogeochemical sample collection and chemical analyses are noted in section 3.3.1.2.

3.3.3 QA level assignment

The statements in section 3.1.3 are applicable to this section.

3.3.4 Required tolerance, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this activity. The levels of accuracy generally achieved in hydrogeochemical analyses and heat flow measurements are entirely adequate for purposes of performing the interpretive and modeling tasks of the activity (see sec. 3.5.4 for further discussion).

If new geochemical analyses are to be conducted in support of the activity, the procedures to be used are expected to provide the following levels of accuracy:

Anions - ion chromatography: 0.1 - 1.0 ppm

Automatic titration: 1.0 ppm

Selective ion electrode: 0.1 ppm (sulfide)

Cations - ICP emission spectroscopy: 0.01 - 1.0 ppm; AA spectroscopy: 0.1 - 1.0 ppb

Gases - gas chromatography: 0.1%

Isotopes - mass spectrometry: typically 0.25 - 1.0 ppm

Temperature: 1 degree Celsius

Oxidation reduction potential (eH): 1 mV

pH: 0.05 pH units

Conductivity: 1 μmho (0 - 2e3), 10 μmho (2e3 - 2e4), 100 μmho (2e4 - 2e5)

3.3.5 Range of expected results

Previous studies in the Yucca Mountain area have not produced any positive evidence that a geothermal resource potential exists in the Yucca Mountain area. Although minor heat-flow anomalies are known from thermal gradients measured in the surrounding region and possible hydrothermal calcite veins cut Tertiary rocks in the Solitario Canyon fault zone on the west side of Yucca Mountain, there are at present no known hot or warm springs on Yucca Mountain (Sass and Lachenbruck, 1982). The range of geochemical characteristics of water samples collected and analyzed in this and related activities is expected to be near Basin and Range background levels (Garside and Schilling, 1979; Reed, 1983). Modeled perturbations of heat flow are expected to show that the present depths to bedrock and of meteoric water circulation would have to be significantly changed (increased and decreased, respectively) in order to provide conditions favorable for the development of a hydrothermal system. The probability of intrusion and (or) extrusion of new magma of sufficient volume to possibly cause heat flow of sufficient magnitude to initiate a future hydrothermal system is a subject being addressed in part by other studies (e.g., Study 8.3.1.8.5.2, Characterization of igneous intrusive features). However, new igneous activity is expected to follow the periodicity of eruptions that has been documented for the past few million years (Crowe and others, 1982; 1986).

3.3.6 Equipment

If new chemical analyses are to be performed, the following equipment will be used:

- Ion chromatograph -- Dionex 4000 series
- Automatic titrator -- Fisher CAT series selective ion electrode; Orion models
- Inductively coupled plasma emission spectroscope -- Perkin Elmer 5500
- Atomic absorption spectroscope -- Perkin Elmer 5500 with HGA 500 graphite furnace
- Gas chromatography -- Perkin Elmer 8410 mass spectrometer; digital thermometer
- eH and pH meter -- Presto-Tek model 550
- Personal computer -- IBM PC
- Mainframe computer -- Cray-YMP

3.3.7 Data-reduction techniques

The accumulated geothermal data will be plotted on 1:24,000-scale base maps (or larger scale maps, if appropriate). The data will also be displayed on cross sections as necessary to adequately portray the geothermal characteristics of the area. Geochemical data will be reduced to common units of measurement by PC conversion programs, specifically following the recommendations of the analytical equipment manufacturers.

3.3.8 Representativeness of results

The planned tests for this activity are designed to provide data that are representative of the existing geothermal regime within 5 km of Yucca Mountain. Hydrogeochemical analyses, however, generally produce results beyond the limits of current interpretive methods (Fournier and Truesdell, 1973; Fournier and Rowe, 1966; Taylor, 1974; Fontes, 1980). These methods are limited by assumptions of geochemical equilibrium, but, in application, utilization of several interpretive schemes yields results ranging from most conservative to liberal estimates of hydrothermal conditions. With regard to Yucca Mountain, generalized models of the hydrothermal behavior of the underlying rocks can be calculated based upon knowledge of their lithologic characteristics. If evidence is found for the presence of hydrothermal anomalies, however, uncertainties as to the validity of such data will remain until confirmed or denied by deep drilling. Previous experience in the region has shown that typical hydrothermal systems in the region are always associated with recognizable surface manifestations and (or) favorable geologic structures, and that heretofore undiscovered geothermal anomalies are not likely to exist.

3.3.9 Relation to performance goals and confidence levels

The geothermal resource assessment to be performed in this activity will contribute to the total study of the natural resources of Yucca Mountain (see secs. 1.2, 3.5.9, and 4).

3.4 Activity 8.3.1.9.2.1.4 Assessment of hydrocarbon resources at and near the site

The objectives of this activity are to:

- Determine the potential for the presence or absence of suitable source rocks, reservoir rocks, and traps and seals at and near the site
- Determine the potential for occurrence of conventional hydrocarbon resources (crude oil and natural gas) at and near the site
- Provide necessary data for the overall mineral and energy resource assessment to be performed in Activity 8.3.1.9.2.1.5

The four planned tests (sec. 2.4) are designed to achieve these objectives through the study and measurement of specific parameters as described in the following sections.

3.4.1 Determine presence (or absence) of hydrocarbon source rocks

3.4.1.1 General approach

This test addresses the parameter, organic content of potential source rocks, by sampling Paleozoic strata cored in boreholes adjacent to the site and exposed in outcrops in nearby areas (fig. 2-1), and by determining the nature and amount of organic matter contained in them through appropriate organic geochemical analyses as described below. The organic geochemical effort will employ pyrolysis assay (Rock-Eval method) as a screening process to detect likely source rocks. The Rock-Eval pyrolysis analyses produces: (1) percent total organic carbon, a measure of the total organic matter richness; (2) the volatile or free hydrocarbons (S_1 peak), an indication of the extent to which liquid hydrocarbons have already been generated; and (3) the pyrolytic breakdown products of the solid organic matter, i.e., kerogen (S_2 peak) which is an indication of the future capacity of the source rock to generate hydrocarbons if subjected to higher temperatures. The amounts of S_1, S_2, or S_1 + S_2, particularly when normalized by total organic carbon, will also indicate the quality of the organic matter or hydrocarbon richness of the source rock.
The potential source rocks thus identified by the analyses discussed above, will be further analyzed by chloroform extraction (to isolate bitumens), gas chromatography (GC), GC-mass spectrometry, stable isotope analysis, and organic petrography. The combined analytical data should result in the identification of organic geochemical signatures for the potential source rocks being studied.

3.4.1.2 Test methods and procedures

Standard, widely-accepted methods and procedures for conducting the various kinds of planned laboratory analyses and measurements are described in several technical and scientific reports. These include:

1. Rock Eval

(a) Sample preparation -- Hatch and others (1989)

(b) Methodology -- Espitalie and others (1977)

(c) Interpretation -- Peters (1986)

2. Gas Chromatography-Mass Spectroscopy -- Palacas and others (1989)

3. Stable Isotope Analysis

(a) Sample preparation -- Prezbindowski (1980)

(b) Interpretation -- Hoess (1980)

4. Organic Petrography (vitrinite reflectance) -- see section 3.4.2.2

3.4.1.3 QA level assignment

The statements in section 3.1.3 are applicable to this section.

3.4.1.4 Required tolerance, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this test. However, standard levels of accuracy will be maintained in all of the analytical procedures to be performed.

3.4.1.5 Range of expected results

To date, no analyses have been performed on potential petroleum source rocks in the immediate area of Yucca Mountain. Analyses of core samples collected from rocks of Mississippian age in the Syncline Ridge area, approximately 35 km northeast of Yucca Mountain, indicate that their organic carbon content ranges from 0.8 to 1.4 wt % (Poole and Claypool, 1984, p. 212). Depending on the nature of the organic matter (and other factors), rocks containing organic carbon in excess of 0.5 wt % may be effective source rocks. Whether rocks with comparable organic carbon content lie beneath Yucca Mountain will not be known until samples are collected for analyses in the present study.

3.4.1.6 Equipment

Items of equipment are listed in the publications cited in section 3.4.1.2.

3.4.1.7 Data-reduction techniques

Analytical results will be tabulated and displayed on tables. Locations of sample sites will be plotted on appropriate base maps.

3.4.1.8 Representativeness of results

The methods and techniques being used in this test are designed to yield representative results for the particular samples being studied and analyzed, and for the specific locations where the samples were obtained. Although nearly all of the cored boreholes and the exposures of Paleozoic strata being studied lie some distance outside the 5 km radius surrounding the center of the surface projection of the perimeter drift of the repository (fig. 2-1), the analytical data are likely to be representative of the Paleozoic strata that directly underlie the site as well. The latter statement is based on the expectation that these strata will not show pronounced changes in lithologic character or composition within short distances across the study area.

3.4.1.9 Relation to performance goals and confidence levels

See sections 1.2, 3.5.9, and 4.

3.4.2 Measure thermal maturity of potential source rocks

3.4.2.1 General approach

The degree of thermal maturation--the parameter for this test--will be determined for those samples of Paleozoic strata that were found to contain sufficient quantities of organic matter in the previous test (sec. 3.4.1) to be considered as potential sources of hydrocarbons. Thermal maturity of organic matter will be measured by several techniques, including: (1) kerogen elemental analysis, (2) kerogen coloration (thermal alteration index, TAI), (3) rock pyrolysis, (4) vitrinite reflectance, and (5) color and translucency of conodonts (conodont alteration index, CAI). Peak paleotemperatures can be computed using an empirical calibration with vitrinite reflectance or CAI data, or from direct measurements on fluid inclusions.

3.4.2.2 Test methods and procedures

Standard, widely-accepted methods and procedures for conducting the various kinds of planned laboratory analyses and procedures are described in several technical and scientific reports. These include:

1. Vitrinite Reflectance

    (a) Kerogen isolation methods -- Barker (1982)

    (b) Sample preparation -- Baskin (1979)

    (c) Organic petrology -- Stach and others (1982)

2. Geothermal Gradient Determination/Formation Temperature -- Gretener (1983); Barker (1989a)

3. Conodont Alteration Index -- Epstein and others (1977)

4. Thermal Alteration Index -- Staplin (1977)

5. Kerogen Elemental Analysis -- Bustin and others (1983); Stach and others (1982)

3.4.2.3 QA level assignment

The statements in section 3.1.3 are applicable to this section.

3.4.2.4 Required tolerance, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this test. However, the procedures involved in all the various methods being used to measure thermal maturation are designed to achieve standard levels of accuracy.

3.4.2.5 Range of expected results

Thermal maturity of Ordovician through Triassic age rocks has been mapped in parts of the Great Basin region by Harris and others (1980) and Poole and others (1983). Harris' maps, based on CAI data, generally indicate that Paleozoic rocks in the vicinity of Yucca Mountain have thermal maturation index values greater than 4, which indicates over-mature conditions and therefore are unlikely to retain significant amounts of oil. A mixture of areas farther to the east and southeast exhibit thermal maturation indexes greater than 2 and some greater than 4 (Harris and others, 1980). The only information in or near the site area shows a CAI of 3 for the Silurian portion of the Paleozoic carbonate sequence encountered in drill hole UE-25p#1 (fig. 2-1; Carr and others, 1986). CAI measurements for five samples of these rocks indicate thermal maturation temperatures of only 140° to 180°, and thus the rocks may still have gas production potential. In the present study, the range of expected results include: vitrinite reflectance, 0.4-6.0%; CAI, 1-5; TAI, 1-5; and fluid inclusions, 50-350°C. However, until additional thermal maturity and paleotemperature data are forthcoming, discussions of expected results can only be speculative.

3.4.2.6 Equipment

Items of equipment are listed in the publications cited in section 3.4.2.2.

3.4.2.7 Data-reduction techniques

Data from the thermal maturation studies will be tabulated and plotted on a map to show trends relative to the Yucca Mountain area.

3.4.2.8 Representativeness of results

The discussion in section 3.4.1.8 is applicable to this section.

3.4.2.9 Relation to performance goals and confidence levels

See sections 1.2, 3.5.9, and 4.

3.4.3 Reconstruct thermal history

3.4.3.1 General approach

Based on hydrocarbon generation studies (e.g., Hunt, 1979; Waples, 1984), most liquid hydrocarbons (crude oil and condensate) are thought to be formed at temperatures between 70° and 150° C; natural gas, exclusive of very low temperature biogenic methane, is produced at temperatures above 150° C. In the present test, the range of temperatures to which potential source rocks have been subjected through time and with depth of burial will be determined as accurately as possible from: (1) thermal data obtained in the first two tests described for this activity (secs. 3.4.1 and 3.4.2), and (2) the depositional, structural, and volcanic history of the site area and surrounding region. The latter will be interpreted from previously published geologic studies (e.g., Carr, 1984; Cornwall, 1972; Maldonado, 1985; Robinson, 1985; Sinnock, 1982; Swadley and others, 1984) and from data that may become available from other studies in the site characterization program, especially those dealing with igneous activity such as Study 8.3.1.8.5.1 (Characterization of volcanic features) and Study 8.3.1.6.5.2 (Characterization of igneous intrusive features). Special attention will be given to the possible effects of volcanic activity on potential source rocks, inasmuch as volcanism may have increased regional thermal gradients to the extent that any previously formed hydrocarbons may not have persisted as either oil or gas through the period of active volcanism. Conversely, the influence of igneous intrusive activity on the enhancement of petroleum reservoirs will also be considered.

3.4.3.2 Test methods and procedures

Data on source rocks, paleogeothermal gradients, and timing and depth of burial of potential source rocks will be combined to determine whether the thermal history of the area was favorable for the generation and subsequent preservation of hydrocarbons. Methods for burial history analysis are described by Waples (1981) and Barker (1989b) and several existing computer programs can be applied toward reconstructing thermal histories (see sec. 3.4.3.7).

3.4.3.3 QA level assignment

The statements in section 3.1.3 are applicable to this section.

3.4.3.4 Required tolerance, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this text.

3.4.3.5 Range of expected results

The discussion in section 3.4.2.5 is applicable to this section.

3.4.3.6 Equipment

No equipment is required for this test.

3.4.3.7 Data-reduction techniques

Several computer programs are being considered to process data bearing on thermal history. These include:

1. Burial History/Paleotemperature Analysis

   (a) BASINMOD -- integrated burial history analysis package using organic maturation kinetics: Platte River Associates, Inc., Denver, Colorado

   (b) MATOIL -- integrated burial history analysis package using organic maturation kinetics: Humble Instrument Co., Humble, Texas

   (c) LOPATIN MODEL -- analysis of time-temperature history and oil generation using Lopatin's method: Geobyte, American Association of Petroleum Geologists, Tulsa, Oklahoma

   (d) LOPATIN -- analysis of time-temperature history and oil generation using Lopatin's method: Platte River Associates, Inc., Denver, Colorado

2. Mapping

   (a) GSMAP -- USGS mapping package

   (b) SURFER -- general mapping package, Golden Software, Golden, Colorado

3. General Data Manipulation/Display

   (a) MS STAT -- general statistics program: Gary Perlman, Wang Inst., Tyngsboro, Massachusetts

   (b) REFLEX -- flat file data base manager: Borland, Scotts Valley, California

   (c) PARADOX -- relational data base manager: Borland, Scotts Valley, California

   (d) GRAPHER -- general graphics package: Golden Software, Golden, Colorado

   (e) GSDRAW -- USGS graphics package

3.4.3.8 Representativeness of results

All available data pertaining to a reconstruction of the thermal (burial) history of the site area and surrounding regions will be utilized in this test. Accordingly, the results are expected to be representative of the area being studied.

3.4.3.9 Relation to performance goals and confidence levels

See sections 1.2, 3.5.9, and 4.

3.4.4 Identify potential reservoir rocks and traps and seals favorable for hydrocarbon accumulation

3.4.4.1 General approach

The stratigraphy and geologic structure of the site area and of areas near the site will be evaluated to identify potential reservoir rocks, traps, and seals. The test will be conducted by reviewing all available and future drill hole and geophysical data, as well as previously published geological reports (e.g., Garside and others, 1988; Peterson, 1988) that are pertinent to determining the presence or absence of these features. An allied exercise will be to evaluate comparable petroleum geology features as they are developed at known hydrocarbon occurrences within the Great Basin of Nevada, and, in particular, the productive trend in the Railroad Valley area (e.g., Grant Canyon and other fields, fig. 2-3) of northeastern Nye County. The possibility that Mesozoic thrusting may provide petroleum traps in the area of Yucca Mountain will also be addressed. This will provide a basis for assessing the degree to which these factors are relevant to the petroleum potential at and near the repository site (Activity 8.3.1.9.2.1.5).

Study 8.3.1.9.2.1: Natural resource assessment of Yucca Mountain, Nye County, Nevada

New data gathered by several geophysical surveys primarily planned by other studies and activities in the site characterization program for Yucca Mountain will be used to assist in evaluating oil and gas potential. Modern hydrocarbon exploration depends on a variety of geophysical methods; of these, seismic reflection profiling is usually the most important. Recent reflection testing in the Amargosa Desert south of Yucca Mountain using 480 channel vibroseis and explosive methods (Brocher and others, 1989) has been quite successful, and new reflection tests are being proposed in the immediate vicinity of Yucca Mountain as part of Study 8.3.1.4.2.1 (Characterization of the vertical and lateral distribution of stratigraphic units within the site area). These tests may include shear wave, three-dimensional, and (or) swath (narrow 3-D) shooting techniques. If successful results are obtained, the intention is to proceed with reflection profiling on a grid spacing of 5 to 10 km; however, a more closely spaced grid pattern may be desirable to identify oil and gas fields comparable in size to the Grant Canyon field in Railroad Valley. Because seismic reflection surveys hold considerable promise for identifying the presence (or absence) of hydrocarbon traps, reservoirs, and seals in the vicinity of Yucca Mountain, the tests proposed for Study 8.3.1.4.2.1 are also essential to hydrocarbon evaluation.

Other geophysical data to be assessed include refraction, magnetic, and gravity surveys. Although these methods have generally produced useful information for subsurface studies in the Yucca Mountain area, they generally lack the resolution necessary for oil and gas exploration. Part of the geophysical data evaluation discussed above will be conducted under Activity 8.3.1.9.2.1.2 (see sec. 3.2), and subsequently applied in the present test to assist in identifying those subsurface geologic conditions capable of forming suitable traps and seals in this complexly deformed terrain.

The reservoir characteristics of Paleozoic strata will be evaluated based on existing analyses of the physical properties of core and outcrop samples (e.g., texture, porosity, permeability, and fluid content), on new information derived from cuttings and cores from future boreholes, and on interpretations of geophysical logs. Comparable data will also be obtained for selected tuffaceous units of Tertiary age that may possess reservoir qualities, because (1) similar strata are known to contain oil and gas elsewhere in the Great Basin of Nevada (e.g., Eagle Springs, Trap Spring, and Blackburn fields), and (2) the possibility exists that the tuffs and Paleozoic strata are juxtaposed in the Yucca Mountain area, permitting generated hydrocarbons (in the Paleozoic rocks) to migrate and accumulate in overlying tuffaceous beds that are potential reservoirs.

All of the information discussed above will be utilized in constructing regional and local maps and cross sections needed to identify trends pertinent to petroleum assessment in the Yucca Mountain area.

3.4.4.2 Test methods and procedures

To a large extent, this test utilizes existing data and data collected in support of other stratigraphic, lithologic, structural, and geophysical studies in the site characterization program to evaluate reservoir qualities and hydrocarbon traps and seals in the vicinity of Yucca Mountain. During the course of this evaluation, however, it will be necessary to collect and analyze cuttings and cores from new boreholes that are scheduled to be drilled into the Paleozoic strata (fig. 2-1; see sec. 2.4.1.1) in order to obtain a better and more complete data base relative to reservoir quality. Standard procedures for physical properties testing will be followed (e.g., Technical Procedure GPP-10, Rock properties analysis of Yucca Mountain core samples). Porosity and permeability studies will be conducted at pressures commensurate with overburden pressures. Selected samples will also be examined petrographically to determine pore geometry and nature of cementation of potential reservoir rocks. Interpretation of appropriate geophysical logs will also aid in physical properties studies.

3.4.4.3 QA level assignment

The statements in section 3.1.3 are applicable to this section.

3.4.4.4 Required tolerance, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this text.

3.4.4.5 Range of expected results

To date, no hydrocarbons have been discovered or verified shows of hydrocarbons reported at or in the vicinity of Yucca Mountain, although relatively few boreholes have been drilled for that purpose. Of the commercially drilled exploratory wells located throughout south-central and southeastern Nevada, none have encountered economic quantities of oil and gas (fig. 3-2). Only minor shows of hydrocarbons have been found in some wells. In view of the foregoing, the probability that geologic conditions favorable for the accumulation of commercial amounts of oil and gas will be found to be present in, or in close proximity to, the site area is considered to be low.

3.4.4.6 Equipment

No equipment is required to conduct this test, except the standard items that may be needed to perform physical properties tests (see sec. 3.4.4.2).

3.4.4.7 Data-reduction techniques

Data bearing on potential reservoir rocks and traps and seals will be plotted on thickness, facies, and structure maps and cross sections designed to show the stratigraphic and structural relations of potential source and reservoir rocks in the Yucca Mountain area as well as the surrounding region. Such information should identify trends that can be projected into the subsurface beneath the repository site where specific data may be lacking.

3.4.4.8 Representativeness of results

The data base resulting from this test will provide essential information for assessing the hydrocarbon potential of the Yucca Mountain area. By characterizing local conditions in as much detail as is possible based on existing data and on new drilling and geological and geophysical studies, and by projecting trends into the area from surrounding regions, the interpretations regarding reservoir quality and traps and seals should be representative of the subsurface conditions beneath the repository site.

3.4.4.9 Relation to performance goals and confidence levels

See sections 1.2, 3.5.9, and 4.

3.5 Activity 8.3.1.9.2.1.5 Mineral and energy assessment of the site, comparison to known mineralized areas, and the potential for undiscovered resources and future exploration

The primary purpose of this activity is to integrate the data from the other four activities in Study 8.3.1.9.2.1 and from published sources to evaluate the known and potential mineral and energy resources of the Yucca Mountain area. Specific objectives are:

- To describe known resources and reserves by grade, tonnage, and other physical parameters that affect their value. If the known resources are presently marketable, gross and net current dollar values will also be given.

- To estimate the character of undiscovered deposits or resources characteristic of the area by reasonable inference based upon geological, geophysical, geochemical and other types of evidence as mandated by 10 CFR 60.21(c)(13), and through the use of (1) grade-tonnage and genetic ore deposit models, (2) extraction-conversion methods in geothermal energy utilization, and (3) models of hydrocarbon generation and entrapment processes.
- To describe mineral resources with potential future markets by tonnage, or other amount, grade, and quality as mandated by 10 CFR 60.21(c)(13).

- To describe possible energy resources using appropriate parameters that define the extent and magnitude of those resources.

- To evaluate the mineral and energy resource potential of the Yucca Mountain site by comparison of concentrations of minerals and elements at the site with other areas of similar size that are representative of and located within the geologic setting as mandated by 10 CFR 60.122(c)(17)(ii).

This activity also provides information necessary for the probabilistic calculations for determining future inadvertent human interference or intrusion (Study 8.3.1.9.3.2).

3.5.1 General approach

Under this activity, analog environments of known natural resources will be compared with the geological, geochemical, and geophysical characteristics of the repository site area. Information on selected mineral deposit analogs will be obtained from the existing literature and from Activities 8.3.1.9.2.1.1 and 8.3.1.9.2.1.3 (see secs. 3.1 and 3.2). To the extent possible, analogs will be selected that consist of similar structures, rock types, and other characteristics which have originated under similar geologic conditions in the surrounding regions. For example, analogs will be selected that compare the site to known areas of mineralization such as those found within calderas (Jefferson caldera, Nevada), on margins of calderas (Round Mountain and Goldfield, Nevada), in carbonate-hosted deposits (Carlin-type), or in deposits discovered near Yucca Mountain (Bullfrog district and northern Bare Mountain, Nevada).

Evaluations will be made of all identified resources in the site area that are presently marketable, with estimates of gross and net value. Any known resources that are not presently marketable, but which may become marketable in the future, will also be described by grade, tonnage, and other physical parameters that affect their value. Evaluations will consist of:

- Descriptions of commodities, including composition, mineralogy, form, deposit type and size, distribution, three-dimensional boundaries, grade, tonnage, quality, factors that affect its relative desirability vis-a-vis similar known deposits, and any other descriptive parameter that will define the nature of the resource.

- Determination of the dollar value of presently marketable commodities, based on calculations of gross and net values that take into account the distances to current markets and consequent shipping costs.

Based upon the concentrations of metals and other elements as determined in the geochemical assessment and geological/geophysical appraisal activities (8.3.1.9.2.1.1 and 8.3.1.9.2.1.2) and on current concepts of ore genesis, the site area will be evaluated in terms of its potential for the existence of undiscovered resources and its potential for future exploration.

Certain types of mineral deposits can be eliminated from consideration, based on unfavorable geologic conditions for those types of deposits to have formed in the Yucca Mountain area (for example, massive sulfide, podiform chromite, or Bushveld-type deposits). Some resources can also be eliminated from practical consideration both now and in the future, if their concentrations approximate average crustal abundances.

Rock types at Yucca Mountain (mainly ash-flow tuffs) may be found to be enriched in certain elements relative to average crustal abundances. These values will be compared with similar rocks elsewhere to ascertain whether the tuffs at Yucca Mountain are anomolously enriched.

The mineral potential for rocks of Paleozoic age, which lie beneath the Tertiary ash-flow tuffs of Yucca Mountain at depths ranging from 1,200 to a few thousand meters (fig. 2-2), will also be evaluated based largely on geochemical analyses of cores from deep boreholes (fig. 2-1) and on interpretations of geophysical data (Activities 8.3.1.9.2.1.1 and 8.3.1.9.2.1.2, respectively). Emphasis will be placed on the possibility that mineralized rocks could be associated with suspected detachment faults (Maldonado, 1989) that form the boundary between the Tertiary tuffs and the Paleozoic rocks in this area. Other faults and fractures will also be evaluated as loci for mineral deposits.

Modeling will be undertaken to compare the geologic characteristics of the site area with standard descriptive mineral deposit models (Cox and Singer, 1986). Recognition of deposit types that best fit the geology of the site will permit assessment of undiscovered mineral deposits. The technique to be used employs standard methodology designed to provide a probabilistic, quantitative estimate of the mineral endowment of a given area by considering both discovered and undiscovered mineral resources, including resources that may not be presently economic. This standard methodology consists of three steps:

- The development or adaptation of descriptive and grade-tonnage models (Cox and Singer, 1986) for deposit types that occur, or may occur, within the study area;
- The delineation of areas considered to be geologically favorable for the occurrence of each selected deposit type, based on available geologic, geochemical, and geophysical data; and
- The estimation of the size and number of undiscovered deposits of each type within the delineated areas.

Preliminary evaluations suggest that several of the standard descriptive mineral deposit models may be applicable to the Yucca Mountain area. These are listed on the table on the following pages; it should be noted that some of the models are based on the characteristics of deposits in nearby areas.

This activity will provide a final qualitative assessment of geothermal resources at the repository site in terms of (1) the presence or absence of favorable conditions, (2) the present-day value and utility if located, and (3) the potential for future exploration. The information needed for this assessment will be obtained in large part from the evaluation and modeling of geothermal systems being conducted in Activity 8.3.1.9.2.1.3 (see sec. 3.3.1.4). The integrated data will be used to assess the potential for undiscovered geothermal resources based on reasonable inferences that can be drawn from all available geologic, hydrogeochemical, and geophysical data.

This activity will also provide a final qualitative assessment of the hydrocarbon resource potential at the repository site in terms of (1) the presence or absence of favorable conditions for hydrocarbon generation and entrapment, (2) present-day value if located, and (3) the potential for future exploration. Information will be drawn principally from Activity 8.3.1.9.2.1.4 (see sec. 3.4) and from the existing literature to provide comparisons between the site and areas of known hydrocarbon accumulations elsewhere in the region with respect to similarities in types and ages of rocks, depositional environments, tectonic regime, and conditions for generating and trapping oil and gas. The resulting analogs will be instrumental in evaluating the potential for undiscovered hydrocarbon resources in the Yucca Mountain area.

3.5.2 Test methods and procedures

This activity utilizes existing data and data obtained from other activities in Study 8.3.1.9.2.1, hence no procedures are required to conduct the planned work.

3.5.3 QA level assignment

The statements in section 3.1.3 are applicable to this section.

3.5.4 Required tolerance, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this activity. Although a large component of this evaluation of mineral and energy resource potential is qualitative and (or) inferential, the following can be noted in terms of the tentative goals established for design or performance parameters corresponding to the characterization parameters of the activity:

Study 8.3.1.9.2.1: Natural resource assessment of Yucca Mountain, Nye County, Nevada

Examples of types of mineral deposits that may be applicable to Yucca Mountain.

Deposit Type Name	Descriptive Model	Grade-Tonnage
Hot springs Hg[1]	Rytuba, 1986a	Rytuba, 1986b
Hot springs Au-Ag	Rytuba, 1986b	Berger and Singer, 1987
Creede epithermal veins	Mosier and others, 1986b	Mosier and others, 1986c
Comstock epithermal veins[2]	Mosier and others, 1986d	Mosier and others, 1986e
Sado epithermal veins	Mosier and others, 1986a	Mosier and Sato, 1986
Epithermal quartz alunite veins[3]	Berger, 1986	Mosier and Menzie, 1986
Volcanogenic U	Bagby, 1986	Mosier, 1986c
Epithermal Mn	Mosier, 1986a	Mosier, 1986b
Polymetallic veins	Cox, 1986	Bliss and Cox, 1986
Gold on flat faults	Bouley, 1986	—
Simple Sb	Bliss and Orris, 1986a	Bliss and Orris, 1986c
Disseminated Sb	Bliss and Orris, 1986a	Bliss and Orris, 1986b
Barite veins[4]	—	—[5]
Fluorspar veins in volcanic rocks	—	—[6]
Distal disseminated Ag-Au	Cox, 1992 [in press]	Cox and Singer, 1992
Sediment-hosted Au	—	Mosier and others, 1992
Porphyry Cu-Mo	Cox, 1986a	Singer and others, 1986
Tungsten skarn	Cox, 1986b	Menzie and Jones, 1986
Copper skarn	Cox and Theodore, 1986	Jones and Menzie, 1986
Zn-Pb skarn	Cox, 1986c	Mosier, 1986d
Bedded barite	Orris, 1986a	Orris, 1986b

Examples of types of mineral deposits that may be applicable to Yucca Mountain. (Contd)

[1] Nearby Thomson Mine may be included based on its size, but it may not conform to the existing grade-tonnage model.

[2] Nearby Tonopah and Bullfrog districts included in model.

[3] Nearby Goldfield district included in model.

[4] Nearby deposit at Mine Mountain may be included – compatibility with grade-tonnage model unknown.

[5] Grade-tonnage model near completion (G. J. Orris, verbal communication, June 27, 1988).

[6] Grade-tonnage model under development (G. J. Orris, verbal communication, June 27, 1988).

- Characterization parameter: characterization of the mineral and energy resource potential of the proposed Yucca Mountain nuclear waste storage site

- Tentative goals for related design or performance parameter: to determine the mineral and energy resource potential with a high degree of confidence

- Expected accuracy: the analysis of information and data from published sources and from other activities in Study 8.3.1.9.2.1 is likely to result in the reliable identification and characterization of the mineral and energy resource potential of the site area

3.5.5 Range of expected results

Existing information suggests that it is unlikely that appreciable amounts of mineral and energy resources will be found at Yucca Mountain. Commodities with the most favorable potential, however, include gold, silver, associated base metals, mercury, and uranium. If indications of mineralization are found, (1) any mercury is likely to be hosted in the volcanic rocks; (2) any uranium may occur in either volcanic or Paleozoic rocks; and (3) any gold, silver, and base metals may be hosted in volcanic rocks, Paleozoic rocks, or along the contact between the two.

Zeolites are the only identified resource at Yucca Mountain, and they occur in tuffs mostly at depths greater than 500 m (Bish and Chipera, 1989). Given the present state of knowledge, it appears unlikely that significantly greater quantities of zeolites will be identified at the site.

The existence of warm springs in the region and the evidence for late Tertiary volcanic activity in the Crater Flat area indicate that there may be at least a low potential for geothermal resources at the Yucca Mountain site. The absence of thermal springs at Yucca Mountain and the fact that the site is located in a regional low for heat flow, however, mitigate against the geothermal potential being very high. It is therefore likely, given the present state of knowledge, that the Yucca Mountain site will have no more than a low potential for geothermal resources.

The potential for hydrocarbon resources is more difficult to evaluate based on the present state of knowledge. The thermal history of the rocks is problematic, with conflicting evidence about whether it will permit the presence of hydrocarbons, and with the nature of traps, seals, and reservoir rocks not being well known. Given the nature and extent of known hydrocarbon resources in the region, it is likely that the potential for hydrocarbon resources at the Yucca Mountain site will also be low.

3.5.6 Equipment

No equipment will be required to obtain the data for this activity. Computers and commercially available software will be used for data reduction and analysis.

3.5.7 Data-reduction techniques

Standard data-reduction techniques will be used to analyze geological, geochemical or other data as part of the mineral resource assessment in this activity. Data will be presented in the form of maps, charts, graphs, tables, cross sections, and other appropriate displays.

3.5.8 Representativeness of results

The information resulting from this activity is expected to be representative of the natural resources of the Yucca Mountain area. The conclusions are based on the results of previous studies in the area and surrounding region, and on the findings of other activities in the site characterization program which have employed the most up-to-date and reliable methods for evaluating mineral and energy resource potential.

3.5.9 Relation to performance goals and confidence levels

It is anticipated that this activity will provide sufficiently accurate data to make an evaluation of the mineral and energy resources of the Yucca Mountain with a high degree of confidence. Accordingly, the results should directly address questions concerning the potential of the site for future exploration. See sections 1.2 and 4 for further discussion of the application of these data to issue resolution and to other studies and activities.

4. APPLICATIONS OF RESULTS

This section identifies other studies that will use the information obtained from this study, as summarized from information in the SCP. Related discussions in Section 1.2 draw on Section 8.3.5 of the SCP to consider the uses of information from the study in the context of issue resolution and performance goals.

Data from this study will be used in Investigation 8.3.1.9.3 (Studies to provide the information required on potential effects of exploiting natural resources on hydrologic, geologic, and rock characteristics) by providing the basis for probabilistic calculations for determining inadvertent human interference and (or) intrusion due to potential exploration for, or extraction of natural resources at Yucca Mountain in the postclosure period (Study 8.3.1.9.3.1). This study will also provide information pertinent to an assessment of initiating events related to human interference that are considered not to be sufficiently credible or significant to warrant further investigation (Activity 8.3.1.9.3.2.2). These data and resulting evaluations are anticipated to facilitate the requisite probabilistic calculations (Study 8.3.1.9.3.2).

In addition, information compiled and evaluated in Activity 8.3.1.9.2.1.3 (assessment of the potential for geothermal energy at Yucca Mountain, Nevada) will be used in conjunction with Activity 8.3.1.8.5.2.3 (heat flow at Yucca Mountain and evaluation of regional ambient heat flow and local heat flow anomalies) to characterize the local geothermal regime as it might relate to repository performance during the postclosure period.

5. SCHEDULE AND MILESTONES

Figure 5-1 and table 5-1 show the principal milestones for Study 8.3.1.9.2.1 and its scheduling ties to other studies. This information is abstracted from the most current and complete schedule information, and is based primarily on the estimate of time involved in evaluating existing data. In the probable event that additional data are required to achieve the objectives of the study, the schedule will be adjusted as required.

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Table 5-1. Schedule information for Study 8.3.1.9.2.1

A. Input from --

Investigation 8.3.1.2.2: Studies to provide description of the unsaturated zone hydrologic system at the site.

Study 8.3.1.2.3.2: Characterization of the site saturated-zone ground-water flow system.

Study 8.3.1.4.2.1: Characterization of the vertical and lateral distribution of stratigraphic units within the site area.

Study 8.3.1.17.4.12: Tectonic models and synthesis.

B. Input from --

Study 8.3.1.3.2.1: Mineralogy, petrology, and chemistry of transport pathways.

Study 8.3.1.3.2.2: History of mineralogic and geochemical alteration of Yucca Mountain.

Activity 8.3.1.5.2.1.5: Studies of calcite and opaline silica vein deposits.

Study 8.3.1.8.5.1: Characterization of volcanic features.

Activity 8.3.1.17.4.3.5: Evaluate structural domains and characterize the Yucca Mountain region with respect to regional patterns of fault movement.

C. Input from --

Activity 8.3.1.17.4.3.1: Conduct and evaluate deep geophysical surveys in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane.

Activity 8.3.1.17.4.3.5: Evaluate structural domains and characterize the Yucca Mountain region with respect to regional patterns of faults and fractures.

Study 8.3.1.17.4.7: Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain.

D. Output to --

Activity 8.3.1.8.5.2.3: Heat flow at Yucca Mountain and evaluation of regional ambient heat flow and local heat flow anomalies.

E. Output to –

Study 8.3.1.9.3.1: Evaluation of data needed to support assessment of the likelihood of future inadvertent human intrusion at Yucca Mountain as a result of exploration and/or extraction of natural resources.

Study 8.3.1.9.3.2: An evaluation of the potential effects of exploration for, or extraction of, natural resources in the hydrologic characteristics at Yucca Mountain.

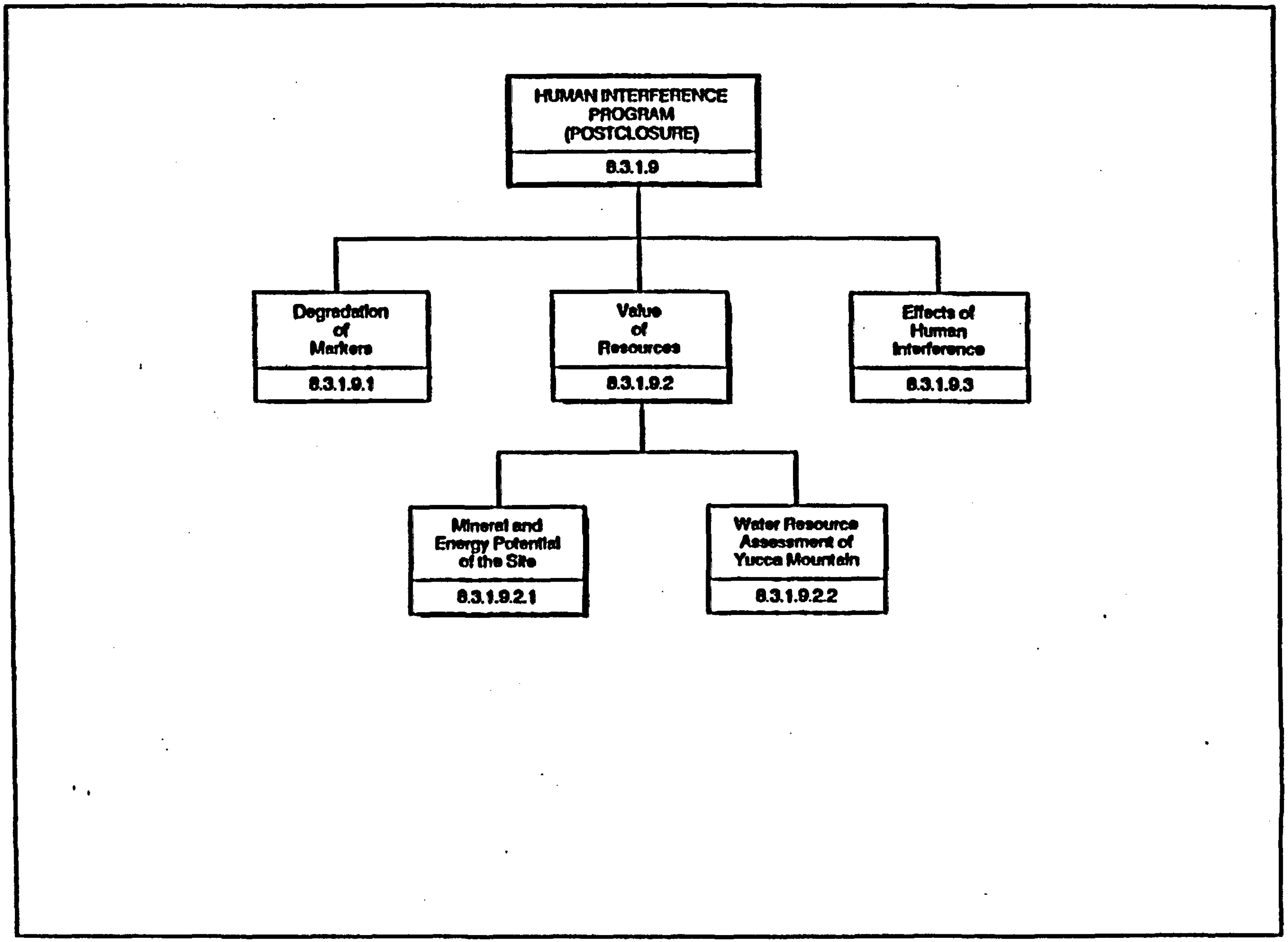


Figure 1-1. Relation of Study 8.3.1.9.2.1 to the postclosure human interference program.

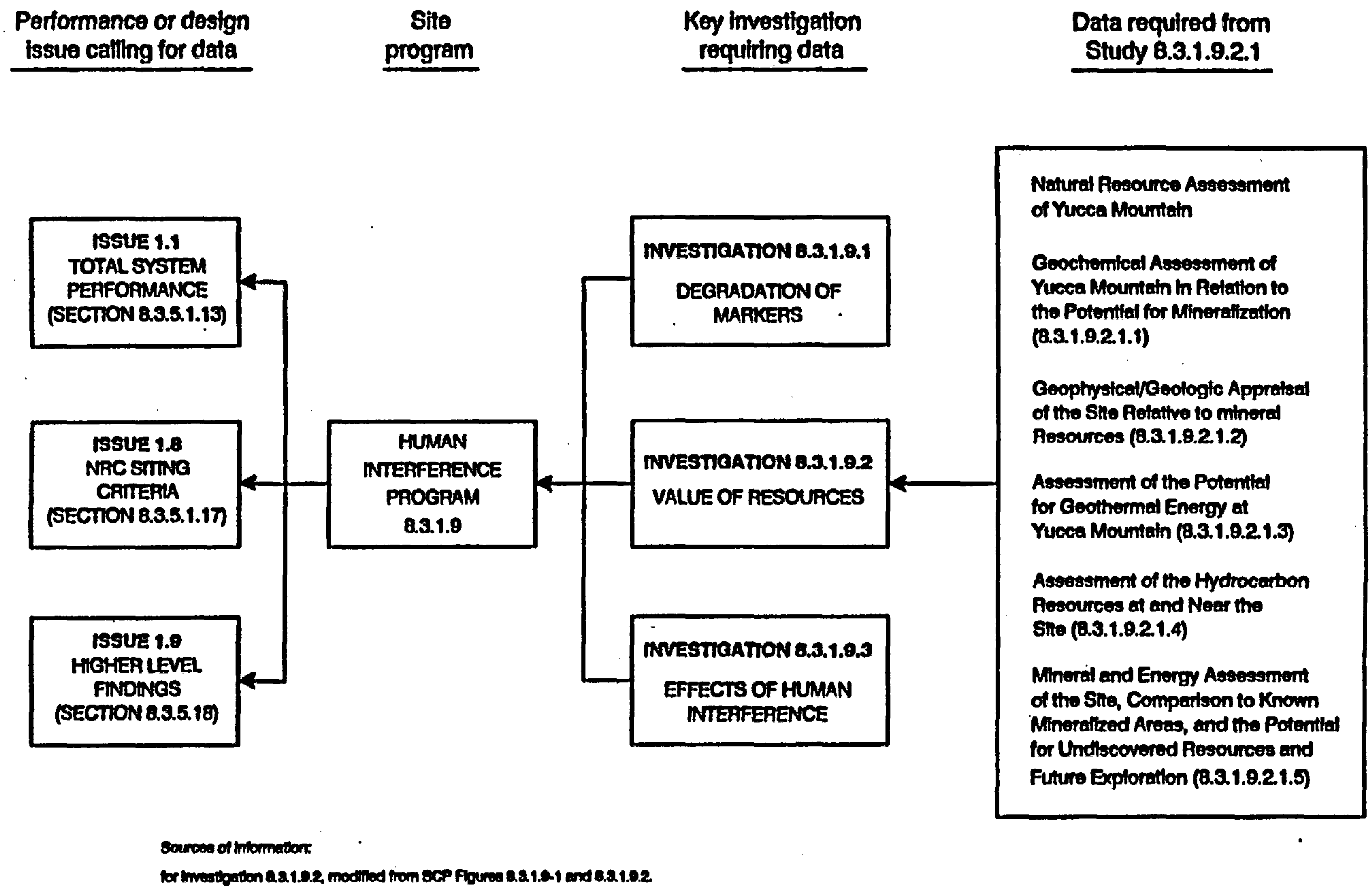


Figure 1-2. Information required from Study 8.3.1.9.2.1 for issue resolution through the human interference program.

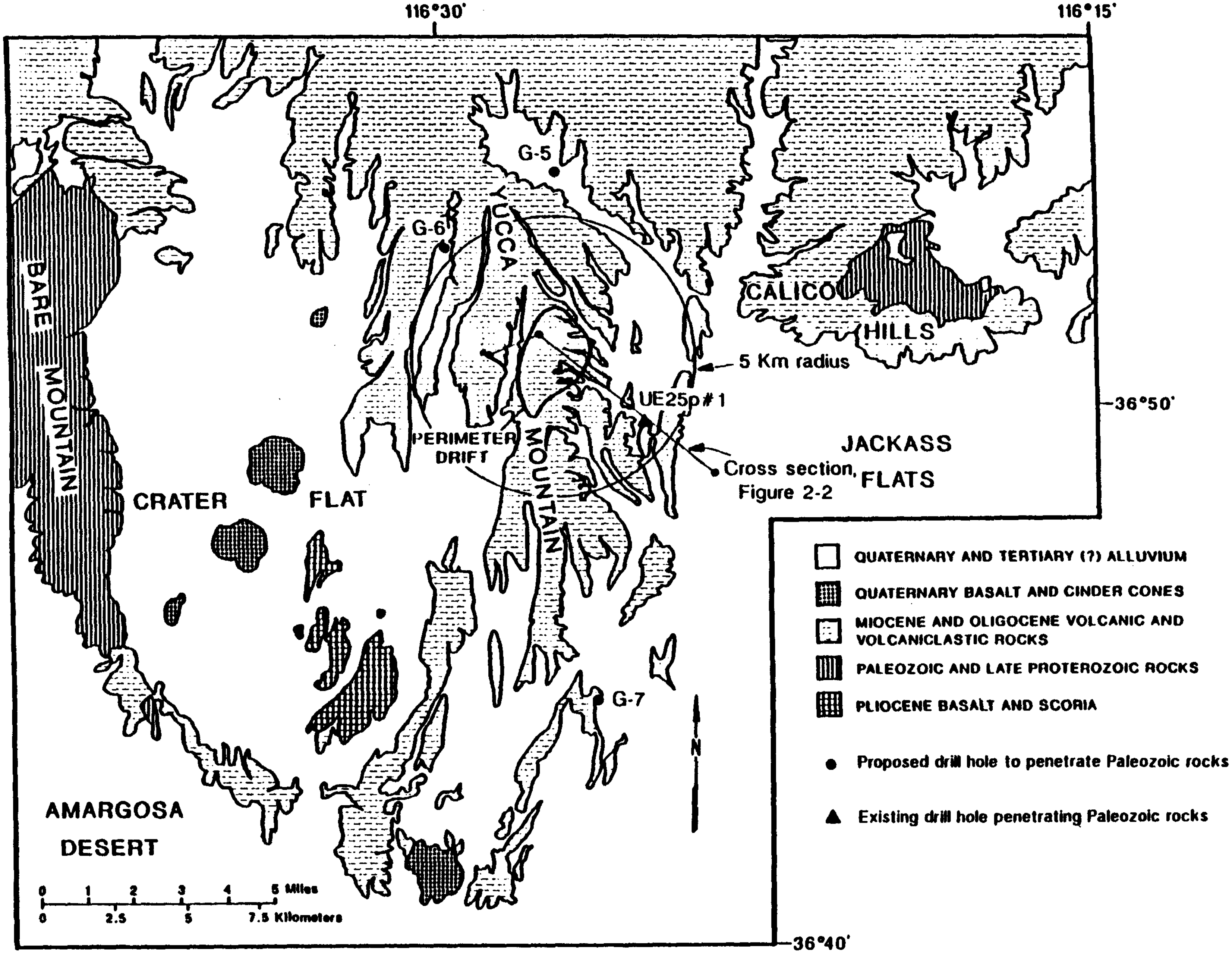
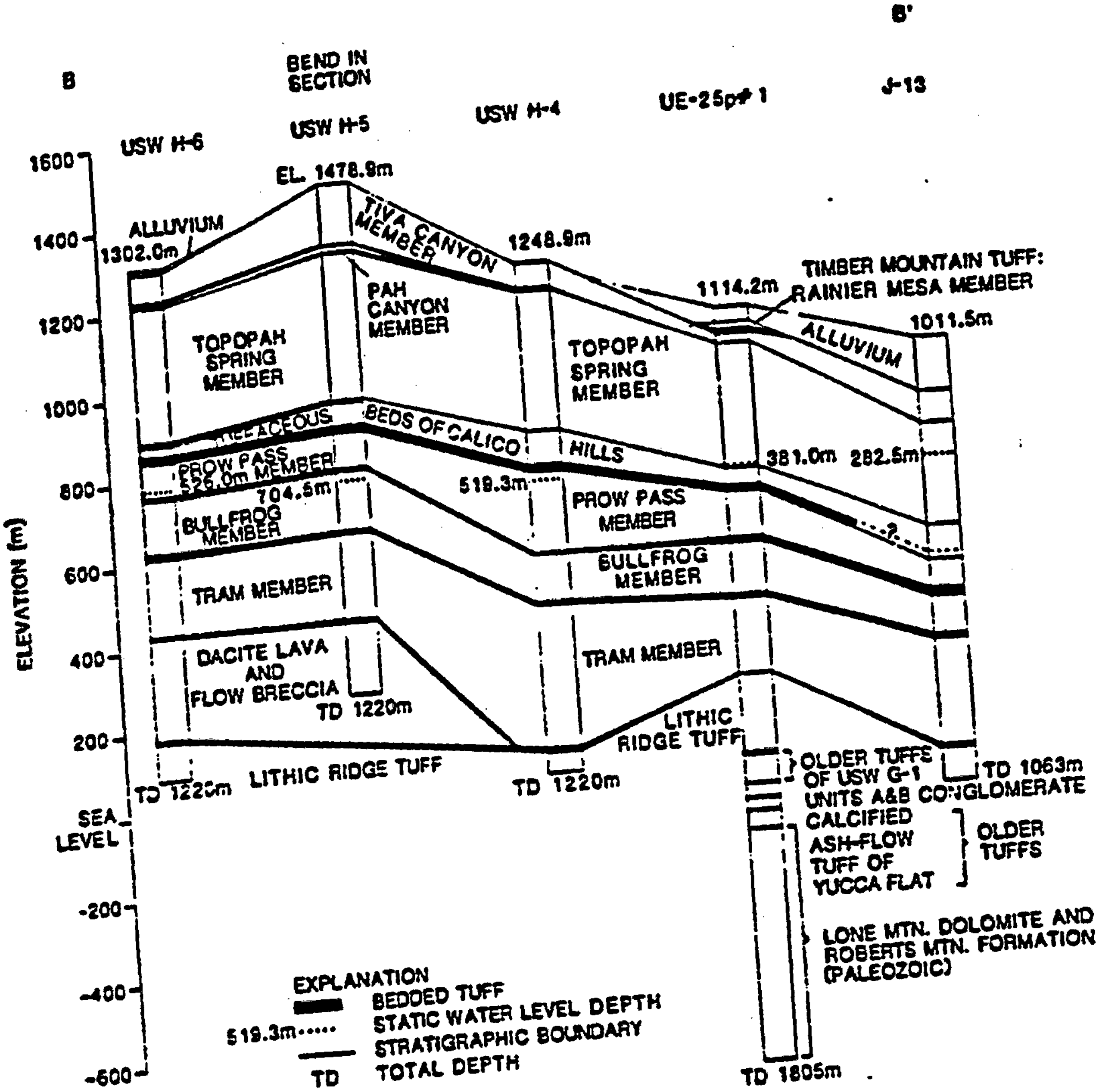


Figure 2-1. Index map showing distrubution of major rock types at Yucca Mountain and vicinity.



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H-5: BENTLEY et al. (1983)
H-4: WHITFIELD et al. (1984)
p# 1: CRAIG & JOHNSON (1984)
J-13: THORDARSON (1983)

HORIZONTAL SCALE
0 — 1 MILE
0 — 1 KILOMETER

Figure 2-2. East-west stratigrphic cross section across Yucca Mountain.

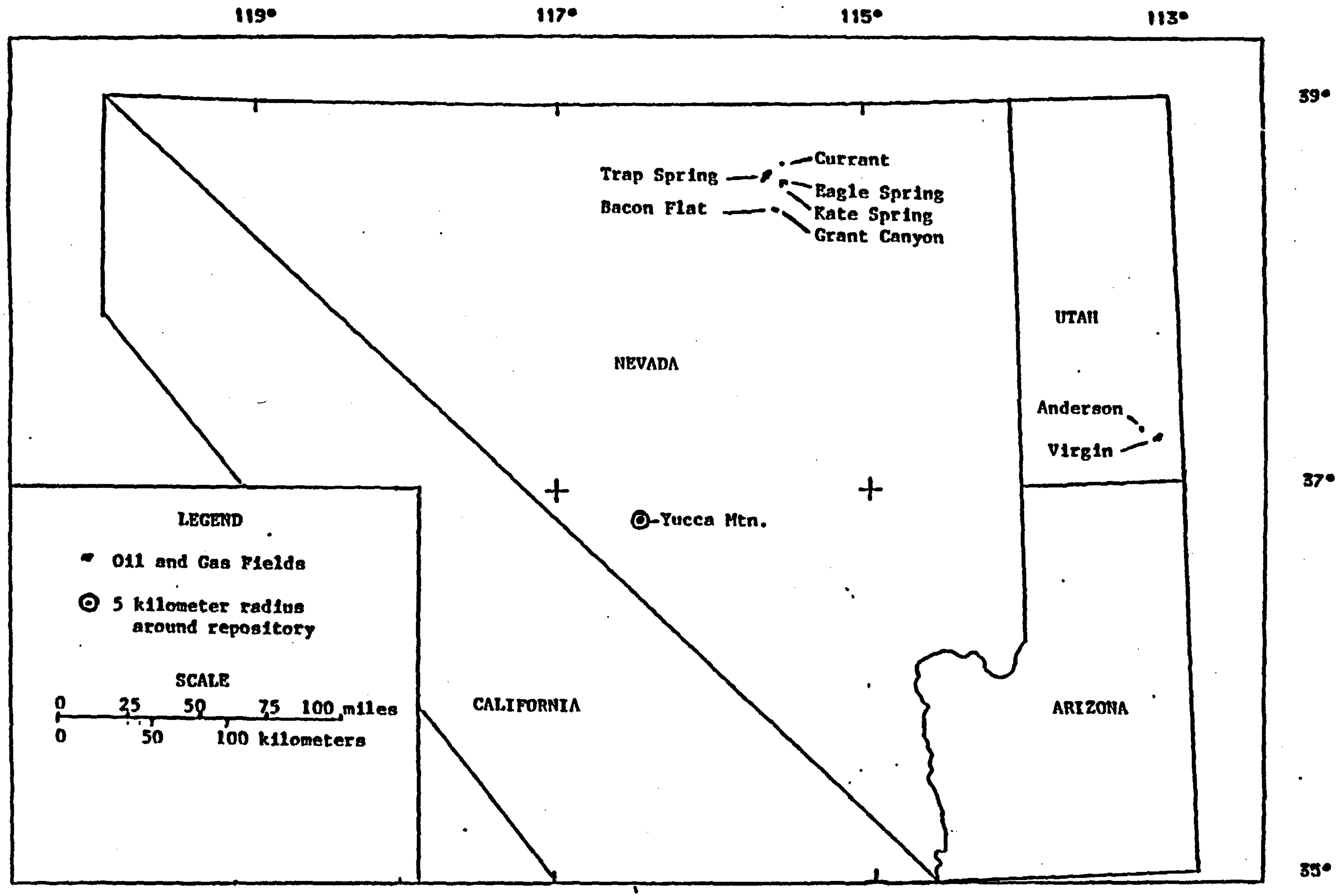

Figure 2-3. Oil and gas fields in the vicinity of Yucca Mountain.

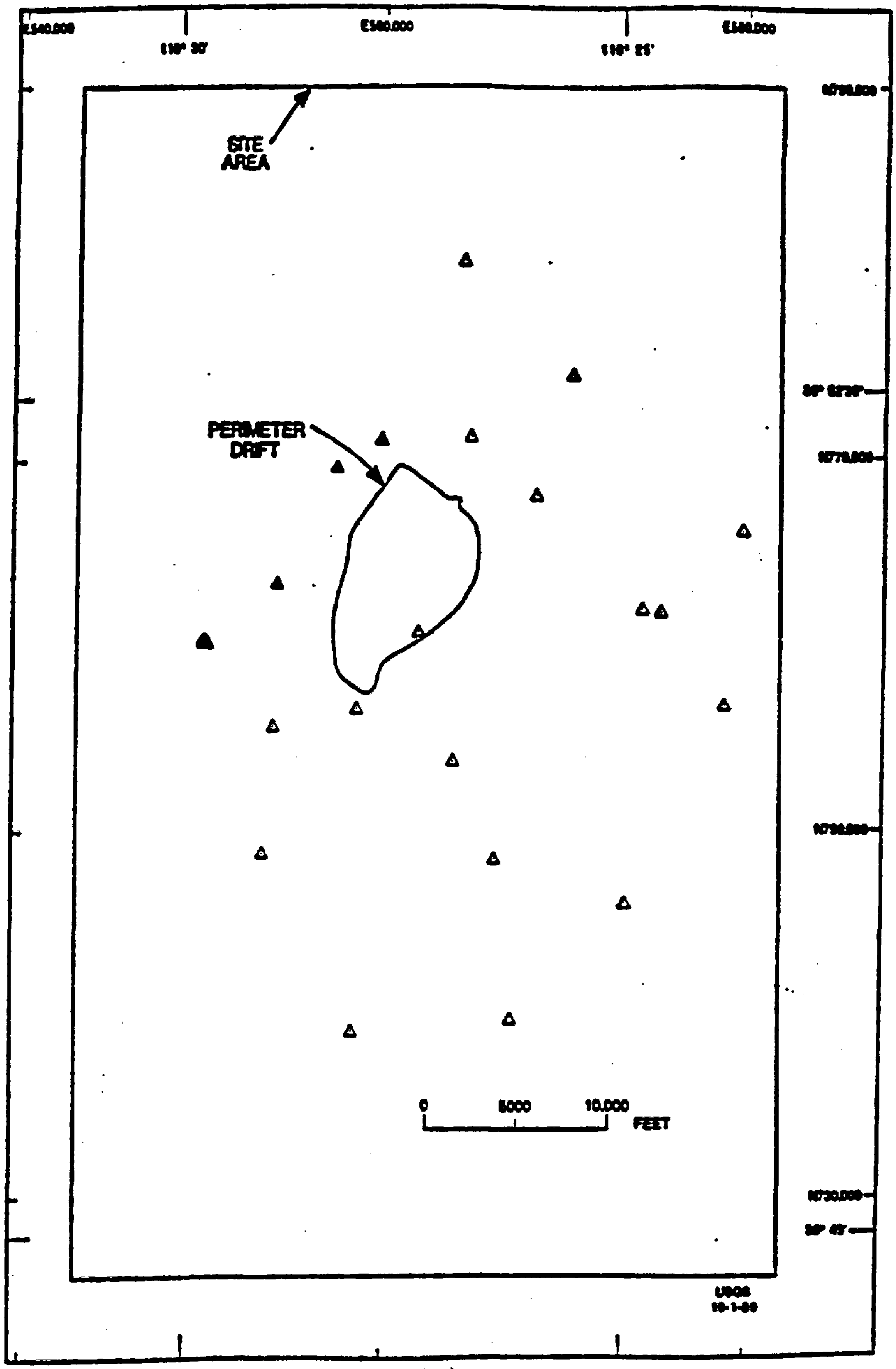

Figure 3-1. Map showing locations of existing (open triangle) and proposed (solid triangle) boreholes deep enough to penetrate the water table within the site area.

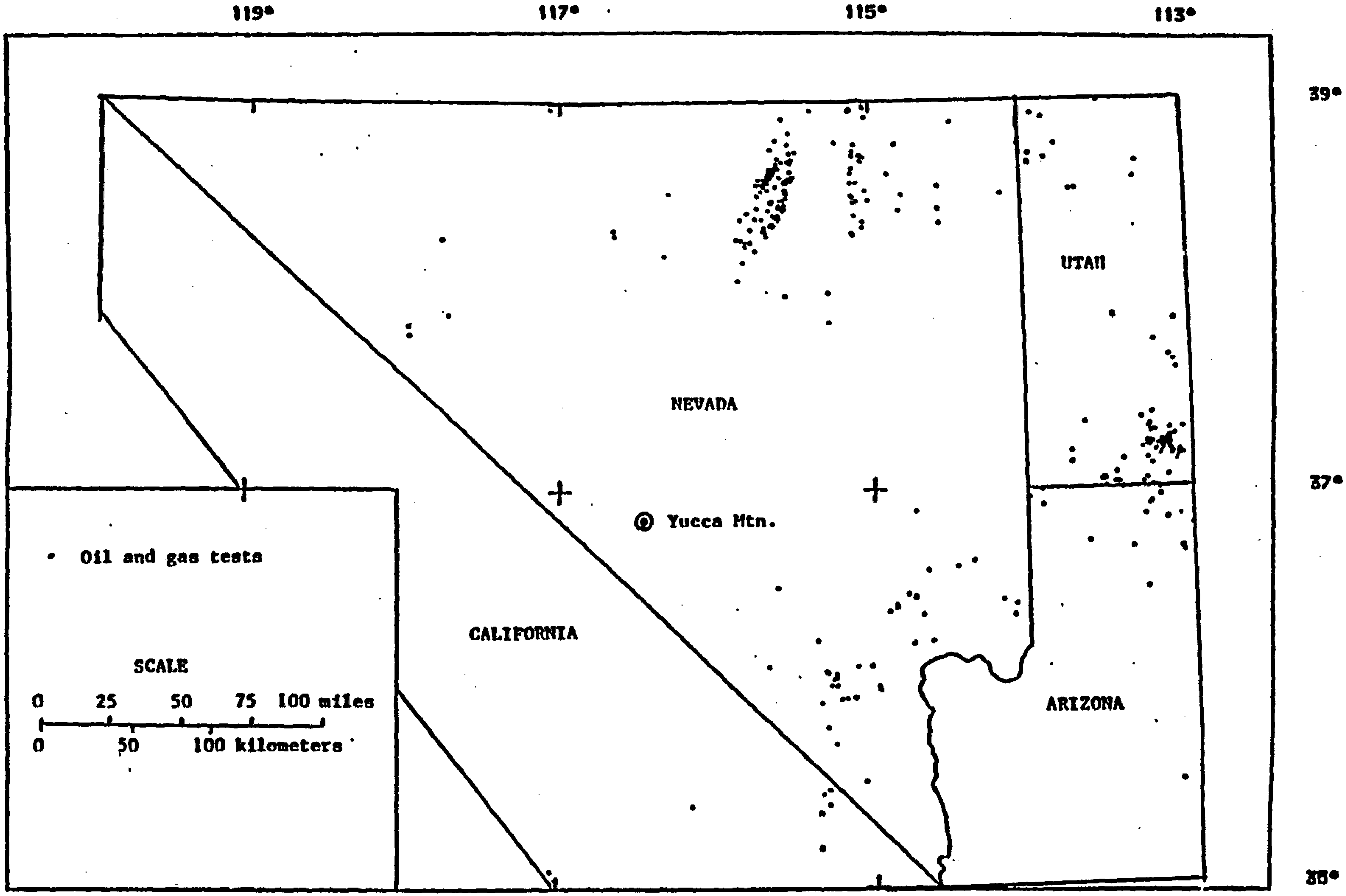

Figure 3-2. Oil and gas test wells in southern Nevada and parts of adjacent states.

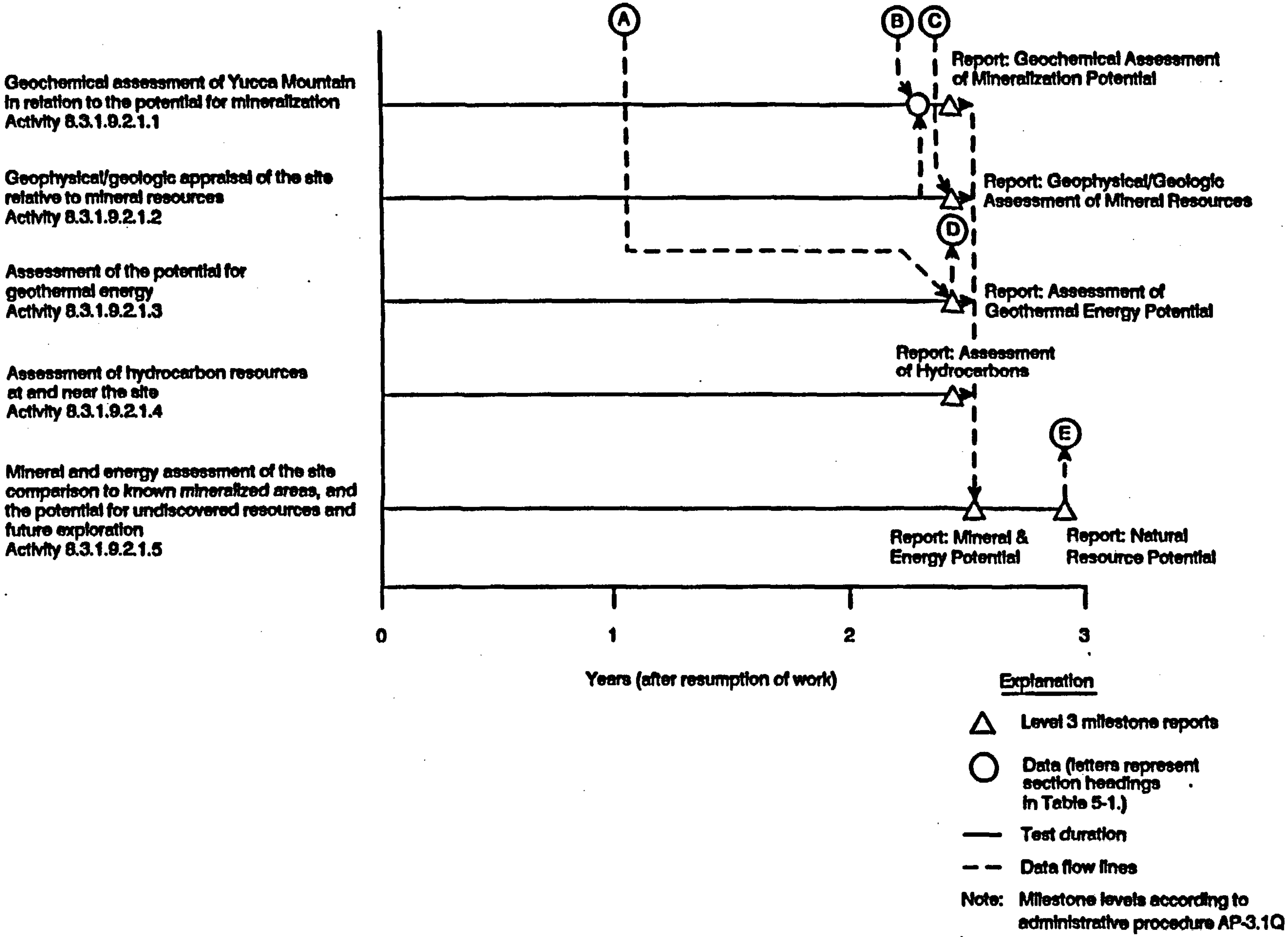

Figure 5-1. Schedule for 8.3.1.9.2.1.

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