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STUDY PLAN APPROVAL FORM

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Study Plan Number 8.3.1.8.5.2

Study Plan Title Characterization of Igneous Intrusive Features

Revision Number

Prepared by: U. S. Geological Survey

Date: 10/08/93

Approved:

Susan Jones 3/7/94
Director, Regulatory and Site Evaluation Division / Date

James Blaylock for 2/11/94
Director, Quality Assurance Division / Date

Effective Date: 3/11/94

STUDY PLAN

FOR

STUDY 8.3.1.8.5.2
CHARACTERIZATION OF IGNEOUS INTRUSIVE FEATURES

Rev 0

October 8, 1993

U. S. GEOLOGICAL SURVEY

ABSTRACT

Study 8.3.1.8.5.2 is part of the site characterization program that provides information required by the analysis and assessment investigations of the post-closure tectonics program. It includes three activities, only one of which (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) is covered in this study plan. The primary objective of the heat flow and rock conductivity measurements being planned for this activity is to provide data for use in detecting temperature and heat-flow anomalies that could be associated with faults, shallow magma bodies, and (or) pathways for preferential ground water flow. Integration of these data with other geophysical data and with existing geologic and hydrologic data will be required in determining the causes of thermal anomalies in the Yucca Mountain area.

TABLE OF CONTENTS

FIGURES AND TABLES

FIGURE

TABLE

STUDY 8.3.1.8.5.2
CHARACTERIZATION OF IGNEOUS INTRUSIVE FEATURES

This study consists of three activities:

- 8.3.1.8.5.2.1 - Evaluation of Curie temperature isotherm
- 8.3.1.8.5.2.2 - Chemical and physical changes around dikes
- 8.3.1.8.5.2.3 - Heat flow at Yucca Mountain and evaluation of regional ambient heat flow anomalies

It is part of the postclosure tectonics program (see figure 1-1) and is one of a series of related studies focused on (1) the identification and measurement of tectonic processes and their Quaternary rates operating at and in the vicinity of the potential repository and (2) the estimation of future rates of these processes whose operation could jeopardize the structural integrity of the potential repository, or lead to a loss of radionuclides into the accessible environment.

This study plan includes discussions of only the third activity listed above. With regard to Activity 8.3.1.8.5.2.1, the USGS is, at this time, suspending all action on this activity pending completion of a review planned in LANL Activity 8.3.1.8.1.1.3 (Presence of magma bodies in the vicinity of the site). The LANL activity is the only user of the Curie temperature isotherm data, which defines the depth at which rocks are essentially nonmagnetic, having been heated to temperatures greater than the Curie temperature ($\approx$580°C for magnetite at atmospheric pressure), and hence may provide some indication of the presence of magma bodies. In the upcoming review, an independent consultant will determine whether or not sufficient information has been obtained to assess the potential presence of magma beneath the Yucca Mountain region, and will evaluate which geophysical methods used for this purpose are most useful, both in an absolute sense, and on a cost/benefit basis.

We believe that no action should be taken on evaluating the depth of the Curie temperature isotherm until this review is complete because:

(1) the most current evaluation of this type of data in central Nevada (Blakely, 1988) suggests that this technique yields results that are too ambiguous, and that are of a scale of detection that is too general to be useful for the application intended at Yucca Mountain, and

(2) the cost of extending the aeromagnetic coverage, required as data input for this technique, over the Yucca Mountain region would be very high, especially in relation to the probable benefit.

Once the LANL-sponsored review is complete, the USGS will seek DOE approval to act on the recommendation it yields regarding evaluation of the depth of the Curie temperature isotherm.

The USGS is also suspending action on Activity 8.3.1.8.5.2.2, because (1) data on the physical changes around dikes are being collected in LANL Study 8.3.1.8.1.2 (Effects of a volcanic eruption penetrating the repository), which is currently underway; and (2) sorptive minerals typically are largely (if not entirely) destroyed within a contact metamorphic aureole, thus eliminating the need to conduct a separate and detailed study of the chemical changes around dikes. As a consequence, the USGS will propose a change to the SCPB to the effect that Activity 8.3.1.8.5.2.2 be eliminated. However, if needs for additional data on physical and chemical changes around dikes are identified during the course of the site characterization program, it is further proposed that such data be collected as part of USGS Activity 8.3.1.8.4.1.1 (Assessment of the change in rock geochemical properties due to igneous intrusions), which is the primary user of the information.

Although the title of this study addresses possible igneous intrusion, the near-surface thermal data and analyses to be provided by Activity 8.3.1.8.5.2.3 are pertinent to the study of all features and processes that influence the distribution of thermal energy in the shallow crust. A principal process affecting thermal-energy distribution is ground-water movement, and thermal anomalies commonly are associated with preferential water flow in aquifers to structurally controlled pathways. During development of the draft Site Characterization Plan in the mid-1980's, heat-flow studies -- like other geophysical methods -- were assigned to an investigation or study that would be a major user of the information, though not necessarily the only or dominant user. At the present time it appears that definitions of hydrologic processes and the causative structural conditions may be the principal products of Activity 8.3.1.8.5.2.3. Sections 2.3.1 and 3.3 of this study plan address the limitations that exist with respect to identifying igneous intrusions.

1. PURPOSE AND OBJECTIVES OF THE STUDY

The objective of this study is to provide a quantitative characterization and analysis of the thermal regime of the Yucca Mountain area based on vertical temperature profiles and thermal conductivity data. Uncharacteristically high heat flows will be assessed in the context of regional and local hydrology to determine whether they provide evidence for fault-controlled groundwater flow paths, molten rock, or cooling magma bodies in the upper part of the crust, and if they do, their potential as geothermal energy resources.

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

This study will gather information on the regional thermal setting of Yucca Mountain and on local ambient heat flow. One intended use of the data will be as part of the evaluation to determine whether there are any indications that magmatic bodies are present in the area or that magmatic processes are currently operating in the crust beneath Yucca Mountain. Previous studies have shown that the near-surface heat flow from this region is heavily influenced by hydrologic processes, which may preclude identification of possible igneous effects. However, the results of this study potentially will provide useful constraints on hydrologic interpretations. Data collected in this study will also be used to define the site ambient thermal conditions (Study 8.3.1.15.2.2) and to assess the potential for a geothermal energy resource at Yucca Mountain (Activity 8.3.1.9.2.1.3). Lastly, results from this study will be integrated with data relevant to tectonics and used as input to tectonic models (Study 8.3.1.17.4.12).

Specific uses of the information for measuring repository performance against goals for performance measures are discussed in section 1.2 below; 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

Tectonic processes identified at or in the vicinity of Yucca Mountain include, among others, uplift and subsidence, faulting, folding, and volcanism. Information regarding the specific location and rates at which these processes are likely to operate during the next 10,000 years is needed in order to safeguard the potential repository from natural events which could cause or lead to (perhaps in conjunction with climatic changes) unacceptable contamination of the accessible environment.

The information from this study will contribute to the body of evidence for evaluating the probability and effects of tectonic "initiating events" that may alter existing conditions at Yucca Mountain and adversely affect repository performance. As noted in sections 1.1 and 4, the information is needed as input to other studies that will determine the probabilities and potential effects of tectonic events such as a volcanic eruption penetrating the repository, a fault disrupting waste packages or locally increasing water percolation. The results of the integrations contribute to the resolution of postclosure Issue 1.1 (Total system performance, SCP 8.3.5.13); Issue 1.8 (NRC siting criteria, SCP 8.3.5.17); Issue 1.9a (Higher level findings [postclosure], SCP 8.3.5.18), and Issue 1.11 (Configuration of underground facilities [postclosure], SCP 8.3.2.2) as illustrated in figure 1-2 and SCP figure 8.3.1.8-1. In addition, the resulting data will contribute to preclosure Issue 4.4 (Technologies for repository construction, operation, closure and decommissioning, SCP 8.3.2.5) as shown in figure 1-3 (see also SCP figure 8.3.1.17-1).

The uses of the information in resolving design and performance issues are discussed in more detail below.

Issue 1.1 (total system performance -- volcanism): Information from the study is intended, in part, to improve the confidence levels in the performance parameter required to assess the annual probability of a volcanic eruption penetrating the repository (SCP table 8.3.1.8-1b and -1a). The responsibility for evaluating the probability of a volcanic eruption is assigned to Study 8.3.1.8.1.1, as shown in Figure 1-2. The performance parameter addresses the single initiating event related to (1) the direct intrusion of magma into the repository, or (2) potential explosive episodes (hydrovolcanism) that may result from such intrusions, either one of which could lead to releases of radioactive materials to the accessible environment. As discussed in SCP sections 1.3 and 1.5, basaltic volcanism is considered the only credible scenario for igneous intrusion in the controlled area during the postclosure time period. Preliminary calculations of the probability of basaltic volcanism (Section 1.5.1.2.1.3) indicate that this type of igneous activity may fall into the range of unanticipated events (between 10^{-5} and 10^{-8} annual probability). Heat flow, when combined with the results of hydrologic, geologic, and geophysical studies, may contribute to the resolution of ambiguities associated with any single line of evidence, increasing confidence in estimated annual probabilities of occurrence.

Issue 1.1 (total system performance -- groundwater flow): Existing thermal data from the saturated zone at Yucca Mountain have been interpreted (Sass et al, 1988; Fridrich et al, 1991) to indicate interception of heat by groundwater flow beneath the present depth of drilling (as deep as 1000 m). Fridrich et al (1991) have related this thermal anomaly also to the geologic cause of the large hydraulic gradient from the north and northwest toward the site, which is important to assessments of the possible effects of future tectonism or climate change on waste isolation. Both the zone of large hydraulic gradient and the area of low heat flow to the south-southeast will be targeted for additional, high-quality thermal data to help resolve the structural and stratigraphic controls on the apparent hydrologic disturbance of the geothermal regime. Potential pathways for preferential flow in the unsaturated zone also are associated with thermal perturbations (Sass et al, 1988), leading to continued plans for temperature profiling and heat-flow determinations in surface-based boreholes and in the ESF.

Issue 1.8 (NRC siting criteria): The study will contribute data on the nature of hydrologic conditions and tectonic processes (i.e., faulting and volcanic events) operating at the site. This information will be used in analyses to determine the degrees to which several of the favorable and potentially adverse conditions listed in 10 CFR 60.122 contribute to or detract from isolation.

Issue 1.9a (higher level findings [postclosure]): Results from the study will contribute to evaluations of the higher-level findings of 10 CFR Part 960, most directly with respect to the postclosure technical guidelines for geohydrology and tectonics.

Study 8.3.1.8.5.2: Characterization of igneous intrusive features

Issue 1.11 (configuration of underground facilities [postclosure]): Detailed thermal data, obtained principally in the ESF, will aid in the identification of preferential hydrologic flow paths within the unsaturated host rock, thereby allowing reconfiguration or relocation of facilities if deemed necessary.

Issue 4.4 (technologies for repository construction, operation, closure, and decommissioning [preclosure]): Information from the study will be provided to Study 8.3.1.15.2.2, Site Ambient Thermal Conditions, where it will support such considerations as repository ventilation.

2. RATIONALE FOR SELECTED STUDY

The activities planned for this study were chosen on the basis that they provide a useful means for obtaining data required to evaluate tectonic processes such as the presence of significant magma bodies in the area or faulting that produces preferential groundwater flow paths.

2.1 Activity 8.3.1.8.5.2.1 - Evaluation of depth of Curie temperature isotherm

See introductory section.

2.2 Activity 8.3.1.8.5.2.2 - Chemical and physical changes around dikes

See introductory section.

2.3 Activity 8.3.1.8.5.2.3 - Heat flow at Yucca Mountain and evaluation of regional ambient heat flow anomalies

2.3.1 Rationale for the selected tests

The selected tests for this activity include: (1) compile and evaluate available heat flow data; (2) assess the need for additional temperature, thermal-conductivity, and heat-flow studies; and (3) collect additional thermal data from existing and planned drill holes, both within the potential repository site and in the surrounding region as opportunities arise. The above tests are designed to provide data for the detection of heat-flow anomalies that could be associated with faults, shallow magma bodies, and (or) areas of anomalous ground-water flow. Integration of these data with other geophysical data and with existing geologic and hydrologic data will assist in determining the actual causes of thermal anomalies in the Yucca Mountain area.

As was discussed in the introduction to this study plan, heat-flow testing was selected during development of the SCP as one component of investigations to identify magma or still-cooling intrusive bodies. Heat flow in areas of youthful and large-scale igneous activity in the western U. S. -- for example, the Rio Grande rift, the Cascade Range, and Long Valley, California -- commonly exceeds 104 mW m^{-2} (milliwatts per square meter; or 2.5 HFU, heat flow units), the generally recognized upper range for "normal" Basin and Range heat flow (Sass et al, 1988). Heat flow substantially exceeding 126 mW m^{-2} (3 HFU) occurs locally in these active areas. In contrast, presently available data from Yucca Mountain (Sass et al, 1988) indicate that the potential site area has below-normal heat flow ($<$63 mW m^{-2}, or 1.5 HFU), whereas near-normal values (70-75 mW m^{-2}) were measured at the southernmost boreholes, USW WT-11 and WT-12, on Figure 2-2.

Study 8.3.1.8.5.2: Characterization of igneous intrusive features

In terms of identifying still-cooling igneous bodies, the small magma volumes that have erupted during Quaternary volcanic episodes in nearby Crater Flat indicate small thermal masses for intrusive bodies that may exist. Small intrusions into the zone of active ground-water flow (upper 2-4 km) would be likely to cool to near-ambient temperatures within centuries or less. Thermal energy from deeper intrusions might persist longer, but the magnitude of the heat-flow anomaly at or near the land surface would be significantly attenuated by thermal dispersion. Consequently, the heat-flow activity of this study would detect only intrusive bodies that are very young and that are very shallow or very large relative to known quaternary intrusives. The likelihood that such bodies exist but have escaped detection by the geophysical surveys already completed is extremely small.

The SCP explicitly calls for review of existing chemical geothermometric data and the collection of such additional data as might be deemed necessary to aid in the characterization of the thermal regime of Yucca Mountain and its surrounding region. This was prompted, in large part, by the work of Swanberg and Morgan (1978), in which an empirical relation was established between conventionally determined heat-flow data and silica temperatures from springs and wells for large areas of the United States and elsewhere. There is no physical or chemical basis for the observed empirical relation. Furthermore, although silica temperatures are in rough agreement with some regional trends, the relation is not at all applicable to areas the size of the proposed repository. In addition, the temperatures of wells and springs in the Yucca Mountain area are below the threshold of the validity of the silica geothermometer (Fournier and Rowe, 1966). Consequently, the studies based on silica geothermometers will not be undertaken in this activity.

The planned tests for this activity will be coordinated closely with Activity 8.3.1.15.2.2.1 (Surface-based evaluation of ambient thermal conditions) and with Activity 8.3.1.9.2.1.3 (Assessment of the potential for geothermal energy at Yucca Mountain, Nevada). These studies depend completely upon this activity for thermal data at Yucca Mountain.

2.3.2 Rationale for selecting the number and location of tests

Temperature and heat-flow data will be collected at all available and appropriate sites in the immediate vicinity of Yucca Mountain, as well as from enough selected localities in the surrounding area to ensure regional as well as local coverage (figs. 2-1 and 2-2). Data of variable quality have previously been obtained from the approximately 35 boreholes shown on Figures 2-1 and 2-2, excluding holes shown as planned (Sass et al, 1988). However, recompletions of some holes to provide improved data are recommended. An accurate estimate as to the actual number and location of new or reoccupied data sources, however, cannot be made until the work is well underway. At this stage, no drill holes dedicated to heat-flow studies are explicitly planned; therefore, the actual number and distribution of sites where heat-flow determinations can be made will be determined by other studies. Holes most likely to be available for proper heat-flow completion include those drilled for geologic characterization, water table monitoring, and saturated-zone hydrology. Holes for geology (G-series) and saturated-zone hydrology (H-series) commonly provide access to depths of 1000-2000 m, allowing significant study of the thermal regime in the saturated zone. Water-table monitoring holes (WT-series) penetrate the entire unsaturated zone, 500-700 m in thickness, but only 50-100m into the saturated zone; however, the WT-holes provide superior areal coverage around the site and, th... the best basis for delineating areal differences of heat flow. Current expectation is that 5-10 new holes will become available and that another 5-10 existing holes will be recompleted for improved data.

It might be necessary to drill one or more heat-flow wells in Crater Flat to address the issue raised by the presence of young volcanic features and the suggestions of a crustal heat source from seismic tomography studies. At this stage, however, it is not possible to document the specific need for such holes until the LANL Activity 8.3.1.8.1.1.3 geophysics evaluation is completed (see ... duction).

2.3.3 Constraints: factors affecting selection of tests

The choice of tests for this activity was unaffected by the following factors: simulation of repository conditions, timing, and interference with other tests or with exploratory study facilities design and construction. With regard to required accuracy and precision, limits and capability of analytical methods, and scale of the phenomena to be measured, the planned tests are considered to be reliable methods for detecting zones of anomalous heat flow that reveal tectonic, igneous and hydrologic conditions.

3. DESCRIPTION OF TESTS AND ANALYSES

3.1 Activity 8.3.1.8.5.2.1 - Evaluation of depth of Curie temperature isotherm

See introductory section.

3.2 Activity 8.3.1.8.5.2.2 - Chemical and physical changes around dikes

See introductory section.

3.3 Activity 8.3.1.8.5.2.3 - Heat flow at Yucca Mountain and evaluation of regional ambient heat flow anomalies

The objectives of this activity are to:

- Compile and evaluate available heat flow data at and near Yucca Mountain.
- Assess the need for additional heat-flow determinations.
- Collect additional thermal data from existing and planned drillholes.
- Identify and evaluate thermal anomalies.

In achieving these objectives, the following parameters will be measured and studied: (1) temperatures in drill holes, and (2) thermal conductivity of core, drill cuttings, and outcrop samples. Compilation and a preliminary evaluation of most currently available data are provided by Sass et al (1988).

3.3.1 General approach

It is unlikely that satisfactory resolution of the issues raised can be achieved by the quality of data published by Sass et al (1988), which were significantly affected by movement of fluids within the boreholes. Existing data are not sufficient in quantity or of high enough quality to provide the degree of resolution required to provide meaningful constraints on tectonic models. Some of the existing wells will have to be retrofitted with water-filled pipes in the unsaturated zone and at least one of the proposed geologic core holes (probably USW G-5; see Fig. 2-1) will need to have a string of tubing grouted in. Heat-flow data will be compiled and calculations made for existing, as well as future, drill holes where feasible. Temperature measurements will also be made in the exploratory study facilities if these are being excavated while the heat flow studies are being conducted.

Temperature logs will be obtained in all appropriate holes at Yucca Mountain and in the surrounding area (figs. 2-1 and 2-2). Temperatures will be logged at 0.3-m depth intervals below the water table and in water-filled casing above the water table. In air-filled casing above the water table, temperatures will be measured at 30-m intervals because the longer times required to equilibrate in air make closer measurements impractical. In all measurements, calibrated thermistor probes will be used.

Thermal conductivities will be measured on cores, drill cuttings, or outcrop samples for determination of heat flow. Where samples are available from cored holes, the sampling interval will generally be 10 m. Least-squares analyses will be performed on nearly linear segments of temperature profiles to determine temperature gradients over these segments. The product of the gradient and the average thermal conductivity over the segment provides the one-dimensional, conductive interval heat flow.

The temperature and heat-flow data will be compiled on profiles, maps, and cross sections (scales 1:50,000 to 1:500,000) and compared with other geologic, hydrologic, and geophysical data in the site area to initiate the interpretation of anomalies. These compilations will also help in evaluating the importance of possible 2- and 3-dimensional effects. Depending upon the results of these data compilations and evaluations, recommendations for additional heat-flow measurements to further evaluate local heat-flow anomalies will be made. Such recommendations could include plans for an additional drill hole(s) specifically located to fill critical gaps in the regional ambient heat flow data base. Additional heat-flow data could also be required to evaluate tectonic or fault models, tectonic history, geothermal resource potential, regional ground-water flow, and (or) calculation of ambient heat flow.

3.3.2 QA Requirements

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.

3.3.3 Required tolerance, accuracy, and precision

Requirements as designated in the SCP are to measure rock temperatures within 2-3°C; the planned tests for this activity will result in measurements better than ±1°C. Temperature gradients can be calculated to within 95 percent confidence limits of 1 percent or better, when thermal equilibrium is reached in the borehole. Temperature gradients are usually within a percent of equilibrium within one drilling period, but actual temperatures do not equilibrate that quickly (a few drilling periods are usually necessary). In sections of holes where significant drilling-fluid losses occur, this period can be greatly extended. The best way to monitor return to equilibrium is through a time-series of temperature logs (e.g., see Sass, et al, 1988).

Individual thermal conductivity determinations of saturated tuffs or carbonates will be accurate to better than ±10 percent, and average thermal conductivities will be specified to better than ±5 percent. For samples from the unsaturated zone, departures from in-situ moisture conditions will increase the uncertainties in mean conductivity to ±10 to 15 percent. Several factors other than statistical uncertainty contribute to the overall accuracy of a heat-flow estimate. Many of these are difficult to quantify and can be identified only by an experienced interpreter of thermal data. Such factors as internal consistency of neighboring heat-flux segments (either vertically or laterally) play an important role in assigning a value for the accuracy of an individual determination. The uncertainty in heat flow will be determined primarily by the uncertainty in average thermal conductivity over the specified depth interval. It will generally be less than the amplitude of the smallest significant heat-flow anomalies (≈ 25 milliwatts per square meter).

3.3.4 Range of expected results

Previous studies (e.g., Sass et al., 1988) show measured subsurface temperatures in the upper 2 km of the crust to be in the range of 15-60 °C. Thermal conductivities range from 0.4 to 6 watts per meter-Kelvin (W m^{-1} K^{-1}); and heat-flow determinations range from 25 to 150 milliwatts per square meter (mW m^{-2}). Both of the extreme heat-flow values can be attributed to convection of water without (in the higher case) calling upon magmatic heat as a source of the anomaly. High heat flow must coincide with other geophysical anomalies (e.g., absence of earthquakes, S-wave attenuation, anomalous gravity field) to constitute strong evidence for magma.

3.3.5 Required equipment

Items of required equipment are identified in pertinent technical procedures.

3.3.6 Data-reduction techniques

Data-reduction techniques for temperature and thermal-conductivity measurements are described in appropriate technical procedures. Calculation of heat flow is summarized in Section 3.3.1. A detailed account of these reduction techniques is given by Sass et al (1971).

3.3.7 Representativeness of results

The areal distribution and number of drillholes involved in the investigations for this activity are expected to yield data that are representative of ambient temperatures and thermal conductivities within the area and depth of exploration. Within the unsaturated zone, difficulties in characterizing the in situ moisture contents cause greater uncertainty in thermal conductivity (see Section 3.3.4), relative to that measured for saturated conditions. The temperature profiles in drill holes may not represent actual formation temperatures because of disturbance by vertical flow of fluids in the hole. The representativeness of conductive heat flows calculated from these primary data is subject to interpretation with respect to possible topographic, geologic or hydrologic disturbances. Lateral or vertical flow of water within the rock formation may transport heat, so that the conductive heat flow is not representative of the total. Previous investigations (Sass et al,, 1988) have also shown the likelihood that heat flow at Yucca Mountain is anomalously low because of lateral flow of water beneath the current depth of exploration.

3.3.8 Relations to performance goals and confidence levels

See Sections 1.2 and 4.

4. APPLICATIONS OF RESULTS

Information from this study will contribute directly and indirectly to several aspects of the Yucca Mountain site-characterization program, as are summarized in Table 4-1. Heat-flow and temperature data will be used in Activity 8.3.1.8.1.1.3 (Presence of magma bodies in the vicinity of the site), together with other geophysical information, to determine whether there are any indications that magmatic bodies are present in the Yucca Mountain area or that such processes are currently operating in the crust beneath Yucca Mountain. It will also provide the primary data to define site ambient thermal conditions (Study 8.3.1.15.2.2) for engineering purposes. In addition, geothermal and calculated heat flow data will contribute to Activity 8.3.1.9.2.1.3 (Assessment of the potential for geothermal energy at Yucca Mountain, Nevada) in assessing the geothermal regime in terms of its energy resource potential for either hydrothermal or conductive reservoir thermal systems. Lastly, results from this study will be integrated with other data relevant to stratigraphy, structural geology, and tectonics, where they will be used as input to Study 8.3.1.4.2.3 (Three-dimensional geologic model) and Study 8.3.1.17.4.12 (Tectonic models and synthesis).

Applications to the geohydrology program are also varied. Data from the ESF and the large number of boreholes that penetrate the unsaturated zone may reveal thermal disturbances related to the movement of water or gases in well integrated fracture zones. Reduced conductive heat flow in the unsaturated zone may also provide evidence for heat consumption during vaporization of unsaturated-zone moisture, a potentially significant contribution to Study 8.3.1.2.2.9 (Site Unsaturated-Zone Modeling and Synthesis). Conceptualization of the saturated ground-water flow systems at regional and site scales (Studies 8.3.1.2.1.3 and 8.3.1.2.3.3) can be greatly facilitated (and verified) by including heat transport as a data set that must be accommodated.

5. SCHEDULE AND MILESTONES

Temperature and thermal conductivity measurements and heat flow calculations are scheduled to continue in available bore holes until at least the end of FY 1996 (fig. 5-1). Progress reports will be issued periodically for data output to activities and studies identified in section 4 and Table 4-1. The complete data set will be analyzed and a final report prepared during FY 1997 if field activities terminate in FY 1996. Factors that could extend this schedule include: (1) a determination that extensive study of heat flow in Crater Flat is necessary to support analyses of igneous activity; (b) delay of the planned drilling program; (c) exploration for other purposes, beyond that currently planned, at locations or depths that would add significantly to the geothermal data base.

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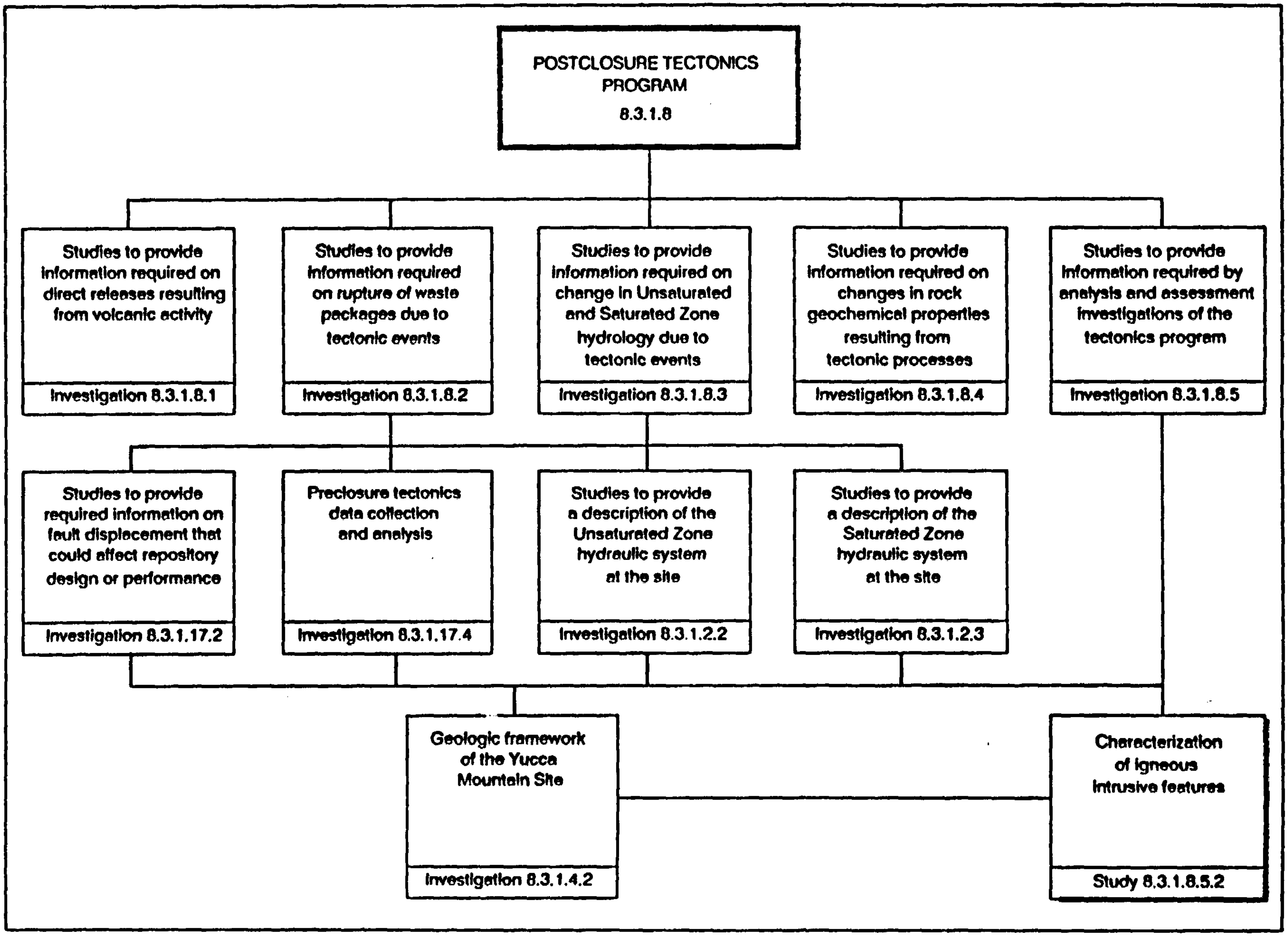


Figure 1-1. Relation of Study 8.3.1.8.5.2 to Postclosure Tectonics Program.

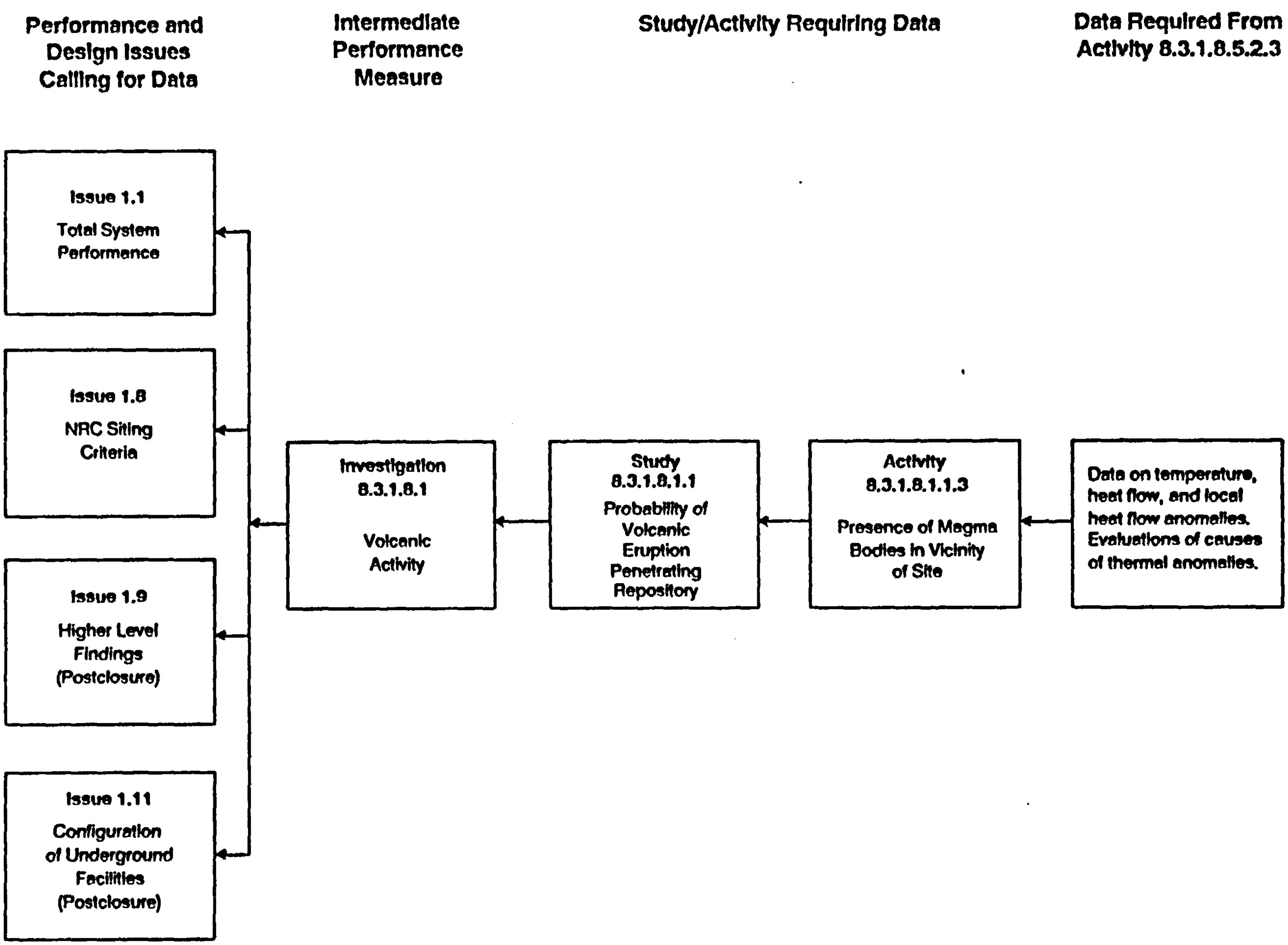
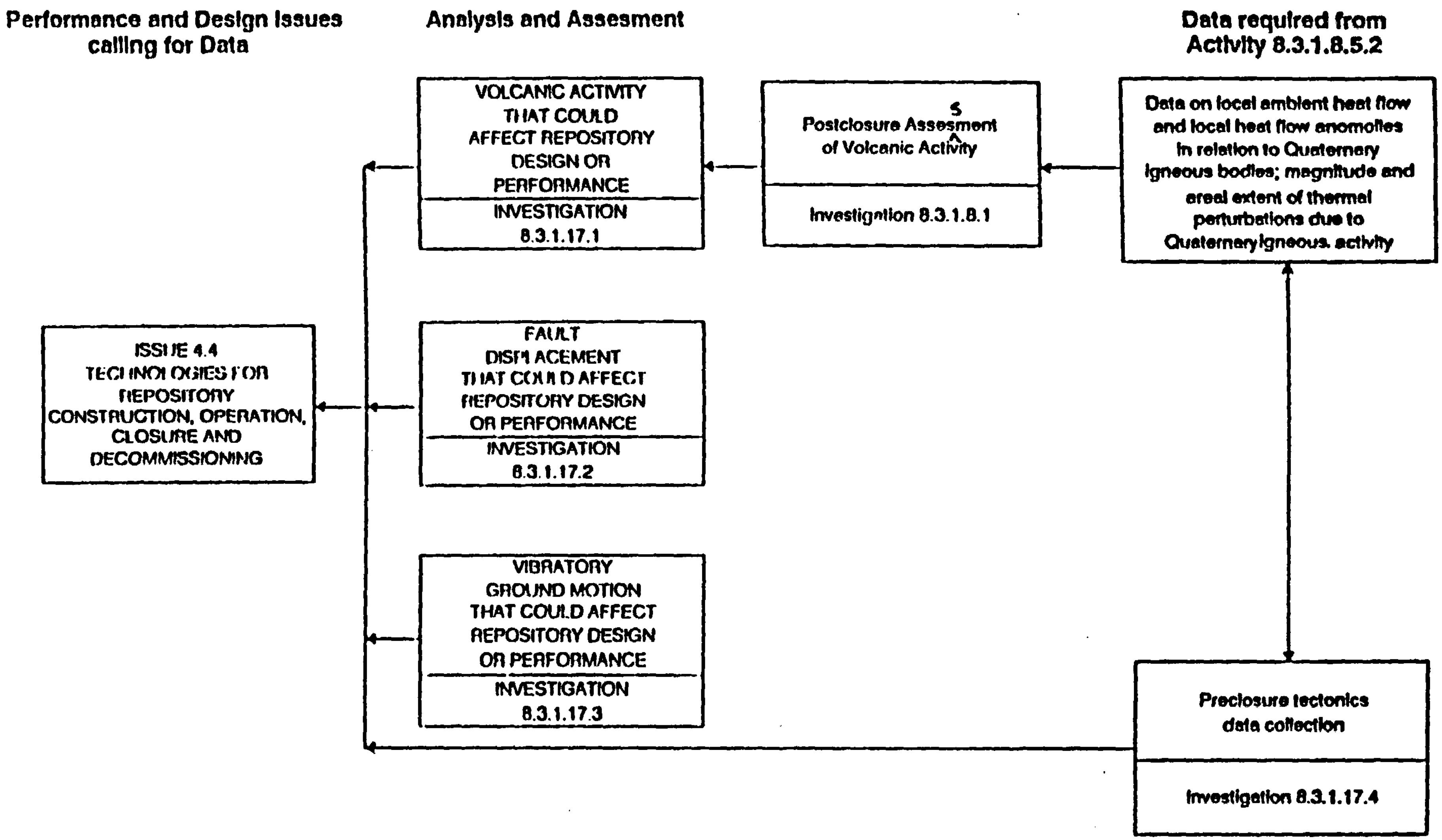


Figure 1-?. Required data supplied by Activity 8.3.1.8.5.2.3 for issue resolution through studies in the postclosure tectonics program.



Source of Information:
modified from SCP Figure 8.3.1.17-1

Figure 1-3. Required data supplied by Activity 8.3.1.8.5.2.3 for issue resolution through studies in the preclosure tectonics program

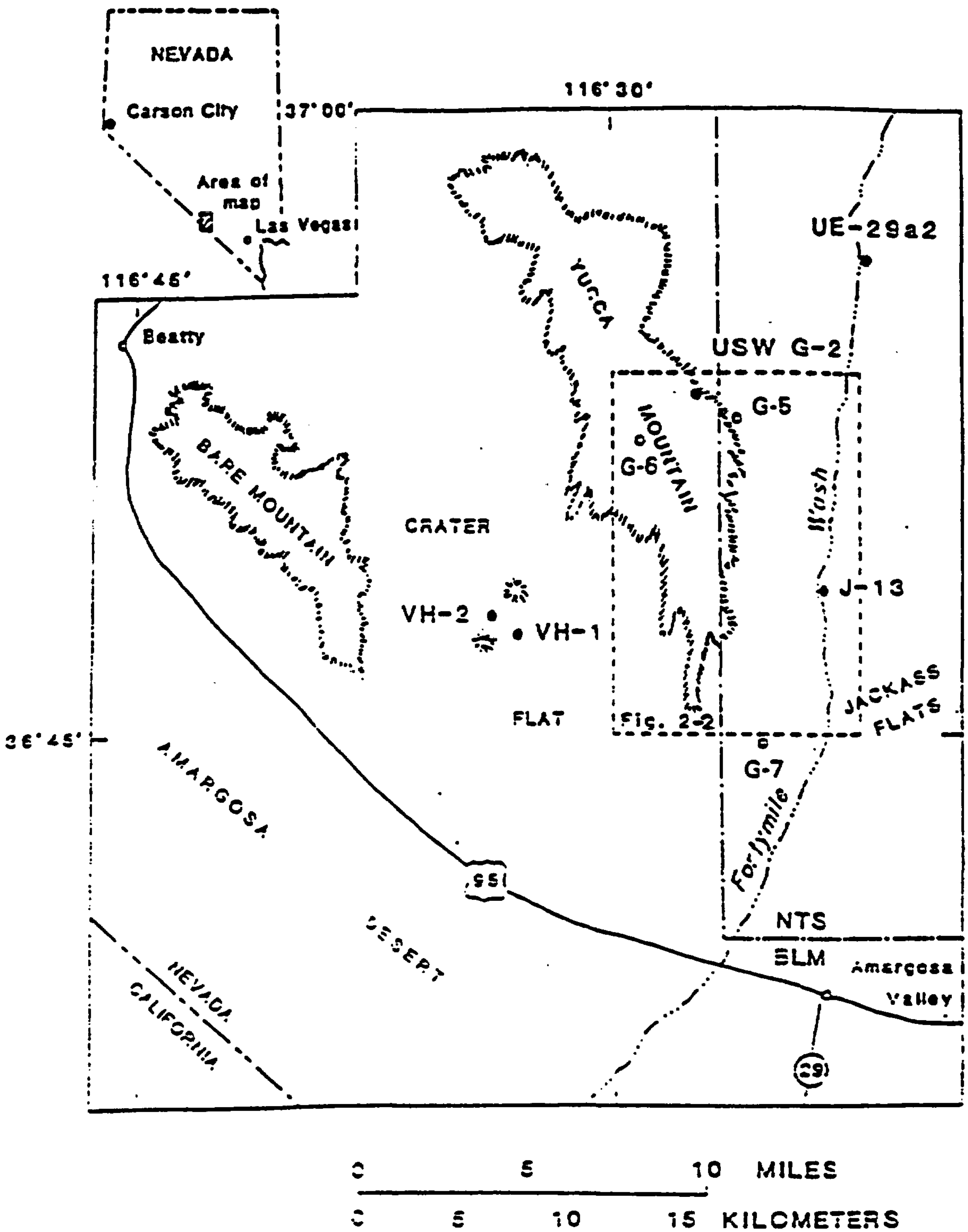


Figure 2-1. Map of Yucca Mountain and vicinity. Locations of selected boreholes shown by solid dots (existing) and open circles (proposed), and by well numbers.

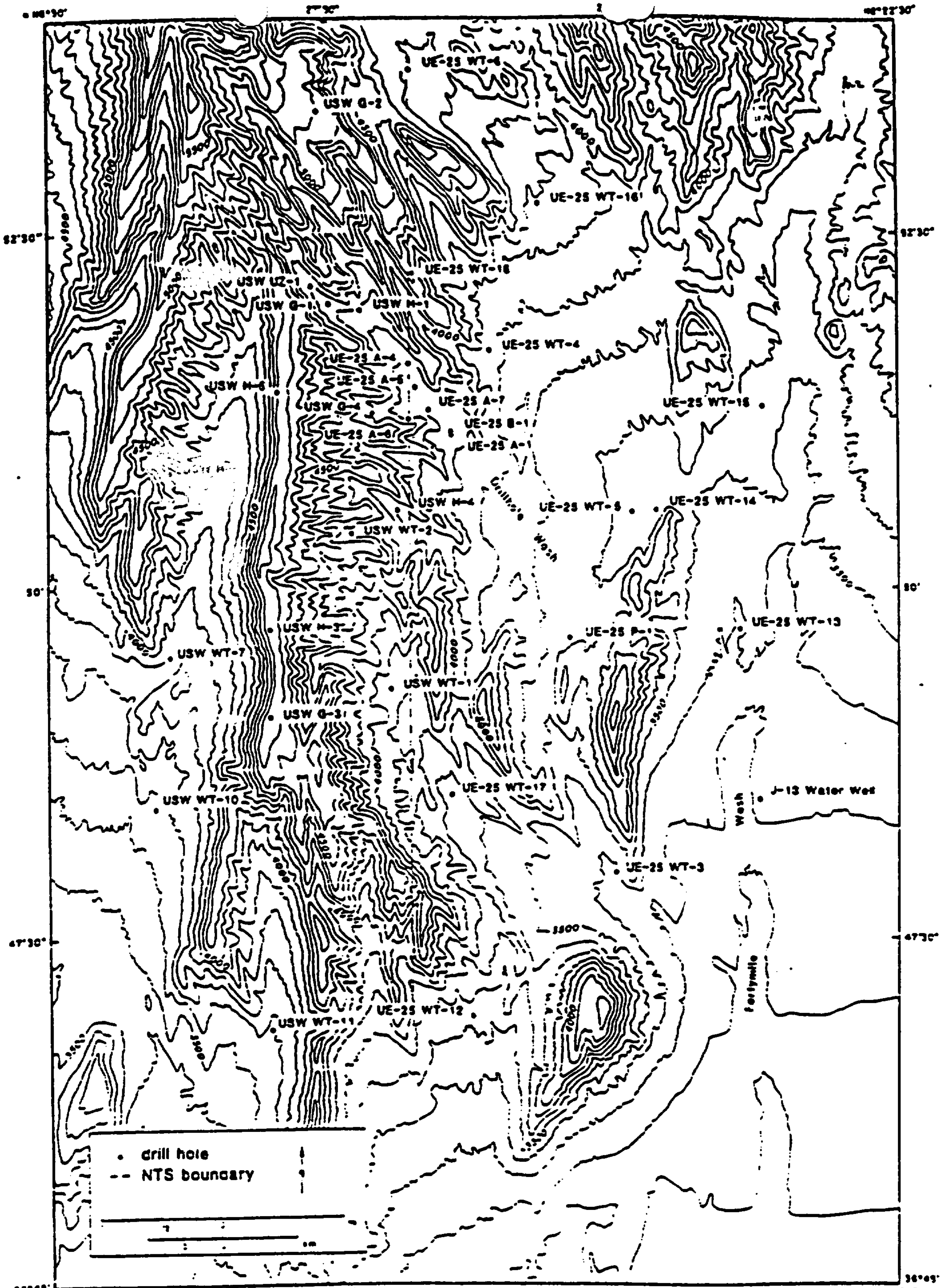


Figure 2-2. Map showing locations of wells in and adjacent to Yucca Mountain that are available for heat flow study.

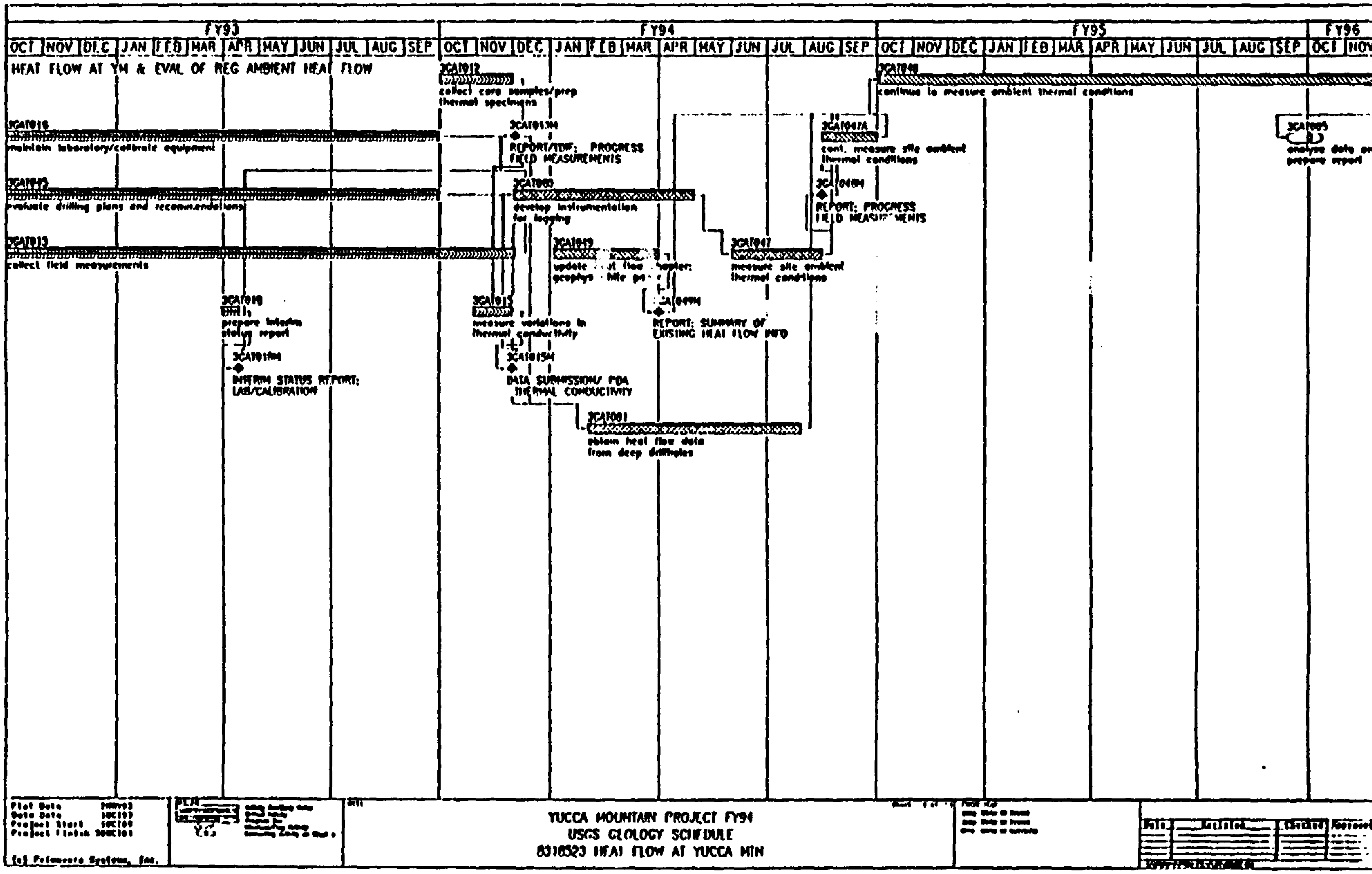


Figure 5-1. Detailed schedule and milestones (numbers ending with "M") for Study 8.3.1.8.5.2

Table 4-1 Information to be provided to other studies by Study 8.3.1.8.5.2

Information to be obtained	Where information will be used *	How Information will be used
Comparison of areas of near surface high temperature isotherms with areas of recent volcanism and areas of high heat flow	8.3.1.8.1.1.3	To evaluate the presence of magma bodies or processes currently operating in the crust beneath the Yucca Mountain area
		To evaluate the magnitude and areal extent of thermal perturbations due to Quaternary igneous activity
	8.3.1.2.2.9	To assist in conceptualization of preferential flow paths and modeling of advective heat transport by bases in unsaturated zone
Temperature, heat flow, and rock conductivity measurements in vicinity of Yucca Mountain	8.3.1.15.2.2.1	To evaluate site ambient thermal conditions for engineering analyses
		To characterize the local geothermal regime as it might relate to repository performance during the postclosure period
	8.3.1.2.1.3 8.3.1.2.3.3 8.3.1.4.2.3	To identify saturated-zone flow paths and hydrogeologic controls
	Performance assessment program	To infer stratigraphic and structural features for 3-dimensional geologic model
Data on regional and local temperature and heat flow	8.3.1.9.2.1.3	To assess the geothermal regime in terms of its energy resource potential for either hydrothermal or conductive reservoir thermal systems
	8.3.1.17.4.12.1	To be integrated with information from other studies to evaluate tectonic processes and stability at the site
	8.3.1.17.4.12.2	To evaluate tectonic models

Table 4-1 Information to be provided to other studies by Study 8.3.1.8.5.2 (continued)

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* Study or Activity in which information will be used:

Activity 8.3.1.8.1.1.3:	Presence of magma bodies
Activity 8.3.1.9.2.1.3:	Assessment of the potential for geothermal energy at Yucca Mountain, Nevada.
Activity 8.3.1.15.2.2.1:	Evaluation of site ambient thermal conditions
Activity 8.3.1.17.4.12.1:	Evaluation of tectonic processes and tectonic stability at the site
Activity 8.3.1.17.4.12.2:	Evaluation of tectonic models
Study 8.3.1.2.1.3:	Characterization of the regional ground-water flow system
Study 8.3.1.2.2.9:	Site unsaturated-zone modeling and synthesis
Study 8.3.1.2.3.3:	Site saturated-zone hydrologic synthesis and modeling
Study 8.3.1.4.2.3:	Three-dimensional geologic model