Rec'd 2/5/93 w/ encl

STUDY PLAN

for

STUDY 8.3.1.17.4.3

QUATERNARY FAULTING WITHIN 100 KM OF YUCCA MOUNTAIN, INCLUDING THE WALKER LANE

REV 0
November 18, 1992

U. S. GEOLOGICAL SURVEY

102.8

YUCCA MOUNTAIN PROJECT

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Study Plan Number 8.3.1.17.4.3

Study Plan Title QUATERNARY FAULTING WITHIN 100 KM OF YUCCA MOUNTAIN, INCLUDING THE WALKER LANE

Revision Number 0

Prepared by: U. S. GEOLOGICAL SURVEY

Date: 11/18/92

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1/22/93
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PREFACE

This study plan summarizes and extends the discussion of Study 8.3.1.17.4.3 in the Site Characterization Plan (SCP). Sections 1, 4, and 5 are drawn from the SCP and from related Yucca Mountain Project documents; these sections show the study in the context of the site characterization program. Sections 2 and 3 discuss the methods and procedures for the planned activities and the various tests, generally in detail beyond the descriptions given in the SCP.

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ABSTRACT

Study 8.3.1.17.4.3 will collect and synthesize data on the abundance, distribution, geographic orientation, displacement rate, and recurrence interval of movement on Quaternary faults within 100 km of Yucca Mountain. This information, combined with information on faults from other site characterization studies, is essential in locating the potential repository and surface facilities in areas that are unlikely to be ruptured by faulting during the next 10,000 years, and for designing all facilities so as to provide reasonable assurance that damage due to ground shaking during earthquakes will not be excessive.

The planned activities include: (1) compilation of fault maps based on existing fault data, photogeologic mapping of lineaments and scarps, verification of such features based on field investigations and trenching as necessary, and determine, where possible, age of fault displacement by absolute and relative dating techniques; (2) seismic reflection and refraction profiling, gravity and magnetic surveys, magnetotelluric soundings, and analysis of teleseismic P-wave residuals and Pv/Sv variations; (3) evaluation of structural domains with respect to regional patterns of faults and fractures based on Landsat V Thematic Mapper imagery and side-looking airborne radar; and (4) paleomagnetic measurements to determine if bedrock units have been rotated as a result of wrench faulting. All of these data contribute to the identification of Quaternary faults that are possible (1) relevant earthquake sources, (2) locations of future ground rupture in the vicinity of the potential repository site and surface facilities, (3) conduits for basaltic magmas at or related to Quaternary volcanic centers near Yucca Mountain, or (4) sources of strain or offset which could affect the hydrologic regime of the site.

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STUDY 8.3.1.17.4.3: QUATERNARY FAULTING WITHIN 100 KM OF YUCCA MOUNTAIN, INCLUDING THE WALKER LANE

The Site Characterization Plan (SCP) lists five activities for this study:

- 8.3.1.17.4.3.1: Conduct and evaluate deep geophysical surveys in an east-west transect crossing the Yucca Mountain, the Walker Lane, and the Furnace Creek fault zone.
- 8.3.1.17.4.3.2: Evaluate Quaternary faults within 100 km of Yucca Mountain.
- 8.3.1.17.4.3.3: Evaluate the Cedar Mountain earthquake of 1932 and its bearing on wrench tectonics of the Walker Lane within 100 km of the site.
- 8.3.1.17.4.3.4: Evaluate the Bare Mountain fault zone.
- 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.

One of the tests designated for the second activity listed above involves an "analysis of rotation (drag) of bedrock along or over suspected wrench faults based on rotation of paleomagnetic poles". Because this work element involves specialized methods that differ significantly from those being employed in the other tests for this activity, and for convenience in planning, budgeting, and staffing, it is treated as a separate activity (Activity 8.3.1.17.4.3.6) in this study plan.

Study 8.3.1.17.4.3 is part of the preclosure tectonics program (fig. 1-1); it is one of a series of related studies that gather and synthesize information that is needed to assess vibratory ground motion and fault displacements in the region surrounding Yucca Mountain (figs. 1-2 and 1-3).

1. PURPOSE AND OBJECTIVES OF THE STUDY

The objective of this study is to supply information pertaining to the abundance, distribution, orientation, displacement rate, and recurrence interval of movement, of Quaternary faults within 100 km of Yucca Mountain. Quaternary faults are those faults along which there has been demonstrated, suspected, or inferred movement during the Quaternary period (approximately the last 1.8 million yr). Potentially significant Quaternary faults include faults that are (1) relevant earthquake sources (earthquakes that could generate severe ground motions at the potential site); (2) possible locations of future ground rupture at surface or underground facilities which are important to safety, (3) possible conduits for basaltic magmas at or related to Quaternary volcanic centers proximal to Yucca Mountain; and (4) possible sources of strain or offset which could materially affect the hydrology of the site.

Objectives specific to each activity are discussed in sections 3.1, 3.2, 3.3, 3.4, 3.5, and 3.6.

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

This study will produce a map of known and suspected Quaternary faults and related geologic features within 100 km of the potential repository site. The map will define the source regions of major earthquakes that have produced surface faulting during Quaternary time, and thus will provide an estimate of regional distribution and rates of occurrence of large magnitude earthquakes. Specific data to be collected include:

- The surface and subsurface location, orientation, length, width, segmentation, and possible interconnections of known and suspected Quaternary faults within 100 km of the site. This information will be used to determine the relation (if any) of these faults to regionally important wrench fault systems, including the Walker Lane, the Pahranagat shear zone, and the Death Valley, Furnace Creek, and Mine Mountain fault zones.

- The location, amount, direction, and time of Quaternary movement on these faults (the amount and timing of Quaternary movement will be used to estimate recurrence intervals and slip rates)

- The nature of the Beatty scarp (erosional feature, tectonic feature, or both)

- The amount of post-middle Miocene vertical-axis rotation of bedrock alongside wrench faults and of bedrock suspected to be part of the upper plate above possible subsurface wrench faults

- Geophysical evidence of possible subsurface extensions of surface or near surface geologic structures of interest. This includes the subsurface geometry of postulated detachment faults, interconnections between northeast-trending and north-trending faults, and possible through-going extensions of the Walker Lane beneath the Oligocene-Miocene cover

- Geophysical evidence relevant to volcanism and to possible mineral resources

Supporting data on subsurface geometry of the faults will be provided by Study 8.3.1.17.4.7 (Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain). In addition, complementary studies of faults at and proximal to the site will be conducted by Study 8.3.1.17.4.2 (Location and recency of faulting near prospective surface facilities); Study 8.3.1.17.4.4 (Quaternary faulting proximal to the site within northeast-trending fault zones); Study 8.3.1.17.4.5 (detachment faults at or proximal to Yucca Mountain); Study 8.3.1.17.4.6 (Quaternary faults within the site area (see figs. 1-4, 2-1, and 2-2), and Study 8.3.1.17.4.9 (Tectonic geomorphology).

Information from Study 8.3.1.17.4.3 will assist in predicting the likely locations, timing, and magnitudes of future faulting and earthquake events that could have an impact on the design or performance of the waste facility. Specific uses of the information 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.

It should be noted that in the discussion of Activity 8.3.1.17.4.3.1 in the SCP (p. 8.3.1.17-115), Activity 8.3.1.4.2.1.6 was referred to as being responsible for integrating all geophysical activities in the site characterization program. The SCP (p. 8.3.1.4-26) also assigns the same responsibility to Activity 8.3.1.4.1.2 (Integration of geophysical activities). In view of the fact that several studies acquire and utilize geophysical data (e.g., the present study), it is considered more appropriate to designate Activity 8.3.1.4.1.2 as the focal point for integrating geophysical activities rather than include it as a part of Study 8.3.1.4.2.1 (Characterization of the vertical and lateral distribution of stratigraphic units within the site area). Accordingly, Activity 8.3.1.4.2.1.6 was not considered part of Study 8.3.1.4.2.1 during the preparation of the study plan for that study.

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, and folding (fig. 1-4). Information bearing on the specific location and rates at which these processes are likely to operate during the next 100, 10,000, and 100,000 years is needed to assist in designing the repository and in evaluating its future performance (figs. 1-2 and 1-3).

In accordance with 10CFR60.122 and 10CFR960.4-2-7(a), projections of rates of tectonic processes into the future are to be based on forward extrapolation of the measured rates at which these processes operated during the Quaternary. In measuring the rates at which these processes operated, it is convenient to divide the Quaternary into two time frames: (1) contemporary and historic, and (284) that part of the Quaternary prior to historic time. This division corresponds approximately to the three classes of records from which these rates might be determined, i.e., (1) contemporary observations, (2) recorded history, and (3) analysis of Quaternary deposits and landforms. Information on pre-Quaternary tectonic processes may also be relevant, where it supplies context useful in evaluating the Quaternary processes and rates.

The information to be gathered by this study (8.3.1.17.4.3) and by other studies of faulting is needed to estimate the locations and rates of faulting at Yucca Mountain and its immediate vicinity during that part of the Quaternary prior to historic time (fig. 1-4). Other studies (e.g., Study 8.3.1.17.4.10, Geodetic leveling) will supply information on the locations and rates of deformation during contemporary and historic time. This entire body of information is needed to locate the repository and surface facilities in areas that are unlikely to be ruptured by faulting, and to design all facilities so as to provide reasonable assurance that damage due to ground shaking during earthquakes will not be excessive. These data are also needed to provide reasonable assurance that erosion and (or) deformation will not cause an unacceptable encroachment of meteoric or ground waters and a resulting release of radioactive material into the accessible environment (see figs. 1-2 and 1-3).

2. RATIONALE FOR SELECTING THE STUDY

The study of Quaternary faulting within 100 km of Yucca Mountain is one of a group of related studies which collect information about Quaternary faulting at Yucca Mountain and in the surrounding regions. Each type of faulting is the focus of one (or more) studies (fig. 2-1). Quaternary faulting is considered an important process within the complex tectonic setting of Yucca Mountain.

That complexity stems in part from the unique location of Yucca Mountain within the Basin and Range province near the intersection of the northwest-trending Walker Lane, and the northeast-trending Mine Mountain-Spotted Range structural zone (Carr, 1984; fig. 2-2). The Walker Lane appears to be a zone of transition between an area to the north and east characterized by dip-slip (normal) faulting, and an area to the south and west characterized by both dip-slip faulting and right-lateral strike-slip faulting. The Walker Lane thus defines the diffuse eastern limit of the zone of northwest-striking right-lateral faults within the western margin of the North American plate. Prominent members of this family of faults near Yucca Mountain include Pahrump-Stewart Valley fault to the south, the Death Valley-Furnace Creek fault to the west, and the fault(s) within the central Walker Lane to the north.

The Mine Mountain-Spotted Range zone is defined by a cluster of northeast to east-northeast striking left-lateral faults that lie athwart the northwest-trending Walker Lane. Faults east and south of Yucca Mountain that are part of this zone include the Mine Mountain, Cane Spring, and Rock Valley faults (fig. 2-3).

Faulting at and near Yucca Mountain appears to involve four styles of faulting: (1) high-angle normal faulting, (2) left-lateral faulting, (3) right-lateral faulting, and (4) detachment faulting. The styles of faulting identified above form part of the basis for the organization of the fault studies in the site characterization program. Each of these types of faulting is the subject of one or more studies (fig. 2-1). The organization of the faulting investigations is complicated in that the nature and detail of the information required varies from place to place (fig. 2-4). Because of this fact, three areas have been defined: (1) the site area, (2) the Midway Valley part of the site area, and (3) the area within 100 km radius of Yucca Mountain, exclusive of the site area.

The site area is a rectangular area encompassing the potential site of the repository, Midway Valley, and the major structural blocks at Yucca Mountain and their bounding faults (figs. 2-2 and 2-5). This area includes several of the major high-angle dip-slip Quaternary faults of potential significance to the potential repository (e.g., Windy Wash, Solitario Canyon, Bow Ridge, Ghost Dance, and the Paintbrush Canyon faults) and one left-lateral strike-slip Quaternary fault (the Stagecoach Road fault). In the site area, information pertaining to Quaternary faulting (Study 8.3.1.17.4.6, Quaternary faulting within the site area) is needed to evaluate possible adverse effects of this tectonic process on the groundwater-flow system, to define locations of possible ground rupture, and to estimate the magnitude of ground shaking that is possible due to earthquakes (fig. 2-4).

Midway Valley, lying within the northeast sector of the site area, is the prospective location of surface facilities. It is desired that such facilities not be located directly on top of faults likely to rupture during the life of the facility. A study (Study 8.3.1.17.4.2: Location and recency of faulting near prospective surface facilities) has accordingly been organized to define areas within Midway Valley that are free of late Pleistocene and Holocene faulting.

The potential adverse effects of faulting on containment increase as a function of the proximity of an earthquake fault, the magnitude of seismic events that a fault is capable of, and the recurrence rate of seismic events on the fault. Fault studies are being extended 100 km from the site because: (1) a few faults that are fairly distant from the site (e.g., Furnace Creek, Rock Valley, and Bare Mountain faults) are larger and more active than more proximal faults and are therefore significant in seismic risk assessments, (2) it is unlikely but still possible that one or more Quaternary faults that would fit into the above category have yet to be identified in the region, and (3) the tectonic regime at Yucca Mountain needs to be understood in the regional context.

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

Geophysical methods are useful for locating possible subsurface extensions of surface or near-surface geologic structures, including the subsurface geometry of postulated detachment faults, interconnections between northeast-trending and north-trending faults, and possible through-going extensions of the Walker Lane beneath Oligocene-Miocene cover. The planned geophysics program for the Yucca Mountain area (Activity 8.3.1.4.1.2, Integration of geophysical activities; also, see Oliver and others, 1990) is designed to obtain different types of data that, when integrated with geologic and seismological data, may help resolve such issues as the width, dip, and geometry of north-trending Quaternary faults at and near the site, and whether there are subsurface structures that are related to known Quaternary structures. If the planned tests are successful, the results may provide sufficient data to meet the needs and objectives of several activities in Study 8.3.1.17.4.7, Subsurface geometry and concealed extensions of Quaternary faults.

Five tests were selected for this activity as follows: (1) seismic reflection survey, (2) seismic refraction survey, (3) gravity survey, (4) magnetic survey, and (5) magnetotelluric survey. Several of these tests include feasibility studies, wherein only a portion of a planned survey will be conducted and the results evaluated before the test is fully implemented. For example, the seismic reflection studies will be preceded by a preliminary test to determine if the results of the technique will be useful for evaluating subsurface structure in the Yucca Mountain region and whether or not additional profiling is justified. These preliminary evaluations will be conducted in Activity 8.3.1.4.2.1.2 (Surface-based geophysical surveys; see fig. 3-1).

The selected tests consist of common and widely accepted seismic methods to provide data for interpreting subsurface geologic relationships. An additional geophysical method that is currently being considered for detecting possible magma bodies based on velocity variations is an analysis of teleseismic P-wave residuals and P_v/S_v variations. This technique has been applied on a limited basis in the Yucca Mountain region (Montfort and Evans, 1982; Evans and Oliver, 1987; Evans and Smith, 1992), and has yielded controversial results with respect to indicating the presence of magma in the lower crust and the upper mantle. Under Study 8.3.1.8.1.1 being conducted by Los Alamos National Laboratory (Probability of magmatic disruption of the repository), the existing teleseismic data and interpretations will be comprehensively reviewed, and recommendations made as to the future course of action of using geophysics to detect magma bodies. If additional teleseismic studies are indicated, then such work would be added to the present activity and undertaken on a cooperative basis with Study 8.3.1.8.1.1, with the USGS collecting the data and LANL (as ultimate data user) being involved in the design and interpretation of the tests.

2.1.1 Rationale for the types of tests selected

2.1.1.1 Deep seismic reflection survey

Seismic reflection methods are used where clear resolution of upper crustal stratigraphy and structure is required. If good quality reflections can be obtained in the Yucca Mountain area (Activity 8.3.1.4.2.1.2), then high-resolution reflection seismology, supplemented by gravity and magnetic surveys (see below), could provide evidence for the width, continuity, and depth of major faults, fault zones, and other structural features, as well as important stratigraphic contacts (such as the Miocene-Paleozoic contact). The definition of faults in the subsurface by these means will contribute significantly in efforts to constrain the location and character of potential sources of ground motion and rupture within 100 km of the potential site.

2.1.1.2 Seismic refraction survey

Seismic refraction methods have been used previously to characterize the general velocity structure of the upper crust in the Yucca Mountain area, and to establish the location and nature of major discontinuities in that velocity structure (Hoffman and Mooney, 1983). When used in conjunction with gravity and magnetic surveys, the method is useful in limiting applicable structural models (e.g., Snyder and Carr, 1984), although the resolution is lower than that obtained by seismic reflection surveys.

2.1.1.3 Gravity survey

Gravity surveys provide an economical method for approximating (1) the depth and general configuration of the buried pre-Tertiary bedrock surface, and (2) the subsurface extent of tectonic features. A detailed gravity survey will be conducted as part of Activity 8.3.1.4.2.1.2 along the same traverses as the seismic surveys (see fig. 3-2). The data resulting from that survey, combined with additional gravity measurements that may be conducted as part of the present activity (see section 2.1.2.3) will assist in identifying geologic structures that juxtapose rocks having different densities in the upper few kilometers of the crust. These anomalies may correlate with structures delineated in the seismic surveys or with resistivity anomalies obtained in magnetotelluric surveys, as well as with structural features exposed at the surface.

2.1.1.4 Magnetic survey

Magnetic surveys help to define buried plutons and volcanic rocks and to locate concealed faults where magnetic strata have been offset. Data resulting from the magnetic measurements made in Activity 8.3.1.4.2.1.2 will be applied in the present activity, and additional magnetic recordings may be obtained if necessary to identify differences in the magnetic field caused by sources in the upper few kilometers of the crust, and to correlate those sources (anomalies) with reflections obtained in the seismic surveys or with resistivity features obtained in magnetotelluric surveys.

2.1.1.5 Magnetotelluric survey

Magnetotelluric soundings in the Yucca Mountain region (Furgerson, 1982) indicate significant conductivity contrasts among Precambrian crystalline rocks, Paleozoic aquifers and aquitards, argillaceous units of the Paleozoic (such as the Eleana Formation), Miocene volcanic rocks, and Quaternary basin-fill deposits. Because Furgerson's (1982) surroundings were too widely spaced to permit reliable structural interpretations, additional soundings that may be obtained during this study should help to: (1) constrain the location of fault zones, (2) identify deep reflectors observed on the high-precision seismic reflection profiles, and (3) distinguish deep-seated bodies of molten rock.

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

The scheduling of geophysical surveys is dictated by the need to provide the data to support other activities (Figure 5-1).

2.1.2.1 Deep seismic reflection survey

Preliminary evaluation of the results of a deep seismic reflection survey in the eastern Amargosa Desert, about 20 km southeast of Yucca Mountain, supports further testing of this method in the immediate vicinity of the potential repository site area (see sec. 3.1.1.1). As a consequence, several intersecting seismic reflection profiles are being planned as part of Activity 8.3.1.4.2.1.2 (Surface-based geophysical surveys); the locations of these profiles are shown in Figure 3-1. Depending on the results of this survey, additional deep reflection surveys may be proposed, perhaps crossing both the Walker Lane and the Furnace Creek fault west of Yucca Mountain as well as other features that are likely to provide valuable information on fault geometry in the region. In this regard it should be noted that other seismic refraction surveys (as described in sec. 2.1.2.2 below), if conducted, may serve as guides for locating additional reflection surveys.

2.1.2.2 Seismic refraction survey

Seismic refraction survey will be conducted along the same traverses as the seismic reflection surveys (sec. 2.1.2.1; fig. 3-1), as well as along any additional reflection profiles that may be planned. Depending upon the applicability of the results of these initial survey to site characterization, other refraction profiles may also be obtained as part of this activity. The locations of four possible additional traverses for seismic refraction are shown on Figure 3-2. Profile 1 extends from Sheep Mountain westward across the Amargosa Desert to the Cottonwood Mountains, and will assist in characterizing the crustal velocity structure and structural setting of Yucca Mountain and the adjacent Walker Lane fault zone. Profile 2, extending southward from Yucca Mountain through Lathrop Wells and across the Amargosa Desert to Shoshone, California, and Profile 3, extending southwest from northern Yucca Mountain across the Amargosa Desert and Death Valley, will assist in identifying potentially significant seismic source zones (major faults) within both the Walker Lane and Furnace Creek fault zones. A fourth profile (Profile 4) though not specifically included in the SCP discussion of seismic refraction, is shown on figure 3-2 for purposes of locating a possible traverse that could be used to identify and trace the 5- and 10-second seismic reflections as recorded in previous Consortium for Continental Reflection Profiling (COCORP) reflection profiles (one of the objectives of this activity; see sec. 3.1). In those surveys, (e.g., see Serpa, 1990), a relatively continuous reflecting zone at a depth corresponding to the 5-second (two-way) travel time is interpreted to be a deep-seated ($\approx$ 15km) detachment fault which appears to truncate the upper crustal faults. The 10-second (two-way travel time) event apparently reflects the Moho at the approximate depth of 30 km.

2.1.2.3 Gravity survey

A detailed gravity survey will be conducted along the seismic reflection survey being planned for Activity 8.3.1.4.2.1.2 (Surface-based geophysical surveys). In addition, a detailed gravity survey of the potential site area itself will be conducted as part of Activity 8.3.1.17.4.7.2 (Detailed gravity survey of the site area). If additional seismic reflection and refraction profiles are obtained as part of the present activity (see secs. 2.1.2.1. and 2.1.2.2), gravity data will also be obtained along these traverses. As shown on Figure 3-3, adequate coverage for regional structural interpretations based on gravity data is available for the area lying within 25-50 km of the potential site. However, several of the 2 km-square cells out to the 100-km radius contain no gravity stations. Regional data (one or more stations per 2 km cell) may possibly be obtained in these areas, based on the needs for such data in the context of the overall site characterization program. It should be emphasized, in this regard, that regional gravity data can be used to significant advantage in guiding local, more detailed geophysical surveys.

2.1.2.4 Magnetic survey

Ground-based magnetic surveys will be conducted along the seismic reflection profile being planned for Activity 8.3.1.4.2.1.2, as well as along additional seismic reflection or refraction surveys that may be conducted in the present activity (see secs. 2.1.2.1 and 2.1.2.2). The magnetic fields in the vicinity of specific features will be measured in detail, including (1) previously known or inferred structures, (2) areas immediately surrounding drill holes and the proposed locations of subsurface ramps and surface facilities, and (3) anomalies identified through other geophysical surveys.

Figure 3-4 shows the existing coverage of aeromagnetic data within (and beyond) 100 km of the potential repository site; much of it is adequate to achieve the objectives of this test. The presently available aeromagnetic data in the region of Death Valley (fig. 3-4), however, is considered inadequate for regional structural interpretations, and it may become necessary to obtain information along more closely spaced flight lines if considered critical to site characterization.

2.1.2.5 Magnetotelluric survey

An existing 100 km-long magnetotelluric (MT) traverse, which crosses many major structural features in the region surrounding Yucca Mountain, is shown in figure 3-5. The location and scope of additional traverse lines will be based on application of expected results to site characterization needs; such traverses may include MT soundings along the same lines followed by the other geophysical surveys being planned for this activity. If more regional coverage is required, some proposed regional lines are shown on figure 3-5.

2.1.3 Constraints

The planned tests for this activity will have no impact on the potential repository, do not involve simulation of repository conditions, and will not interfere with other tests or with the design or construction of the exploratory shaft facilities. With regard to accuracy and precision, limits and capability of the selected methods and techniques, and the scale of the phenomena to be measured, the well-established procedures involved in the proposed geophysical surveys have been previously demonstrated to provide the quality of data needed to satisfy the objectives and parameters of the activity.

2.2 Activity 8.3.1.17.4.3.2: Evaluate Quaternary faults within 100 km of Yucca Mountain

2.2.1 Rationale for the types of tests selected

The following tests are being planned to achieve the objectives and to address the designated parameters (see sec. 3.2) for this activity:

- Compile from existing literature, a map of Quaternary faults within 100 km of the potential repository site, but with supplemental compilations extending as far as Las Vegas on the southeast and Cedar Mountain on the northwest

- Prepare a photogeologic map of Quaternary scarps within 100 km of the potential repository site using both conventional and low sun-angle aerial photographs

- Verify the tectonic origin of scarps and lineaments in the field, and for those found to have a tectonic origin, estimate their age, amount of displacement, and recurrence interval of surface faulting events
- Map Quaternary faults and deposits in the Beatty 1:100,000 quadrangle
- Evaluate nature of the Beatty scarp
- Determine Quaternary recurrence rate of the Death Valley-Furnace Creek fault zone
- Perform a seismic risk analysis
- Prepare a final map of Quaternary faults within 100 km of Yucca Mountain

The above tests are designed to provide the type and quality of information required to comprehensively evaluate Quaternary faults within 100 km of the potential repository site at Yucca Mountain, and to assess their potential for producing future earthquakes with magnitudes sufficient to affect the design or performance of the waste facility. The Bare Mountain Fault, a known late Quaternary fault approximately 15 km west of Yucca Mountain, is the subject of a separate activity (8.3.1.17.4.3.4) in this study plan. The tests employ a combination of current and standard procedures, including field, laboratory, and trenching methods, for identifying and characterizing Quaternary faults and for compiling pertinent fault data on appropriate maps (see sec. 3.2). For the activity as a whole, no reasonable alternatives to these planned tests would result in more reliable information on the locations and nature of Quaternary faults within 100 km of Yucca Mountain.

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

Many Quaternary faults and scarps are present within 100 km of the potential repository site at Yucca Mountain (fig. 2-2; Reheis, 1991; Reheis and Noller, 1991), but an accurate estimate of the total number of individual features that will be mapped and studied during the conduct of this activity cannot be made at present. The same is true regarding estimates of the number of trenches that may be required to evaluate fault relationships at critical localities, as well as the number of samples of surficial deposits and other materials to be collected for radiometric age determinations.

Studies will be conducted in the area lying within 100 km of the potential repository site (fig. 2-2), but will probably be concentrated within approximately 45 km because faults in this area are considered to have the greatest potential for producing ground motions that may affect repository design and performance. However, selected structural features will be examined as far to the northwest and as far to the southeast as Cedar Mountain and Las Vegas, respectively, to provide a better understanding of the relationships between the Walker Lane and other major tectonic elements in the region. Some of the more specific tests will be conducted in relatively limited areas in closer proximity to Yucca Mountain, as described in detail in section 3.2.

Some scoping and feasibility work for this activity has been completed. For example, photogeologic maps of Quaternary scarps have been completed by Reheis (1991) and Reheis and Nollar (1991). The scheduling of planned tests in this activity is designed to coincide with the need to provide information to other site characterization studies according to the integrated schedule for the Yucca Mountain project (see secs. 4 and 5).

2.2.3 Constraints

The tests for this activity will be conducted for the most part outside the immediate vicinity of the potential repository site; data on Quaternary faults within the site area will be obtained primarily by Study 8.3.1.17.4.6 (Quaternary faulting within the site area). Test selection was therefore unaffected by its impact on the potential site. Neither was test selection affected by the need to simulate repository conditions or for any interference with other tests on the construction and design of the exploratory study facilities. With regard to accuracy and precision, limits and capability of analytical methods, and scale of the phenomena to be measured, the planned tests involve widely-used methods and techniques designed to provide reliable data (and measurements) on the designated parameters for the activity (see sec. 3.2), and consequently, essential information on potential sources of future vibratory ground motions caused by displacements on faults within 100 km of the potential repository site.

2.3 Activity 8.3.1.17.4.3.3: Evaluate the Cedar Mountain earthquake of 1932 and its bearing on wrench tectonics of the Walker Lane within 100 km of the site

The Cedar Mountain earthquake of 1932 (M = 7.2 to 7.3) occurred on the central part of the Walker Lane, approximately 175 km northwest of the potential repository site (fig. 2-2). Details of this event in terms of the resulting shear patterns and the types and magnitudes of fault displacements that took place will be helpful in providing a better insight as to the nature of the structural movements that may have occurred within the Walker Lane zone closer to (within 100 km) the potential site area, and which may occur in the future.

2.3.1 Rationale for the types of tests selected

This activity is not subdivided into individual tests, but several work elements are planned, including (1) a review of the published geologic literature concerning the 1932 Cedar Mountain earthquake, (2) photogeologic mapping of the areas surrounding the locale of the event based on interpretation of vertical aerial photographs, (3) limited field investigations, and (4) an evaluation of concurrent research by investigators not affiliated with the Yucca Mountain project (for example, Bell, 1988; DePalo and others, 1987; Doser, 1987). Pursuit of these studies should provide a more comprehensive understanding of the tectonics involved in the Walker Lane belt as it approaches and extends beneath the Yucca Mountain area. Alternatives include a program that would place greater emphasis on large-scale, detailed geologic mapping of all the features associated with the Cedar Mountain earthquake. However, in view of what is already known about the event, and from what can be learned additionally from the limited field investigations and other work now being planned, detailed mapping (and its commensurately greater cost) of the entire area is not considered necessary to obtain the required data.

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

The work involved in this activity will be conducted near Cedar Mountain, which lies along the Walker Lane about 175 km northwest of the potential repository site (fig. 2-2). The location is dictated by where the Cedar Mountain earthquake occurred in 1932. The future work is estimated to require 6 to 12 person-months during the first 2½ years of the study. The timing should coincide with the need to provide information to other site characterization studies according to the integrated schedule for the Yucca Mountain project (see secs. 4 and 5).

2.3.3 Constraints

The discussion in section 2.1.3 is applicable to this section.

2.4 Activity 8.3.1.17.4.3.4: Evaluate the Bare Mountain fault zone

Bare Mountain lies about 15 km west of Yucca Mountain (fig. 2-5). This large structural feature has a steep, curvilinear eastern range front, the configuration of which is controlled by a complex of steeply eastward and moderately southeastward-dipping faults having Quaternary displacement that is referred to as the Bare Mountain fault zone (fig. 3-7). Because of its close proximity to the potential repository site and its history of Quaternary movement, this fault zone is considered to be a potential source for significant future ground motions at the site.

2.4.1 Rationale for the types of tests selected

This activity involves: (1) detailed geologic mapping of the fault zone, and (2) trenching and dating of deposits cut by the fault zone. Both of these planned work elements are essential for evaluating the potential for future ground shaking associated with future movement along the Bare Mountain fault zone, which is the primary purpose of the study. The planned work will emphasize detailed field investigations supplemented by trenching and large-scale trench-wall mapping at selected sites rather than following an alternative that involves less comprehensive and definitive methods such as photogeologic mapping and observing relationships only in natural exposures.

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

The planned work for this activity will be concentrated along the Bare Mountain fault zone, which lies approximately 10-15 km west of Yucca Mountain (fig. 2-5) and whose location is relatively well established from previous studies in the region (e.g., Reheis, 1988). Numerous field observations will be made all along the known extent (about 18 km) of the fault zone, one new trench is planned, and one existing trench is planned to be enlarged. The need for additional trenches and excavations will be determined after detailed field studies are completed (see sec. 3.4.1 for specific trench locations). The activity is estimated to require about 2½ years to complete (Figure 5-1).

2.4.3 Constraints

The discussion in section 2.1.3 is applicable to this section.

2.5 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

2.5.1 Rationale for the types of tests selected

This activity is not divided into individual tests, but a variety of remote sensing techniques based on high-quality Landsat Thematic Mapper (TM) imagery and side-looking airborne radar (SLAR) mosaics will be applied to geologic problems being investigated in the region, including (1) analysis of linear features detectable with the high-resolution TM data and SLAR mosaics, and characterization of regional fracture patterns; (2) mapping of the distribution of hydrothermal alteration related to near-surface igneous processes based on the spectral reflectance characteristics of alteration-associated minerals by using computer-enhanced TM supplemented by ground-truth studies; and (3) mapping of surfaces with a coating of desert varnish to aid in defining areas of tectonic stability. The analysis of linear features (item #1) will utilize data shown on fault maps resulting from the interpretation of aerial photographs (e.g., Reheis, 1991; Reheis and Noller, 1991). The age and degree of development of desert varnish (item #3) are considered to be a measure of tectonic stability. However, the techniques involved are not well established, and additional feasibility studies may be required before data on rock varnish can be used for this purpose.

Data resulting from the application of remote sensing techniques will help to delineate structural domains within 100 km of Yucca Mountain based on regional variations in fracture density and fracture patterns, especially as it relates to Quaternary features. At present, the density of Quaternary faults that have been identified at and near the potential site area substantially exceeds that of much of the surrounding region. This may be because past geologic investigations have been concentrated at Yucca Mountain, hence less

2.6.1 Rationale for the types of tests selected

This activity is based on one individual technique. Miocene ash flows will be cored at several locations and paleomagnetic declinations measured to determine if bedrock in the Yucca Mountain area is rotated (dragged). Data from these measurements will be used to determine if Yucca Mountain is oroflexurally bent due to the presence of wrench faults at depth beneath or marginal to Yucca Mountain.

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

Individual Miocene ash flows in the immediate vicinity of Yucca Mountain will be sampled (cored) at possibly five or six locations. The planned work is estimated to take about one person-year over 2 2/3 years. If the rotation of Yucca Mountain is confirmed by these preliminary studies, then additional sampling will be performed as discussed in section 3.6.1.

2.6.3 Constraints

The discussion in section 2.1.3 is applicable to this section.

3. DESCRIPTION OF TESTS AND ANALYSES

3.1 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

The objectives of this activity are to:

- Help identify and locate potentially significant seismic source zones, including possible through-going extensions of the Walker Lane beneath the Oligocene-Miocene cover of the Yucca Mountain area; to determine the width and subsurface geometry of such extensions and of the Furnace Creek fault zone and the relation of these features to detachment faults and to Quaternary faults; and to evaluate the postulated incipient rift zone and mid-crustal magma body beneath Crater Flat

- Characterize the crustal velocity structure and define lateral inhomogeneities in that structure in the Yucca Mountain area as an aid in the interpretation of the tectonic and hydrologic setting

- Trace the 5- and 10-s events found on Death Valley Consortium for Continental Reflection profiling (COCORP) profiles through the Yucca Mountain region and, if possible, trace reflections from the upper and lower carbonate aquifers, the Precambrian-Cambrian Pahrump Group and Noonday Dolomite, and the Proterozoic basement across the Furnace Creek fault and through the area of the projected northwest continuation in the subsurface of the Las Vegas Valley shear zone

- Identify differences in rock masses caused by variation in lithology in the upper few kilometers of the crust, and correlate those variations with reflections obtained in the seismic reflection surveys, or with conductivity features obtained in the magnetotelluric survey

- Identify differences in magnetic field caused by sources in the upper few kilometers of the crust and correlate those sources with reflections obtained in the seismic reflection surveys, or with conductivity features obtained in the magnetotelluric survey

- Characterize the electrical conductivity structure of the crust in the Yucca Mountain region, focusing in particular on the conductivity signature of the Walker Lane fault zone, and if possible, tracing the signature into the subsurface of conductive units such as the Eleana Formation or nonconductive units such as the lineated and mylonitized gneisses (lower plate?) of the northern Amargosa Desert, and to correlate these features, or their offsets, with Quaternary faults

- Provide data for analysis to determine if buried magma bodies or hot (solidus) regions are present in the vicinity of Yucca Mountain. These data and analyses will be used to address the objective of Activity 8.3.1.8.1.1.3 (Presence of magma bodies in the vicinity of the site)

Five tests will be conducted to achieve the above objectives, and to address the following parameters: (1) lateral discontinuities in seismic refraction profiles, (2) lateral discontinuities in seismic reflection profiles, (3) gravity anomalies, (4) magnetic anomalies, and (5) lateral and vertical discontinuities in crustal conductivity structure.

3.1.1 General approach

3.1.1.1 Deep seismic reflection survey

Preliminary testing and evaluation of the deep seismic refection method was conducted in January 1988, along a 27 km-long, east-west trending line in the eastern Amargosa Desert, about 20 km southeast of Yucca Mountain. In addition, testing of field acquisition parameters was performed along a 6 km-long line located in the western Amargosa Desert about 10 km southwest of Beatty. Preliminary results of this testing have been described by Brocher, et al. (1990), and an evaluation of these results by a DOE peer panel in September 1990, supports further testing of intermediate and deep seismic reflection methods along a series of intersecting traverses eastward and northeastward across Crater Flat and Yucca Mountain, and northwest along Yucca Wash (fig. 3-2). As indicated earlier, this survey will be conducted in Activity 8.3.1.4.2.1.2 (Surface-based geophysical surveys). Based on the results of this further testing (in Activity 8.3.1.4.2.1.2), additional profiles may be proposed, possibly crossing the Walker Lane and the Furnace Creek fault west of Yucca Mountain, as part of the seismic work planned in this activity.

With regard to the 27-km test line in the eastern Amargosa Desert, Oliver, et al. (1990, p. 72) reported that vibrator reflection data were acquired by continuous profiling at 60-fold, and explosive-source data were acquired in single-fold, split-spread configuration. The comparison of explosive and vibroseis sources indicates that explosive sources in shot holes provide high-quality images of the lower crust and Moho, owing to the high energy levels and better coupling to the earth. The explosive source data are more interpretable below about 5 sec two-way travel time, despite the high fold of the vibrator data. A similar approach to acquiring deep seismic reflection data will be used along the profiles planned for this activity, depending on the success of the reflection survey being run in Activity 8.3.1.4.2.1.2.

3.1.1.2 Seismic refraction survey

Location of high-resolution upper crustal seismic refraction surveys are shown on figure 3-1, and the results of these surveys are discussed by Oliver and others (1990. p. 47-55). Four additional profiles are proposed for this test; the locations of these are also shown on figure 3-1 and described in section 2.1.2.1. Each of these profiles will be recorded by at least 320 portable seismographs, and borehole shotpoints will be drilled at 25-50 km intervals to provide optimum interface velocity and depth control. The profiles will be tied to existing and planned seismic profile data, and to non-seismic geophysical data, and to features exposed at the surface.

Based on experience obtained near Yucca Mountain and elsewhere within the southern Basin and Range Province, high-quality data can be obtained from seismic shots consisting of 2,000-6,000 pounds of ammonium-nitrate explosives detonated within 140-180-foot-deep boreholes. Seismograph spacing of 1,000-5,000 m are needed to provide sufficient resolution of lateral variations in crustal structure. Accurate timing of shots and seismic arrivals will be obtained through the use of satellite-calibrated chronometers. All positions will be determined by Global Positioning System (GPS) receivers or maps, whichever is more accurate. Seismic data will be processed and interpreted in digital form.

All results will be tied to available borehole sonic logs and to previous seismic refraction surveys. Validity of proposed seismic structures will be evaluated by quantitative comparison with gravity and aeromagnetic data.

3.1.1.3 Gravity survey

Gravity measurements along the traverses listed in section 2.1.2.3 will be made using La Coste and Romberg Model G gravity meters. Parallel profiles of gravity data located on both sides of the seismic lines will also be implemented to provide off-axis control. Spacing between stations will be 500 feet along these traverses, and locations and elevations of stations will be surveyed using standard field methods.

The additional gravity stations needed to complete a detailed survey within the potential site area will be located as necessary on east-west lines 500 feet apart (where topography permits), with spacing between stations at about 200 feet. All measurements will have an estimated accuracy of 0.1 mgal. Figure 3-3 shows the density of gravity stations in regions surrounding Yucca Mountain. If gravity measurements are made within those 2x2 km cells that do not presently have any stations (see sec. 2.1.2.3), similar methods will be used to obtain the data.

3.1.1.4 Magnetic survey

The aeromagnetic surveys along the proposed seismic refraction and reflection lines will be flown at about 600 feet above the ground surface, and will include three parallel profiles spaced 1/4 mile apart along and on both sides of each seismic line. These additional profiles will be used to determine whether local geophysical anomalies detected by the seismic surveys are the result of larger-scale features.

A 1:12,000-scale aeromagnetic map of the potential site area will be constructed from measurements of the magnetic field and gradient along east-west flight lines spaced 200 m (1/8 mile) apart. The survey will be draped over topography, maintaining a nominal terrain clearance (absolute altitude) of about 100 m. For the ground-based surveys at selected localities, observations will be made at 10- to 20-foot intervals. Measurements will be made using portable devices, and surveying will employ standard field methods.

3.1.1.5 Magnetotelluric survey

Natural ambient magnetic fields and their induced electric fields at frequencies between 0.001 and 100 Hz will be measured along the proposed traverses shown on figure 3-5, as well as along the planned seismic reflection and refraction profiles. Soundings should be acquired at 2-4 km spacing along the seismic lines, and 3-6 km elsewhere; the actual spacing is dependent on the local ambient noise level. The method for obtaining magnetotelluric soundings will use: (1) high-precision voltage measurements across 75- to 150-m-long electrode spreads; (2) high-sensitivity induction coils; (3) four-matched-channel, band-passed filtering with amplification; and (4) real-time, floating-point, digital processing, and recording.

3.1.2 Test methods and procedures

The test methods and technical procedures to be used in this activity are listed in table 3-1.

3.1.3 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 document. All applicable procedures will be identified on the basis of the findings in the Grading Report and will be prepared in accordance with applicable QA requirements.

3.1.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this activity. The variety of methods being applied are considered to be the best means available for obtaining geophysical data of the quality required to characterize the crustal structure in the Yucca Mountain area. The resolution with which subsurface faults and other features (especially deep-seated ones) are defined cannot be precisely predicted until the final results are analyzed; however, model resolution will be accurately calculated for the data that are collected. The highest resolution of structure will be obtained from seismic reflection data (on the order of tens of meters for the upper crust), and potential fields data will provide resolution that is 5-10 times lower.

3.1.5 Range of expected results

Previous studies in the Yucca Mountain area suggest the following results:

- Seismic reflection methods have been used to detect buried faults, map the extent of fault zones, and investigate the subsurface geometry of fault zones. Of all geophysical methods used near Yucca Mountain, seismic reflection methods offer the highest spatial resolution in determining structural details. To best constrain allowable interpretations, however, the method should be used in conjunction with gravity, magnetic, seismic refraction, and other geophysical methods, and reflections should be calibrated by drill hole information whenever possible. Shallow, Mini-Sosie reflection studies have demonstrated complex subsurface faulting on the east side of Crater Flat and the absence of detectable recent faulting of the Beatty scarp (Harding, 1988). Testing of the intermediate to deep seismic reflection method in the Amargosa Desert shows that reflections can be observed as shallow as 25 meters and as deep as 33 km (Brocher et al., 1990). These data provide clear images of the Tertiary basin fill, and show where this fill has been offset by subsequent faulting. For example, the reflection data indicate that the important north-south trending and well-defined gravity gradient is a west-facing listric normal fault. The Amargosa Desert reflection profile shows tilted Tertiary basin fill that reaches thickness of locally in excess of 1.5 km. A shallow, widespread, subhorizontal low-frequency reflection about 100 m deep is interpreted as a basalt flow; nearby shallow drill data suggest that the flow is 10 m.y. old (T. Brocher, written commun., 1991). Thus, the reflection data may also provide important constraints on the timing of the basin evolution and the extent of late volcanism associated with the Tertiary rifting. This reflection line also images the pre-Tertiary/Tertiary contact as a series of tilted basement blocks, apparently bounded by high-angle normal faults (T. Brocher, written commun., 1991). Prominent reflections are observed from the middle to lower crust, corresponding to two-way travel times of 5 to 10 seconds, indicating that this method will be successful in imaging this portion of the crust. The top of the reflective lower crust appears to become shallower towards the west, possibly due to increased extension in the direction of Death Valley. More seismic reflection profiling will be required to allow definitive statements to be made on the role of the lower crust in the Tertiary rifting.

- Seismic refraction studies have been used to map the major horizons within the volcanic cover rocks in three dimensions and to determine the geometry of the pre-Tertiary surface (Hoffman and Mooney, 1983; Mooney and Schapper, written commun., 1991). These studies have identified the subsurface extent of the range-front fault on the east side of Bare Mountain, and have defined the geometry of the structural depression beneath Crater Flat and western Yucca Mountain. In contrast, a north-south seismic refraction profile in Forty Mile Wash to the east of Yucca Mountain indicates no significant structures with an overall flat-lying seismic section. When used in conjunction with gravity and magnetic surveys, the method is useful in testing and refining applicable structural models (e.g., Snyder and Carr, 1984). These geophysical data are consistent with a structural model for Yucca Mountain as a complex extensional feature, with west-dipping normal faults and east-tilted blocks.

- Gravity studies are particularly useful for detecting concealed or previously unrecognized faults, estimating the offset or extent of known faults, and detecting and characterizing igneous features such as calderas and plutons. Gravity methods can detect shallow as well as deep features that juxtapose rocks of significantly different densities. Gravity methods have identified several regional subsurface features, including the general configuration of buried pre-Tertiary bedrock under Yucca Mountain and adjoining basins (Snyder and Carr, 1984), the existence of the Silent Canyon caldera underlying Pahute Mesa (Healey, 1968), and the location and extent of concealed faults within Yucca Mountain (i.e., the Fortymile Canyon and Paintbrush faults (Ponce, 1992).

- Magnetic data are needed to help locate concealed faults as well as buried plutons and Quaternary volcanic rocks. Elongate magnetic highs and associated lows are associated with mapped faults in the site area, some of which are only partially exposed (Kane and Bracken, 1983; Ponce, in press). Ground magnetic data have been collected at Wahmonie and Calico Hills to better delineate aeromagnetic highs interpreted as buried intrusions and magnetite-rich altered argillite; the magnetic highs extend under the northern third of Yucca Mountain suggesting that the buried basement rocks there are magnetite-bearing argillites (Oliver and others, 1991). Modeling of ground magnetic data collected near Lathrop Wells in an area apparently underlain by reversely magnetized Quaternary basalts has provided constraints on the maximum depth to the top of causative bodies for proposed drilling (Langenheim et al., in press).

- Magnetotelluric (MT) surveys performed in the Yucca Mountain region were discussed by Furgerson (1982) and Hoover and others (1982a,b). These surveys yielded information on resistivity contrasts in the Earth's crust inferred to be related to the presence of intrusions, major high-angle fault zones, regional structural anisotropy, conductive argillic horizons, alteration, and possible anomalous temperatures. The data presented by Furgerson (1982) also indicate the presence of substantial conductivity contrasts between Precambrian crystalline rocks, Paleozoic aquifers and aquitards and argillaceous units such as the Eleana Formation, Miocene volcanic rocks, and Quaternary basin-fill deposits. The depth of investigation spans the range from 1 to 30 km. Early data were of quite low reliability for the interpretation of structures because of wide spacing of stations (Furgerson, 1982), or high-noise levels (Hoover et al., 1982a,b, citing unpublished contract data: Williston, McNeil and Associates, 1979). Future MT surveys, however, will utilize closer sounding spacing and improved noise-reduction capabilities that will allow the MT method to realize improved reliability in resolution and interpretation. Current MT capabilities typically allow resolution of major resistivity structures to about 10 to 20 percent of the penetration radius, a radius which increases for lower frequencies.

3.1.6 Equipment

This activity will use a variety of standard field and computer equipment for geophysical data collection and processing; typical items are (or will be) listed in the technical procedures for the six planned tests.

3.1.7 Data-reduction techniques

Standard data-reduction techniques described (or to be described) in the technical procedures listed in Table 3-1 will be used to compile the field observations. The recorded and processed data will be plotted on scale-stable topographic base maps (scale 1:24,000, or other, as appropriate).

The seismic reflection data are recorded on digital magnetic tapes and will be processed using standard industry procedures. These procedures will include: sort to CDP geometry, bandpass filter, velocity analysis, application of elevation and refraction statics, application of normal moveout corrections, stack of CDP gathers, deconvolution, and migration.

The seismic refraction data will be processed using procedures that include: bandpass filter, application of reduced-traveltime and normal-movement corrections, and application of time-term (or equivalent) refraction statics.

3.1.8 Representativeness of the results

The information obtained from each of the tests in this activity is expected to be as representative of crustal structure as current technology permits. The locations of the different planned surveys, and the methods to be used for each one, were selected on the basis that they would provide pertinent and reliable data for use in characterizing many of the primary geologic structures and related features that may affect the performance of the potential repository. However, because conditions which give rise to optimum recordings and data sets are seldom met--for example, contrasts between stratigraphic units in some areas may not be great enough to be measured by the geophysical methods involved--uncertainties in interpretations are likely to occur and to impose corresponding limitations on the ability of the planned tests to provide totally unambiguous results with regard to the designated parameters for the activity.

3.1.9 Relations to performance goals and confidence levels

See sections 1.2 and 4.

3.2 Activity 8.3.1.17.4.3.2 Evaluate Quaternary faults within 100 km of Yucca Mountain

The objectives of this activity are to:

- Establish the age, abundance, distribution and geographic orientation of known and suspected Quaternary faults within 100 km of the site
- Characterize the Quaternary (Pleistocene and Holocene) fault and fracture pattern within 100 km of the site and, if feasible, to relate that pattern to regionally important wrench fault systems, including the Walker Lane, the Death Valley, Furnace Creek, and Mine Mountain fault zones, and the Pahranagat shear zone
- Characterize those Quaternary faults within 100 km of the site whose apparent length, recurrence rate, or slip rate indicate potential for future earthquakes of magnitude sufficient to possibly affect design or performance of the waste facility
- Evaluate the recurrence history of that part of the Death Valley-Furnace Creek fault zone within 100 km of the site
- Identify fault scarps within 100 km of the site that may have been overlooked during conventional geologic field surveys and that may not have been apparent on conventional vertical aerial photography
- Determine whether the Beatty scarp originated through tectonic or fluvial processes, or both; the nature of movement along the scarp, if tectonic; and the age of the scarp

To achieve these objectives, the following parameters will be addressed: (1) location, orientation, patterns, displacement, age and nature of Quaternary faults, (2) fault-scarp morphology and offset of Quaternary deposits, (3) relative and absolute ages of Quaternary faults, (4) abundance, dimensions, and orientations of Quaternary ruptures in the path of suspected subsurface wrench faults, and (5) Quaternary rate of fault movement. Evaluation of the age of faulting will be made primarily through the correlation of mapped deposits with similar Quaternary deposits in the potential site area where detailed surficial studies are being conducted (e.g., Activity 8.3.1.5.1.4.2, Surficial deposits mapping of the Yucca Mountain area).

The information which is necessary to determine the nature and rate of Quaternary faulting within 100 km of the proposed repository site, will be acquired by the work elements described in the following section.

3.2.1 General approach

3.2.1.1 Compile map of Quaternary faults within 100 km of the site, but extending as far as Las Vegas on the southeast and Cedar Mountain on the northwest.

Known and suspected Quaternary faults within 100 km of the site will be identified from published and unpublished sources, and from new data obtained from other Quaternary fault studies in the site characterization program (e.g., Study 8.3.1.17.4.6, Quaternary faulting within the site area). These fault data will be compiled on a map at a scale of 1:500,000, or larger.

3.2.1.2 Prepare a photogeologic map of Quaternary scarps within 100 km of the site using both conventional and low sun-angle aerial photographs

Quaternary fault scarps within 100 km of the site will be identified through photogeologic interpretation of existing black-and-white, vertical aerial photographs (scale 1:20,000 to 1:80,000), and compiled on 1:100,000-scale base maps. Medium-scale vertical aerial photographs taken during periods of low sun angle will be procured for that part of the Walker Lane belt lying close to Yucca Mountain; the focus will be on Jackass Flats, Crater Flat, and northern Amargosa Desert. Photographs will be interpreted using conventional procedures, and the identified scarps will be plotted on 1:100,000-scale base maps. Existing photogeologic studies such as those by Reheis (1991) and Reheis and Noller (1991) will be evaluated for their quality and usefulness.

3.2.1.3 Verify the tectonic origin of scarps and lineaments in the field

The scarps and lineaments identified from the above work items will be examined in the field. Their ages will be estimated on the basis of scarp morphology and by the ages of deposits that are offset by or overlie the scarp or lineament. Trenching will be done at selected scarps or lineaments to determine their origin and/or constrain the amount of displacement and recurrence interval of faulting events. Detailed work will only be done on those faults or lineaments that have the potential for producing significant ground motions at the site or that have a direct bearing on the current tectonic framework of the Yucca Mountain region.

3.2.1.4 Map Quaternary faults and deposits of the Beatty 1:100,000 quadrangle

Quaternary deposits and faults displacing those deposits will be mapped within the Beatty 1:100,000 quadrangle (fig. 2-2) using standard field methods, including annotating contacts on 1:20,000-scale aerial photographs, or other scales as appropriate, and compiling the data at 1:24,000 and 1:100,000 scales. Local stratigraphic type localities and sections will be established. Deposits will be dated using soil development, cation ratio (desert varnish), radiocarbon dating (conventional and AMS) of organic material recovered from the deposits, uranium-trend and uranium-series analyses, and tephronchronology, as appropriate. The density of Quaternary faults in all parts of the quadrangle will be compared to the density of faults in the areas immediately surrounding the potential repository site to determine whether the incidence of faulting is uniform throughout, or is more concentrated in the site area as seems apparent from the existing data.

3.2.1.5 Evaluate nature of the Beatty scarp

The apparent length of the Beatty scarp, including its poorly defined southeastern extension, is 15 to 25 km (fig. 3-6). Existing studies suggest that the Beatty scarp is the result of fluvial erosion (Swadley, et al, 1986). These studies will be evaluated and, if required, detailed mapping of Quaternary deposits will be done along the scarp and may be supplemented by mapping of Quaternary horizons in additional trenches excavated across the scarp. Ages of the horizons may be determined, if possible, by analysis of soil properties, uranium-series and uranium-trend analyses, radiocarbon dating, and cation-ratio (desert varnish) dating. Shallow seismic reflection (Mini-sosie) and seismic refraction (Bison-type) surveys along traverses crossing the scarp and extending 1 to 2 km to either side may be performed to investigate the relation of the scarp to faults at depth.

3.2.1.6 Determine Quaternary recurrence rate of the Death Valley-Furnace Creek fault zone

The Quaternary offset and recurrence rate of the Death Valley-Furnace Creek fault zone will be evaluated using published and unpublished data supplemented by limited field reconnaissance. The field investigations will focus on scarp morphology and age of the surficial deposits that are cut by, or which overlap, the fault. Trenching of the fault zone is not presently being planned, but could be done if suitable exposures are found and if allowed within the national park boundaries.

3.2.1.7 Perform a seismic risk analysis.

Fault and lineament data (length, slip rate, recurrence interval) compiled from existing information and as determined from other tests in this activity will be used to perform a seismic risk analysis. This analysis will be used to determine what faults or lineaments are the most critical to the site and hence require the most intense investigation. An existing program, SEISRISK III (Bender and Perkins, 1989), will be used in this analysis.

3.2.1.8 Prepare a final map of Quaternary faults within 100 km of Yucca Mountain

Based on the data and information collected as part of the above work elements, a map of Quaternary faults having surficial expression as well as those faults suspected of Quaternary activity will be prepared at a scale of 1:250,000. The map will provide information on the estimated age of the identified faults. Data on amount of displacement, age of the most recent faulting event, recurrence intervals of surface faulting events, and the probable slip rates will be provided in tabular form and/or written text.

3.2.2 Test methods and procedures

The methods and technical procedures for this activity are given in table 3-2.

3.2.3 QA requirements

See section 3.1.3

3.2.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for the tests in this activity. However, certain levels of accuracy are implied in several of the stated objectives and fault parameters to be addressed in the studies being planned. Although the actual fault lengths, recurrence rates or other fault parameters are not specified in the SCP with respect to this activity, a logic diagram shown in SCP figure 8.3.1.17-4 indicates the kinds of information required for faults that are in or near the potential repository in order to determine whether their apparent length or recurrence rate indicate potential for earthquakes of magnitude sufficient to affect design or performance of the waste facility. These include: (1) fault zone widths and recurrence of movement on potentially significant faults within 5 km of proposed surface facilities important to safety, (2) locations of faults in or near the repository block with 1 m or greater offset of Quaternary material or with 100 m or greater offset of Tertiary rocks, and (3) surface and subsurface locations of faults with Quaternary slip rate 0.005 mm per year that intersect underground facilities. With regard to the above, Study 8.3.1.17.4.6 (Quaternary faulting within the site area) is primarily responsible for characterizing Quaternary faults within 5 km of the potential repository site, but Activity 8.3.1.17.4.3.2 is shown as contributing key data in response to those information needs. The requirement, therefore, is to map and describe Quaternary faults within 100 km of Yucca Mountain in enough detail to determine whether one or more of them pose an earthquake hazard. Locations of mapped features, including faults, linear features, geologic contacts, and sample locations, will be plotted within about 1 mm on base maps. At scales of 1:24,000 and 1:500,000, this represents a location on the ground within about 24 m and 500m, respectively.

3.2.5 Range of expected results

Previous studies (e.g., Swadley et al., 1984; Moring, 1986; McKittrick, 1988; Reheis, 1988) suggest the following ranges of expected results for studies of Quaternary faulting. The surface traces of faults are likely to be a few hundred meters to perhaps 20 km in length. They will commonly trend northwest to northeast, but may also trend east-west. The fault planes will commonly have steep dips (exceeding 50°). Fault scarps expressed in surficial deposits are likely to be as much as 5 km in length, tens of meters high, and less than 100,000 years old. Most faults will exhibit dip-slip movement, but some, especially those associated with the Death Valley-Furnace Creek, Pahrump, and Rock Valley fault systems may display strike-slip movement. Net displacements may range from a few centimeters to several meters in the past few thousand years. Recurrence intervals may range from several hundred to several hundred thousand years. Surficial deposits in the 100 km-radius study area will range in age from modern to 1 to 2 million years old.

3.2.6 Equipment

This activity will use a large variety of standard field, office, and laboratory equipment; typical items are listed in the technical procedures for the different planned tests (see table 3.2).

3.2.7 Data-reduction techniques

Maps produced by this activity will be compiled from observations made on aerial photographs, on the ground surface, and in natural or excavated exposures using standard data reduction techniques. Observations made or plotted on aerial photographs will be transferred to scale-stable base maps using the Kern PG-2 stereographic plotter or, in some cases, visually. Information derived from seismic, paleomagnetic, or dating studies will be reduced using standard techniques, and will be presented on maps or in accompanying reports.

3.2.8 Representativeness of results

The information obtained for each of the tests in this activity is expected to be as representative of the distribution of Quaternary faults, scarps, and other photogeologic features within 100 km of Yucca Mountain as current technology permits. Because conditions are seldom ideal, however, some data gaps and uncertainties are likely to occur, and to impose limitations on the ability of the planned tests to provide comprehensive information on each of the activity's designated parameters. In particular, the quality and completeness of the resulting data is dependent upon (1) the quality and extent of natural exposures and the degree to which faults and evidence of fault movements are expressed in surficial deposits, (2) the extent to which aerial photographs reveal linear features and fault scarps, and (3) the suitability of the materials being sampled for age determinations and paleomagnetic studies.

3.2.9 Relations to performance goals and confidence levels

See sections 1.2 and 4.

3.3 Activity 8.3.1.17.4.3.3: Evaluate the Cedar Mountain earthquake of 1932 and its bearing on wrench tectonics of the Walker Lane within 100 km of the site

The objective of this activity is to evaluate the relevance of the Cedar Mountain earthquake of 1932 (fig. 2-2) to potential sources of ground shaking and rupture in that part of the Walker Lane within 100 km of Yucca Mountain. To achieve this objective, the following parameters will be addressed:

- Geologic structure of Stewart and Monte Cristo valleys
- Stewart and Monte Cristo valley faults and their relation to the Walker Lane
- Surface ruptures formed during 1932 Cedar Mountain earthquake
- Focal mechanism of the 1932 Cedar Mountain earthquake

3.3.1 General approach

Individual tests are not listed in the SCP for this activity, but several work elements are planned as listed in section 2.3.1. Emphasis will be on the tectonic setting, (is it part of

Walker Lane, Churchill Arc, or both?) continuity with Quaternary faults of Stewart Valley and with through-going shears mapped by Ekren and Byers (1985), distribution and character of surface breaks, and recurrence history.

Ruptures will be classified according to style and length based on descriptions by Gianella and Callaghan (1934a,b) and Molinari (1984). Selected ruptures will be examined in the field. The width of the rupture zone, the width of individual ruptures, and other attributes (length, offset, aperture, fissure-fillings, brecciation) will be noted. The rupture zone has been trenched previously (by non-YMP investigators); additional trenching is not anticipated. The ground ruptures for the Cedar Mountain event will be analyzed in light of the dominant strike-slip focal mechanism for the event and in comparison to other historic surface-faulting events in the Basin and Range.

3.3.2 Test methods and procedures

Methods and technical procedures for this activity are given in table 3-3.

3.3.3 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 document. All applicable procedures will be identified on the basis of the findings in the Grading Report and will be prepared in accordance with applicable QA requirements.

3.3.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this activity. Data bearing on the designated parameters will be made as specific as is possible from the existing records and reports of the earthquake, and from the additional work being planned.

3.3.5 Range of expected results

Previous studies (Gianella and Callaghan (1934a,b) and Molinari (1984); Doser, 1987) suggest that ground rupture was discontinuous, that ground ruptures will trend generally N-S within a zone that trends N25°W, and that ground rupture included both normal and strike-slip components. It is expected that the faults will be nearly vertical and that displacement on individual ruptures will be less than is expected for a $M = 7.2$ to 7.3 earthquake (probably less than 1 m).

3.3.6 Equipment

Lists of required equipment are given in the technical procedures listed in table 3-3.

3.3.7 Data-reduction techniques

A report on the interpretation of selected areas of ground rupture produced in the 1932 earthquake will be based on evaluation of existing reports and limited field investigations. A report on the relationship of Stewart and Monte Cristo Valley faults to the Walker Lane will also be based on interpretations derived from existing reports. Maps produced by this activity will be compiled from observations made on aerial photographs and on the ground surface using standard data reduction techniques. Observations made or plotted on aerial photographs will be transferred to scale-stable base maps using the Kern PG-2 stereographic plotter or, in some cases, visually.

3.3.8 Representativeness of results

The work planned for this activity is being designed to provide a thorough review of existing information and a comprehensive evaluation of newly acquired data pertinent to the 1932 Cedar Mountain earthquake. The results are therefore expected to be representative of the geologic structures and other parameters associated with this event. It should be noted, however, that the quality of data bearing on the fault plane solution (Doser, 1987) must be assessed in view of the limited number of seismograph stations operating in 1932. The reported normal fault scarps (dip-slip movement) of some ground ruptures need to be reconciled with the right lateral slip of the fault plane solution.

3.3.9 Relations to performance goals and confidence levels

See sections 1.2 and 4.

3.4 Activity 8.3.1.17.4.3.4 Evaluate the Bare Mountain fault zone

The objectives of this activity are to:

- Evaluate the potential for ground shaking associated with future movement along the Bare Mountain fault zone
- Estimate the age of the most recent faulting on the Bare Mountain frontal fault
- Estimate the recurrence intervals of faulting

- Determine the nature and age of faulting within the fault complex east of the frontal zone, and determine if there is any tectonic control on the location and orientation of the Main Wash in Crater Flat

- Determine the near-surface configuration of fault zones

Geologic mapping of the Bare Mountain fault zone (fig. 3-7) and trenching and dating of deposits cut by the fault zone will be conducted to achieve these objectives and to provide information on the designated parameters--age of horizons, amount and direction of offset of horizons, and geologic structure and stratigraphy.

3.4.1 General approach

Alluvial fans and stream deposits within Crater Flat along the eastern flank of Bare Mountain will be mapped and deposits dated, if possible, through soil development, uranium-series, and uranium-trend analysis, thermoluminescence, and (or) cation ratios (desert varnish) methods. Trenches intersecting the trace of the frontal fault will be excavated and mapped. Deposits offset by, and which overlap the rupture zones exposed in the trenches, will be dated, if possible.

One new trench is planned and an existing prospect pit is planned to be enlarged (fig. 3-7):

1. Backhoe or bulldozer trench just south of Tarantula Canyon (T.12.S., R.48 E.), estimated depth of 2 to 5 m, length of 30 to 40 m.

2. Enlargement of existing prospect pit immediately east of Wildcat Peak (T.13 S., R.48 E.).

The need for, and location of, additional trenches will be determined based on the results of the above excavations and on the results of detailed aerial photograph interpretation and geologic field mapping along the suspected trace of the Bare Mountain fault.

The results of the above studies will be integrated with information on bedrock geology (Activity 8.3.1.17.4.5.2, Evaluate postulated detachment faults in the Beatty-Bare Mountain area), geomorphology (Activity 8.3.1.17.4.9.3, Evaluate variations in the nature and intensity of Quaternary faulting within 100 km of Yucca Mountain through morphometric and morphologic analysis), and geophysics (Activity 8.3.1.17.4.12.1, Evaluate tectonic processes and tectonic stability at the site) in order to meet the planned objectives.

3.4.2 Test methods and procedures

The methods and technical procedures for this activity are given in table 3-4.

3.4.3 QA requirements

See section 3.1.3

3.4.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, and precision have been specified for this activity. However, in order to satisfy the stated objectives and parameters, it will be necessary to measure fault displacements and determine age of movements as accurately as is possible from the relationships that can be observed in exposures along the fault zone and in trenches.

3.4.5 Range of expected results

Previous studies (Reheis, 1988; Swadley et al., 1984; Mansen et al., 1990) suggest the following ranges of expected results.

- Fault distribution--The Bare Mountain fault zone is about 18 km long. Fault strands in the southern 13 km of the zone trend north and are confined to a narrow strip a few tens of meters wide bounding the eastern front of the range, whereas fault strands in the northern 5 km are mostly north-northeast and occupy a zone nearly 4 km wide. The fault zone may be segmented into shorter lengths of 3-5 km.

- Fault character--The faults are mostly dip-slip, but some oblique-slip motion may have occurred. Fault dips range from 60° to 80°, except for one fault near Chuckwalla Canyon which dips about 40°. Fractures associated with an individual fault may extend several tens of meters away from the fault.

- Fault displacement--Net displacements may range from as much as 1.75 m in the past several thousand years to several tens of meters in the past several hundred thousand years. The most recent movement on the fault zone apparently occurred in Holocene time, and at least two movements may have occurred on some fault strands since the late Pleistocene.

- Age of deposits--Surficial deposits cut by the faults range in age from early Holocene to as much as 2 million years; deposits that overlap the faults range from late Holocene to several hundred thousand years.

3.4.6 Equipment

Standard items of equipment will be used in this activity, as listed in the technical procedures cited in table 3-4.

3.4.7 Data-reduction techniques

Field observations and other data pertinent to characterizing the Bare Mountain fault zone will be plotted on scale-stable topographic base maps, scale 1:24,000. Large-scale (1:20) trench-wall maps will also be prepared as necessary to show detailed fault relationships. Analytical data from samples collected for soils, sedimentology, or age control will be reduced using standard techniques (see technical procedures listed in table 3-5).

3.4.8 Representativeness of results

The field and laboratory investigations being planned for this activity are expected to provide data representative of the age and rate of movement within the Bare Mountain fault zone. The accuracy with which these parameters can be determined, however, is dependent upon how clearly fault relations are displayed in their natural setting, and whether or not suitable materials are available for dating fault movements. Because conditions are seldom ideal, some data gaps and uncertainties may occur.

3.4.9 Relations to performance goals and confidence levels

See sections 1.2 and 4.

3.5 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

The objectives of this activity are to:

- Map faults and lineaments within a 100-km radius of the site and identify those having geomorphic expression indicative of Quaternary faulting.

- Classify the area into subareas (domains) containing relatively homogeneous fault and lineament populations (prominent geomorphic expression, density, and orientation) suggestive of Quaternary faulting. This information will be used in Activity 8.3.1.17.2.1.2 (Assess the potential for displacement on faults that intersect underground facilities) to help assess the faulting potential in areas of emplaced waste.

- Map the areal extent of desert varnish coatings. This information will be used in Activity 8.3.1.17.4.9.1 (Evaluate age and extent of tectonically stable areas at and near Yucca Mountain) to help establish the areal extent of tectonically stable areas near Yucca Mountain.

- Identify areas of suspected hydrothermal alteration. This information will be used in Study 8.3.1.9.2.1 (Natural resource assessment of Yucca Mountain, Nye County, Nevada) to evaluate the relationship of the suspected hydrothermal alteration to potential mineralization, in Activity 8.3.1.5.2.1.5 (Studies of calcite and opaline vein deposits) to aid in evaluating the possible origin of calcite-silica deposits, and in Study 8.3.1.8.5.2 (Characterization of igneous intrusive features) to aid in evaluating local heat flow anomalies.

The SCP parameters include fracture orientation, length, distribution; optical reflectance and absorption for selected wavelengths; age and distribution of desert varnish; and distribution of hydrothermal alteration.

3.5.1 General approach

In this activity, a variety of remote sensing techniques will be applied to geologic problems being investigated in the region, including (1) analysis of linear features detectable with the high-resolution digital Landsat Thematic Mapper (TM) data and side-looking airborne radar (SLAR) mosaics, and characterization of regional fracture patterns, (2) mapping of the distribution of hydrothermal alteration related to near-surface igneous processes based on the spectral reflectance characteristics of alteration-associated minerals by using computer-enhanced TM data supplemented by field evaluations, and (3) mapping of surfaces with a coating of desert varnish to aid in defining areas of tectonic stability.

The study area for this activity comprises large parts of four 1:100,000-scale quadrangles--Beatty, Indian Springs, Pahute Mesa, and Pahranagat Range (fig. 2-2). Tapes of the four TM V scenes encompassing this area will be purchased, and spectral and spectral ratio maps will be prepared including bands sensitive to hydroxyl-containing minerals in the ultraviolet part of the spectrum. Computer-enhanced images will be interpreted, linear features identified, and their length and orientation measured. Analysis of SLAR radar mosaics for fracture patterns through the area of the projected northwest continuation of the Las Vegas Valley shear zone will be included.

The lineaments will be categorized as to whether they represent Quarternary faults, using the following criteria (in decreasing order of confidence, with the most reliable listed first):

1. Lineaments that are coincident with mapped faults and fractures.

2. Lineaments that represent extensions of known faults, or that connect mapped fault segments.

3. Lineaments along which there is evidence of stratigraphic or topographic offset.

4. Lineaments that represent long-continuing linearity of image tonal contrast.

5. Lineaments that represent aligned volcanic landforms or drainage segments.

Domains containing distinctive patterns of fractures and lineaments will be delineated. The density of lineaments in all parts of the Beatty 1:100,000 quadrangle will be compared to the density of lineaments in the areas immediately surrounding the potential site to determine whether the incidence of fracturing is uniform throughout, or is more concentrated in the site area, as seems apparent from the existing data.

Color-ratio composite TM images will be used to identify areas of alteration. These areas will be reconnoitered in the field to determine the type of alteration and the nature of the causal volcanic or igneous processes.

The overall plan for the acquisition and processing of remote sensing geophysical data is described by Oliver and others (1990). Accordingly, the proposed plans for remote sensing studies, surveys, and data processing to be conducted as part of the present activity will be reviewed and evaluated within the broader context of the total requirements and project funding available for geophysical data throughout the site characterization program.

3.5.2 Test methods and procedures

The methods and technical procedures for this activity are given in the table 3-5.

3.5.3 QA requirements

See section 3.1.3

3.5.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this activity. The methods being employed are considered to be reliable means for obtaining and processing remote sensing data of the quality required to characterize the fracture pattern in the Yucca Mountain area. Whether or not resolution will be great enough to map faults and other features with a high degree of accuracy will not be determined until the final results are analyzed.

3.5.5 Range of expected results

Based on experience with similar terrane in the basin and range province, it is expected that the remote sensing techniques will identify some heretofore unknown faults and fractures. Some of these newly identified features will probably be associated with geologic evidence for Quaternary movement. It is also expected that this activity will confirm the existence of domains of different concentrations of faults and fractures within the Yucca Mountain region.

3.5.6 Equipment

Equipment will be listed in the technical procedures cited in table 3-5.

3.5.7 Data-reduction techniques

Magnetic tapes of Landsat Thematic Mapper (TM) digital data on computer disks will be used to produce experimental color composite transparencies of selected spectral bands to determine the optimum combinations that show most effectively the desired geologic information at 1:100,000 scale (initially for the Beatty 1:100,000 quadrangle).

3.5.8 Representativeness of results

The planned remote sensing surveys and studies are expected to produce results that will be representative for the Yucca Mountain area and surrounding region and should provide pertinent data for use in characterizing many of the primary geologic structures and related features that may affect the performance of the repository. However, some degree of bias may be introduced by the look angle in SLAR and sun direction on Landsat imagery.

3.5.9 Relations to performance goals and confidence levels

See sections 1.2 and 4.

3.6 Activity 8.3.1.17.4.3.6: Analyze rotation (drag) of bedrock along or over suspected wrench faults based on rotation of paleomagnetic declinations

3.6.1 General approach

The available paleomagnetic data show that a systematic overall pattern of declination change within the Tiva Canyon Member of the Paintbrush Tuff provides strong evidence for a southward increase in clockwise vertical-axis rotation at Yucca Mountain (Scott and Rosenbaum, 1986). Additional sites (as many as 30) will be selected, primarily in the Crater Flat basin, for the collection of samples from the Tiva Canyon Member as well as from older rock units to determine the spatial and temporal patterns of oroflexure bending in that area.

Individual Miocene ash flows will be cored using hand-held drills at localities to be selected. Eight or ten oriented samples will be obtained per site. After alternating field demagnetization (to be done in conjunction with Activity 8.3.1.4.2.1.5, Magnetic properties and stratigraphic correlations), the orientation of the magnetic pole for each specimen will be measured and corrected for inclination of the strata at the sample site. Comparison of paleomagnetic site-mean declinations will provide a measure of relative vertical-axis rotation.

3.6.2 Test methods and procedures

The test methods and procedures for this activity are given in table 3-6.

3.6.3 QA requirements

See section 3.1.3.

3.6.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this activity. With regard to the reproducibility of the paleomagnetic declination measurements, the expected range among the number of samples collected at any given site is 3-4 degrees.

3.6.5 Range of expected results

Paleomagnetic measurements are expected to be within the ranges shown in Table 3-7.

3.6.6 Equipment

Typical items of equipment for this activity are (or will be) included in the technical procedures listed in Table 3-6.

3.6.7 Data-reduction techniques

Information resulting from paleomagnetic studies will be processed using standard techniques as (or will be) described in the technical procedures listed in Table 3-6.

3.6.8 Representativeness of results

Although the quality of the paleomagnetic measurements depends upon the suitability of the materials that are present and being sampled for study, it is expected that the resulting data will be representative of the area and of the stratigraphic units involved.

3.6.9 Relations to performance goals and confidence levels

See sections 1.2 and 4.

4. APPLICATIONS OF RESULTS

This section identifies other studies that will use the information obtained in this study of Quaternary faults within 100 km of the potential repository site, 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.

Information from this study will be used in both the preclosure tectonics program (Program 8.3.1.17) and the postclosure tectonics program (Program 8.3.1.8), as shown in figures 1-2 and 1-3 and in table 4-1, and as discussed below.

In the preclosure tectonics program (fig. 1-2; table 4-1), the information will be used to:

- Identify earthquake sources that could generate severe ground motion at the site (Studies 8.3.1.17.2.1, 8.3.1.17.3.1, 8.3.1.17.5.5, and 8.3.1.17.3.6)
- Characterize those aspects of lithology and structure of the concealed lithosphere at and in the vicinity of Yucca Mountain which are or could be relevant to the performance, siting, design, and construction of a high level nuclear waste repository (Study 8.3.1.17.4.5; Activities 8.3.1.17.4.6.2 and 8.3.1.17.4.12.1)
- Characterize the Quaternary and Holocene fault and fracture pattern within 100 km of the site and, if feasible, to relate that pattern to regionally important wrench fault systems, including the Walker Lane, the Death Valley, Furnace Creek, and Mine Mountain fault zones, and the Pahranagat shear zone; synthesize and evaluate information pertaining to Quaternary wrench faulting in the Walker Lane (Las Vegas to Cedar Mountain); constrain, if possible, the rate of offset and recurrence interval of movement of potentially significant faults (including the Bare Mountain fault and faults analogous to those near Cedar Mountain); ascertain the amount of post-middle Miocene vertical-axis rotation of bedrock alongside wrench faults and of bedrock suspected to be part of the upper plate above subsurface wrench faults (Activities 8.3.1.17.4.9.1 and 8.3.1.17.4.12.1) and evaluate the applicability of this information to geologic hazards at the site

In the postclosure tectonics program (fig. 1-3; table 4-1), information from this study will be integrated with information from other studies/activities to:

- Aid in evaluating the possible origin of calcite-silica deposits (Activity 8.3.1.5.2.1.5)
- Provide data to assist in determining the probability of magmatic disruption of the repository (Study 8.3.1.8.1.1)
- Calculate the number of waste packages that a fault penetrating the repository would intersect (Activity 8.3.1.8.2.1.2)
- Summarize and evaluate data on slip rates on faults in and near the controlled area (Activity 8.3.1.8.2.1.3)
- Estimate slip rates, recurrence intervals, and possible cumulative offset on Quaternary faults in and near the potential repository site (Activity 8.3.1.8.3.1.3)
- Evaluate the effect of tectonic processes on water table elevation (Study 8.3.1.8.3.2) and ground water travel time (Study 8.3.1.8.3.3)
- Aid in evaluating local heat flow anomalies (Study 8.3.1.8.5.2)
- Evaluate the relationship of suspected hydrothermal alteration to potential mineralization (Study 8.3.1.9.2.1)

5. SCHEDULE AND MILESTONES

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

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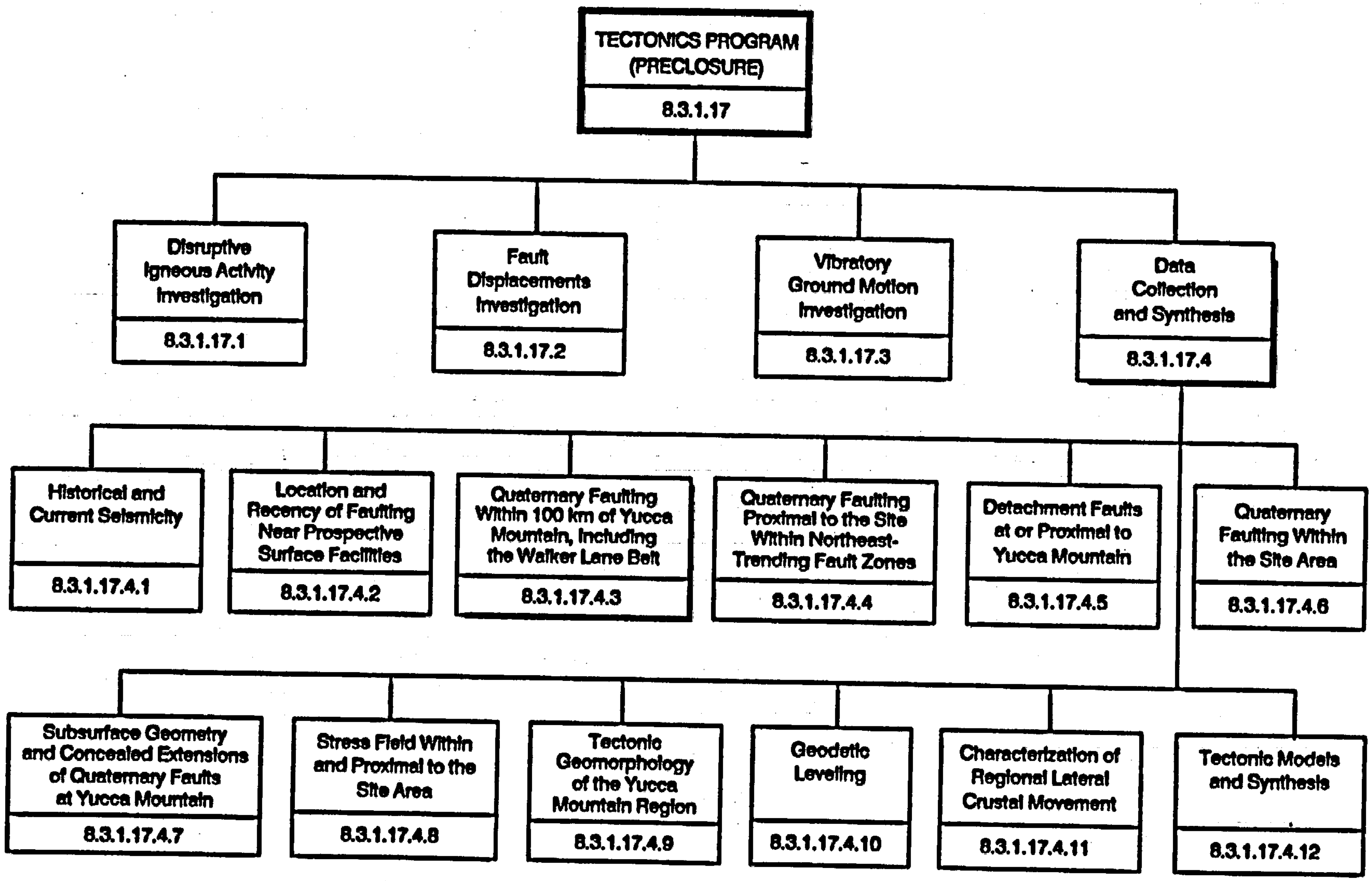
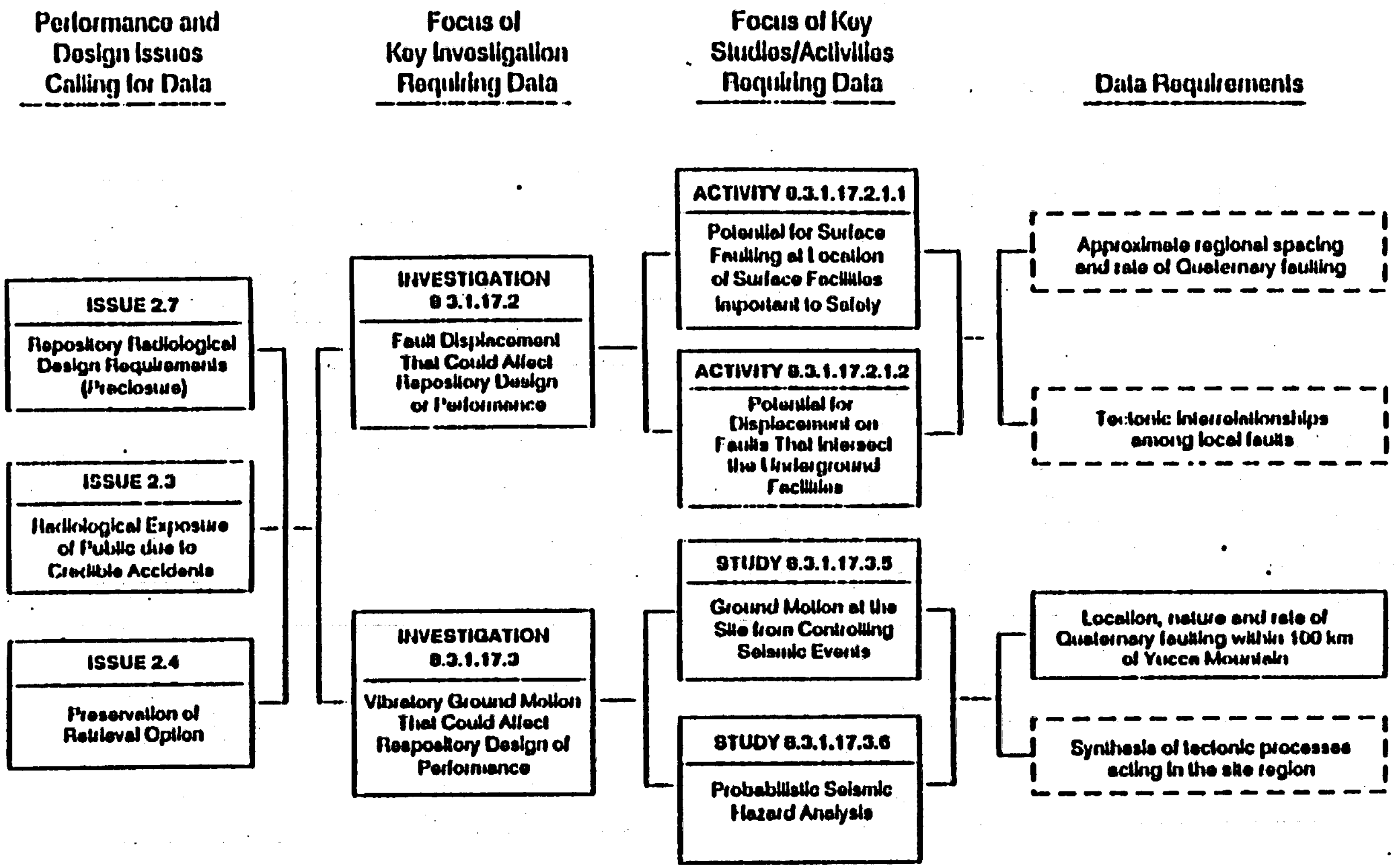
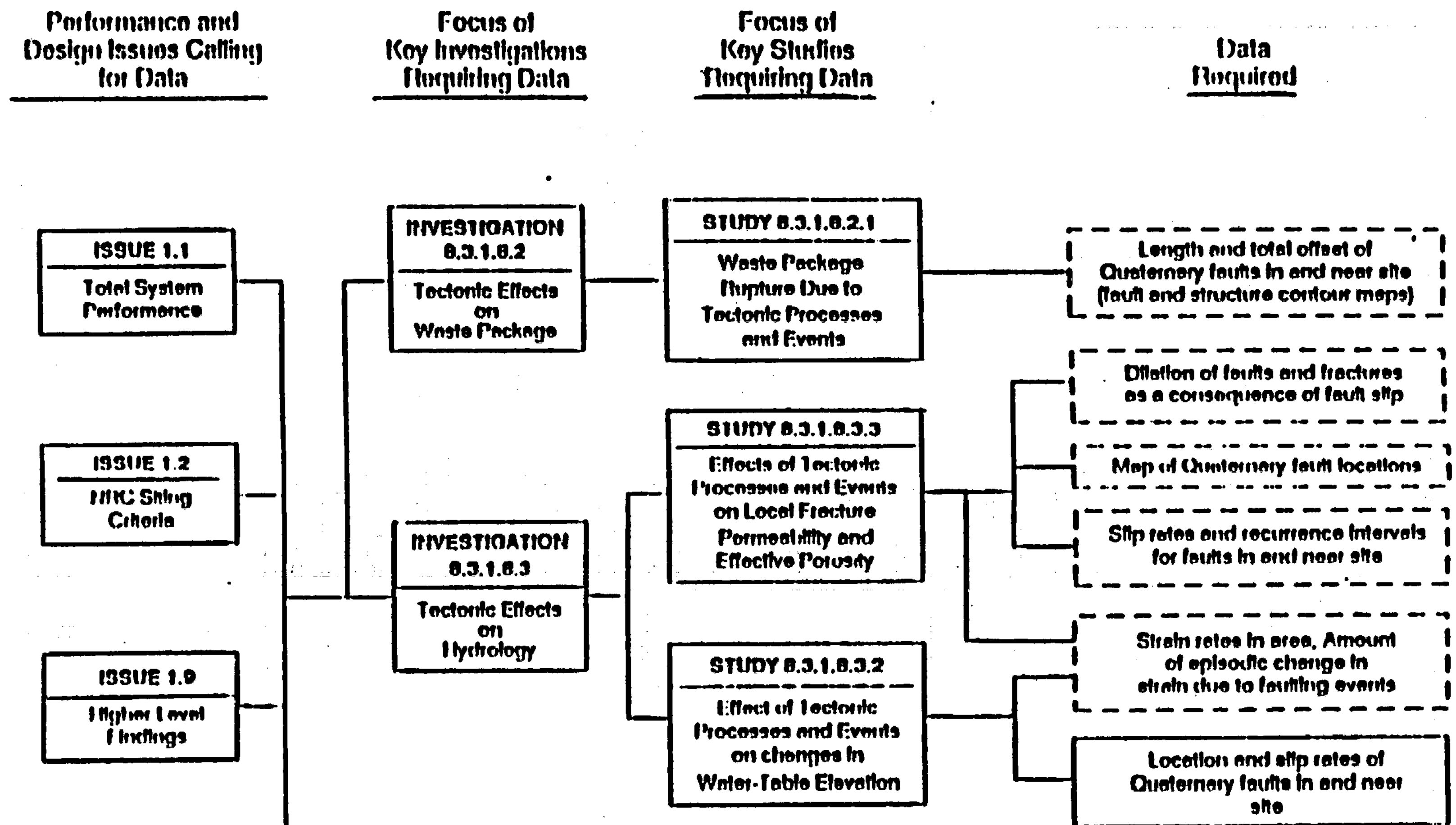


Figure 1-1.--Relation of Study 8.3.1.17.4.3 to the preclosure tectonics program.



Sources of information:
for Investigation 8.3.1.17.2, modified from SCP Figures 8.3.1.17-1, 8.3.1.17-4;
for Investigation 8.3.1.17.3, modified from SCP Figures 8.3.1.17-1, 8.3.1.17-5.

Figure 1-2 Required data supplied (in part) by Study 8.3.1.17.4.3 for issue resolution through studies in the preclosure tectonics program (Dashed box indicates data requirement supplied indirectly through contribution to Study 8.3.1.17.4.12, Tectonic Models and Synthesis).



Sources of Information:

Investigation 8.3.1.8.2, modified from SCP Figure 8.3.1.8-1 and Figure 8.3.1.8-4;
for Investigation 8.3.1.8.3, modified from SCP Figures 8.3.1.8-1, 8.3.1.8-5, 8.3.1.8-6, and 8.3.1.8-7.

Figure 1-3 Required data supplied (in part) by Study 8.3.1.17.4.3 for issue resolution through studies in the postclosure tectonics program (Dashed box indicates data requirement supplied indirectly through contribution to Study 8.3.1.17.4.12, Tectonic Models and Synthesis).

		TECTONIC PROCESS		
		Uplift and Subsidence	Faulting	Folding
Quaternary	Contemporary and Historical Time	Study 8.3.1.17.4.10 (Geodetic Leveling)	Study 8.3.1.17.4.1 (Historical and Current Seismicity) Study 8.3.1.17.4.8 (Stress Field Within and Proximal to the Site Area) Study 8.3.1.17.4.10 (Geodetic Leveling) Study 8.3.1.17.4.11 (Characterization of Regional Lateral Crustal Movement)	
	Holocene (Prior to Historical Time) and Pleistocene	Study 8.3.1.17.4.9 (Tectonic Geomorphology of the Yucca Mountain Region)	Study 8.3.1.17.4.2 (Location and Recency of Faulting Near Prospective Surface Facilities) Study 8.3.1.17.4.3 (Quaternary Faulting Within 100 Km of Yucca Mountain, Including the Walker Lane) Study 8.3.1.17.4.4 (Quaternary Faulting Proximal to the Site Within Northeast-Trending Fault Zones) Study 8.3.1.17.4.5 (Detachment Faults at or Proximal to Yucca Mountain) Study 8.3.1.17.4.6 (Quaternary Faulting Within the Site Area) Study 8.3.1.17.4.7 (Subsurface Geometry and Concealed Extensions of Quaternary Faults at Yucca Mountain)	Study 8.3.1.8.5.3 (Investigation of Folds in Miocene and Younger Rocks of the Region)

Figure 1-4. Logic diagram, showing area of responsibility of this study in the investigation of the location rates of tectonic processes operating during the Quaternary.

AREA		FAULTING SUBPROCESSES			
		High-angle normal faulting	Left lateral strike-slip faulting	Right lateral strike-slip faulting	Detachment low-angle extensional faulting
Midway Valley part of Site area (Surface investigations related to siting of facilities)		Study 8.3.1.17.4.2: Location and recency of faulting near prospective surface facilities	No left-lateral faulting recognized	No right lateral faulting recognized	No detachment faulting recognized
Site Area (includes Midway Valley area)	Surface investigations	Study 8.3.1.17.4.6: Quaternary faulting within the Site Area	Study 8.3.1.17.4.4: Quaternary faulting proximal to the site within northeast-trending fault zones	No right lateral faulting recognized at surface	No detachment faulting required at surface
	Subsurface investigations	Study 8.3.1.17.4.7: Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain	Study 8.3.1.17.4.7: Subsurface geometry and concealed extensions of Quaternary Faults at Yucca Mountain	No right lateral faulting recognized	Study 8.3.1.17.4.7: Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain
Area within 100 km of Yucca Mountain, exclusive of Site Area		Study 8.3.1.17.4.3: Quaternary faulting within 100 km of Yucca Mountain, including the Walker Lane belt [This study]	Study 8.3.1.17.4.4: Quaternary faulting proximal to the site within northeast-trending fault zones	Study 8.3.1.17.4.3: Quaternary faulting within 100 km of Yucca Mountain, including the Walker Lane belt [This study]	Study 8.3.1.17.4.5: Detachment Faults at or proximal to Yucca Mountain

Figure 2-1. Approach to characterization of prehistoric Quaternary faulting at and proximal to Yucca Mountain

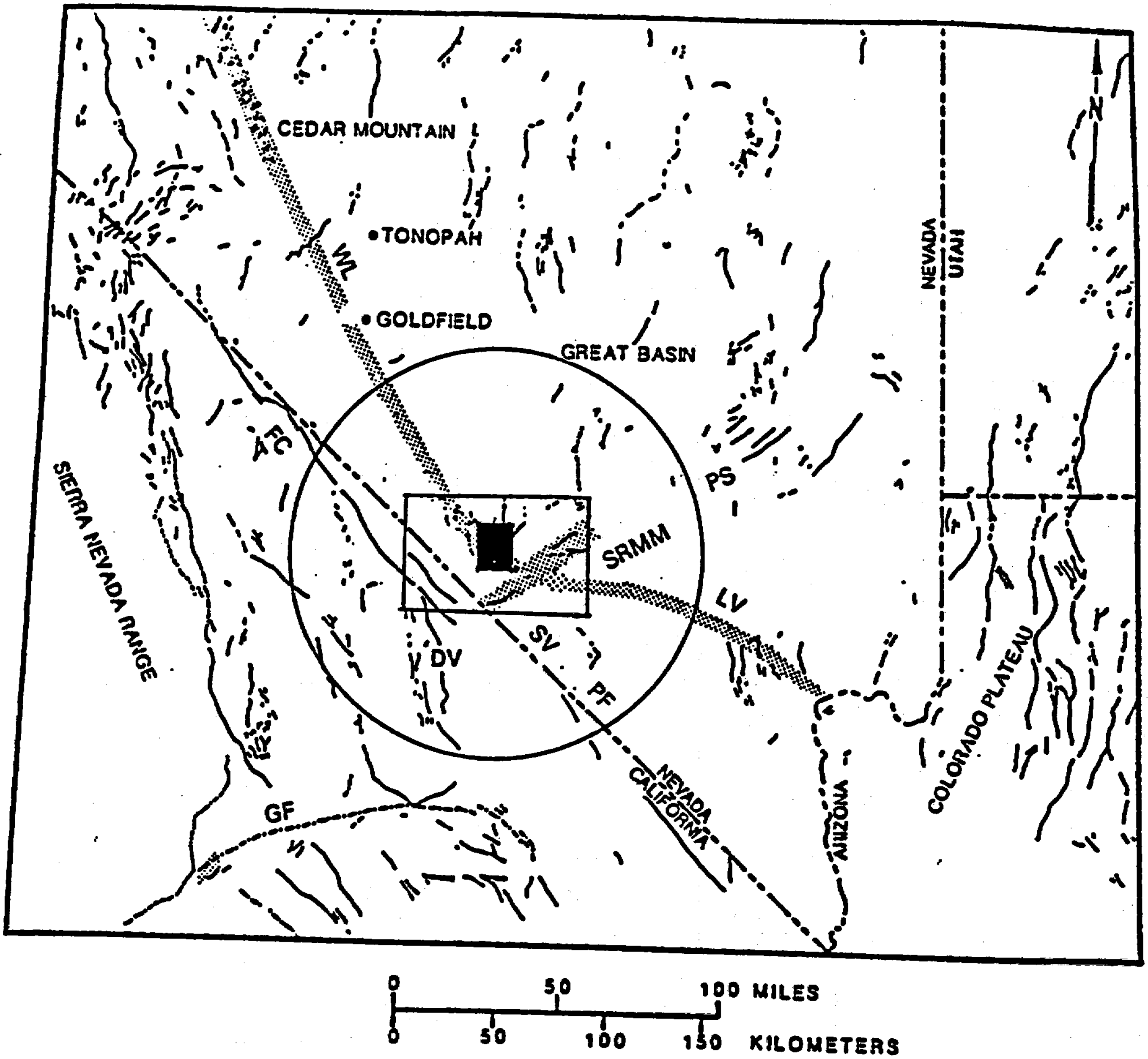


Figure 2-2. Regional structure map, showing location of major Quaternary structural features. Potential repository site area at Yucca Mountain is indicated by the black rectangle, the open rectangular area is the outline of the Beatty 1:100,000 quadrangle, and the large circle defines the area lying within 100 Km of the site. Labeled fault and shear zones are: WL-Walker Lane; FC-Furnace Creek; DV-Death Valley; GF-Garlock; SRMM-Spotted Range-Mine Mountain; PS-Pahranagat; LV-Las Vegas; SV-Stewart Valley; PF-Pahrump.

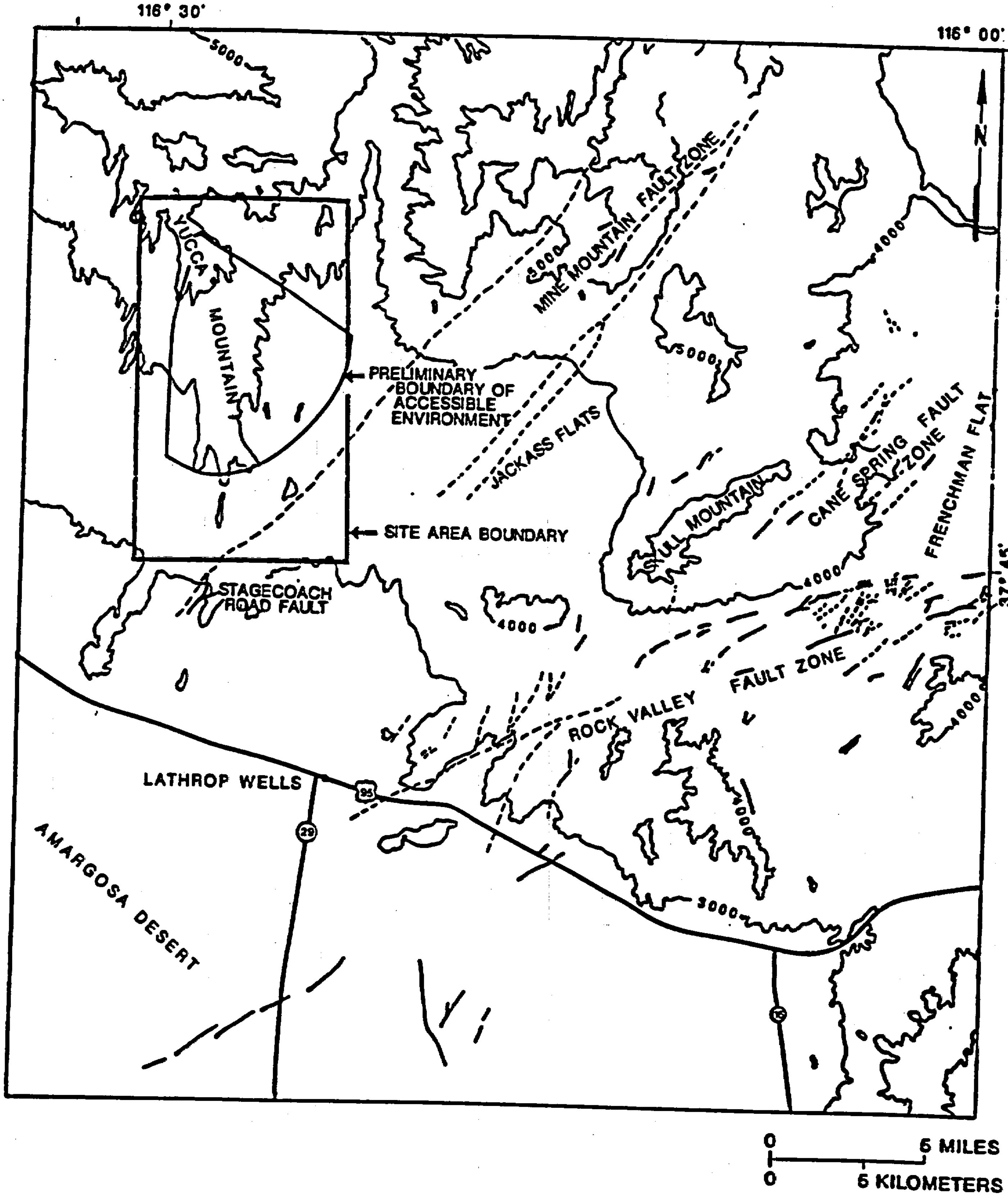


Figure 2-3. Map showing relation of potential repository area to Mine Mountain, Cane Spring, Rock Valley, and Stagecoach Road fault zones.

	REQUIRED INFORMATION				
Area (and designated study(ies))	Verification of rupture-free area(s)	Potential locations of ground rupture	Source and magnitude of ground shaking (earth-quakes)	Potential effects of faulting on hydrology	Kinematics and nature of faulting (input to study of Tectonic Models)
Site of facilities in Midway Valley (Study 8.3.1.17.4.2: Location and recency of faulting near prospective surface facilities)	Yes	No	No	No	No
Site Area (including Midway Valley) (Study 8.3.1.17.4.6: Quaternary faulting within the site area) (Study 8.3.1.17.4.7: Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain) (Study 8.3.1.17.4.4: Quaternary faulting proximal to the site within northeast-trending fault zones)	Yes	Yes	Yes	Yes	Yes
Area within 100 km of Yucca Mountain, exclusive of Site Area (Study 8.3.1.17.4.3: Quaternary Faulting within 100 km of Yucca Mountain, including the Walker Lane belt) (Study 8.3.1.17.4.4: Quaternary faulting proximal to the site within northeast-trending fault zones) (Study 8.3.1.17.4.5: Detachment faults at or proximal to Yucca Mountain)	No	No	Yes	Yes	Yes

Figure 2-4. Information on faulting required within the Potential site of surface facilities in Midway Valley, the Site Area, and the area within 100 km of Yucca Mountain

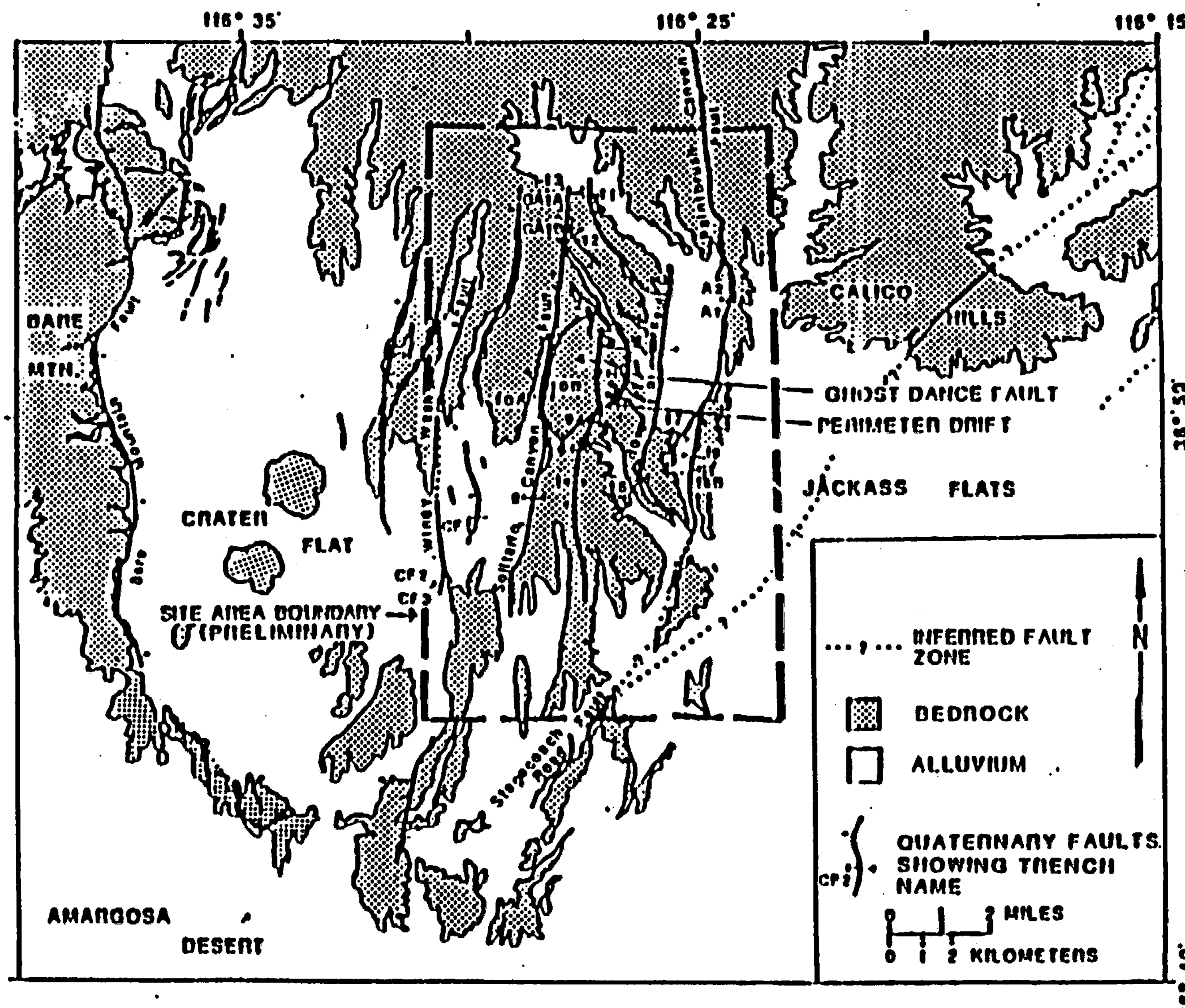


Figure 2-5 Generalized Quaternary fault map of Yucca Mountain and vicinity, showing trench locations (CF1, 1, GA1A, etc.) and site area.

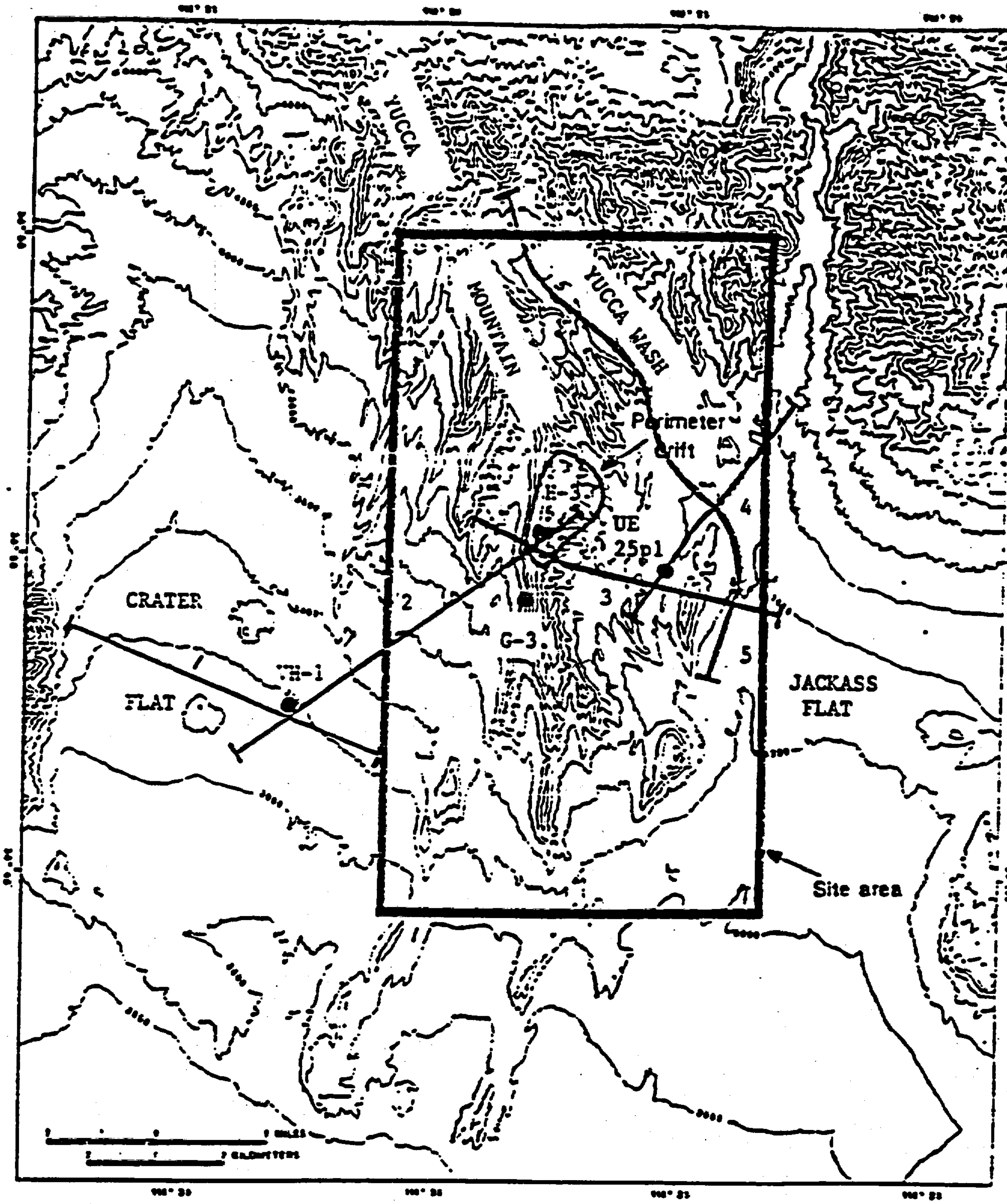
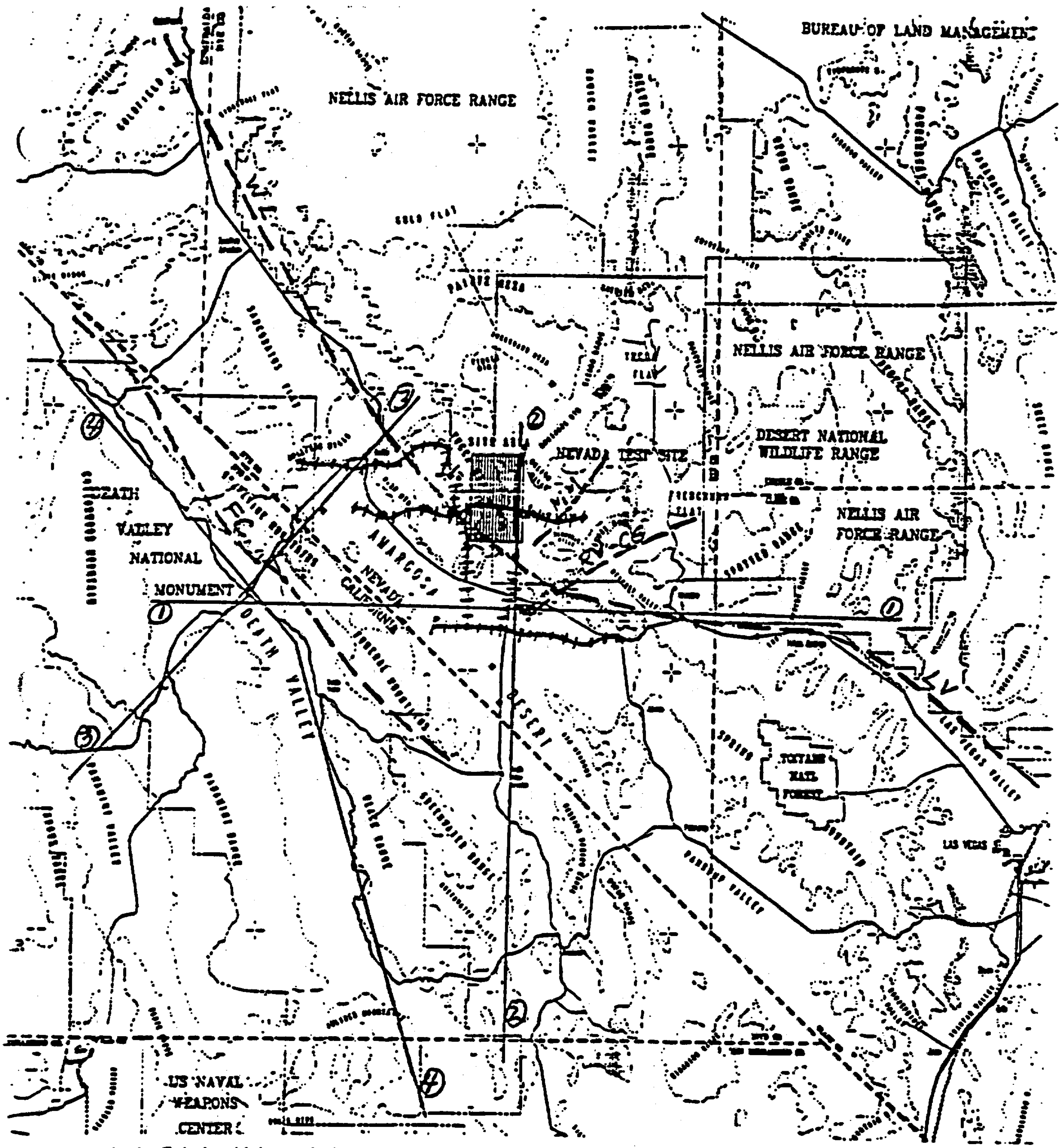


Figure 3-1. Location of seismic reflection surveys (labeled 1-5) to be conduct in Activity 8.3.1.14.2.1.2 (Surface-based geophysical surveys); the resulting data will be applied in Activity 8.3.1.17.4.3.1. Small solid circles are borehole locations (labeled with well numbers).



++++ Existing high-resolution upper-crustal seismic refraction profiles

—— Proposed seismic refraction profiles for Activity 8.3.1.17.4.3.1. Numbers refer to individual profiles described in section 2.1.2.2

— — Fault zones: WL - Walker Lane; LV - Las Vegas Valley; FC - Furnace Creek; MM - Mine Mountain; RV-CS - Rock Valley - Cane Spring.

Figure 3-2. Location of Seismic Refraction Profiles

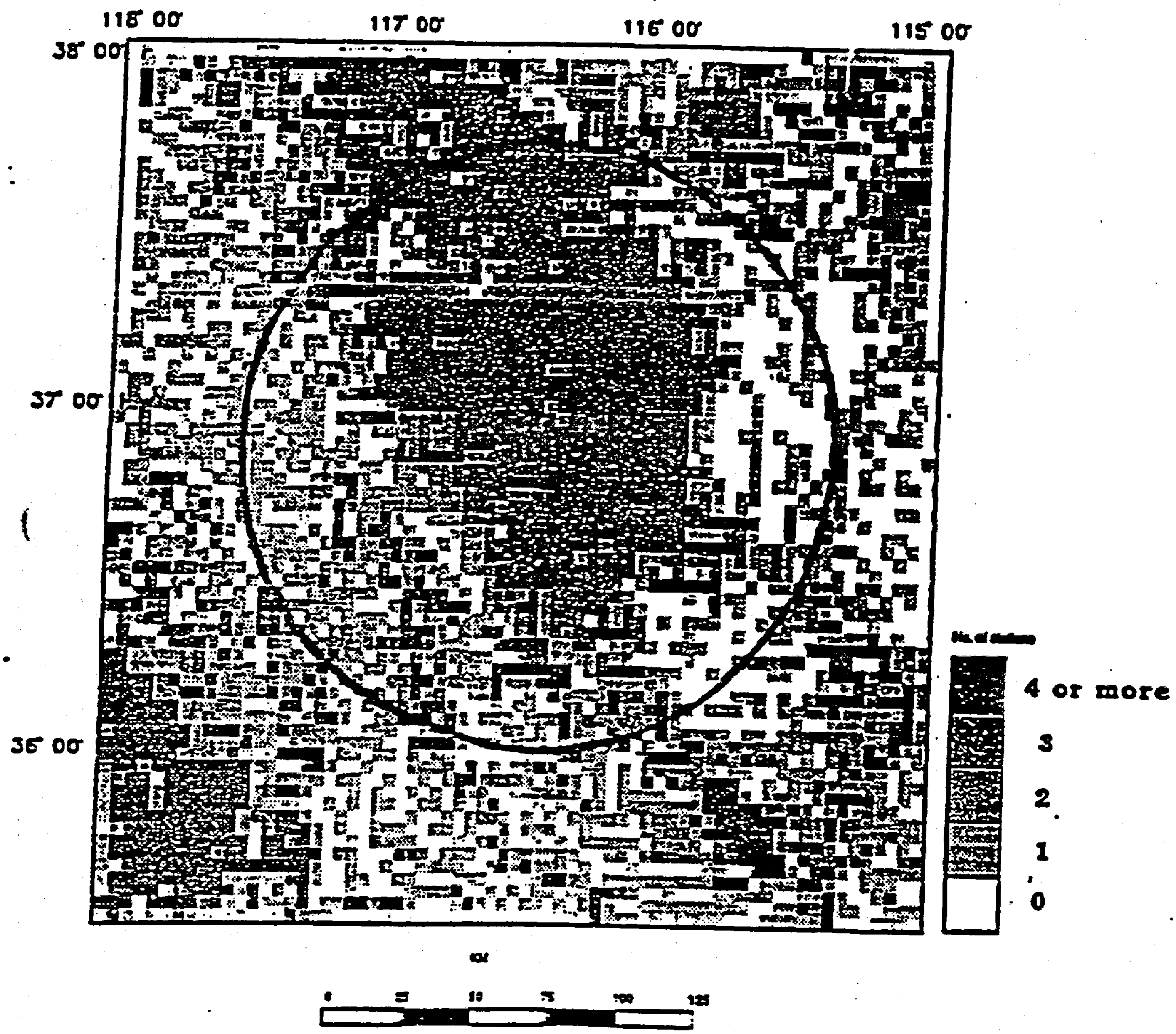


Figure 3-3 Distribution of gravity stations within 2x2 km cells. Black areas indicate regions where gravity coverage is adequate for detecting concealed faults; white areas--no stations. Circled area--area within 100 Km of potential repository site.

Figure 3-4. Aeromagnetic Index Map of Regional Study Area Showing Flight Line Spacing of Available Data. (From Oliver, et al, 1990, fig. 2.2-1)

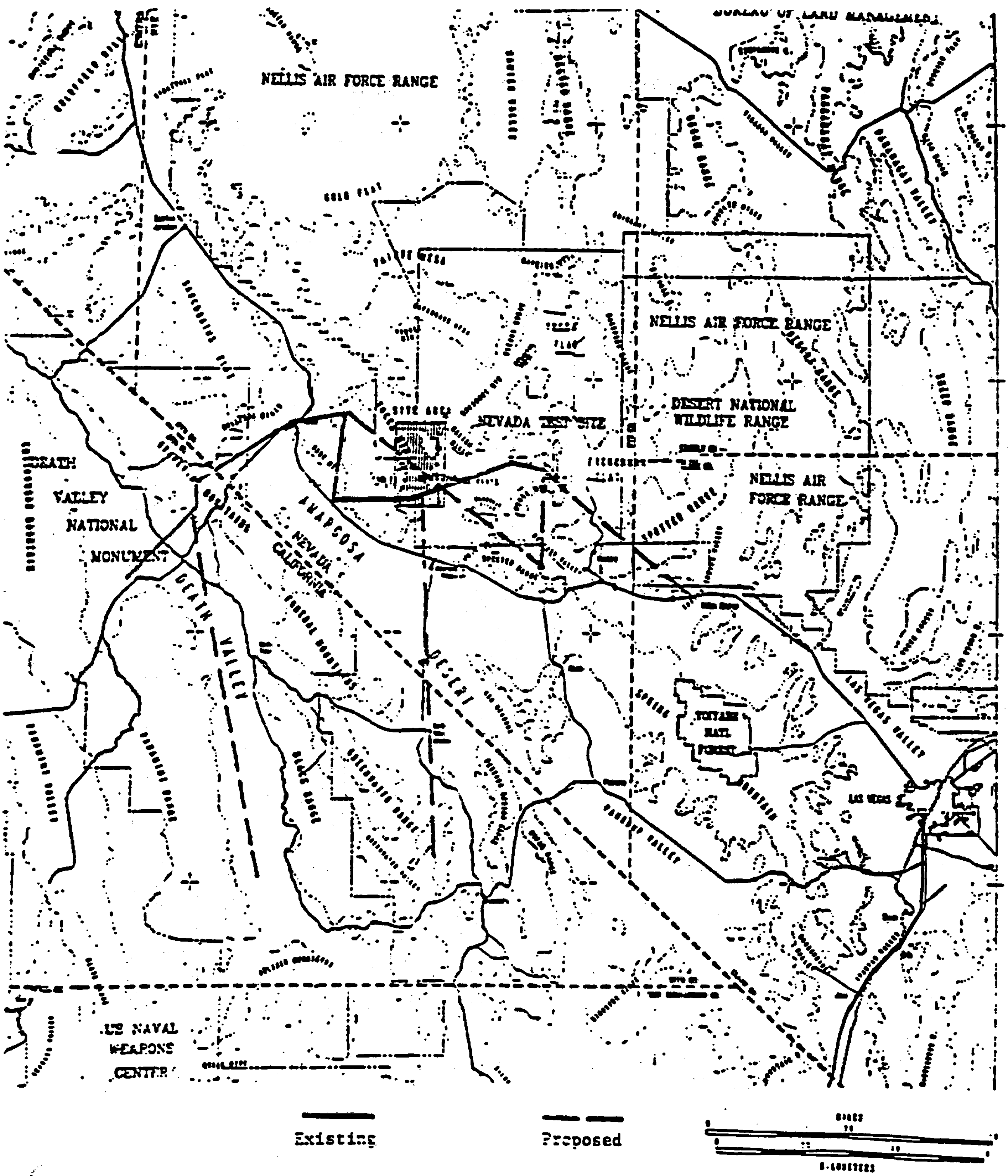


Figure 3-5. Locations of existing and proposed magnetotelluric survey traverses. (In part from Oliver, et al, 1990, fig. 2.3-1).

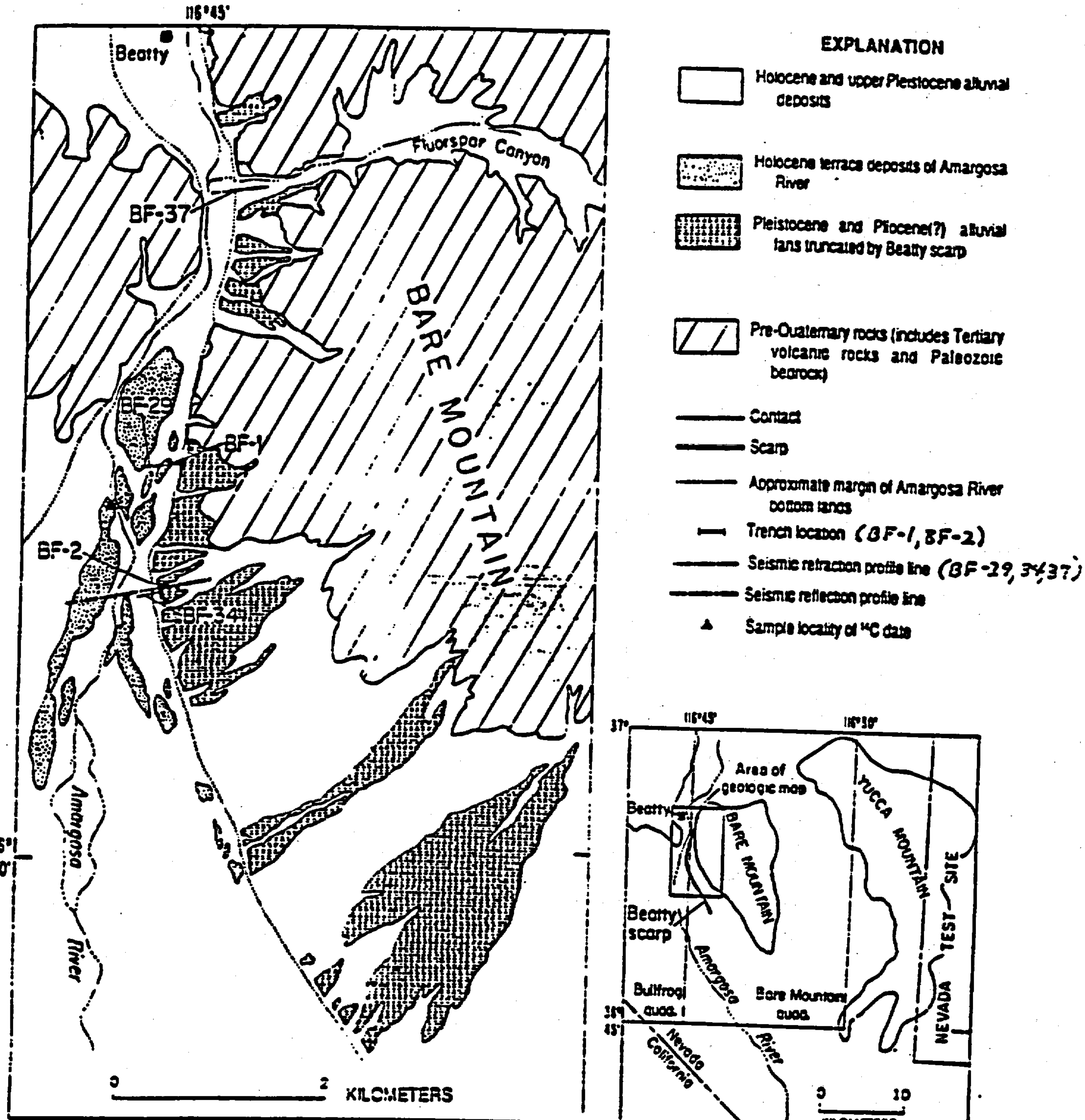


Figure 3-6. Index map and simplified geologic map of Beatty scarp area, Nevada. (From Swadley et al, 1988).

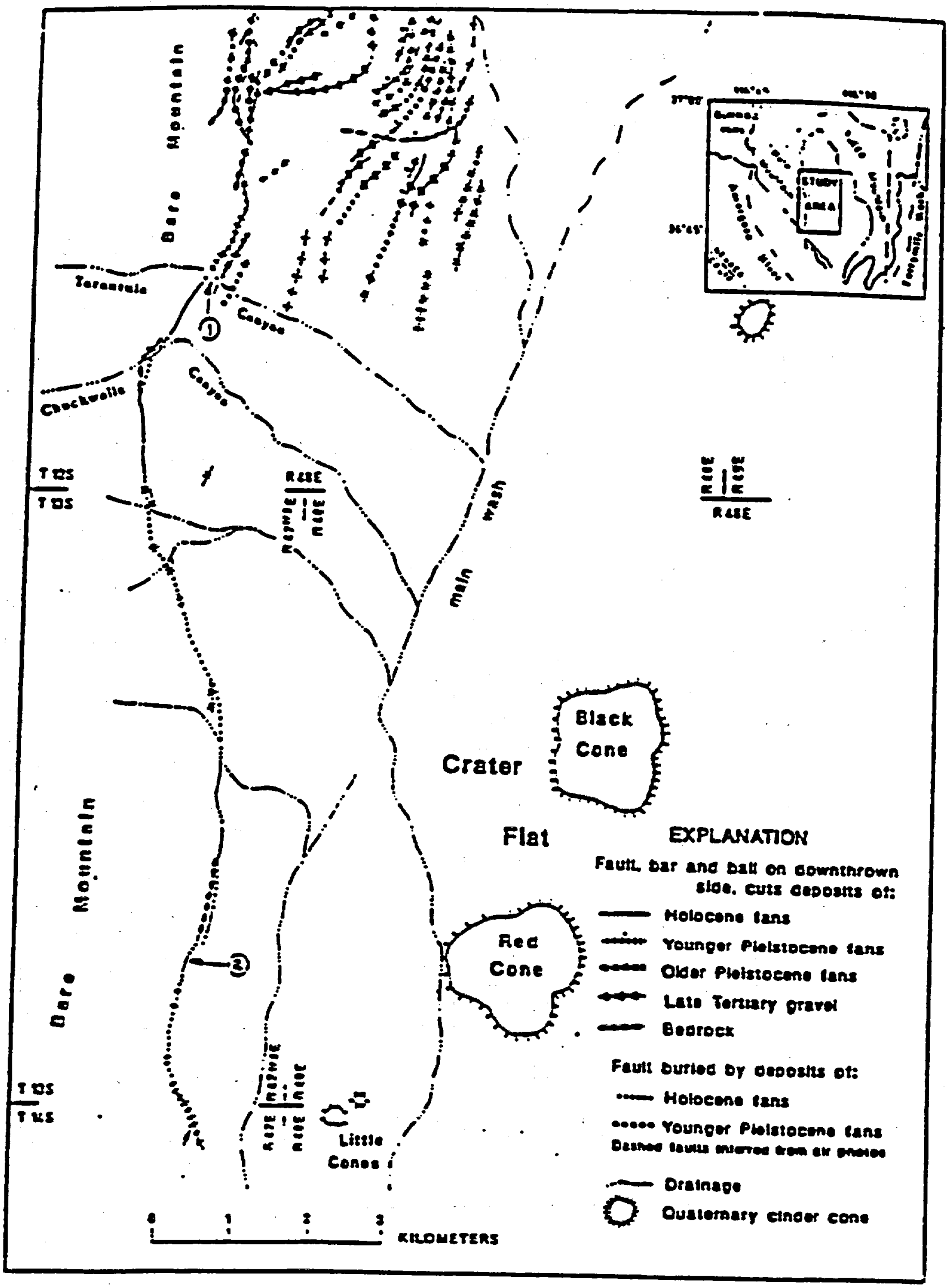


Figure 3-7 Quaternary faulting on east side of Bare Mountain. Faults with no bar and ball are down to the south and east. Circled numbers 1 and 2 refer to trench locations cited in section 3.4.1. (Map from Reheis, 1988).

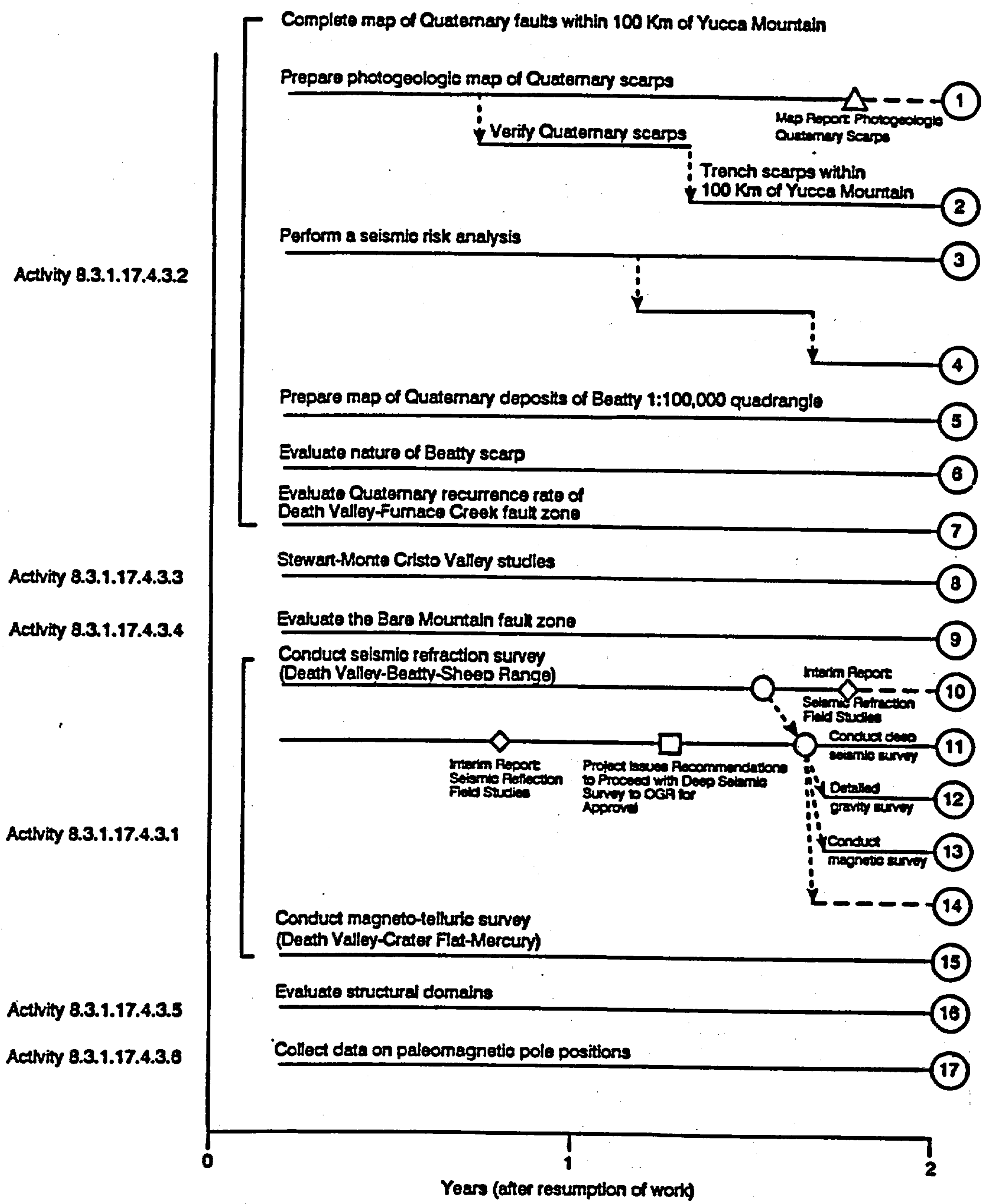


Figure 5-1. Schedule for 8.3.1.17.4.3: Quaternary faulting within 100 km of Yucca Mountain, including the Walker Lane

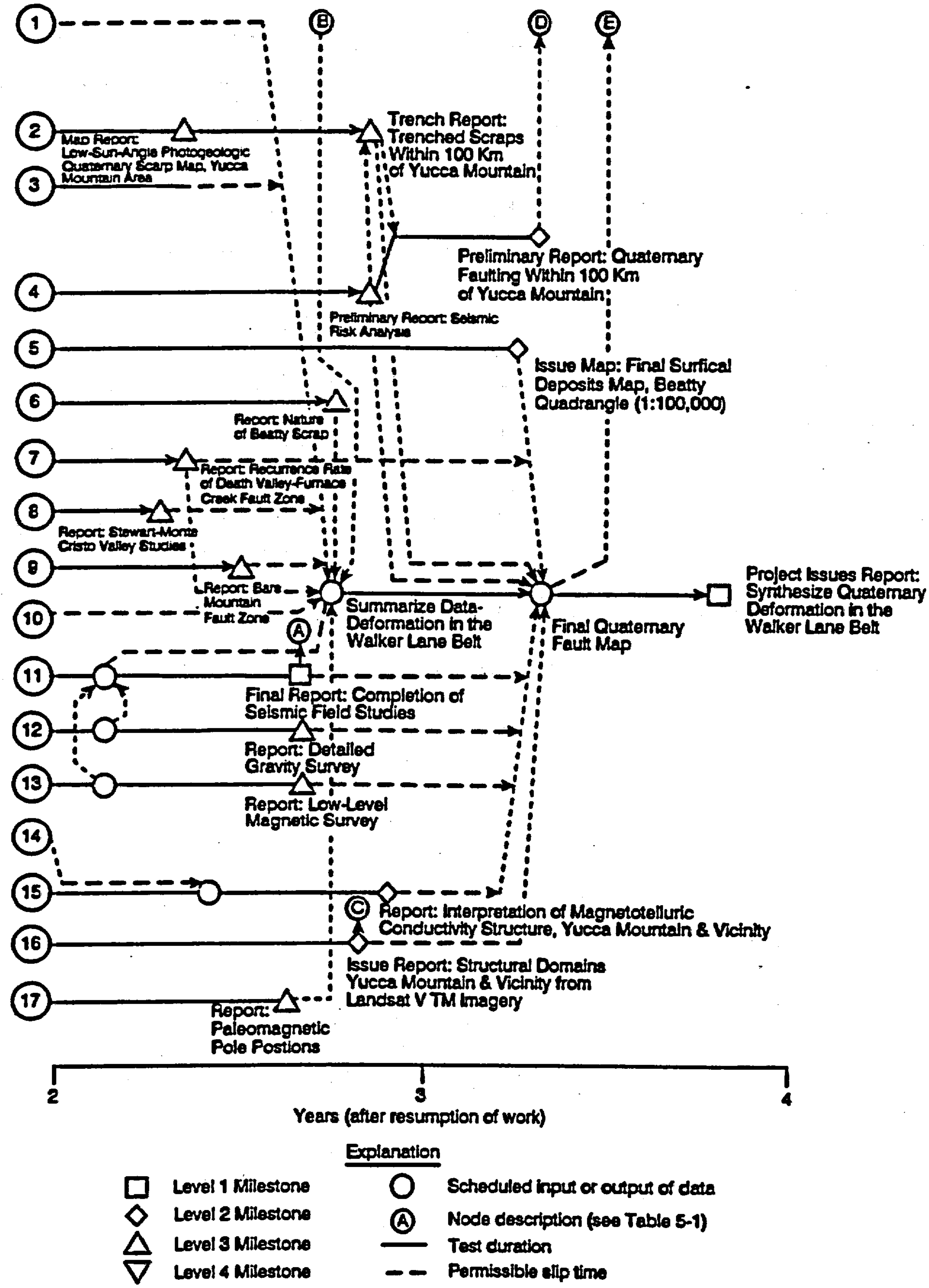


Figure 5-1. (Cont.) Schedule for 8.3.1.17.4.3: Quaternary faulting within 100 km of Yucca Mountain, including the Walker Lane

Table 3-1. Methods and technical procedures for Activity 8.3.1.17.4.3.1

Method	Technical Procedure Number	Technical Procedure Title
Seismic refraction survey	SP-08	Seismic study of the tectonic environment
Seismic reflection survey	SP-10	Seismic reflection survey
Gravity survey	GPP-01	Gravity measurement and data reduction
Low-level magnetic survey	GPP-11	Aeromagnetic and ground-based magnetic survey
Magnetotelluric survey	GPP-18	Magnetotelluric survey

Table 3-2. Methods and technical procedures for Activity 8.3.1.17.4.3.2

Method	Technical Procedure Number	Technical Procedure Title
Compile map of Quaternary faults within 100 km of the site	GP-01	Geologic mapping
Prepare photogeologic map of Quaternary scarps within 100 km of the site	TBD	Photogeologic evaluation of faults using conventional and low sun-angle aerial photographs
Perform seismic risk analysis	TBD	Seismic risk analysis
Verify scarps and lineaments in the field	GP-01	Geologic mapping
	GP-03	Stratigraphic studies
	GP-04	Structural studies
Map Quaternary geology of the Beatty 1:100,000 quadrangle	GP-01	Geologic mapping
	GP-03	Stratigraphic studies
	GP-04	Structural studies
	GP-17	Describing and sampling soils in the field
	GCP-01	Radiometric-age data bank
	GCP-02	Labeling, identification, and control of samples for geochemistry and isotope geology
	GCP-03	Uranium-series dating
	GCP-04	Uranium-trend dating

Table 3-2. Methods and technical procedures for Activity 8.3.1.17.4.3.2

Method	Technical Procedure Number	Technical Procedure Title
Compile map of Quaternary faults within 100 km of the site	GP-01	Geologic mapping
Prepare photogeologic map of Quaternary scarps within 100 km of the site	TBD	Photogeologic evaluation of faults using conventional and low sun-angle aerial photographs
Perform seismic risk analysis	TBD	Seismic risk analysis
Verify scarps and lineaments in the field	GP-01	Geologic mapping
	GP-03	Stratigraphic studies
	GP-04	Structural studies
Map Quaternary geology of the Beatty 1:100,000 quadrangle	GP-01	Geologic mapping
	GP-03	Stratigraphic studies
	GP-04	Structural studies
	GP-17	Describing and sampling soils in the field
	GCP-01	Radiometric-age data bank
	GCP-02	Labeling, identification, and control of samples for geochemistry and isotope geology
	GCP-03	Uranium-series dating
	GCP-04	Uranium-trend dating

Table 3-2. Methods and technical procedures for Activity 8.3.1.17.4.3.2 (Contd.)

Method	Technical Procedure Number	Technical Procedure Title
	TBD	Tephrochronology
	TBD	Cation ratio (desert varnish) dating
	TBD	Radiocarbon dating, conventional and tandem accelerator methods
Evaluate nature of Beatty scarp	GP-01	Geologic mapping
	GP-03	Stratigraphic studies
	GP-04	Structural studies
	GP-07	Geologic trenching studies
	GCP-01	Radiometric-age data bank
	GCP-02	Labeling, identification, and control of samples for geochemistry and isotope geology
	GCP-03	Uranium-series dating
	GCP-04	Uranium-trend dating
	TBD	Cation ratio (desert varnish) dating
	TBD	Radiocarbon dating, conventional and tandem accelerator methods
	TBD	Shallow seismic reflection and refraction surveys

Table 3-2. Methods and technical procedures for Activity 8.3.1.17.4.3.2 (Contd.)

Method	Technical Procedure Number	Technical Procedure Title
Determine Quaternary recurrence rate of the Death Valley-Furnace Creek fault zone	GP-01	Geologic mapping
	GP-02	Subsurface investigation
	GP-03	Stratigraphic studies

TBD = to be determined

Table 3-3. Methods and technical procedures for Activity 8.3.1.17.4.3.3

	Technical Procedure	
Method	Number	Title
Analysis of tectonic setting and ruptures (1932 Cedar Mountain earthquake)	GP-01	Geologic mapping
	TBD	Photogeologic evaluation of faults using vertical aerial photographs
Determination of focal mechanism, Cedar Mountain earthquake	SP-06	Determination of earthquake focal mechanism

TBD = to be determined

Table 3-4. Methods and technical procedures for Activity 8.3.1.17.4.3.4

	Technical Procedure	
Method	Number	Title
Evaluate age of Bare Mountain frontal zone faulting based on offset of Quaternary datums	GP-01	Geologic mapping
	GP-07	Geologic trenching studies
	GP-17	Describing and sampling soils in the field
	GCP-01	Radiometric-age data bank
	GCP-02	Labeling, identification, and control of samples for geochemistry and isotope geology
	GCP-03'	Uranium-series dating
	GCP-04	Uranium-trend dating
	TBD	Cation ratio (desert varnish) dating
	TBD	Thermoluminescence dating
	TBD	Radiocarbon dating, conventional and tandem accelerator methods

TBD = to be determined

Table 3-5. Methods and technical procedures for Activity 8.3.1.17.4.3.5

Method	Technical Procedure Number	Technical Procedure Title
Analysis of Landsat V thematic mapper imagers and radar (SLAR) mosaics of the Yucca Mountain region	TBD	Analysis of linear features
	TBD	Analysis of hydrothermal alteration
	TBD	Analysis of desert varnish coating

TBD = to be determined

Table 3-6. Methods and technical procedures for Activity 8.3.1.17.4.3.6

	Technical Procedure	
Method	Number	Title
Analysis of vertical-axis rotation of bedrock alongside or over suspected wrench faults based on rotation of paleomagnetic declinations	GPP-06	Rock and paleomagnetic investigations
	TBD	Hand-held drilling and oriented-core sampling for paleomagnetic studies

TBD = to be determined

Table 3-7. Ranges of values for paleomagnetic measurements

Susceptibility - 0.00001 to 0.04 (SI)
Natural remanent magnetization - 0.01 to 30 Amperes/meter (A/m)
Saturation isothermal remanent magnetization - 0.1 to 100 A/m
Saturation magnetization - 0.1 to 1000 A/m
Coercivity - 10 to 150 millitesla (mT)
Curie temperature - 500° to 640° C

Table 4-1 Information to be provided to other studies by Study 8.3.1.17.4.3

Information to be obtained	Where information will be used[1]	How information will be used
(Activity 8.3.1.17.4.3.1)		
Geophysical data on near- and far-field attributes of the lithosphere including gravity, magnetic, electromagnetic and elastic properties	8.3.1.8.1.1	To provide data for analysis to determine if buried magma bodies are present in the vicinity of Yucca Mountain and to evaluate the structural controls of volcanic activity.
Subsurface location, orientation, length, width, segmentation, and possible interconnections of known and suspected Quaternary faults within 100 km of the site.	8.3.1.17.4.5 8.3.1.17.4.6.2 8.3.1.17.4.12.1	To be incorporated with information from other gravity gravity studies to define regional variations in mass, and attribute them, as appropriate, to variations in crustal thickness, degree of melting, shallow intrusions, distribution of specific stratigraphic units, and faults.
		To be incorporated with information from other magnetic studies to define areal variations in the magnetic field; to relate variations in magnetic field to the distribution of specific stratigraphic units, shallow intrusions, and subsurface configurations of faults.
		To help identify and locate potentially significant seismic source zones, including possible through-going extensions of the Walker Lane belt, beneath the Oligocene-Miocene cover of the Yucca Mountain area; to determine the width and subsurface geometry of such extensions and of the Furnace Creek fault zone and the relation of these features to detachment faults and to Quaternary faults; and to evaluate the postulated incipient rift zone at Crater Flat.

Table 4-1 Information to be provided to other studies by Study 8.3.1.17.4.3 (Contd)

Information to be obtained	Where information will be used[1]	How information will be used
		To characterize the conductivity structure of the crust in the Yucca Mountain region, focusing in particular on the conductivity signature of the Walker Lane and if possible, tracing the signature into the subsurface of conductive units such as the Eleana Formation or nonconductive units such as the lineated and mylonitized gneisses (lower plate?) of the northern Amargosa Desert, and to correlate these features or their offsets with Quaternary faults.
(Activity 8.3.1.17.4.3.2)		
Surface location, distribution, geometry, patterns, displacement rate, age, and nature of Quaternary faults within 100 km of Yucca Mountain.	8.3.1.17.4.12.1 8.3.1.17.4.12.2	To characterize the quaternary and Holocene fault and fracture pattern within 100 km of the site and, if feasible, to relate that pattern to regionally important wrench fault systems, including the Walker Lane, the Death Valley-Furnace Creek fault zone, and the Mine Mountain-Pahranagat shear zone.
Identification and characterization of faults whose length or recurrence rate indicate potential for earthquakes of magnitude sufficient to affect design or performance of the waste facility.		
Geologic map(s) of Quaternary faults within 100 km of the site (includes definition of the source regions of major earthquakes that have produced surface faulting during the late Quaternary time).		To synthesize and evaluate information pertaining to Quaternary wrench faulting in the Walker Lane (Las Vegas to Cedar Mountain), constrain, if possible, the rate of offset and recurrence interval of potentially significant faults (including the Bare Mountain fault and faults analogous to those near Cedar Mountain), and evaluate the applicability of this information to geologic hazards at the site.

Table 4-1 Information to be provided to other studies by Study 8.3.1.17.4.3 (Contd)

Information to be obtained	Where information will be used[1]	How information will be used
Rotation of upper-plate rock in Yucca Mountain region as defined by deflections of paleomagnetic pole declinations.		To ascertain the amount of post-middle Miocene vertical axis rotation of bedrock alongside wrench faults and of bedrock suspected to be part of upper plate above subsurface wrench faults.
	8.3.1.17.2.1 8.3.1.17.3.1 8.3.1.17.3.5 8.3.1.17.3.6	To be incorporated with information from other studies to predict the likely locations, timing, and magnitudes of future faulting and earthquake events that could impact the design or performance of the waste facility.
	8.3.1.8.2.1.2	To be integrated with information from other activities to calculate the number of waste packages that a fault penetrating the repository would intersect.
	8.3.1.8.2.1.3 8.3.1.8.3.3.2	To be integrated with information from other activities to summarize and evaluate data on slip rates and recurrence intervals on faults in and near the controlled area.
	8.3.1.8.3.1.3 8.3.1.8.3.3.2	To be integrated with information from other studies to estimate slip rates, recurrence intervals, and possible cumulative offset in 10,000 years on Quaternary faults in and near the controlled area.
	8.3.1.8.3.2.3 8.3.1.8.3.3.3	To be integrated with information from other studies to estimate magnitude and location of strain associated with possible future faulting events.

Table 4-1 Information to be provided to other studies by Study 8.3.1.17.4.3 (Contd)

Information to be obtained	Where information will be used[1]	How information will be used
(Activity 8.3.1.17.4.3.3)		
Geologic structure, stratigraphy, and tectonic setting of Stewart and Monte Cristo Valleys including width, length, nature of offset, and recurrence history of typical ruptures of the 1932 Cedar Mountain earthquake.	8.3.1.17.4.12.1	To provide information pertaining to Quaternary wrench faulting in the Walker Lane (Las Vegas to Cedar Mountain), constrain, if possible, the rate of offset and recurrence interval of potentially significant faults (including the Bare Mountain fault and faults analogous to those near Cedar Mountain), and evaluate the applicability of this information to geologic hazards at the site.
Relation of Stewart and Monte Cristo Valley faults with respect to potential sources of ground motion and rupture in that part of the Walker Lane within 100 km of Yucca Mountain.		
Focal mechanism of the 1932 Cedar Mountain earthquake.		
(Activity 8.3.1.17.4.3.4)		
Characterization of Bare Mountain frontal fault zone including age of horizons, amount and direction of offset of horizons, subsurface configuration of fault zone, and recurrence intervals of faulting.	8.3.1.17.4.12.1	To provide information pertaining to Quaternary wrench faulting in the Walker Lane (Las Vegas to Cedar Mountain), constrain, if possible, the rate of offset and recurrence interval of potentially significant faults (including the Bare Mountain fault and faults analogous to those near Cedar Mountain), and evaluate

Table 4-1 Information to be provided to other studies by Study 8.3.1.17.4.3 (Contd)

Information to be obtained	Where information will be used[1]	How information will be used
Nature and age of faulting within the fault complex east of the frontal zone, and to determine nature of tectonic control of the location and orientation of the main wash in Crater Flat.		the applicability of this information to geologic hazards at the site.
(Activity 8.3.1.17.4.3.5)		
Map of faults and lineaments within a 100 km radius of the site and identification of those with geomorphic expression indicative of Quaternary faulting.	8.3.1.17.4.12.1	To be integrated with information from other activities to help establish the abundance, distribution, and geographic orientation of known and suspected Quaternary faults within the Las Vegas to Cedar Mountain portion of the Walker Lane; to establish the accuracy limits of the number and age of faults depicted by the photogeologic scarp map of the Walker Lane; to identify fault scarps that may have been overlooked during conventional geologic field surveys and that may not have been apparent on conventional vertical aerial photography.
Domains containing distinctive patterns of fractures and lineament populations (prominent geomorphic expression, density, and orientation) suggestive of Quaternary faulting.	8.3.1.17.2.1.2	To help assess the faulting potential in areas of emplaced waste.
Age and areal extent of desert varnish	8.3.1.17.4.9.1	To help establish the areal extent of tectonically stable areas proximal to Yucca Mountain.

Table 4-1 Information to be provided to other studies by Study 8.3.1.17.4.3 (Contd)

Information to be obtained	Where information will be used[1]	How information will be used
Areas of suspected hydrothermal alteration.	8.3.1.9.2.1	To evaluate the relationship of suspected hydrothermal alteration to potential mineralization.
	8.3.1.5.2.1.5	To aid in evaluating the possible origin of calcite-silica deposits.
	8.3.1.8.5.2	To aid in evaluating local heat flow anomalies.
(Activity 8.3.1.17.4.3.6)		
Rotation of upper-plate rock in Yucca Mountain region as defined by deflections of paleo-magnetic pole declinations.	8.3.1.17.4.12.1	To ascertain the amount of post-middle Miocene vertical axis rotation of bedrock alongside wrench faults and of bedrock suspected to be part of upper plate above subsurface wrench faults.

Table 4-1 Information to be provided to other studies by Study 8.3.1.17.4.3 (Contd)

[1] Studies or activities in which information will be used:

Activity 8.3.1.5.2.1.5:	Studies of calcite and opaline silica vein deposits.
Study 8.3.1.8.1.1:	Probability of magmatic disruption of the repository.
Activity 8.3.1.8.2.1.2:	Calculation of the number of waste packages intersected by a fault.
Activity 8.3.1.8.2.1.3:	Probability and rate of faulting.
Activity 8.3.1.8.3.1.3:	Faulting rates, recurrence intervals, and probable cumulative offset in 10,000 years.
Study 8.3.1.8.3.2:	Effect of tectonic processes and events on changes in water table elevation.
Activity 8.3.18.3.2.3:	Assessment of the effect of strain changes on water table elevation.
Activity 8.3.1.8.3.2.5:	Effects of faulting on water table elevation.
Activity 8.3.1.8.3.2.6:	Assessment of the effects of faulting on water table elevation.
Activity 8.3.1.8.3.3.2:	Assessment of the effects of faulting on local fracture permeability and effective porosities.
Activity 8.3.1.8.3.3.3:	Assessment of the effects of stress or strain on hydrologic properties of the rock mass.
Study 8.3.1.8.5.2:	Characterization of igneous intrusive features.
Study 8.3.1.9.2.1:	Natural resource assessment of Yucca Mountain, Nye County, Nevada.
Study 8.3.1.17.2.1:	Faulting potential at the repository.
Activity 8.3.1.17.2.1.2:	Assess the potential for displacement on faults that intersect underground facilities.
Study 8.3.1.17.3.1:	Relevant earthquake sources.
Study 8.3.1.17.3.5:	Ground motion at the site from controlling seismic events.
Study 8.3.1.17.3.6:	Probabilistic seismic hazard analysis.
Study 8.3.1.17.4.5:	Detachment faults at or proximal to Yucca Mountain.
Activity 8.3.1.17.4.6.2:	Evaluate age and recurrence of movement on suspected and known Quaternary faults.
Activity 8.3.1.17.4.9.1:	Evaluate age and extent of tectonically stable areas at and near Yucca Mountain.
Activity 8.3.1.17.4.12.1:	Evaluate tectonic processes and tectonic stability at the site.
Activity 8.3.1.17.4.12.2:	Evaluate tectonic models.

Table 5-1. Schedule information for Study 8.3.1.17.4.3

A. OUTPUT--

to Study 8.3.1.8.1.1: Probability of magmatic disruption of the repository

to Study 8.3.1.17.3.1: Relevant earthquake sources

to Study 8.3.1.17.4.5: Detachment faults at or proximal to Yucca Mountain

to Activity 8.3.1.17.4.6.2: Evaluate age and recurrence of movement on suspected and known Quaternary faults

to Activity 8.3.1.17.4.12.1: Evaluate tectonic processes and tectonic stability at the site

B. INPUT--

from Study 8.3.1.17.4.4:

from Study 8.3.1.17.4.5:

from Activity 8.3.1.17.4.9.1: Evaluate age and extent of tectonically stable areas near Yucca Mountain (includes regional geomorphic map and report on age and extent of tectonically stable areas at and near Yucca Mountain)

from Activity 8.3.1.17.4.12.1: Evaluate tectonic processes and tectonic stability at the site (includes Beatty 1:100,000 fault map)

C. OUTPUT--

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

to Study 8.3.1.8.5.2: Characterization of igneous intrusive features

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

to Activity 8.3.1.17.2.1.2: Assess the potential for displacement on faults that intersect underground facility

to Activity 8.3.1.17.4.9.1: Evaluate age and extent of tectonically stable areas at and near Yucca Mountain

Study 8.3.1.17.4.3: Quaternary faulting within 100 km of Yucca Mountain, including the Walker Lane

to Activity 8.3.1.17.4.12.1: Evaluate tectonic processes and tectonic stability at the site

to Activity 8.3.1.17.4.12.2: Evaluate tectonic models (includes project report on preliminary regional tectonic model)

Table 5-1. Schedule information for Study 8.3.1.17.4.3 (contd)

D. OUTPUT--

to Study 8.3.1.17.4.6: Quaternary faulting within the site area (includes report on synthesis of Quaternary north-trending faults, Yucca Mountain)

to Site Assessment Report

E. OUTPUT--

to Activity 8.3.1.8.2.1.2: Calculation of the number of waste packages intersected by a fault

to Activity 8.3.1.8.2.1.3: Probability and rate of faulting

to Activity 8.3.1.8.3.1.3: Faulting rates, recurrence intervals and probable cumulative offset in 10,000 years

to Activity 8.3.1.8.3.2.3: Assessment of the effects of faulting on water table elevation

to Activity 8.3.1.8.3.3.2: Assessment of the affects of stress or strain on hydrologic properties of the rock mass

to Activity 8.3.1.8.3.3.3: Assessment of the effects of stress or strain on hydrologic properties of the rock mass

to Study 8.3.1.17.2.1: Faulting potential at the repository

to Study 8.3.1.17.3.1: Relevant earthquake sources

to Study 8.3.1.17.3.5: Ground motion at the site from controlling seismic events

to Study 8.3.1.17.3.6: Probabilistic seismic hazard analysis

to Study 8.3.1.17.4.6: Quaternary faulting within the site area (includes report on synthesis of Quaternary north-trending faults, Yucca Mountain)

to Activity 8.3.1.17.4.12.1: Evaluate tectonic processes and tectonic stability at the site