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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
STUDY PLAN APPROVAL FORM

Study Plan Number 8.3.1.17.4.5

Study Plan Title Detachment Faults at or Proximal to Yucca Mountain

Revision Number 1

Prepared by: U. S. Geological Survey

Date: 04/12/94

Approved:

[signature] 10/28/94
Assistant Manager for Scientific Programs / Date

[signature] for 10/26/94
Director, Quality Assurance Division / Date

Effective Date: 11/21/94

PREFACE

This study plan summarizes and extends the discussion of Study 8.3.1.17.4.5 in the statutory SCP. Sections 1, 4 and 5 are drawn from the SCP and from related Yucca Mountain Project documents; those sections show the study in the context of the SCP. Sections 2 and 3 discuss the basis for the planned tests and the plans themselves, generally in detail beyond that in the SCP.

This study plan was prepared by Kenneth F. Fox, Jr., Michael D. Carr, and Ralph R. Shroba. Frances R. Singer, W. R. Keefer and David Schleicher shared in the preparation and review of the plan.

ABSTRACT

Study 8.3.1.17.4.5 will gather information on detachment faulting at or proximal to Yucca Mountain. To do so, three activities are planned that will prepare geologic maps of areas known or hypothesized to expose detachment faults. A fourth activity will evaluate the origin of distinctive breccia masses proximal to Yucca Mountain, which appear to have formed as a consequence of tectonic activity and may have formed in conjunction with detachment faulting. A fifth activity will generate isotopic dates of geologic materials that are cut by or that overlap detachment faults, or otherwise are affected by the processes associated with detachment faulting such that the dates will constrain the age of faulting. Information from this study and from related studies will be integrated to characterize the location, nature, and displacement rate of any detachment fault that might constitute or conceal a relevant earthquake source in the vicinity of Yucca Mountain.

The information from this study is needed to improve confidence levels in fault parameters used to predict repository performance. The information will be used in the preclosure tectonics program to assess the likelihood of seismic shaking that could affect the design or performance of a repository. It also will be used to reduce the uncertainties associated with certain conceptual models important to the postclosure tectonics program.

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FIGURES

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STUDY 8.3.1.17.4.5: DETACHMENT FAULTING AT OR PROXIMAL TO YUCCA MOUNTAIN

This study consists of five activities:

- 8.3.1.17.4.5.1: Evaluate the significance of the Miocene-Paleozoic contact in the Calico Hills area to detachment faulting within the site area
- 8.3.1.17.4.5.2: Evaluate postulated detachment faults in the Beatty-Bare Mountain area
- 8.3.1.17.4.5.3: Evaluate the potential relationship of breccia within and south of Crater Flat to detachment faulting
- 8.3.1.17.4.5.4: Evaluate postulated detachment faults in the Specter Range and Camp Desert Rock areas
- 8.3.1.17.4.5.5: Evaluate the age of detachment faults using radiometric ages

This study is part of the preclosure tectonics program (fig. 1-1); it is one of a series of related studies that gathers and synthesizes information that is needed to assess vibratory ground motions and faults displacements in the region surrounding Yucca Mountain (figs. 1-2 and 1-3).

As used herein, the term "detachment fault" refers to large-displacement faults with shallow dip (less than 45 degrees, commonly less than 10 degrees) which displace rocks within the hanging wall down relative to rocks within the footwall, thus attenuating the upper crustal section. This may be shown by juxtaposition of crystalline basement rocks against sedimentary rocks, by omission of large portions of the stratigraphic sequence, or by the presence of faulted ductile deformation structures. Thrust faults, which also dip gently, displace rocks within the hanging wall up relative to those within the footwall, and thus thicken the upper crustal section. Older geologic maps of areas within the Yucca Mountain region commonly do not distinguish these two types of faults, and instead refer to them collectively as thrust faults. This is troublesome, because although both types are common, the actual thrust faults are relatively ancient structures that formed during a period of compressional tectonism that ended many tens of millions of years ago, whereas the detachment faults are young structures formed through extensional tectonism during and since the middle Tertiary. The dispute centers on whether the faults dip steeply or gently when active, and resolution of this problem bears on Yucca Mountain tectonics. If present at depth, detachment faults could control the location, slip rate, and slip direction of the numerous high angle normal faults active in the Quaternary that intersect the surface of Yucca Mountain.

Study 8.3.1.17.4.5: Detachment faulting at or proximal to Yucca Mountain

The role of detachment faulting in Basin-Range extensional tectonism, and evidence pointing to the presence of detachment faults at depth in the area of Yucca Mountain, is presented in the SCP (Chapter 1, section 1.3.2.2.1, page 1-102 through 1-110). Alternative models invoking detachment faulting are also listed in the SCP (Chapter 8, Table 8.3.1.17-7, pages 8.3.1.17-40 through -47). Additional discussion of detachment faults at and near Yucca Mountain, including supporting maps, diagrams, and cross-sections, has been published since preparation of Chapter 1 of the SCP. For example, Hamilton (1988) described detachment faulting in the Death Valley region, and postulated that high-angle faults at Yucca Mountain formed the headwall of the regionally extensive Funeral Mountains-Bullfrog Mountains-Bare Mountain detachment system. In his view, the locus of rapid crustal extension moved gradually westward from its middle Miocene position at the Nevada Test Site to its current position at and west of Death Valley.

Maldonado (1990b) described evidence for two superposed detachment faults in the Bullfrog Hills area. Middle plate rocks are unmetamorphosed, brecciated, highly attenuated Paleozoic rocks; upper plate rocks are much-faulted Tertiary strata extended in excess of 100 percent. Spengler and Fox (1990) described the geometry of high-angle faults and associated closely spaced conjugate faults and reverse-drag flexures at Yucca Mountain, and suggested that the major faults are listric to a detachment fault at depth. Young and Stirewalt (1990) constructed balanced cross sections through Yucca Mountain, using data from Scott and Bonk (1984), and proposed that a detachment fault underlies the Mountain at a depth of less than 4 km. Fox and others (in press) integrated Quaternary slip rates of high-angle faults at Yucca Mountain, and assuming they are listric to a detachment at the Tertiary-Paleozoic contact, estimated a minimum slip rate for the detachment. Fox and others (in press) also discussed the potential role of detachment faulting on the hydrology of Yucca Mountain. Myers and others (in press) present a map and cross section of the detachment fault forming the Tertiary-Paleozoic contact in the Camp Desert Rock area, and suggest that the Tertiary-Paleozoic contact below Yucca Mountain is an analogous detachment fault. Scott (1990) provided a comprehensive summary of evidence bearing on the presence of detachment faults at Yucca Mountain, and inferred that the high-angle faults must connect with a detachment fault or faults, or zone of accommodation, at a maximum depth of 4 km on the north, shallowing possibly to 1 km to the south. All of these studies assumed that the faults dipped gently when active.

The strategy employed by the Yucca Mountain Project to characterize detachment faults is discussed in the SCP (Chapter 8, pages 8.3.1.17-144 and -145). That strategy, as reformulated here, contains seven elements: 1) mapping and study of the detachment faults where they intersect the surface (crop out) in areas peripheral to Yucca Mountain; 2) tracing of the detachment faults in the subsurface toward and below Yucca Mountain using geophysical methods; 3) definition of the extent of shallow detachment faults in the subsurface through drilling; and mapping and characterization of deformational features at Yucca Mountain that potentially formed in conjunction with and perhaps as a consequence of detachment faulting; 4) estimation of slip rates, direction of displacement, and age of detachment faults through study of Quaternary high-angle faults at Yucca Mountain that potentially merge with and transfer movement to the subjacent detachment faults; 5) evaluation of the possibility that the upper plate of detachment faults at Yucca Mountain conceals significant seismic sources in the lower plate, through detection of major Quaternary high-angle strike-slip faults projecting toward Yucca Mountain; 6) evaluation of evidence bearing on the dips of recognized detachment faults when active, and of the geometry of their subsequent deformation through time; and 7) synthesis and integration of data gathered pertaining to the five elements listed above. Each of these elements is discussed further below.

1) Mapping and study of detachment faults at the surface. Detachment faults have as yet not been identified in outcrop at Yucca Mountain itself. Postulated outcrops of detachment faults do occur in several areas proximal to Yucca Mountain. These include the Calico Hills area (Simonds and Scott, 1987), 11 km to the east of Yucca Mountain; the Specter Range-Camp Desert Rock area (e.g., Myers, 1987; Myers and others, in press), centered 45 km to the east-southeast of Yucca Mountain; and the Beatty-Bare Mountain area (Maldonado, 1990; Monson and others, 1990), centered 27 km to the west of Yucca Mountain. At each of these areas, the proposed subsurface continuation of the outcropping detachment fault(s) projects toward Yucca Mountain. Gathering of field data pertaining to this element is the responsibility of this Study (8.3.1.17.4.5, Detachment Faulting at or proximal to Yucca Mountain).

2) Tracing of detachment faults in the subsurface using geophysical methods. Preliminary mapping of postulated detachment faults at the surface in the three areas noted above indicates that the postulated detachment faults form the contact between low density, low seismic velocity late Tertiary strata above, and high density, high seismic velocity Paleozoic strata below. Thus it is likely that this contact can be detected in the subsurface using geophysical methods provided that velocity and density contrasts are laterally persistent. However, certain limitations must be considered. Geophysical methods cannot determine whether the contact is or is not a detachment fault, nor can they determine its age, slip rate, direction of displacement, or precise location. If the velocity contrast disappears, or evidence for detachment faults is found wholly within the Paleozoic sequence or wholly within Tertiary rocks, then the geophysical responses will need to be calibrated by drilling. Gathering of geophysical data pertinent to the location of the Tertiary-Paleozoic contact below Yucca Mountain is a collateral responsibility of Study 8.3.1.17.4.7 (Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain), and below areas proximal to Yucca Mountain, of Study 8.3.1.17.4.3 (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).

3) Definition of detachment faults and calibration of geophysics through drilling, and mapping and characterization of deformational features at Yucca Mountain that potentially formed in conjunction with and perhaps as a consequence of detachment faulting. Penetration of detachment faults by drilling can contribute precise information as to their location, and also data bearing on the identity and properties of rocks above and below the detachment. The Paleozoic-Tertiary contact below Yucca Mountain was penetrated but not cored by drill hole UE25p#1. The contact was inferred to be a steep fault, (Carr and others, 1986), although no direct evidence of its dip was obtained. No other drill hole has reached depths great enough to intersect this contact, although others are planned.

The presence of detachment faults and their likely depth and geometry can be inferred through analysis of balanced cross sections. For example, balanced cross sections prepared using data from the detailed map of Scott and Bonk (1984) were used to imply the presence of a detachment fault at a depth of less than 4 km below the surface of Yucca Mountain (Young and Stirewalt, 1990). The validity of this type of analysis is a function of the detail and accuracy of the geologic data base.

Gathering and interpreting of drill-hole data bearing on the location of possible detachment faults below Yucca Mountain, and data required to prepare balanced cross sections, is a collateral responsibility of Study 8.3.1.4.2.2 (Characterization of the structural features within the Site Area).

4) Estimation of slip rates, direction of displacement, and age of detachment faults through study of Quaternary steep faults at Yucca Mountain that might merge with and transfer movement to the subjacent detachment faults. The steep faults (e.g., Windy Wash, Solitario, Ghost Dance, Bow Ridge, Paintbrush Canyon, and Stagecoach Road faults) may flatten to gentle westward dips and merge with a subjacent detachment fault(s). If so, movement on the steep faults is transferred to the detachment. It follows that movement on the detachment fault(s) can be estimated through integration of measured slip on the exposed high-angle faults. Gathering of this data is the responsibility of Study 8.3.1.17.4.6 (Quaternary faulting within the site area), Study 8.3.1.17.4.2 (Location and recency of faulting near prospective surface facilities), and Study 8.3.1.17.4.4 (Quaternary faulting proximal to the site within northeast-trending fault zones).

5) Evaluation of the possibility that the upper plate of detachment faults at Yucca Mountain conceals significant seismic sources in the lower plate, through detection of major Quaternary high-angle strike-slip faults projecting toward Yucca Mountain. Major strike-slip faults of the Walker Lane or the Stewart Valley-Pahrump-State Line fault zone are not exposed at the surface of Yucca Mountain, or the adjoining Jackass Flats, or Crater Flat. Nevertheless, subsurface extensions of these faults could conceivably be concealed in the lower plate, below detachment faults decoupling the Tertiary cover from the basement rocks at Yucca Mountain. This possibility is discussed in the SCP (Chapter 1, p. 1-112; Chapter

8, p. 8.3.1.17-101). Identification and dating of major strike-slip faults projecting toward Yucca Mountain is chiefly the responsibility of Study 8.3.1.17.4.3 (Quaternary faulting within 100 km of Yucca Mountain, including the Walker Lane).

6) Evaluation of evidence bearing on the dips of postulated detachment faults near Yucca Mountain when active, and of the geometry of their subsequent deformation through time. With regard to fault dips, there are two alternate views: (a) the faults have gentle dips when active, and only moderate footwall deformation is needed to bring them to the surface; and (b) the faults dip steeply through the upper crust when active and extensive footwall deformation is required to expose them at the surface. The good exposures in the Bare Mountain-Bullfrog area provide an excellent opportunity to study the true fault relationships.

7) Synthesis and integration. Considered independently, each of the elements listed above illuminates a particular aspect of detachment faulting. However, formulation of viable alternative models that address the location, geometry, age, slip rate, and interlinkage of detachment faults requires integration and rationalization of this entire data set. Other data that could be relevant (e.g., in-situ stress data, earthquake focal mechanisms, or geologic data from other areas) must also be considered. This task is a collateral responsibility of Study 8.3.1.17.4.12 (Tectonic models and synthesis).

To summarize, Yucca Mountain Project strategy (fig. 1-4) to characterize the detachment faulting process at Yucca Mountain involves collection of relevant data by seven key studies, and integration and evaluation of that data in an eighth study. The data collection studies variously emphasize field mapping, trenching, drilling, and geophysical methods, and focus on Yucca Mountain, or on key localities in the vicinity of Yucca Mountain. The study described in this study plan is one of the seven data collection studies, and is responsible for examining, describing, and mapping detachment faults at locations where they are exposed proximal to Yucca Mountain.

1. PURPOSE AND OBJECTIVES OF THE STUDY

The objective of this study is to supply information pertaining to the distribution, displacement rate, geometry, and age of detachment faults proximal to Yucca Mountain. The key questions to be addressed are whether or not detachment faults:

- are present at or near Yucca Mountain, and represent a significant earthquake source;

- project toward the subsurface below Yucca Mountain, and conceal a significant earthquake source at depth; and

- have been active during the Quaternary.

Toward this end, activities include a focus on resolving the location, geometry, and age of postulated detachment faults. Detachment faults will be studies in the general area of the Beatty 30 X 60' quadrangle, a rectangular area of approximately 4,800 km^2 generally centered on the repository and encompassing Yucca Mountain (fig. 1-5). The area contains all known or postulated detachment faults proximal to Yucca Mountain that currently are judged significant to site characterization (fig. 1-5); the specific boundaries of the study area ultimately are judged on the basis of geologic structure.

Objectives specific to each activity in the study are discussed in sections 3.1 through 3.5.

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

This study will produce maps of selected areas proximal to Yucca Mountain in which the presence of detachment faults and related geologic features is suspected or has been confirmed. The study also will generate isotopic dates of geologic materials that are cut by, or that overlap, detachment faults, or otherwise are affected by the geologic processes associated with detachment faulting such that the isotopic dates will provide constraints on the age of faulting. Information from this study will be incorporated with information from other activities to determine the subsurface extent, geometry, and possible segmentation of detachment faults, to constrain the locations, ages, and geometric histories of detachment faults, and to identify areas that may contain concealed detachment faults or that may contain other seismogenic faults concealed beneath detachment faults. Synthesis and interpretation of the combined data set is the responsibility of Study 8.3.1.17.4.12 (Tectonic models and synthesis). This study will gather information on:

- the surface location, orientation, length, width, segmentation, and possible interconnections of all detachment faults that can be identified proximal to Yucca Mountain

- the location, amount, direction, and time of movement on these faults

- the geometric histories through time of these faults

This information will be gathered through structural studies, geologic mapping, trenching of fault zones (if judged necessary); dating and correlation of deposits (including Quaternary surficial deposits) that are offset by, or that overlap, the detachment faults; and studies of petrologic and other indicators of time-depth histories.

The information from the study will be combined with information from other studies, as noted above, and used to determine the histories, directions, amounts, rates, and recurrence intervals of detachment faulting as a function of location and time and thus 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.

The information to be obtained in each activity is discussed in sections 3.1.1 through 3.1.5. Specific uses of the information for measuring repository performance against goals for performance measures are discussed in section 1.2 below; uses of the information for supporting other studies are discussed in section 4.

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

Tectonic processes identified at or in the vicinity of Yucca Mountain include, among others, uplift and subsidence, faulting, and folding. Information bearing on the specific location and rates at which these processes are likely to operate during the preclosure period and the 10,000, and 100,000 years is needed to safeguard the proposed repository from natural events which could cause or lead to (perhaps in conjunction with climatic changes) unacceptable contamination of the accessible environment.

The preclosure period encompasses the waste emplacement and retrieval periods (10CFR60.102(d)), possibly totaling 100 years. The 10,000 year period is the period for which the overall performance objective is to be achieved (10CFR60.112 and 40CFR191), hence the period for which the siting criteria of 10CFR60.122 (including potentially favorable and potentially adverse conditions within the geologic setting) are to be evaluated. The 100,000-year period is the period for which the effects of geohydrologic processes on repository performance (i.e., containment of waste) are to be predicted (e.g., 10CFR960.4-2-1(b)(2)) and SCP, p. 8.3.1.2-3).

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 three time frames: (1) contemporary, (2) historic, and (3) prehistoric 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) 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 (8.3.1.17.4.5) 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. 1-6). Other studies will supply information on the location and rates of faulting 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 result in unacceptable reduction in travel time of waste products to the accessible environment through excessive encroachment of meteoric or ground waters (see figs. 1-2 and 1-3).

2. RATIONALE FOR SELECTING THE STUDY

The study of detachment (low-angle extensional) faults is one of a group of related studies which collect information about Quaternary faulting at Yucca Mountain and the nearby region. Each type of fault in this area is the focus of one (or more) studies (fig. 2-1). Detachment faults are an important element of the faulting 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 belt, and the northeast-trending Mine Mountain-Spotted Range structural zone (Carr, 1984; see fig. 2-2). The Walker Lane belt in one interpretation is 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, and these terms define the diffuse eastern limit of the zone of northwest-striking right-lateral faults within the western margin of the North American plate which distribute movement of the Pacific Plate inland. Prominent members of this family of faults near Yucca Mountain include the 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 belt to the north.

The Mine Mountain-Spotted Range structural zone is defined by a cluster of northeast- to east-northeast striking left-lateral strike-slip faults that lie athwart the northwest-trending Walker Lane belt. Faults east and south of Yucca Mountain that are part of this belt include the Mine Mountain, Cane Springs, and Rock Valley faults.

Faulting at and near Yucca Mountain thus apparently involves elements of four subprocesses: (1) steep normal faulting, (2) left-lateral strike-slip faulting, (3) right-lateral strike-slip faulting, and (4) detachment faulting. The subprocesses defined above form the primary basis for organization of studies of faulting. Each of these types of faulting is the subject of one or more studies (fig. 2-1). However, an additional complication has been taken into account in the organization of the investigation of faulting, namely, that the nature and detail of the information required varies from place to place (fig. 2-3). 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 proposed site of the repository, Midway Valley, and the major structural blocks at Yucca Mountain and their bounding faults. This area includes several of the major steep dip-slip Quaternary faults of potential significance to the repository (e.g., Windy Wash, Solitario Canyon, Bow Ridge, and Paintbrush Canyon faults) and one left-lateral strike-slip Quaternary fault (the Stagecoach Road fault). In the site area, information pertaining to Quaternary faulting 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. 2-3).

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 are greatest for faults within the site area, and diminish with increasing distance from the faults. It is unlikely that faulting processes occurring beyond 100 km from Yucca Mountain could directly affect waste containment at the site. However, ground shaking and strain associated with earthquakes on major faults within 100 km of the site (e.g., Rock Valley, Bare Mountain, Death Valley-Furnace Creek faults) could adversely affect regional groundwater-flow systems, and also should be taken into account in siting and design of facilities at the site. It is also possible that major structures within the 100-km region could project into the subsurface beneath the site area (e.g., right-lateral faults of the Walker Lane belt, or more likely, detachment faults). Studies, including this study of detachment faulting, have therefore been planned to collect information on Quaternary faulting processes within the 100-km region (fig. 2-2).

Detachment (low-angle extensional) faults have not been recognized at the surface within the site area. They have been recognized to the east and west of the site area (fig. 1-4), where they form the contact between Tertiary rocks and subjacent Paleozoic rocks and project in the subsurface toward the site area. It has, therefore, been suggested that these faults may be present at relatively shallow depths (~ 1,250 m) below the surface of the site area (Scott, 1986; Myers, 1987). Research in other areas in western Nevada (Hardyman and Oldow, 1990) has shown that the contact between the Tertiary volcanic sequence and underlying rocks has served to localize detachment faulting. Consequently, this contact will be carefully studied in the areas surrounding Yucca Mountain to identify any faulting that has occurred along it. Our studies will not be restricted to this contact, however, and all units will be mapped with the same care and detail to identify potential faulting. The detachment faults proximal to Yucca Mountain were most active in late Miocene; the age of detachment faulting becomes progressively younger to the west, and is likely Quaternary in Death Valley (Hamilton, 1988).

It is not known if the detachment fault(s) at depth within and proximal to the site area have been active during the Quaternary. If the known Quaternary high-angle faults within the site area merge listrically with the detachment fault(s) at depth, then the detachment fault(s) are necessarily Quaternary. On the other hand, if the high-angle faults cut and offset the detachment(s), then the detachments are likely pre-Quaternary. If the detachment fault(s) at depth in the site area are Quaternary, they could conceivably conceal major through-going Quaternary strike-slip faults within the lower plate.

In summary, the information required to better understand the detachment faulting process at Yucca Mountain includes: (1) identification of detachment faults, (2) age of detachment faults in the subsurface, (3) geometry of detachment fault surfaces, and (4) identification of possible strike-slip (wrench) faults concealed below the detachment(s) in the subsurface of the site area. Studies concerning faulting and geophysics both within and outside the site area will contribute relevant information (figs. 1-4 and 2-4). This study (Study 8.3.1.17.4.5, Detachment faults at or proximal to Yucca Mountain) will supply information on the detachment faulting process obtained from examination of detachment faults exposed at the surface both east and west of Yucca Mountain.

The five activities in this study were chosen as complementary means for obtaining the required information on detachment faults exposed at or proximal to Yucca Mountain. Three of the activities will provide detailed information on known or hypothesized detachment faults in the site area. A fourth activity will evaluate the origin of distinctive breccia masses a few kilometers southwest of Yucca Mountain, which appear to have formed as some consequence of tectonic activity, perhaps in conjunction with detachment faulting. The fifth activity will provide data that will help constrain the age of detachment faulting. The latter may also result in information related to the rate of uplift of rocks formed at middle crustal levels in the earth, in the area having the greatest amount of tectonic denudation of any area near Yucca Mountain. This tectonic denudation is generally accepted as being, at least in part, a consequence of detachment faulting. These data will be integrated with other data relevant to detachment faulting in other studies (table 2-1) to develop geologic models. The bases for selecting the types of tests that are planned for each activity are discussed below. The test plans themselves are discussed in section 3.

2.1 Activity 8.3.1.17.4.5.1: Evaluate the significance of the Miocene-Paleozoic contact in the Calico Hills area to detachment faulting within the site area

The contact between Miocene volcanic (and volcaniclastic) rocks and subjacent Paleozoic strata, which lies a kilometer or more below the ground surface at the site of the proposed repository at Yucca Mountain, is exposed at the surface a few kilometers to the northeast in the Calico Hills (Topopah Springs and Jackass Flats quadrangles, fig. 2-5). The volcanic rocks in these exposures are broken by faults, some with displacement in excess of 200 m, and locally are moderately to steeply tilted. The present activity is designed to: (1) establish whether the Miocene-Paleozoic contact is tectonic or depositional and (2) if the contact is tectonic, determine whether the Miocene volcanic rocks are part of a detachment-bounded upper plate and what the age of movement and rate of fault displacement are.

2.1.1 Rationale for the types of tests selected

A single test -- detailed mapping and analysis of suspected tectonic contact between Miocene rocks and Paleozoic rocks in Calico Hills area -- was chosen to provide the essential information for determining the true nature of the Miocene-Paleozoic contact in this area. If the contact is shown to be tectonic, the mapping may also provide information on the age and rate of fault movement. No reasonable alternatives to the actual mapping and study of this contact in natural exposures (and shallow excavations, if needed) would result in the quality of data needed for these purposes.

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

2.1.2.1 Number

The area has been previously mapped at 1:24,000 scale (McKay and Williams, 1964; Orkild and O'Connor, 1970). Judging from field relations shown on these maps and from the expected quality of exposures, detailed remapping should provide the information required to evaluate this contact. If additional tests (e.g., trenching) prove necessary and warranted, they will be planned following completion of the test described above.

2.1.2.2 Location

The location of this activity will be the Calico Hills area (fig. 1-4), because that area is one of only a few areas near Yucca Mountain where the Miocene-Paleozoic contact can be studied at the surface.

2.1.2.3 Duration and timing

The work planned for this activity is estimated to be about 75 percent complete and the duration of the remaining work is estimated to be 6 person-months. The planned timing of the activity is dictated by the need to provide information from this activity to other studies according to the integrated schedule of the Yucca Mountain Project (see secs. 4 and 5).

2.1.3 Constraints: factors affecting selection of tests

Because this activity consists of geologic mapping and data compilation, the choice of the test method was unaffected by the following factors: potential impacts on the Site, simulation of repository conditions, limits and capabilities of analytical methods, timing, scale and applicability of measurements, and interference with other tests or the exploratory shaft.

2.2 Activity 8.3.1.17.4.5.2: Evaluate postulated detachment faults in the Beatty-Bare Mountain area

The Beatty-Bare Mountain area, centered about 27 km west of the proposed repository, is another area close to Yucca Mountain where suspected detachment fault-bounded plates are present on the surface (fig. 1-5). There, moderately to weakly metamorphosed Precambrian and Paleozoic strata forming the Bare Mountain massif overlie older Precambrian crystalline and metamorphic rocks and, in turn, are overlain by Miocene volcanic and volcaniclastic strata. The contacts between these three rock assemblages are currently interpreted as being major detachment faults. The primary purpose of the present activity is to determine if these suspected detachments have been active during the Quaternary and, if so, to establish their nature, displacement rates, and locations.

2.2.1 Rationale for the types of tests selected

In order to determine the nature, age, and displacement rates of suspected detachment faults in the Beatty-Bare Mountain area, field investigations will be required in parts of three 7½-minute quadrangles: Bare Mountain SW (plus parts of adjacent quadrangles), Bare Mountain NW, and Bullfrog NE (fig. 2-5). No reasonable alternatives to the detailed examination and mapping of these contacts in natural exposures (and in shallow excavations, if needed) will result in the quality of data needed to determine their true nature.

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

2.2.2.1 Number

The discussion in section 2.1.2.1 is largely applicable to this section; the status of geologic mapping for this activity is given in section 2.2.2.3, below.

2.2.2.2 Location

This activity will be concentrated in the three quadrangles listed in section 2.2.1, because one or another of the suspected detachment faults can be observed in each of these localities.

2.2.2.3 Duration and timing

The estimated times involved in completing the mapping and related studies and compilations for this activity are as follows:

- Bullfrog NE quadrangle -- a geologic map has been completed (Maldonado and Hausback, 1990), but additional field work (geologic mapping, collection of samples for age-dating) is planned to determine the nature and age of the detachment faulting, as well as the rate of fault displacement if Quaternary movement is demonstrated. This additional effort is expected to take about 6 person-months.

- Bare Mountain NW quadrangle -- the work planned for accomplishing this mapping will require about 1 person-year.
- Bare Mountain SW quadrangle and adjacent areas -- this mapping is approximately 75 percent completed, and the remainder will take about 6 person-months.

The timing for completing all tests in this activity is being planned so as to provide information to other studies according to the integrated schedule of the Yucca Mountain Project (see secs. 4 and 5).

2.2.3 Constraints: factors affecting selection of tests

The discussion in section 2.1.3 is applicable to this section.

2.3 Activity 8.3.1.17.4.5.3: Evaluate the potential relationship of breccia within and south of Crater Flat to detachment faulting

Breccias intersected in VH-2 (Carr and Parrish, 1985), located in the central part of Crater Flat (fig. 2-5), could be the lateral extension of similar materials that crop out above, or intercalated within, Miocene volcanic rocks along the southern rim of Crater Flat. The source of these breccias and their relationship to Quaternary or older faulting have not been established.

2.3.1 Rationale for the types of tests selected

In order to resolve the problem noted above, the existing geologic map of the area within which the breccias crop out (Swadley and Carr, 1987) will be systematically reviewed, selected exposures will be reexamined and remapped in the field, and cores from USW VH-1 and USW VH-2 (fig. 2-5) will be examined for the presence of breccia zones. There are no reasonable alternatives to these planned tests that would provide the data necessary to make reliable conclusions regarding the true origin of these deposits.

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

2.3.2.1 Number

Field work for this activity will involve examination of the breccia at all localities along the southern rim of Crater Flat where their stratigraphic and structural relations are well exposed and can be studied in detail. How many such exposures will be included cannot be estimated in advance. Available data on cores from two boreholes (USW VH-1 and USW VH-2) will be reviewed and additional studies made as necessary.

2.3.2.2 Locality

Field work will be concentrated in breccia outcrops along the southern rim of Crater Flat (fig. 1-5).

2.3.2.3 Duration and timing

This activity is expected to take about 6 person-months. The timing is dictated by the need to provide information to other studies according to the integrated schedule of the Yucca Mountain Project (see secs. 4 and 5).

2.3.3 Constraints: factors affecting selection of tests

Because this activity consists of geologic observations and compilation of data from outside of the controlled area, it will have no effect on other tests, on the design and construction of the exploratory shaft, or on the ability of the Site to isolate waste. Accordingly, the choice of the SCP test method for this activity was affected neither by those factors nor by the need to simulate repository conditions; the limits and capabilities of analytical methods; timing, nor scale and applicability of measurements.

2.4 Activity 8.3.1.17.4.5.4: Evaluate postulated detachment faults in the Specter Range and Camp Desert Rock areas

The contact between Miocene strata and Paleozoic strata crops out in the Specter Range and Camp Desert Rock areas (fig. 1-5). Preliminary reconnaissance indicates that in places this contact is tectonic and that the Miocene rocks locally form a detachment-fault-bounded upper plate. The geologic structure and stratigraphy of these areas need to be worked out in greater detail to test the validity of the preliminary findings and to determine the extent and age of the detachment faulting, if present.

2.4.1 Rationale for the types of tests selected

Conventional geologic mapping and related stratigraphic and structural studies will be conducted in the Specter Range and Camp Desert Rock areas. There are no alternatives to examining the stratigraphic and structural relations of the Miocene-Paleozoic contact in natural exposures if the true nature of the contact is to be determined with a high degree of confidence.

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

2.4.2.1 Number

The discussion in section 2.1.2.1 is applicable to this section (also, see sec. 2.4.2.3, below).

2.4.2.2 Location

The location of this activity will be the Specter Range and Camp Desert Rock areas, because the contact between Miocene and Paleozoic strata can be observed and studied in exposures in those localities.

2.4.2.3 Duration and timing

The work planned for this activity is approximately 50 percent completed. The duration of the remaining work is estimated to be 2 person-years, based on factors related to field mapping as listed in section 2.1.2.1. The planned timing of the activity is dictated by the need to provide information from this activity to other studies according to the integrated schedule of the Yucca Mountain Project (see secs. 4 and 5).

2.4.3 Constraints: factors affecting selection of tests

The discussion in section 2.1.3 is applicable to this section.

2.5 Activity 8.3.1.17.4.5.5: Evaluate the age of detachment faults using radiometric ages

Detachment faulting and the uplift of core complexes in the Yucca Mountain region may be closely related in time and space. Accordingly, and as a further means of determining the age of detachment faulting in this area, appropriate geologic materials will be collected from detachment fault zones and from core complexes and other rocks now occupying the lower plates of detachments for purposes of radiometric dating.

2.5.1 Rationale for the types of tests selected

The choice of test methods for this activity is based on the ability of these methods to provide radiometric ages that will help to constrain the age of detachment faulting in the Yucca Mountain area. The planned methods are as follows:

- Fission-track dating of the Northern Amargosa Desert core complex

- Potassium-argon or Ar-Ar dating of the Northern Amargosa core complex

- Fission-track and potassium-argon or Ar-Ar dating of miscellaneous samples supplied by other activities in support of program objectives

- Integration of dates with petrologic and other evidence for pressures and temperatures of deformation

For the activity as a whole, no reasonable alternatives to actual isotopic dating of the fault zone materials and lower plate rocks would provide reliable information on the numerical ages of these materials and their uplift and thermal histories. Isotopic dating methods other than those specified in the test methods listed above might also contribute useful data. These other methods, as well as the circumstances and procedures under which they might be added to this activity, are discussed in section 3.5.1.

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

2.5.2.1 Number

The number of samples of geologic materials for radiometric dating purposes cannot be accurately estimated in advance. The number will depend ultimately on the distribution and extent of good exposures of the fault zones and underlying rocks in the areas being studied, and the kinds of materials present that are suitable for age determinations.

2.5.2.2 Location

The primary location of this activity will be the Beatty-Bare Mountain area (fig. 1-5). The sites being sampled will be concentrated in exposures along the southern edge of the Bullfrog Hills and from the central part of Bare Mountain (see sec. 3.5.1 for description of the rocks being sampled). Samples will also be collected from other areas, particularly the Funeral Mountains.

2.5.2.3 Duration and timing

This activity is estimated to be 25 percent completed, and the remainder of the work to take about another 4 person-years. The timing is dictated by the need to provide information to other studies and activities according to the integrated schedule of the Yucca Mountain Project (see secs. 4 and 5).

2.5.3 Constraints: factors affecting selection of tests

Because this activity consists of collection and analysis of small surface samples from outside of the controlled area, it will have no effect on other tests, on the design and construction of the exploratory shaft, or on the ability of the site to isolate waste. Accordingly, the choice of the SCP test method for this activity (as for Activity 8.3.1.17.4.5.1) was affected neither by those factors nor by the need to simulate repository conditions; the limits and capabilities of analytical methods; timing; nor scale and applicability of measurements. Additional methods not discussed in the SCP could result in useful data that would enhance the ability to achieve the goals of this activity. These methods and the circumstances and procedures under which they will be considered and might be employed are discussed in section 3.5.1.

3. DESCRIPTION OF TESTS AND ANALYSES

3.1 Activity 8.3.1.17.4.5.1: Evaluate the significance of the Miocene-Paleozoic contact in the Calico Hills area to detachment faulting within the site area

The objectives of this activity are:

- to determine whether the contact of the Miocene volcanic rocks on Paleozoic strata in the Calico Hills area is tectonic or depositional, and, if found to be tectonic (i.e., a fault),
- to determine the nature of Quaternary activity, if any, along that contact (specifically, the direction and age of movement, attitude of the fault plane, and nature of deformation of the Miocene stratigraphic sequence).

3.1.1 General approach

This activity will produce a 1:24,000-scale geologic map of the Calico Hills area, focusing on the contact of the Miocene volcanic rocks on Paleozoic strata (fig. 1-5). The current status of mapping in this area, and the time involved in completing the planned work, are noted in section 2.1.2.3. The area will be mapped on the basis of natural rock exposures using conventional field methods, including annotation of field observations on 1:12,000-scale aerial photographs (color or false color, where available) and compilation on scale-stable topographic base materials at 1:24,000 scale (Jackass Flats and Topopah Spring, Nevada, 7.5-minute quadrangles, fig. 2-5). Shallow excavations and (or) mechanical clearing of exposures will be considered in the event that natural exposures prove inadequate for resolving the objectives of this activity.

The map will show the specified parameters -- the geologic structure and stratigraphy within the mapped area. It will also show the nature of the contact and, if the contact proves to be a fault, the relative age, attitude, and approximate direction and maximum/minimum rate of movement if determinable.

Potential Quaternary activity will be evaluated through examination of Quaternary surficial deposits intersected by the detachment fault(s), or intersected by the upward projection of the detachment fault(s). That examination will include inspection of aerial photographs of these intersections for evidence of lineaments or scarps, and inspection of natural exposures of contacts between detachment faults and surficial deposits. Trenching or shallow excavations may be employed if contact relations observed at natural exposures are ambiguous. Trenching may also be employed if judged necessary to define the cause of lineaments in the surficial deposits. The age of surficial deposits cut by or depositionally overlapping the detachment faults will be estimated through stratigraphic correlation with dated deposits, or if deemed advisable, through use of direct dating methods similar to those employed in Study 8.3.1.17.4.6 (Quaternary faulting within the site area).

The extent of the area to be mapped will depend on observations and judgments made during the course of mapping. The suspect contact between Miocene and Paleozoic rocks in the Calico Hills will be mapped with particular attention to evidence indicating a depositional origin for any part of the contact and (or) bearing on the age of movement and displacement rate of any part of the contact judged to be a fault. Mapping will not, however, be limited to the contact between Miocene and Paleozoic rocks. Areas exposing geologic relationships bearing on the geometry and movement history of any fault that offsets or terminates at the contact between Miocene and Paleozoic rocks will also be mapped, as will areas exposing relationships germane to establishing the stratigraphy of the map area. Although the area of primary interest is the Calico Hills area, field observations may be made in other areas for background and as a basis for comparison, to whatever extent is judged necessary to achieve the goals of this activity.

3.1.2 Test methods and procedures

This activity will use conventional geologic mapping techniques. The test method and technical procedure to be employed in this activity are listed on table 3-1.

3.1.3 Quality assurance 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 procedures applicable to this activity will be identified on the basis of the findings in the Grading Report and will be prepared in accordance with applicable QA requirements.

3.1.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for the tests in this activity. The planned mapping is expected to show the locations and orientations of faults and stratigraphic contacts as accurately as current technology and the available geologic data permit. Locations of mapped features will be plotted within about 1 mm on the 1:24,000-scale base map, hence, within about 24 m on the ground, which adheres to standard map accuracy requirements. The orientations of faults, contacts, and other planar geologic features will be measured, exposures permitting, within about 5 degrees, and the locations where representative measurements will be made will be plotted on the map to approximately the same degree of accuracy as the locations of the faults and stratigraphic contacts.

3.1.5 Range of expected results

The contact between Miocene and Paleozoic rocks in the Calico Hills will be demonstrated to be either depositional or tectonic (unless the available geologic information proves to be insufficient for drawing reliable conclusions). If found to be tectonic, the contact will be classified either as a high angle normal fault or a detachment fault. Different segments of the contact may fall into different fault classifications. Movement in the Calico Hills will probably be found, at least in part, to be Miocene in age; however, any fault may also be found to have Quaternary movement and to remain active. If found to be Quaternary, direction and rates of movement may be consistent with those of other Quaternary faults at or near Yucca Mountain (Windy Wash, Solitario Canyon, and Paintbrush Canyon faults).

3.1.6 Equipment

This activity will use a variety of conventional geologic field equipment. Typical equipment to be used is identified in the technical procedure listed on table 3-1.

3.1.7 Data-reduction techniques

In this activity, standard data-reduction techniques will be used to synthesize and compile field observations. Observations made on the ground surface, in natural (or excavated) exposures, and on aerial photographs will be compiled onto scale-stable topographic base maps at a scale of 1:24,000.

3.1.8 Representativeness of results

The information obtained in this activity is expected to be representative of the Miocene-Paleozoic contact in the Calico Hills, because all known exposures of that contact will be studied in detail. This activity will not extrapolate the information outside the Calico Hills area; it will, however, provide a partial basis for such extrapolations to be done in Study 8.3.1.17.4.12 (Tectonic models and synthesis). The degree to which the contact between Miocene and Paleozoic rocks in the Calico Hills is representative of the contact between Tertiary and Paleozoic rocks regionally will be judged within the broader context of that investigation.

The test method for this activity is designed to yield comprehensive information with which to make accurate conclusions concerning the nature of the contact between Miocene and Paleozoic rocks in the Calico Hills. Despite the close field examinations planned for the activity, however, unfavorable exposures or lack of diagnostic geologic relationships could affect the ability of the activity to produce wholly conclusive results. Thus, data gaps and uncertainties regarding field data may occur, imposing limitations on classifying the Miocene-Paleozoic contact of the Calico Hills area.

3.1.9 Relations to performance goals and confidence levels

See sections 1 and 4 for discussions applicable to this topic.

3.2 Activity 8.3.1.17.4.5.2: Evaluate postulated detachment faults in the Beatty-Bare Mountain area

The objective of this activity is:

- to determine if detachment faults in the Beatty-Bare Mountain area have been active during the Quaternary.

In order to determine this it will be necessary --

- to establish the location, nature, age, and displacement rate (if Quaternary) of the detachment faults along the south edge of the Bullfrog Hills. Strands of this fault zone separate lineated, mylonitized, and variably recrystallized gneiss from essentially unmetamorphosed Paleozoic rocks, and the Paleozoic rocks from the Miocene volcanic, volcaniclastic, and sedimentary rocks that form the Bullfrog Hills. It will also be necessary to ascertain the nature and age of deformation in the Miocene rocks forming the uppermost plate of the detachment fault complex.

- to establish the location, nature, age, and displacement rate (if Quaternary) of the detachment fault between the upper Proterozoic and Paleozoic rocks that form Bare Mountain and the Miocene volcanic rocks forming the hills of northernmost Bare Mountain, as well as ascertain the nature and age of deformation in the Miocene rocks forming the upper plate of that fault.

- to ascertain the nature of internal deformation and the degree of metamorphism of the Proterozoic and Paleozoic rocks in the Bullfrog Hills-Bare Mountain area.

3.2.1 General approach

The discussion in section 3.1.1 is applicable to this section, except that the areas involved are the Bullfrog NE, Bare Mountain NW, and Bare Mountain SW 7½-minute quadrangles (fig. 2-5). The current status of mapping in these areas, and the times involved in completing the planned work, are noted in section 2.2.2.3.

Study 8.3.1.17.4.5: Detachment faulting at or proximal to Yucca Mountain

A surficial geologic map of the Bare Mountain 15-minute quadrangle has already been published (Swadley and Parrish, 1988). This map will be reviewed to assist in evaluating whether there has been Quaternary movement in conjunction with any of the detachment faulting in the Beatty-Bare Mountain area.

3.2.2 Test methods and procedures

Conventional geologic mapping techniques will be used to address the designated parameters of this activity -- geologic structure and stratigraphy, age of datums, and direction and amount of offset of datums. The methods and technical procedure to be employed are listed on table 3-1.

3.2.3 Quality assurance requirements

See section 3.1.3.

3.2.4 Required tolerances, accuracy, and precision

The discussion in section 3.1.4 is applicable to this section.

3.2.5 Range of expected results

The detachment faults in the Beatty-Bare Mountain area, and genetically related upper-plate faults cutting the Miocene rocks that form the Bullfrog Hills and northernmost Bare Mountain, are known to have Miocene activity (Ransome and others, 1910; Cornwall and Kleinhampl, 1961; Carr and Monsen, 1988; Maldonado, 1990a, 1990b; Maldonado and Hausback, 1990); some or all of these detachment faults may be found to have also been active during the Quaternary. If found to have Quaternary activity, the rates of movement on the faults cutting the Miocene rocks in the Beatty-Bare Mountain area will probably be consistent with those of other active faults at or near Yucca Mountain. The only published movement rate corresponding to active displacement on a postulated major detachment fault in the region is the minimum average slip rate of 2 to 3.2 mm/yr for the opening of the northern Panamint Valley (Burchfiel and others, 1987, p. 10,424). It is not known how this rate might relate to detachment faulting proximal to Yucca Mountain. If found to have Quaternary activity, however, detachment faults in the Beatty-Bare Mountain will need to be evaluated as to their potential to be, or to conceal, a relevant earthquake source within 100 km of Yucca Mountain, and their potential for influencing the hydrology of Yucca Mountain.

3.2.6 Equipment

This activity will use a variety of conventional field equipment for mapping of the ?Beatty-Bare Mountain area. Typical equipment to be used is identified in the technical procedures listed on table 3-1.

3.2.7 Data-reduction techniques

The discussion in section 3.1.7 is applicable to this section.

3.2.8 Representativeness of results

The discussion in section 3.1.8 is applicable to this section, except that it relates to the Beatty-Ba. e Mountain area.

3.2.9 Relations to performance goals and confidence levels

See sections 1.2 and 4 for discussions applicable to this section.

3.3 Activity 8.3.1.17.4.5.3: Evaluate the potential relationship of breccia within and south of Crater Flat to detachment faulting

The objective of this activity is to determine whether breccias tectonically emplaced on low-angle surfaces beveled across Paleozoic and younger strata within and south of Crater Flat are slide masses (i.e., sedimentary deposits) or are near-surface parts of the upper plates of detachment faults, and, if either of these, to determine how the formation of such breccias might relate to known or postulated Quaternary faults.

3.3.1 General approach

In this activity, a single test method -- evaluation of megabreccia in and south of Crater Flat -- will be conducted to address the following SCP parameters:

- distribution of breccia in the subsurface below Crater Flat
- nature of fragmentation of the breccia
- nature of contacts of the breccia, including indicators of direction of relative movement

Existing geologic maps of the Crater Flat area (Swadley and Carr, 1987; Swadley and Parrish, 1988; Cornwall and Kleinhampl, 1961) will be reviewed, as will cores from drill holes USW VH-1 and VH-2 (fig. 2-5). Information generated by the review of the maps and core data will be combined with additional studies of outcrops and cores focusing on the parameters listed above, as well as the internal character and sources of the breccias. For example, the size and angularity of clasts might give evidence as to whether they had been milled or transported by water. The degree of chemical weathering might also address this question. Presence of sedimentary structures such as graded bedding or channel deposits might also suggest sedimentary origin. Similar breccia units elsewhere in the southern Great Basin will be examined as background and as a basis for comparison, to whatever extent is necessary for achieving the goals of this activity. Trenching of the basal contact of the breccias will probably be necessary.

3.3.2 Test methods and procedures

This activity will use conventional methods for geologic observation, description, and interpretation. The technical procedures to be used are listed on table 3.1.

3.3.3 Quality assurance requirements

See section 3.1.3.

3.3.4 Required tolerances, accuracy, and precision

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

3.3.5 Range of expected results

Some of the breccia deposits in the vicinity of Crater Flat probably will be found to be gravity slide masses. Others, especially south of Crater Flat, could be near-surface segments of the upper plates of detachment faults. In either case, the breccias are likely to have formed as a consequence of some type of tectonic activity, whether they are primarily sedimentary deposits that resulted from the disintegration of large rock masses and subsequent gravity sliding, or are the product of brittle deformation resulting directly from fault movement. Most of the breccias probably will be identified as having originated in late Tertiary time, but for some the process of breccia formation may be found to have continued into Quaternary time, based on its relationship to overlying Quaternary deposits.

3.3.6 Equipment

This activity uses a variety of conventional field equipment. Typical equipment to be used is identified in the technical procedures listed on table 3-1. A conventional petrographic microscope and standard thin sections will be used if petrographic study is judged to be necessary.

3.3.7 Data-reduction techniques

In this activity, standard data-reduction techniques will be used to synthesize and compile field, drill core, and if needed, petrographic observations. Observations and conclusions will be documented in a descriptive report.

3.3.8 Representativeness of results

The information obtained in this activity is expected to be representative of breccias in the vicinity of Crater Flat, because all known breccias in that area will be studied. The information will provide a basis for extrapolating conclusions concerning the origins of these particular breccias to questions relating to the origins of such breccias, in general, and their relationships to tectonism.

3.3.9 Relations to performance goals and confidence levels

See sections 1.2 and 4 for discussions applicable to this section.

3.4 Activity 8.3.1.17.4.5.4: Evaluate postulated detachment faults in the Specter Range and Camp Desert Rock areas

The objectives of this activity are --

- to determine whether the basal contact of the Horse Spring (and related Tertiary sedimentary units) in the Specter Range and Camp Desert Rock areas is depositional or tectonic,

  and if tectonic,

- to determine the age of movement (specifically, whether there has been movement during the Quaternary),

  and if Quaternary,

- to determine the direction and amount of displacement (extension), the rate of movement, and the style of deformation within the upper plate.

3.4.1 General approach

The discussion in section 3.1.1 is applicable to this section, except that the areas to be mapped are the Specter Range and Camp Desert Rock areas, and the mapping will focus on the basal contact of the Horse Spring Formation (and related Tertiary sedimentary units) on Late Proterozoic and Paleozoic strata (fig. 1-4), and on low angle faults within the Proterozoic and Paleozoic rocks that were previously mapped as thrust faults. The current status of mapping in these areas, and the time involved in completing the planned work, are noted in section 2.4.2.3.

The internal stratigraphy, structure, provenance, and age of the Horse Spring Formation and related Tertiary deposits will be investigated using conventional procedures to establish a basis for recognizing offset datums and to determine the ages of fault movement. Mapped faults will be traced from areas of bedrock exposures into areas covered by surficial deposits in order to establish whether there has been any tectonic activity during the Quaternary period. Within the Proterozoic and Paleozoic section, known low-angle faults in which younger rocks are faulted over older rocks will be examined for evidence of Tertiary (and Quaternary) extensional movement.

3.4.2 Test methods and procedures

This activity will use conventional geologic mapping techniques for locating, depicting, and describing the geologic structure and stratigraphy proximal to the basal contact of the Horse Spring Formation and related Tertiary sedimentary units in the Specter Range and Camp Desert rock areas. The test method and technical procedure to be employed are listed on table 3-1.

3.4.3 Quality assurance requirements

See section 3.1.3.

3.4.4 Required tolerances, accuracy, and precision

The discussion in section 3.1.4 is applicable to this section.

3.4.5 Range of expected results

The discussion in section 3.1.5 is applicable to this section, except that it relates to the contacts of the Horse Spring Formation and related Tertiary sedimentary deposits on Late Proterozoic and Paleozoic strata in the Specter Range and Camp Desert Rock areas.

3.4.6 Equipment

This activity will use a variety of conventional geologic field equipment, as identified in the technical procedures listed on table 3-1.

3.4.7 Data-reduction techniques

The discussion in section 3.1.7 is applicable to this section.

3.4.8 Representativeness of results

The discussion in section 3.1.8 is applicable to this section, except that it relates to the contacts of the Horse Spring Formation and related Tertiary sedimentary deposits on Late Proterozoic and Paleozoic strata in the Specter Range and Camp Desert Rock areas.

3.4.9 Relations to performance goals and confidence levels

See sections 1.2 and 4 for discussions applicable to this section.

3.5 Activity 8.3.1.17.4.5.5: Evaluate the age of detachment faults using radiometric ages

The objectives of this activity are to --

- determine if the rocks in the lower plates of the detachment faults in the Bullfrog Hills and at Bare Mountain cooled through the blocking temperatures of zircon and apatite during the Quaternary period, and
- determine if the Northern Amargosa core complex cooled through the blocking temperatures of hornblende, muscovite, and biotite during the Quaternary period.

3.5.1 General approach

Samples will be collected from (1) the lineated and locally mylonitized gneiss, and schist that form the lower plate of the zone of detachment faults exposed along the southern edge of the Bullfrog Hills (northern Amargosa Desert core complex); (2) the shear zones marking the detachment surfaces between the core complex and the overlying plate of Paleozoic rocks, and between that plate and the uppermost plate of Miocene volcanic, volcaniclastic, and sedimentary rocks that form the Bullfrog Hills; and (3) the Miocene rocks in this uppermost plate (fig. 1-5). At Bare Mountain, samples will be collected at low elevations from the deeply dissected central part of the mountain, from the shear zone marking the detachment fault at the northern end of the mountain, and from the shear zone exposed at low elevations along the eastern front of the range. Zircon and apatite separated from these samples will be dated using standard fission-track dating methods. Hornblende, muscovite, biotite, and K-feldspar will be separated out of samples collected from the central part of the core complex, from suitable targets near the shear zone marking the detachment surface separating the core complex from structurally overlying plate of Paleozoic rocks, and from dike rocks within the uppermost plate that are truncated by the basal detachment of that plate for age determinations and thermochronologic analysis. In addition to other conventional techniques, $^{40}Ar/^{39}Ar$ thermochronology will be employed to evaluate the cooling history of lower-plate rocks. Such analysis will not only provide information on the uplift history of the fault, but may help constrain when the fault was most active. Employing the above mentioned analytical techniques will supplement and permit critical evaluation of a substantial existing, but largely unpublished, database.

The current status of the work elements described above, and the time involved in completing the planned tasks, are noted in section 2.5.2.3.

Although the Bullfrog Hills and Bare Mountain areas are the focus of this activity, samples may be collected from other areas, particularly the Funeral Mountains (fig. 1-5), and ages determined using the techniques discussed above for background and as a basis for comparison. Ages of mineral species other than those specified above may also be determined if, during the course of the investigation, it is considered necessary in order to achieve the goals of the activity. Other dating methods may also be employed, using standard procedures and techniques.

3.5.2 Test methods and procedures

This activity will use current, standard geologic and geochronologic procedures for locating, collecting, and determining numerical ages of geologic materials through isotopic and chemical analyses. Some of the methods and technical procedures to be employed in this activity are listed on table 3-1;l all are described by Geyh and Schleicher (1990).

3.5.3 Quality assurance requirements

See section 3.1.3.

3.5.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, and precision have been specified for this activity.

Sample locations will be plotted within about 1 mm on topographic maps or and (or) aerial photographs at scales ranging from 1:12,000 to 1:100,000, hence, within about 12 to

100 m on the ground depending on the scale of the base material being used. Accuracy of numerical age determinations of geologic materials of unknown age and (or) thermal history cannot be determined because of lack of independent age control. Precision given with numerical age determination by the fission-track methods generally are within 5 to 20 percent of the indicated age, depending on the particular age involved and the conditions of the sample; other methods and materials must be evaluated in terms of the findings.

3.5.5 Range of expected results

Numerical ages of geologic materials from the core complex and from Bare Mountain are expected to correspond with geologic time periods ranging from the Jurassic to Quaternary. Hornblende is likely to yield K-Ar or Ar-Ar ages within the ranges of the Mesozoic and early Cenozoic Eras. Muscovite and biotite are likely to have cooled through their respective blocking temperatures during late Tertiary uplift, thus are likely to yield K-Ar or Ar-Ar ages within the range of the Miocene Epoch. Ages of apatite and zircon should also be set during late Tertiary uplift and denudation, thus zircon is likely to yield fission-track ages within the range of the Cenozoic Era, and apatite is likely to yield fission track ages within the ranges of the late Tertiary and Quaternary Periods.

3.5.6 Equipment

The activity will require equipment as specified in the technical procedures listed on table 3-1 and by Geyh and Schleicher (1990). No additional major equipment is required for this activity. Maintenance and repair of existing equipment, however, may be necessary.

3.5.7 Data-reduction techniques

Standard data-reduction techniques will be used for data generated by the isotopic dating techniques discussed above.

3.5.8 Representativeness of results

The numerical ages generated by this activity are likely to be representative for the minerals on which they are determined and the areas from which the minerals were collected. The degree to which the results are representative for any larger area will depend on the consistency of results from one area to another. Uncertainties are likely to remain because of the complexity of the geologic and thermal histories in the region and the complexity of natural isotopic systems. It may not be possible to calculate exact values for derivative parameters such as uplift rate, but even with large experimental errors, uplift rates determined in this activity potentially will provide a valuable comparison for rates of fault movement determined on the basis of data from Activity 8.3.1.17.4.5.2.

Study 8.3.1.17.4.5: **Detachment faulting at or proximal to Yucca Mountain**

This activity will not extrapolate the information outside of the Bullfrog Hills-Bare Mountain area. It will, however, provide a partial basis for such extrapolations to be done in Study 8.3.1.17.4.12, Tectonic models and synthesis.

3.5.9 Relations to performance goals and confidence levels

See sections 1.2 and 4 for discussions applicable to this section.

4. APPLICATION OF RESULTS

This section indicates where the information obtained in the present study will be used in other studies. The description is summarized from information that appears in the Site Characterization Plan. Related discussions in section 1.2 consider the uses of information from the study in the context of issue resolution and performance goals.

Information from this study will be used both in the preclosure tectonics program (Program 8.3.1.17) and the postclosure tectonics program (Program 8.3.1.8). Figures 1-2 and 1-3 and table 4-1 show what information from the study will be used and how that information will be used in specific studies in those programs. In the following, the discussion of where the information will be used is summarized from the SCP discussion of each activity.

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

- to supply data requirements needed 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 (Study 8.3.1.17.3.1); and
- to evaluate the possibility that one or more detachment faults are present in the subsurface below or in the vicinity of proposed repository site; if considered likely, to evaluate (1) the direction and rate of movement of the upper plate, (2) the depth and configuration of fault surfaces, (3) the nature of the association, if any, between the detachment fault(s) and the normal faults in the upper plate, and (4) the possibility that major through-going faults could be concealed at depth below the upper plate(s) (Study 8.3.1.17.4.12).

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 evaluate the effect of tectonic processes on water table elevation (8.3.1.8.3.2) and ground water travel time (8.3.1.8.3.3) (see fig. 1-3);
- to calculate the number of waste packages that a fault penetrating the repository would intersect (8.3.1.8.2.1.2);
- to summarize and evaluate data on slip rates in and near the controlled area (8.3.1.8.2.1.3); and

- to estimate slip rates, recurrence intervals, and possible cumulative offset in 10,000 years on Quaternary faults in and near the controlled area (8.3.1.8.3.1.3).

In the mineral resource assessment study (8.3.1.9.2.1) information from this study will be used to evaluate the possibility that mineralization is associated with detachment faults as noted by Maldonado (1989) in the Bullfrog Hills area.

5. SCHEDULE AND MILESTONES

The schedule and milestones for this study are shown on figure 5-1. This information is abstracted from the most current and complete project schedule network.

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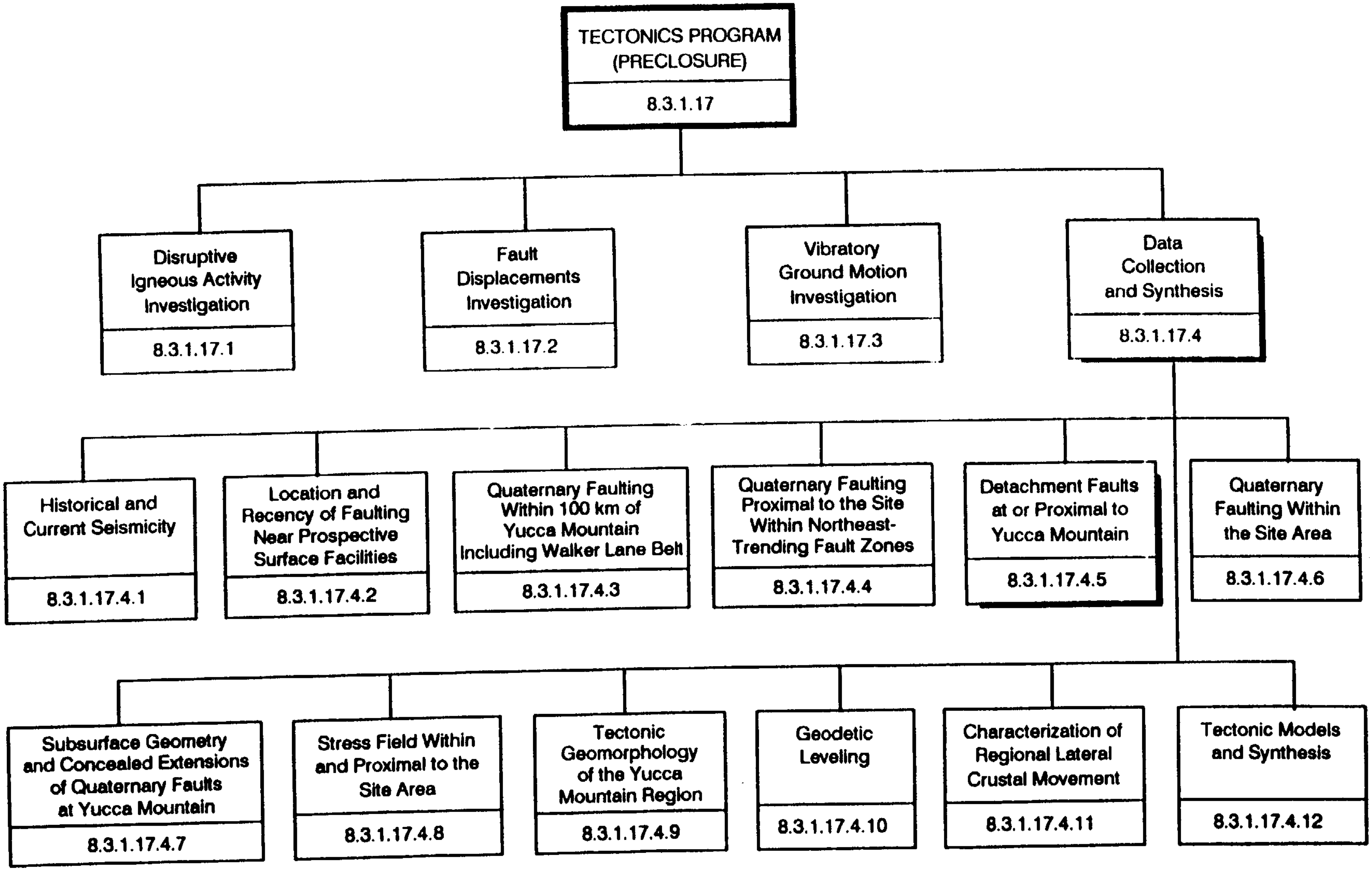
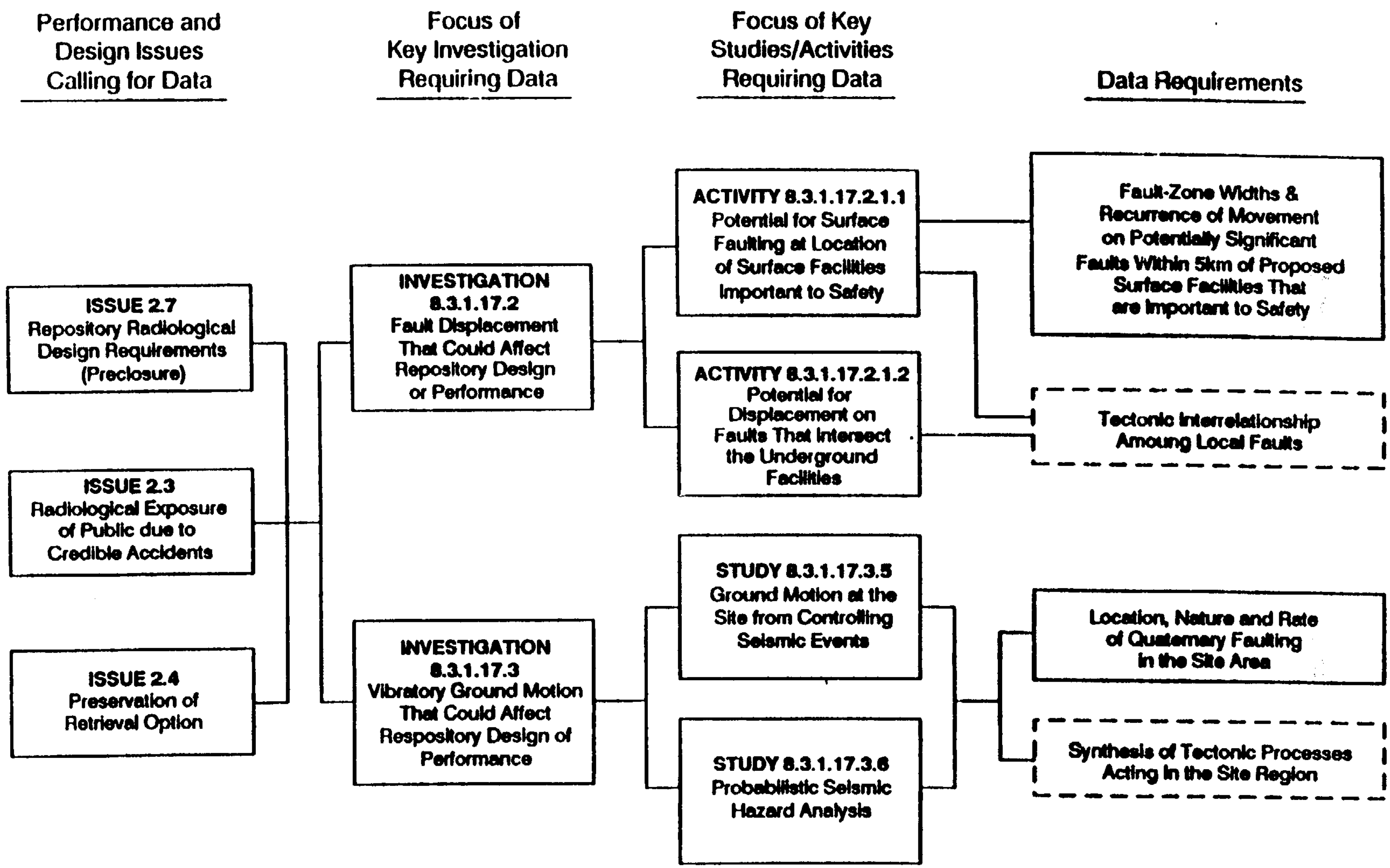


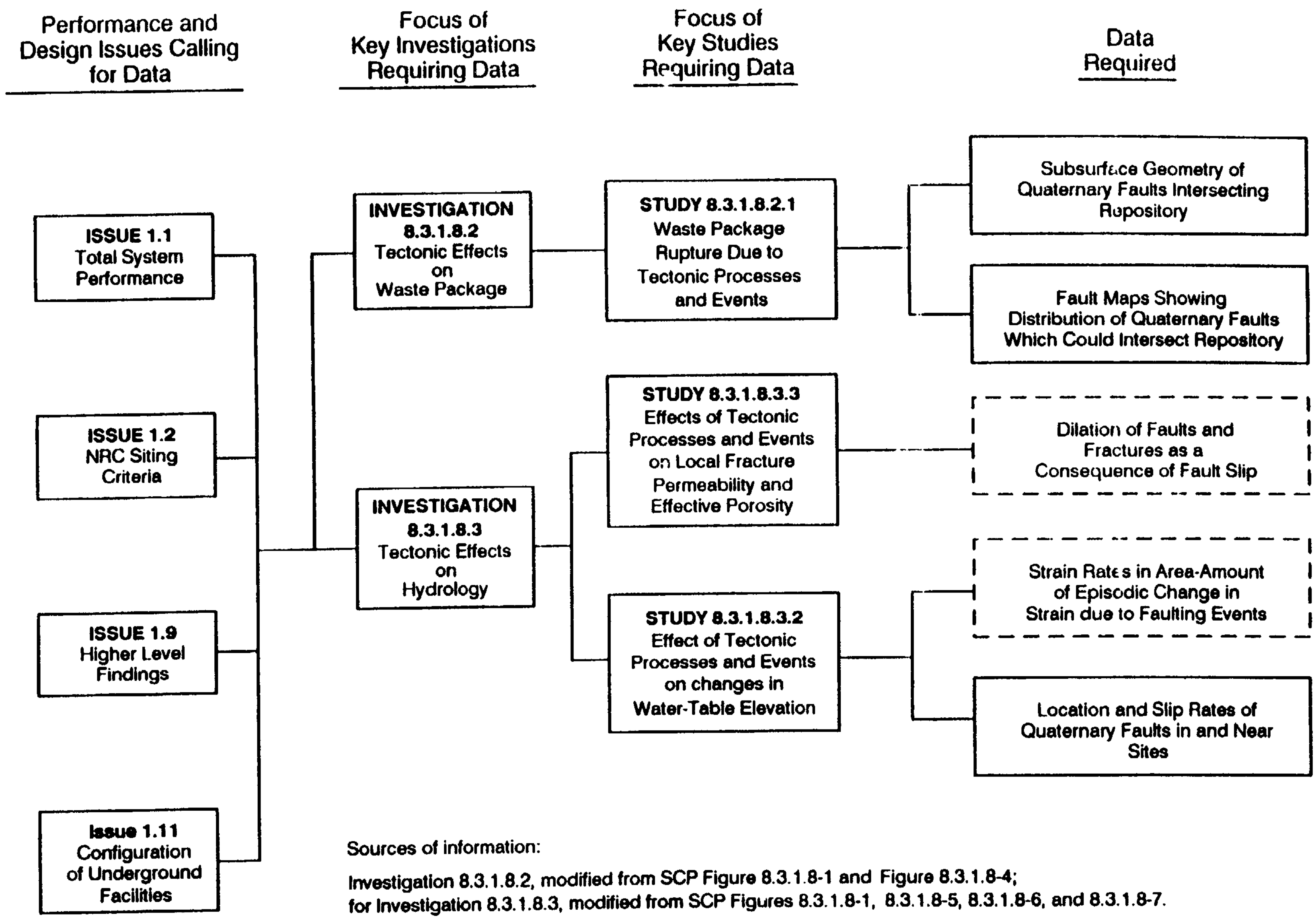
Figure 1-1.--Relation of Study 8.3.1.17.4.5 to the preclosure tectonics program.



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 8.3.1.17.4.5 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 8.3.1.17.4.5 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).

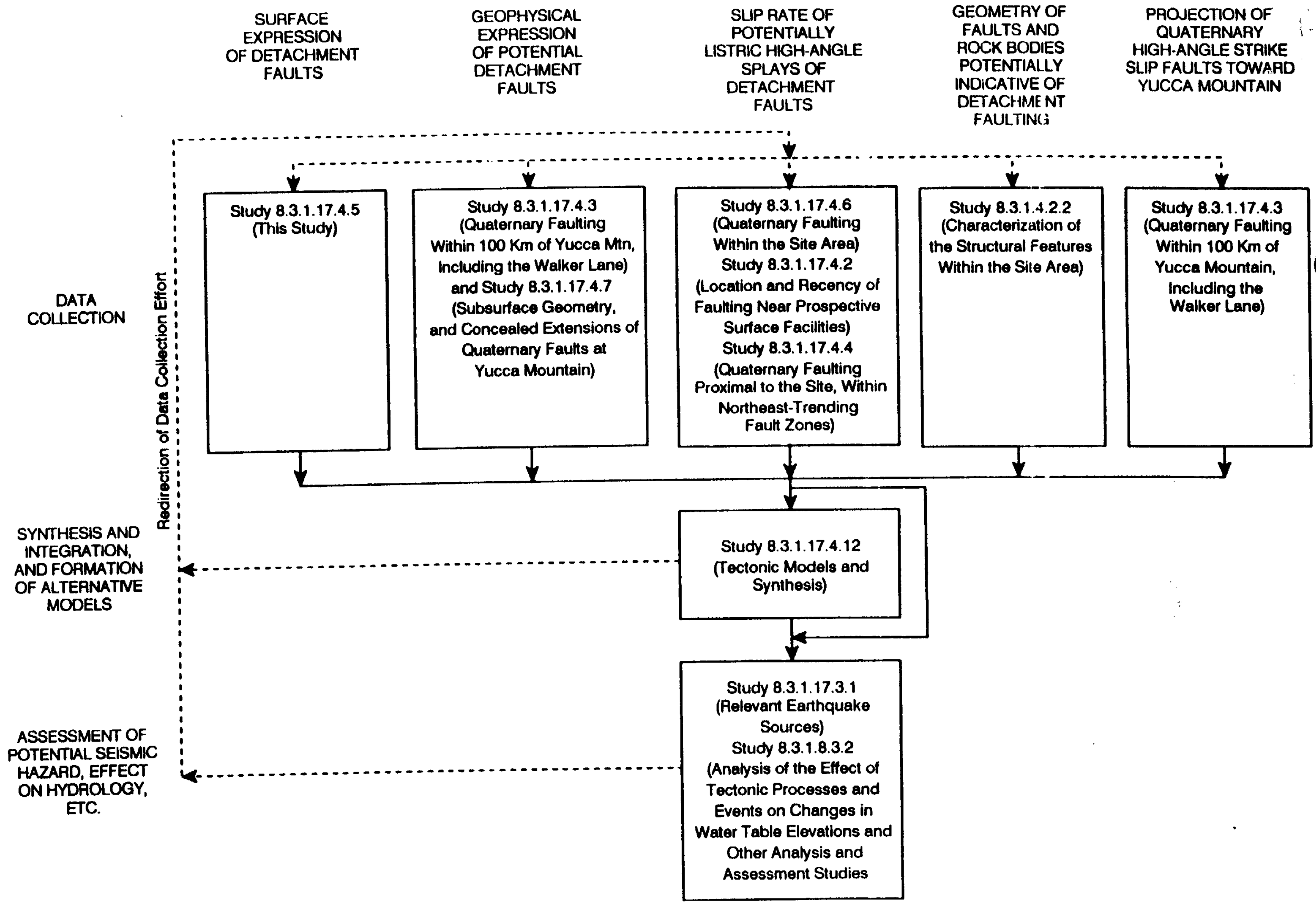


Figure 1-4. Flow chart showing strategy to characterize detachment faults at and proximal to Yucca Mountain.

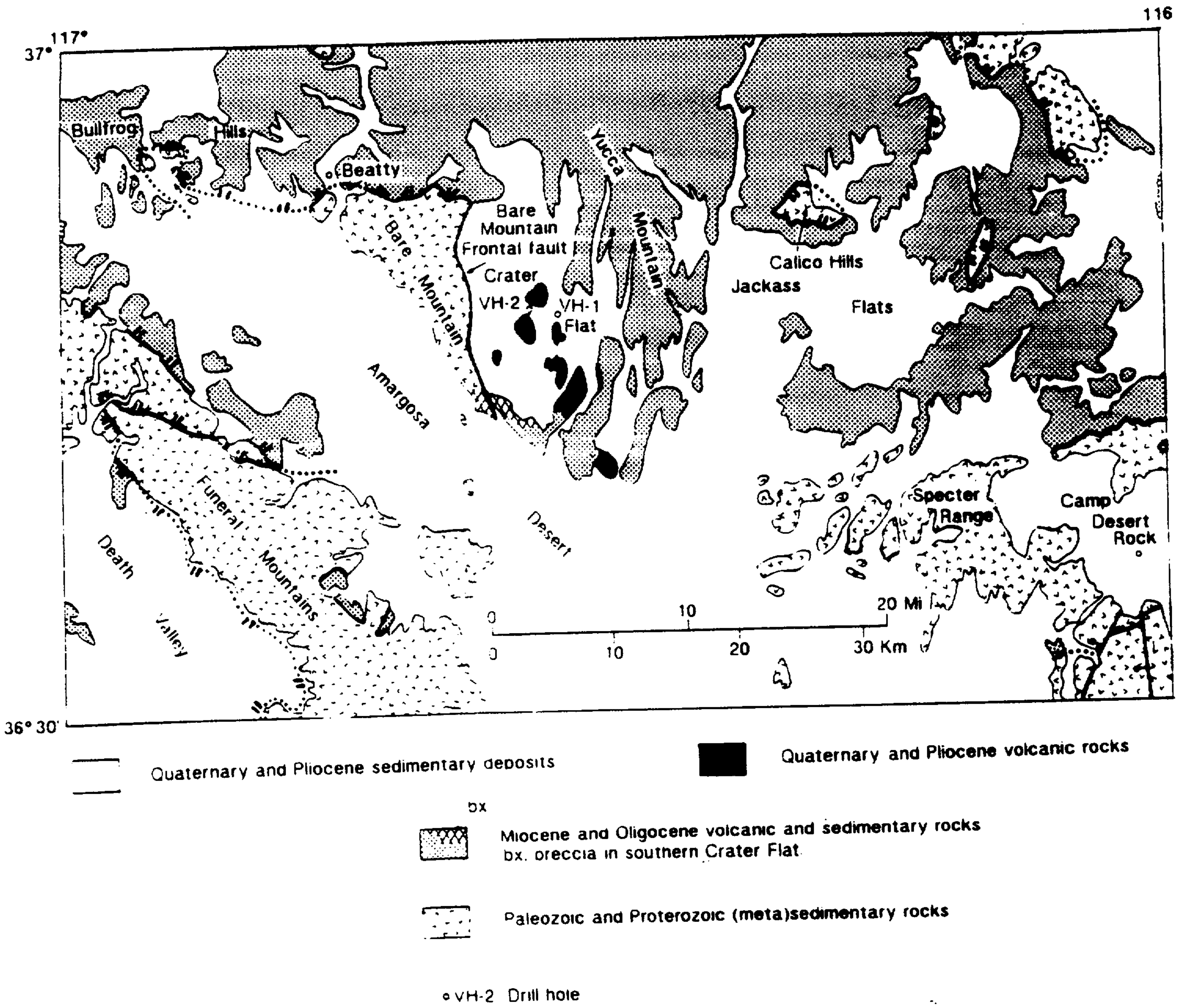


Figure 1-5. Generalized geologic map of the Beatty 30x60-minute sheet showing mapped and inferred detachment faults. Faults which are widely accepted as detachment faults are shown by heavy lines with double hachures. Correlation of these faults across concealed intervals and their subsurface extent and geometry are controversial and a focus of numerous geologic and geophysical studies. The Tertiary-Paleozoic contact is interpreted everywhere as a detachment fault by some geologists; this contact is shown by a heavy line.

		TECTONIC PROCESS		
		Uplift and Subsidence	Faulting	Folding
Quaternary	Contemporary and Historical Time	Study 8.3.1.17.4.10 (Geodetic Leveling)	Study 8.3.1.17.4.10 (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 8.3.1.17.4.11 (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 1-6 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 (extensional) 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 recognized 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)	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)	Study 8.3.1.17.4.5 Detachment faults at or proximal to Yucca Mountain) [This study]

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

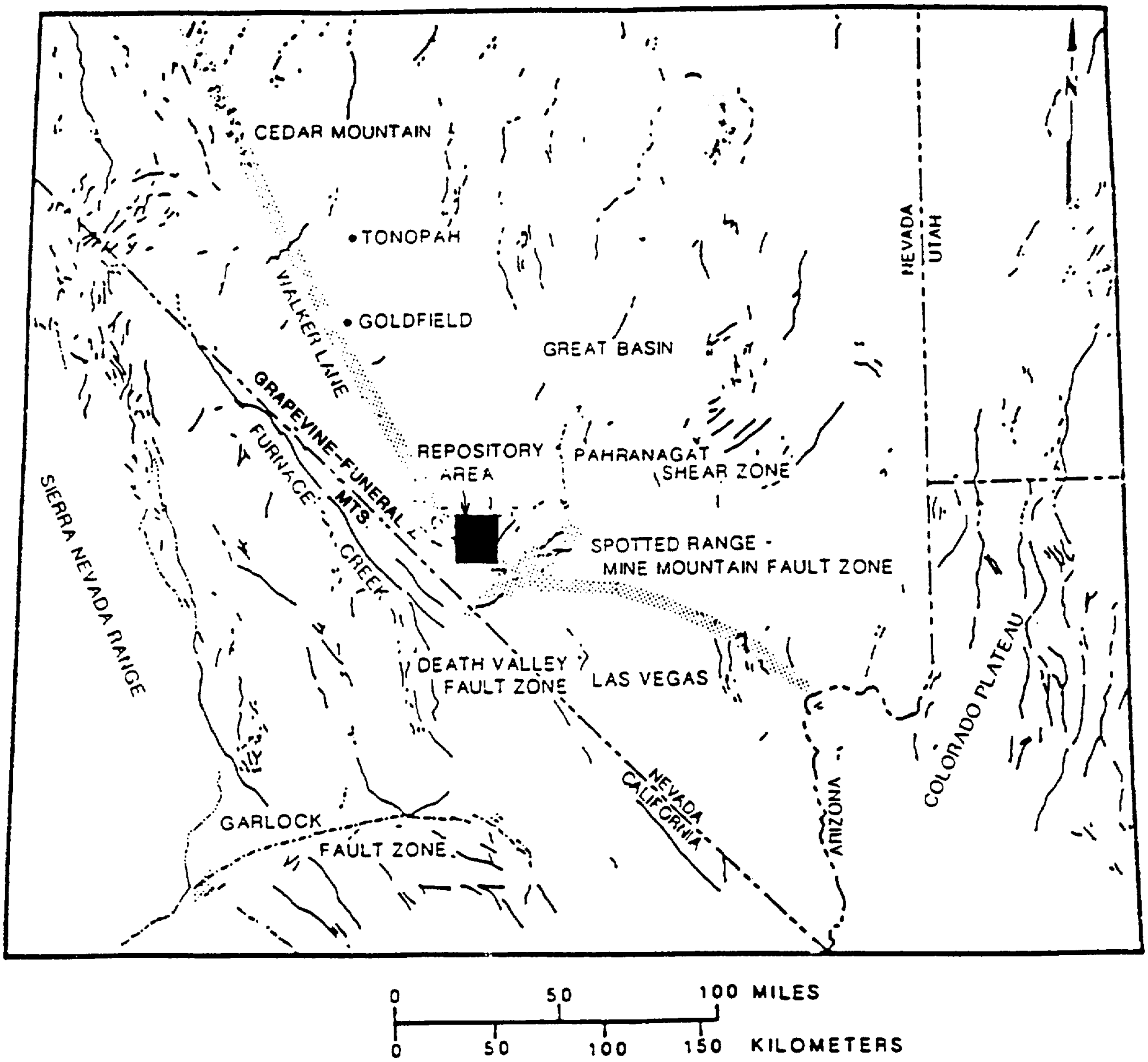


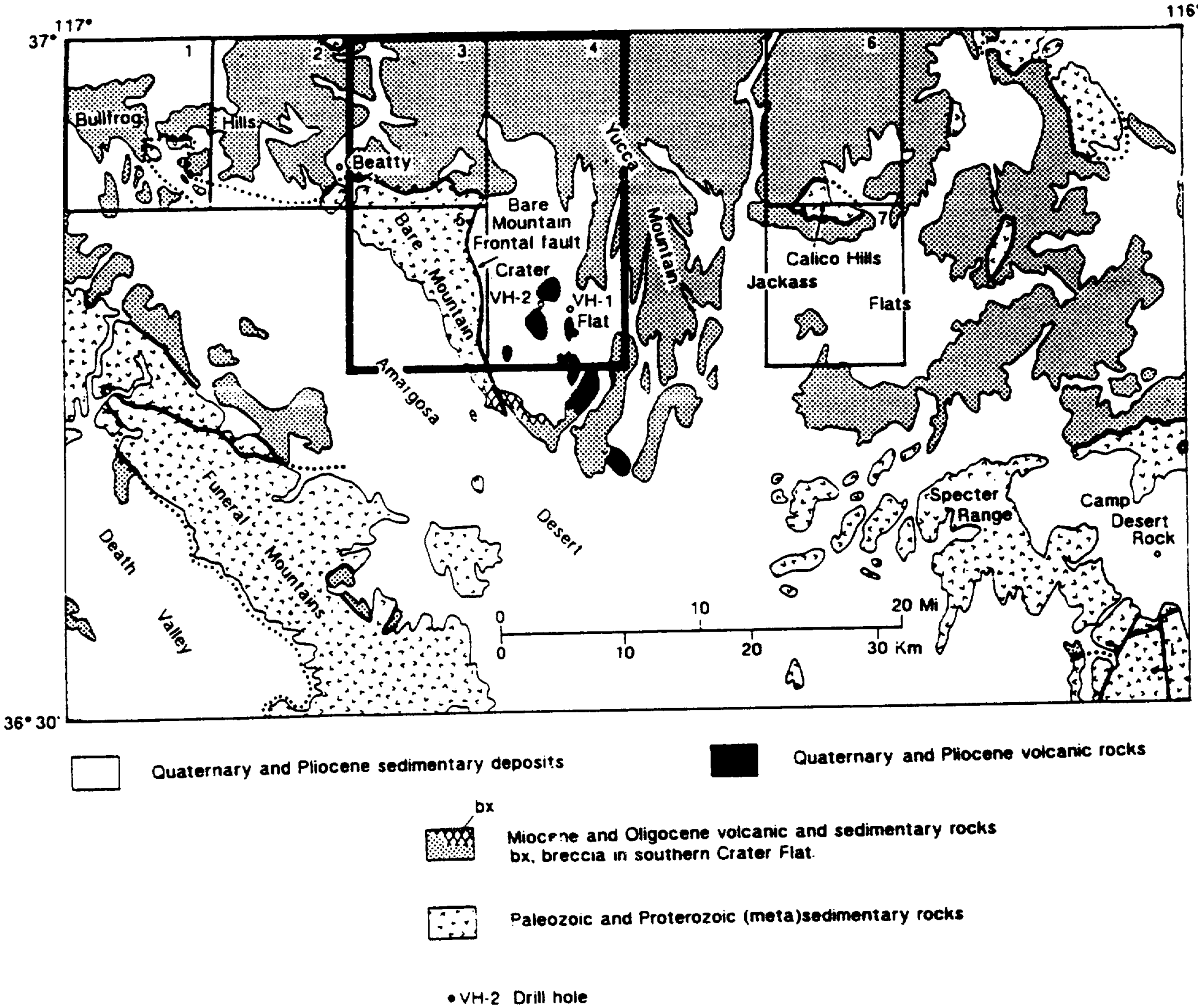
Figure 2-2. Regional structure map, showing location of major structural features.

Area (and designated study(ies))	REQUIRED INFORMATION: 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)	No	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 2-3 Information on faulting required within the proposed site of surface facilities in Midway Valley, the Site Area, and the area within 100 km of Yucca Mountain

Area of Study	REQUIRED INFORMATION ON DETACHMENT FAULTING				
	Age in subsurface of Site Area		Geometry in subsurface of Site Area		Strike-slip faults concealed in subsurface of the Site Area
	Inferred from age at outcrop	Inferred from geometry of intersection with known faults	Inferred from surface expression of detachment	As constrained by geophysics	Projections of surface trace of Quaternary strike slip faults toward site area
Site Area (including Midway Valley)	No detachment identified at surface in site area	Study 8.3.1.17.4.7 (Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain)	No detachments identified at surface in Site Area	Study 8.3.1.17.4.7 (Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain)	Lower plate not exposed in Site Area
Area within 100 km of Yucca Mountain exclusive of site area	THIS STUDY (Study 8.3.1.17.4.5: Detachment faults at or proximal to Yucca Mountain)	Activity 8.3.1.17.4.3.1 (Conduct and evaluate deep geophysical surveys in an eastwest transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane belt)	THIS STUDY (Study 8.3.1.17.4.5: Detachment faults at or proximal to Yucca Mountain)	Activity 8.3.1.17.4.3.1 (Conduct and evaluate deep geophysical surveys in an eastwest transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane belt)	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 zone)

Figure 2-4 Strategy for obtaining information necessary to evaluate potential effects of detachment faulting on source and magnitude % ground shaking due to earthquakes, and to evaluate potential effects of detachment faulting on hydrology



1. NW 1/4 Bullfrog Hills, Nev.-Calif. 15-minute quadrangle
2. NE 1/4 Bullfrog Hills, Nev.-Calif. 15-minute quadrangle
3. Beatty Mtn., Nev. 7 1/2-minute quadrangle (NW 1/4 Bare Mtn., Nev. 15-minute quadrangle)
4. Bare Mtn., Nev. 15-minute quadrangle (outlined in bold)
5. SW 1/4 Bare Mtn., Nev. 15-minute quadrangle
6. Topopah Spring, Nev. 7.5-minute quadrangle
7. Jackass Flats, Nev. 7.5-minute quadrangle

Figure 2-5. Index map showing boundaries of USGS topographic quadrangles.

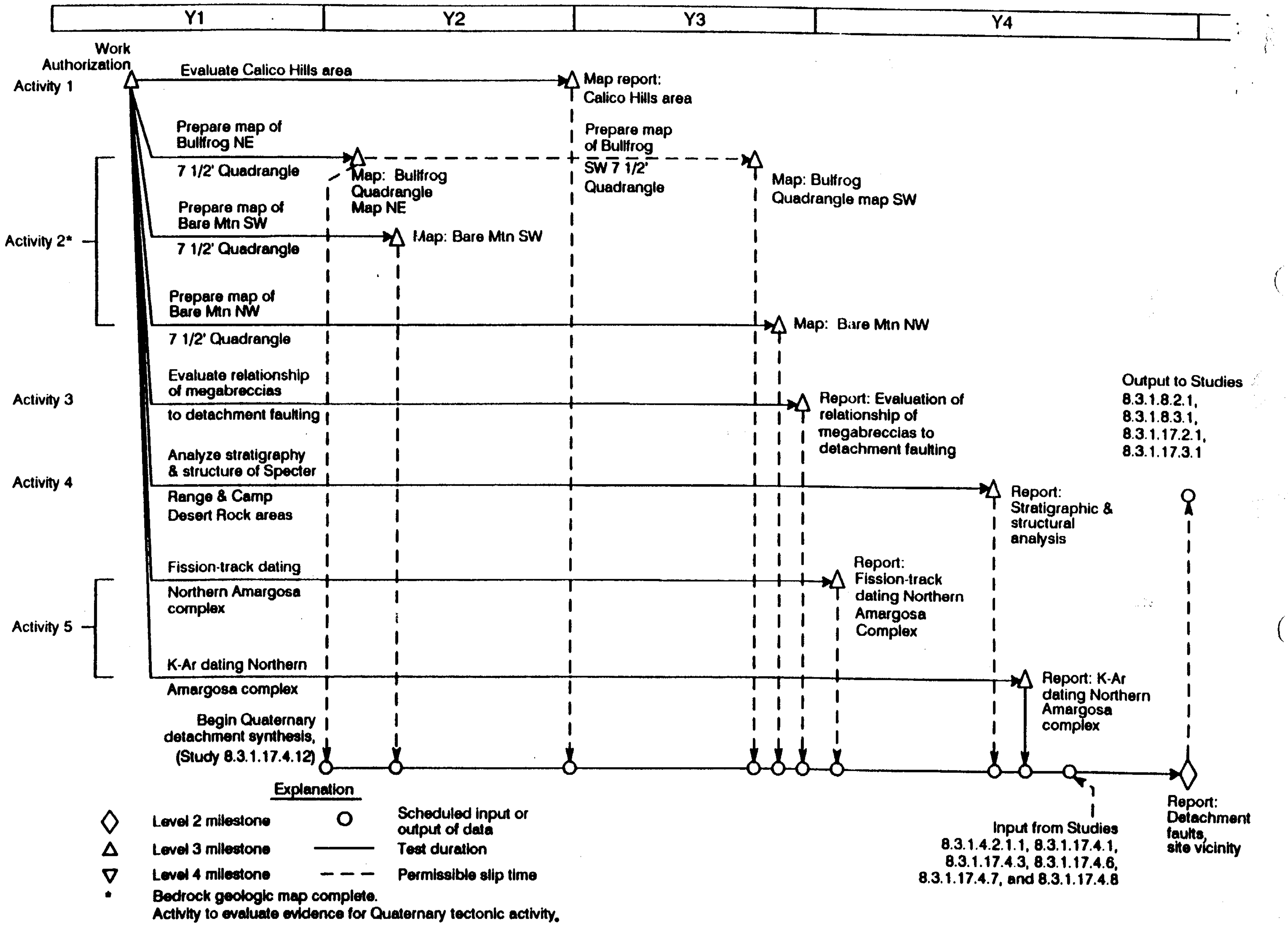


Figure 5-1. Schedule for Study 8.3.1.17.4.5

Table 2-1 Information to be provided to Study 8.3.1.17.4.5 by other studies

Information to be provided	Source of information	Use of information
Geometric relationship of detachment faults (as deduced from geophysical studies and drillhole data) to Quaternary high-angle faults	8.3.1.17.4.3.1 8.3.1.17.4.7 8.3.1.4.2.1.1	To evaluate the age and displacement rate of detachment faults
Recurrence rate and displacement history of Quaternary high-angle faults that could merge with detachment faults in the subsurface	8.3.1.17.4.6	To evaluate the age and displacement rate of detachment faults
In situ stress data	8.3.1.17.4.8.4	To evaluate possible decoupling of upper and lower plates
Focal mechanism solutions	8.3.1.17.4.1	To evaluate nature of movement on detachment faults, and differing stress-faulting mechanisms in upper and lower plates

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Study or activity from which information will be obtained:

Activity 8.3.1.4.2.1.1 Surface and subsurface stratigraphic studies of the host rock and surrounding units

Study 8.3.1.4.3.1 Conduct and evaluate deep geophysical surveys in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane

Study 8.3.1.17.4.1 Historical and current seismicity

Investigation 8.3.1.4.6 Quaternary faulting within the site area

Investigation 8.3.1.4.7 Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain

Activity 8.3.1.17.4.8.4 Evaluate theoretical stress distributions associated with potential tectonic settings of the site

(Source of information: SCP, pp. 831.17-144, -145; 8.3.1.4-33)

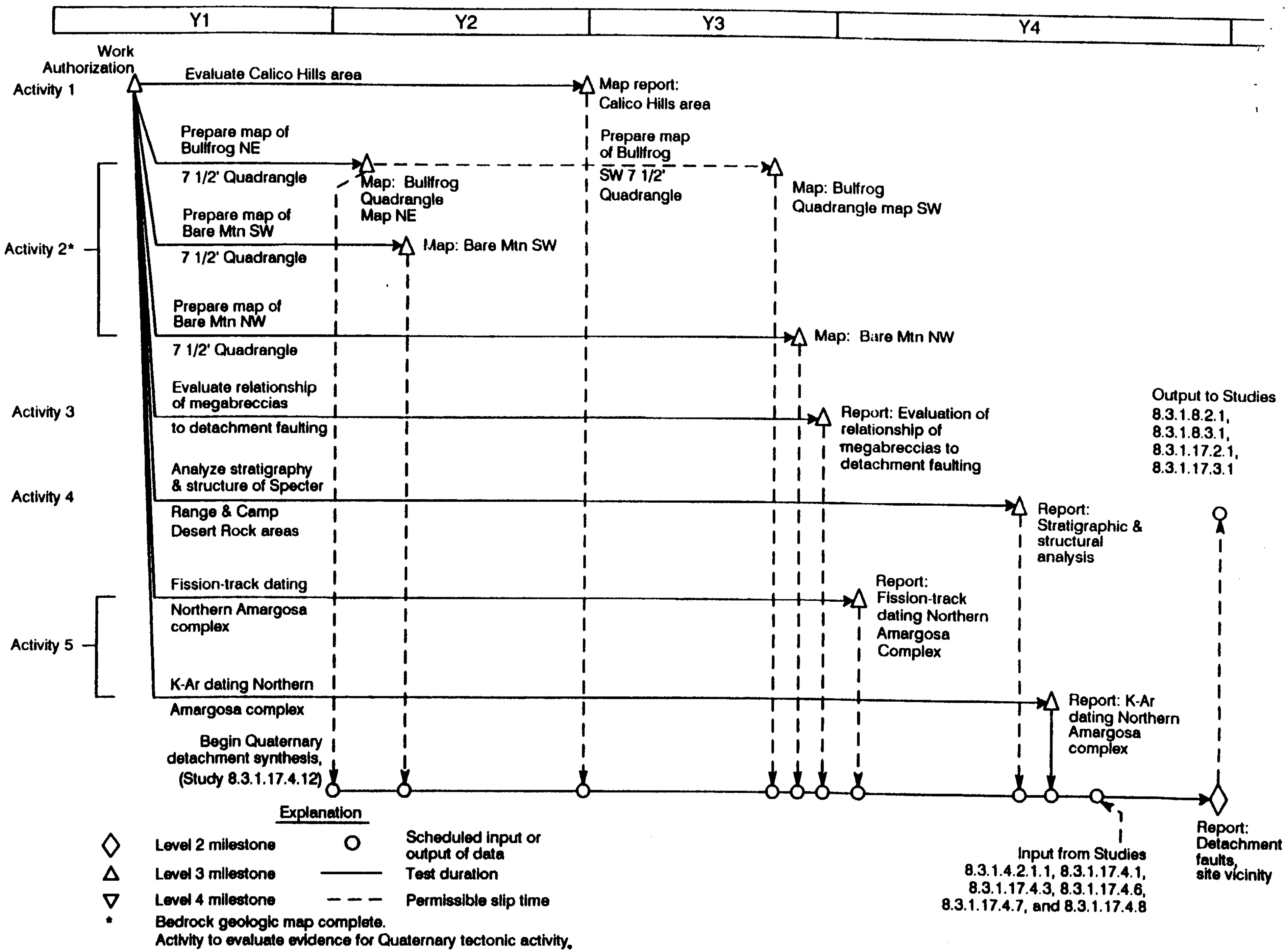

Figure 5-1. Schedule for Study 8.3.1.17.4.5

Table 2-1 Information to be provided to Study 8.3.1.17.4.5 by other studies

Information to be provided	Source of information	Use of information
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Recurrence rate and displacement history of Quaternary high-angle faults that could merge with detachment faults in the subsurface	8.3.1.17.4.6	To evaluate the age and displacement rate of detachment faults
In situ stress data	8.3.1.17.4.8.4	To evaluate possible decoupling of upper and lower plates
Focal mechanism solutions	8.3.1.17.4.1	To evaluate nature of movement on detachment faults, and differing stress-faulting mechanisms in upper and lower plates

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Study or activity from which information will be obtained:

Activity 8.3.1.4.2.1.1 Surface and subsurface stratigraphic studies of the host rock and surrounding units

Study 8.3.1.4.3.1 Conduct and evaluate deep geophysical surveys in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane

Study 8.3.1.17.4.1 Historical and current seismicity

Investigation 8.3.1.4.6 Quaternary faulting within the site area

Investigation 8.3.1.4.7 Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain

Activity 8.3.1.17.4.8.4 Evaluate theoretical stress distributions associated with potential tectonic settings of the site

(Source of information: SCP, pp. 831.17-144, -145; 8.3.1.4-33)

Table 3-1. Methods and technical procedures for Study 8.3.1.17.4.5

Activity	Method	Technical Procedure Number	Technical Procedure Title
		(NWM-USGS-)	
8.3.1.17.4.5.1	Detailed mapping and analysis of suspected tectonic contact between Miocene rocks and Paleozoic rocks in Calico Hills area	GP-01	Geologic mapping
8.3.1.17.4.5.2	Detailed mapping and analysis of Beatty-Bare Mountain area -- Bullfrog NE 7.5' quadrangle	GP-01	Geologic mapping
	Detailed mapping and analysis of Beatty-Bare Mountain area -- Bare Mountain NW 7.5' quadrangle	GP-01	Geologic mapping
	Detailed mapping and analysis of Beatty-Bare Mountain area -- Bare Mountain SW 7.5' quadrangle, plus parts of adjoining quadrangles	GP-01	Geologic mapping
8.3.1.17.4.5.3	Evaluation of megabreccia in and south of Crater Flat	GP-01	Geologic mapping
		GP-02	Subsurface investigations
		GP-04	Structural studies
8.3.1.17.4.5.4	Evaluation of the stratigraphy and structure of the Horse Springs-Pavits Spring sequence in the Specter Range and Camp Desert Rock areas	GP-01	Geologic mapping
		GP-03	Stratigraphic studies
		GP-04	Structural studies
		GP-06	Geodetic, leveling and trilateration surveys

Table 3-1. Methods and technical procedures for Study 8.3.1.17.4.5 (Contd)

Activity	Method	Technical Procedure Number (NWM-USGS-)	Technical Procedure Title
8.3.1.17.4.5.5	Fission-track dating of the Northern Amargosa Desert core complex	GCP-01	Radiometric-age data bank
		GCP-02	Labeling, identification, and control of samples for geochemistry and isotope geology
		GCP-08	Fission-track dating
	Potassium-argon dating of the Northern Amargosa core complex	GCP-10	Radiometric-age data bank
		GCP-02	Labeling, identification, and control of samples for geochemistry and isotope geology
		GCP-06	Potassium-argon dating
	Fission-track and potassium-argon dating of miscellaneous samples supplied by other activities in support of program objectives	TBD *	Fission-track and potassium argon dating of miscellaneous samples supplied by other activities in support of program objectives

* TBD - to be determined

Table 4-1 Information to be provided to other studies by Study 8.3.1.17.4.5

Information to be obtained	Where information will be used[1]	How information will be used
Location, distribution, geometry displacement rate, and age of detachment faults proximal to Yucca Mountain; geologic maps	8.3.1.17.4.12 8.3.1.8.3.2.5	To evaluate the possibility that one or more detachment faults are present in the subsurface below or in the vicinity of the proposed repository site.
		If considered likely, to evaluate the direction and rate of movement of the upper plate, the depth and configuration of fault surfaces, the nature of the association, if any, between the detachment fault(s) and the normal faults in the upper plate and the possiblity that mineralization is associated with detachments.
	8.3.1.17.3.1	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.

USGS-SP-8.3.1.17.4.5, R1

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