U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

STUDY 8.3.1.17.4.5

DETACHMENT FAULTS AT OR PROXIMAL TO YUCCA MOUNTAIN

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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
STUDY PLAN APPROVAL FORM

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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

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Director, Quality Assurance Division / Date

Effective Date: 11/21/94

Exhibit YAP-2.2Q.3

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;

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 deta`hment 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

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 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.

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Study 8.3.1.17.4.5: Detachment faulting at or proximal to Yucca Mountain

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List of Technical Procedures for Study Plan 8.3.1.17.4.5

GP-01	Geologic Mapping
GPC-02	Labeling, Identification and Control of Samples for Geochemistry and Isotope Geology
GPC-08	Fission Track Dating

ENCLOSURE 2