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DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

NATURE AND CONTINUITY OF THE SUNDANCE FAULT, YUCCA MOUNTAIN, NEVADA

Administrative Report

"PRELIMINARY DRAFT"

Prepared in cooperation with the

NEVADA OPERATIONS OFFICE

U.S. DEPARTMENT OF ENERGY, under
Interagency Agreement DE-AI08-92NV10874

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By Christopher J. Potter, Robert P. Dickerson, and Warren C. Day

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Denver, Colorado

1995

DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, Director

ADMINISTFATIVE REPORT

"PRELIMINARY DRAFT"

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Abstract

Detailed geologic mapping (1:2400 scale) of the Sundance fault zone, Yucca Mountain. Nevada, shows that this northwest-striking fault zone can be traced for about 750 m in the northern part of the potential nuclear waste repository area, from Dead Yucca Ridge to Live Yucca Ridge. This study concludes that the Sundance fault zone has a significantly smaller along-strike extent than the 4.5-km (or greater) extent suggested by previous workers. The term "Sundance fault" is applied, in this report, to a northwest-trending fault zone that cuts both the crystal-poor and crystal-rich members of the Tiva Canyon Tuff across Dead Yucca Ridge and the unnamed ridge that lies between Dead Yucca Ridge and Live Yucca Ridge; and to the southeastern continuation of this zone across Live Yucca Ridge where it loses displacement and is less prominent. At its northwest end, the Sundance fault zone appears to terminate abruptly north of Dead Yucca Ridge. The faults in this zone are almost exclusively characterized by northeast-side-down displacement. The maximum width of the Sundance fault zone is about 75 meters and the cumulative northeast-side-down vertical displacement across the fault zone does not exceed 11 m. Significant strike-slip displacement along the Sundance fault zone is not suggested by the field relations.

Southeast of the mapped extent of the Sundance fault zone, the Ghost Dance fault can be projected along an essentially straight trend beneath the Quaternary cover in Split Wash (with no apparent offset along the Sundance trend). This contradicts suggestions by previous workers that the Ghost Dance fault is offset in a right-lateral sense across the Sundance fault beneath Split Wash. On the south slope of Antler Ridge near the projected trend of the Sundance fault zone, several northwest striking faults occur over a 170-m-wide area, but they can be mapped only locally in the crystal-poor member of the Tiva and do not appear to be through-going structures.

The Sundance fault zone does not appear to continue north of Dead Yucca Ridge, and faults with the Sundance trend and displacement patterns were not found on the Little Prow. Abundant breccia float on the Little Prow is related to a north-northeasterly trending splay of the Solitario Canyon fault, and to a northwest-striking fault that continues downslope into Drill Hole

Wash and is not on the Sundance trend. A prominent northwest-trending, northeast-side-down fault, previously mapped by Scott and Bonk (1984) cuts both members of the Tiva Canyon Tuff, about 600 m northwest of the Little Prow, but this fault cannot be traced southeast to the Little Prow.

Individual faults in the Sundance fault zone and elsewhere at Yucca Mountain are vertically and laterally discontinuous; one or more mechanisms of strain accommodation must operate in the Tiva Canyon Tuff to accommodate displacements in the rock volume between the discontinuous discrete fault segments. Two probable mechanisms are distributed brittle deformation, associated with diffuse breccia bodies, and minor offsets along numerous pre-existing cooling joints.

Introduction

Detailed geologic mapping of the potential high-level nuclear waste repository site at Yucca Mountain, Nevada, provides valuable data for site characterization and repository design. A rigorous understanding of the geometry, structural style and relative age of faulting is critical for realistic seismic hazard analysis, for specific siting of storage drifts in the repository, and (in conjunction with detailed fracture studies) for development of improved hydrologic models.

This report summarizes geologic mapping within the potential repository along the trace of the northwest-trending Sundance fault system (Spengler and others, 1994) and its proposed continuation to the northwest of the potential repository (fig. 1). In this report, the term "Sundance fault zone" is used, rather than "Sundance fault system," because the specific geometric and kinematic relations among the individual fault strands are obscure. Because the Sundance is a recently-discovered fault zone whose age and extent were unknown prior to this study, it is critically important to document its length and to evaluate possible cross-cutting relations with known or suspected Quaternary faults. These findings affect the calculation of seismic moment associated with a hypothetical Sundance earthquake and the evaluation of the likelihood of fault rupture of the repository. During the Spring of 1995, we mapped a 4-km-long, 565-m-wide northwest-trending swath at a scale of 1:2400 (Plates 1, 2 and 3 together comprise this continuous strip map). The study focused on characterization of the geometry and continuity of northwest-trending faults in the Sundance fault zone, and any faults that may intersect the Sundance fault zone.

This work was performed in response to a request by the Department of Energy for a 1:2400-scale map and letter report that address the geometry and continuity of the Sundance fault, along a 1,500 ft wide northwest-trending corridor from Antler Ridge to "1000 ft northwest of the Solitario Canyon fault." Because the work scope was defined by geographic boundaries that are not necessarily tied to the Sundance fault zone, we mapped numerous faults that have no apparent relation to the Sundance fault zone, particularly in the northwestern part of the map area. Although the work request specifies that "selected stratigraphic units will be locally ... mapped" in order to characterize the structure of the study area, our strategy was to produce a nearly complete geologic map. However, in a few cases, because of poor exposure, several contacts are locally unmapped. In addition, the southeast end of Plate 1 and the northwest end of Plate 3 are beyond the limits of the study area, and the geologic map is less complete in those areas.

Previous Work

The Sundance fault "system" was identified by Spengler and others (1994) as a zone of near-vertical, N30°-40°W-trending faults, at least 274 m wide, within the northern part of the potential repository area at Yucca Mountain. Many of the faults within the Sundance "system" exhibit minor amounts of northeast-side-down offset, and Spengler and others (1994) also inferred significant components of dextral strike-slip offset. In fact, Spengler and others (1994) suggested that the Ghost Dance Fault was offset in a dextral sense along the Sundance fault system by about 50 m.

C.A. Braun and L.G. Martin (Science Applications International Corporation, written communication, 1995) prepared a detailed 1:480-scale map along the Ghost Dance fault and adjacent parts of the repository block at Yucca Mountain. The northern part of their map overlaps our map (parts of Plates 1 and 2). and in this area we tied our map to the same precise survey control that they established with permanent survey markers on a 200-foot spacing, tied to the Nevada State coordinate system. Braun and Martin (Science Applications International Corporation, written communication, 1995) mapped the Sundance fault on the south flank of Live Yucca Ridge, based principally on a 1-meter wide northwest-trending breccia zone. They inferred the presence of the Sundance fault beneath Quaternary cover in Split Wash, and mapped a 6-m stratigraphic offset along the Sundance fault on the southeast flank of Antler Ridge. In addition, they mapped numerous minor northwest-trending faults within 150 m of the proposed Sundance fault; these are the faults included in the "Sundance fault system" of Spengler and others (1994).

As originally proposed by Spengler and others (1994), the Sundance fault system was about 1.5 km long, extending from southeast Antler Ridge, across Split Wash to Live Yucca Ridge. They suggested that it may continue an unspecified distance to the southeast and northwest, based on observations of structural lineaments, "concentrations of brecciated rock", and other northwest trending fault sets. On the basis of geologic reconnaissance, C.A. Braun and L.G. Martin (Science Applications International Corporation, written communication, 1995) reported that the Sundance fault could be traced for at least 4.5 km, from the southeast flank of Antler Ridge, across the northern part of the repository area, and into a northwest -trending fault mapped by Scott and Bonk (1984) between the Little Prow and the Prow of Yucca Mountain. Scott and Bonk (1984) did not map the Sundance fault, but they used aerial photographs to infer several northwesterly fracture trends that comprise a 750-m-long feature across Live Yucca Ridge just west of the Ghost Dance Fault, and across the three ridges to the north (including Dead Yucca Ridge and the two unnamed ridges that flank it). This feature corresponds in part to the Sundance fault as defined by Spengler and others (1994).

Map Units

The bedrock in the map-area is entirely within the 12.7 Ma Tiva Canyon Tuff (Sawyer and others, 1994). We employed map units that are based on the revised stratigraphic nomenclature (Buesch and others, in press; Geslin and others, 1995) and are, in general, separated by boundaries that can be mapped at 1:2,400. Plates 1-3 indicate the correlation between our map-units and those of Buesch and others (in press).

Map-units used here in the crystal-poor member of the Tiva Canyon (lower nonlithophysal, lower lithophysal, middle nonlithophysal, upper lithophysal) are similar to zones defined in that member by Buesch and others (in press). The vitric zone at the base of the Tiva Canyon is only sporadically present in one part of the map area so it was not mapped here. The middle nonlithophysal map-unit used here (cmn3 on Plates 1-3) corresponds to the upper subzone (pmn3) of the middle nonlithophysal zone (Buesch and others, in press; Geslin and others, 1995) . The lower lithophysal map-unit in this report includes the lower lithophysal zone as well as the two lower subzones of the middle nonlithophysal zone as defined by Buesch and others (in press). An "upper lithophysal - middle nonlithophysal - undifferentiated" map-unit is used in the northwestern part of the map area (Wren Wash , Diabolus Ridge, Little Prow area), as it is extremely difficult to recognize the contact between the middle nonlithophysal and upper lithophysal zones there (because of the abundance of lithophysae in the upper part of the middle nonlithophysal zone in this area). Although the identity of map-units in the crystal-poor member are largely based on the presence or absence of lithophysae, which are a secondary feature, the contacts between the map units are continuous smooth surfaces that are amenable to geologic mapping.

Map-units in the crystal-rich member of the Tiva Canyon correspond to four subzones (crystal-transition, mixed-pumice, pumice-poor, vitrophyre) defined within that member (Buesch and others, in press; Geslin and others, 1995). The first three of these (map-units cr1, cr2, and cr3; Plates 1-3) are primary depositional units, in contrast to the zones of the crystal-poor member, which are based on secondary features. The base of each of these three depositional units (cr1, cr2, and cr3) is a gradational contact. However, straightforward mesoscopic criteria can be applied to the bases of the mixed-pumice and pumice-poor subzones, so that those contacts can be accurately identified within one meter, where it they are well-exposed in the field. The base of the crystal-transition subzone is somewhat more difficult to pinpoint, as it is characterized by a more gradual gradation and usually requires the use of a hand lens, but where it is well exposed, it can be accurately identified within one to two meters. Where outcrops are not plentiful, placement of these contacts is less accurate.

General Results of the Geologic Mapping

This study was conducted to test a hypothesis that a single through-going northwest-trending "Sundance fault system" occupies the map area. Although the geologic mapping revealed numerous faults within the map-area (Plates 1-3), a continuous zone of northwest-trending faults that cut both the crystal-poor and crystal-rich members of the Tiva Canyon Tuff could be traced for only 0.5 km along strike, crossing Dead Yucca Ridge and the unnamed ridge (informally named "Purgatory Ridge" in this report) that lies between Dead Yucca Ridge and Live Yucca Ridge (Plate 2). The faults in this zone are almost exclusively characterized by northeast-side-down displacement. The maximum width of this zone is 75 meters and the cumulative northeast-side-down vertical displacement across the fault zone does not exceed 11 m. The term "Sundance fault zone" is applied herein only to the zone where both the crystal-poor and crystal-rich members of the Tiva Canyon Tuff are displaced by faults, and to fault strands directly along strike where displacement is diminishing. By this definition, the Sundance fault zone extends from Dead Yucca Ridge to the south flank of Live Yucca Ridge, and is about 750 m long, considerably shorter than the "Sundance fault system" proposed by Spengler and others (1994).

Several northwest trending faults occur over a 170-m-wide area on the south flank of Antler Ridge to the east of the Ghost Dance fault (Plate 1), but they can be mapped only locally in the crystal-poor member of the Tiva, and do not appear to be through-going structures because they do not cut the crystal-rich member. Thus, although we recognize the presence of minor northwest-trending faults in the ridges to the south of Split Wash, we infer that the southeast extent of the Sundance fault zone lies north of Split Wash, within Live Yucca Ridge. The Ghost Dance fault can be projected along an essentially straight trend beneath the Quaternary cover in Split Wash and is not offset by the Sundance fault zone, in contrast to the conclusion of Spengler and others (1994). Details are discussed in a subsequent part of this report.

The Sundance fault zone does not appear to continue north of Dead Yucca Ridge, and faults with the Sundance trend and displacement patterns were not mapped on the Little Prow (Plate 3). Abundant breccia float on the Little Prow is related to a north-northeasterly trending splay of the Solitario Canyon fault, and to a northwest-trending fault that continues downslope into Drill Hole Wash (not on the Sundance trend). A prominent northwest-trending, northeast-side-down fault, previously mapped by Scott and Bonk (1984) cuts both members of the Tiva Canyon Tuff, about 600 m northwest of the Little Prow, but this fault cannot be traced southeast to the Little Prow.

Sundance fault zone

The Sundance fault zone, as mapped on Live Yucca Ridge, "Purgatory Ridge," Dead Yucca Ridge, and in the intervening washes (Plate 2), displays many of the general characteristics of faulting seen throughout Yucca Mountain. These characteristics include a lack of vertical and lateral continuity of individual fault strands, apparent exploitation of cooling joints by faults, prominent breccia zones that may or may not correlate with mappable stratigraphic displacement, and a general lack of slickenlines or other fabrics that would, if present, aid in kinematic determinations.

The Sundance fault is expressed on the south flank of Live Yucca Ridge as a 0.7-m-wide tabular breccia body that trends 340° (N 20° W), dips vertically, and can be traced in outcrop within the lower lithophysal zone of the Tiva Canyon Tuff for about 9 m up from the base of the slope (Plate 2). Crude subhorizontal corrugations in the scarp of the breccia zone may be interpreted as mullions (Spengler and others, 1994). Higher in the slope, breccia float is common along the projected trend of the breccia zone. Northwest of the breccia zone, the tops of the lower lithophysal and middle nonlithophysal zones are offset in an east-side-down sense by about 1.5 m; we infer that this is the trace of the Sundance fault. This fault projects across a saddle at the top of Live Yucca Ridge; this saddle lies below the base of the crystal-rich member of the Tiva Canyon Tuff. However, the outcrop pattern of the base of the crystal-rich member on either side of the saddle does not require an intervening fault (i.e., an unfaulted cross-section can be drawn across this saddle). Thus, it is not clear that the northwest-trending fault mapped on the south flank of Live Yucca Ridge actually crosses the top of the ridge. This fault is included in the Sundance zone because it projects into the area where the Sundance fault zone is well expressed in the next wash to the north, as described below.

Much of the bedrock on the north slope of Live Yucca Ridge is obscured by colluvial cover, including several large talus fans, so small fault offsets are difficult to map. However, small breccia bodies are present near the projection of the Sundance fault, and one northwest trending breccia zone was mapped at the top of the middle nonlithophysal zone, approximately on trend with the northwest-trending Sundance fault mapped on the south side of the ridge.

Along the Sundance trend, northwest-trending faults exposed on "Purgatory Ridge" cut contacts in the crystal-rich and crystal-poor members, displacing them in a northeast-side-down sense. Low on the south slope of the ridge, four northwest-trending faults define a 70-m-wide fault zone that produces a cumulative 10 m of northeast-side-down displacement of the top of the middle nonlithophysal zone. There is abundant brecciation in this zone. Two of the faults can be traced south across the wash along a 335° trend to the base of the north slope of Live Yucca Ridge, where they displace the top of the middle nonlithophysal zone where it is sparsely exposed through talus. Higher on the south slope of "Purgatory Ridge," two faults, about 8 m apart, produce 7 m of cumulative northeast-side-down displacement of the top of the upper lithophysal zone (base of the crystal-rich member). The more easterly of the two faults is marked by a prominent breccia zone. In the saddle at the top of "Purgatory Ridge," there appears to be just one fault that produces 7-8 m of displacement of the base of the mixed-pumice subzone in the crystal-rich member. This displacement can be mapped on both the north and south sides of the saddle. Lower contacts on the north side of Purgatory Ridge are difficult to map, because the slope is largely mantled by talus, and Sundance displacements mapped in the crystal-poor member on this slope are inferred, based on faults mapped near the top of "Purgatory Ridge" and on the north side of Coyote Wash, which together define a 330° trend.

On the north side of Coyote Wash (south slope of Dead Yucca Ridge), the Sundance fault zone is mapped low in the slope as four faults that comprise a 25-m -wide, northwest-trending fault zone and together produce about 11 m of northeast-side-down displacement of the top of the middle nonlithophysal zone. This contact is sporadically exposed between thick Quaternary deposits here, but the faults can be inferred as the exposed segments of the contact "step up" to the west. At the top of Dead Yucca Ridge, one northwest-striking fault offsets the base of the crystal-rich member by about 8 m (northeast-side-down). If the trend of this fault, mapped high on Dead Yucca Ridge (Plate 2), were continued down the ridge to the south, its projected position would be about 35 m east of the of the east edge of the fault zone mapped low on Dead Yucca Ridge. This is one of the most prominent examples of the discontinuous nature of individual faults within the Sundance fault zone.

The Sundance fault zone does not continue north of Dead Yucca Ridge. On the next ridge to the north, the base of the crystal-poor member is exposed on both sides of a low saddle toward which the Sundance projects. This contact is subparallel to the top of the ridge. The contact projects across the saddle with an easterly dip of 4°-6°, which is consistent with (actually slightly less than) typical dips in this part of Yucca Mountain. Thus, the map pattern appears to rule out any fault displacement in excess of a meter or two across this saddle. No fault was mapped on the south slope of this ridge, although there is a prominent northwest-trending joint set exposed in the upper lithophysal zone on that slope.

We do not recognize the Sundance fault zone south of Split Wash because our mapping does not demonstrate the presence of a through-going, northwest-trending fault zone that cuts both the crystal-rich and crystal-poor members on Antler Ridge (Plate 1). Although several minor northwest trending faults are mapped in the crystal-poor member on the south slope of Antler Ridge, we mapped unfaulted, northeast-dipping contacts at the top of the middle nonlithophysal zone, at the base of the crystal-rich member and at the base of the mixed-pumice subzone across the slope north and northwest of drill hole USW H-4. Braun and Martin (Science Applications International Corporation, written communication, 1995) mapped the Sundance fault on this slope, with about 6 m of northeast-side-down displacement of the base of the crystal-rich member of the Tiva Canyon Tuff, and their 325°-striking Sundance fault projects through a point about 50 m east of drill hole USW H-4 in the wash south of Antler Ridge. The mapping for this report, which was tied to the same survey control pins used by Braun and Martin, indicates that the Sundance fault is not present at this location.

Where the Sundance fault zone is most fully developed, on "Purgatory Ridge" and Dead Yucca Ridge, the fault zone is widest in the middle nonlithophysal zone, and appears to narrow to a single strand in the overlying crystal-rich member. The implications of this unusual structural pattern are discussed in a subsequent part of this report.

Ghost Dance fault zone

A portion of the north-trending Ghost Dance fault zone is exposed in the southern part of this study area on Antler Ridge, Live Yucca Ridge, and "Purgatory Ridge" (Plates 1 and 2). (For a broader discussion of the Ghost Dance fault over its entire mapped extent, see Day and others, 1995). On the south slope of Antler Ridge, the Ghost Dance fault, which herein is considered the fault with maximum displacement within the zone, is exposed near the southwest edge of the map (Plate 1), and is marked by a 1-2-m-wide breccia zone along which contacts have been displaced about 13 m down-to-the west. The fault trends 005° low in the slope, and bends to a 000° (due north) trend in the middle of the slope. A 345° trending fault, which is about 20 m west of the Ghost Dance fault at the top of the ARP-1 pavement (low on the slope), is marked by a prominent breccia zone and produces 3 m of west-side-down offset of the top of the middle nonlithophysal zone. The displacement diminishes upsection; there is about 1 m of displacement of the base of the crystal-rich member and the fault cannot be identified above that contact.

The Ghost Dance fault crosses Antler Ridge to the north of ARP-1, about 110 m east of a pronounced saddle, and produces about 13 m of west-side-down displacement of the base of the crystal-rich member on the north slope of Antler Ridge (Plate 1). However, this fault does not affect the base of the upper lithophysal zone, directly downslope from the footwall cutoff of the base of the crystal-rich member. Fifteen meters to the east, a north-trending fault occupies the middle of the slope and produces about 13 m of west-side-down displacement of the base of the upper lithophysal zone. This latter fault strand has all of the hallmarks of the Ghost Dance fault, including its orientation, the presence of a 1-m-wide breccia zone, and the amount and sense of displacement. The locus of the Ghost Dance fault, therefore, thus "jumps" 15 m to the east on this slope. This relation was originally shown on the unpublished map of Braun and Martin, and the current mapping confirms their findings on the position of the Ghost Dance fault(s) on this slope.

The continuity of the top of the middle nonlithophysal zone beneath the "upper," westerly Ghost Dance fault strand strongly suggests that the Ghost Dance fault is not offset by a younger fault in this location. The two overlapping fault strands probably meet at depth, and are part of an upward-branching Ghost Dance fault system. The abundant breccia float that is present between the two fault tips probably formed in an accommodation zone through which brittle deformation was distributed in the mass of rock between the two fault splays. Alternatively, the Ghost Dance fault may have stepped over along a pre-existing discontinuity such as a northwest-trending cooling joint or a set of closely spaced northwest-trending cooling joints. In such a case, the pre-existing cooling joint would be the site of intense brecciation and dip-slip displacement compatible with the displacement of the Ghost Dance strands.

Sixteen meters east of the "upper," westerly Ghost Dance strand, a northwest-trending fault offsets the base of the crystal-rich member by 5 m (west-side-down). This fault projects into the brecciated area between the two Ghost Dance fault strands, and may be related to the syn-Ghost-Dance accommodation.

In the vicinity of the overlap of the two Ghost Dance strands on the north slope of Antler Ridge, we inferred the presence of several other northeast-and northwest-striking faults. On the Ghost Dance hanging-wall, two northeast-striking faults offset the base of the crystal-rich member by a total of 11 m; these faults are not exposed but are based on careful mapping of the contact where it is sporadically exposed through abundant talus cover. The projected intersection of the main northeast-striking fault with the Ghost Dance fault is covered by a thick talus mantle. We infer that the northeast striking fault merges with the Ghost Dance fault. Because the northeast striking fault has an east-side-down sense of displacement and appears to be confined to the footwall, this fault intersection has the effect of reducing the total displacement across the Ghost Dance fault by about 11 m. This may, in part, explain the decreased displacement observed across the Ghost Dance on the north side of Split Wash.

The northwest-striking faults mapped east of the "lower," easterly Ghost Dance strand are based on offsets of the top of the middle nonlithophysal zone, and are somewhat speculative, as they cannot be traced more than a few meters on the outcrop-poor, talus-covered slope. However, they may merge with the Ghost Dance fault downslope, beneath the covering deposits.

If the northwest- and northeast-striking faults were coeval with the deformation on the main splay of the Ghost Dance fault, these splays may be part of a larger upward-widening ("horsetailing") of the Ghost Dance fault zone. This geometry was documented by Day and others (1995) in the Ghost Dance fault zone to the south in the Whale Back Ridge area and along several smaller faults in the Azreal Ridge area. Unfortunately, the sparse bedrock exposure on the north slope of Antler Ridge along the Ghost Dance fault zone restricts further conjecture.

Low in the north slope of Antler Ridge, the Ghost Dance fault is marked by a persistent 010°-trending breccia zone in an area of sparse outcrop. From there, the Ghost Dance fault projects across Split Wash on a 010° trend, to meet the mapped exposure of the Ghost Dance fault where it cuts the top of the lower nonlithophysal zone (in the footwall) near the base of the south slope of Live Yucca Ridge (Plate 1). Thus we do not support the interpretation of Spengler and others (1994) that the Ghost Dance is offset by 50 m in a right-lateral sense across Split Wash, or the alternative interpretation proposed by Spengler and others (1994), that the Ghost Dance fault steps to the right along a pre-existing northwest-trending structure. A key difference is that Spengler and others (1994) mapped the Ghost Dance fault low on the nose of the ridge that separates the two main tributaries of Split Wash (Spengler and others, 1994, fig. 3). This is a critical "piercing point" for Spengler and others' (1994) interpretation of 50 m of dextral displacement of the Ghost Dance fault by the Sundance fault. Spengler and others' (1994) interpretation of this proposed fault intersection is based on the mapping of Braun and Martin (Science Applications International Corporation, written communication, 1995), who mapped a juxtaposition of the "hackly" and "clinkstone" subzones of the Tiva Canyon Tuff across the Ghost Dance fault in this locality. (Their "hackly" unit spans the boundary between our lower nonlithophysal and lower lithophysal, and their "clinkstone" is roughly equivalent to our middle nonlithophysal unit.) We mapped this proposed fault contact as a normal transition between the two parts of the lower lithophysal zone (from the hackly-fractured part of the unit up into a higher part of the unit that lacks hackly fracture). This transitional nature is well-exposed in cleared pavements nearby at the base of the south slope of Live Yucca Ridge. Additionally, there is no breccia along their proposed Ghost Dance fault (between the tributaries of Split Wash). (Similarly, we do not recognize the proposed stratigraphic break that defines the Sundance Fault nearby on the same slope, on Braun and Martin's map). Because the Ghost Dance fault does not appear to exist on the nose of the ridge separating the two main tributaries of Split Wash, there is no need to invoke any strike-slip displacement of the Ghost Dance fault by a younger fault, or right-stepping of the Ghost Dance fault along an older structure. As stated above, the Ghost Dance fault appears to project beneath the Quaternary cover straight across Split Wash.

On the south slope of Live Yucca Ridge (Plates 1 and 2), the Ghost Dance fault trends due north to slightly west of north and has about 3 m of west-side-down displacement. A second fault, about 12-21 m to the east, strikes 020° and offsets the upper and lower contacts of the middle nonlithophysal unit by 3 m (west-side-down). This latter fault does not appear to continue up or down the slope for any significant distance as a discrete fault. The displacement along the Ghost Dance fault on this slope can be identified by discrete offsets at the base of the middle nonlithophysal map-unit and the base of the crystal-rich member. At the top of the middle nonlithophysal zone, there is no discrete fault displacement, but there is a distinct west-side-down flexure in this contact (with an amplitude of about 3 m) across the breccia zone associated with the main trace of the Ghost Dance fault. At the top of the ridge (Plate 2), the mapped location of the Ghost Dance fault jumps eastward by about 17 m; the two splays do not connect in map view but probably connect at depth. On the north slope of Live Yucca Ridge and on the eastern nose of "Purgatory Ridge", there is about 5 m of west-side-down displacement along the Ghost Dance fault (Plate 2). North of there, the Ghost Dance fault continues beyond the present map area, and displacement diminishes to zero in the Wren Wash vicinity (Scott and Bonk, 1984).

<u>Character of faulting in the southern part of the map area</u>

In addition to the Ghost Dance and Sundance fault zones, we mapped numerous minor faults on Antler Ridge, Live Yucca Ridge, and on the two small ridges that lie between the tributaries of Split Wash (Plates 1 and 2).

On the south slope of Antler Ridge (Plate 1), for 400 m east of the Ghost Dance fault, numerous northwest-striking faults and several north-and northeast-striking faults offset contacts within the crystal-poor member, but do not continue up into the crystal-rich member of the Tiva Canyon Tuff. As stated previously, none of these faults are considered to be part of the Sundance Fault zone, because they do not constitute a continuous well-defined zone. Breccia occurs along many of these faults, and there are also pods of breccia distributed across the slope with no apparent relation to faults. On this slope, we mapped displacement of the base of the crystal-rich member along only one fault in addition to the Ghost Dance fault. However, the base of the crystal-rich member is poorly exposed along most of this slope, so it is possible that there are additional minor concealed offsets (with one meter or less of displacement) of this contact. Stratigraphic throw across the mapped minor faults ranges from 0.3 m to 6 m, with most displacements in the 1-3 m range. Almost all of these faults have a mapped length of less than 50 m and none of them has a mapped length in excess of 100 m. We do not view this as an artifact of poor bedrock exposure. In nearly every case, the limited extent of fault strands are constrained by unfaulted contacts that cross the projected location of known faults that are mapped either upslope or downslope. "PRELIMINARY DRAFT"

The discontinuous nature of faulting requires that fault displacements be balanced by some sort of distributed deformation within the rock mass between the mapped discrete faults. We infer that much of the breccia on this slope (most of which is seen only in float) developed as part of a distributed brittle deformation that operated in concert with the discontinuous discrete faults to accommodate strain in these strata. This deformational style is best seen on Plate 1 near coordinates 762,500 N., 563,350 E. (Nevada State Coordinate System). The field relations in this area are illustrated at a larger scale on Figure 2. There, a small graben is bounded by a northeast-striking and a northwest-striking fault along which the lower lithophysal / middle nonlithophysal contact is offset by 5 m and 7 m of displacement, respectively. Downslope (to the south), the northwest-trending breccia zone appears to truncate the northeast-trending breccia zone (or the northeast-trending zone merges into the northwest-trending zone). Neither the northeast- nor the northwest-trending fault can be traced an appreciable distance upslope. The breccia zone that marks the northeast-trending fault cannot be traced above the base of the middle nonlithophysal unit (in the footwall), and the top of the middle nonlithophysal zone is not offset along the projected trace of this fault. Instead, a northeast-trending fault located 20 m to the west offsets this contact by 5 m. Pods of breccia occupy the middle nonlithophysal unit between the two non-continuous northeast-striking faults; we suggest this is a zone of distributed brittle deformation accommodating the displacement on the two northeast -trending faults. The northwest-trending fault that bounds the west side of the small graben cannot be traced upslope as a single discrete fault, but appears to branch into several smaller northwest-trending splays that offset the top of the middle nonlithophysal zone. Thus, one of the faults bounding this small graben jumps laterally as it moves upsection, via an accommodation zone that exhibits distributed brittle deformation; and the other bounding fault branches into at least three splays upsection. The result is a complex zone of deformation that constitutes an instructive case example of common styles of deformation in the Tiva Canyon Tuff at Yucca Mountain (fig. 2).

Little Prow area.

One of the initial objectives of this study was to evaluate the proposed intersection of the Sundance and the Solitario Canyon faults, just west of the Little Prow. We carefully mapped the Little Prow area and could find no evidence that the Sundance fault crosses Yucca Crest near the Little Prow. Instead, we found that breccias exposed on the Little Prow are related to a pattern of northwest- and northeast-striking faults. Three subzones of the crystal-rich member of the Tiva Canyon Tuff (the mixed-pumice, pumice-poor, and vitrophyre subzones) are distinctive map units on top of the Little Prow; juxtapositions of these three units define the fault patterns mapped in this area on Plate 3. About 165 m north of drill hole UZ-N27 (Plate 3), abundant breccia float litters the surface near the tips of two faults, a northwest-striking fault and a north-northeast-striking fault, that bound a prow-shaped horst.

The northwest-striking fault is identified on the Little Prow by a juxtaposition of the mixed-pumice subzone against the pumice-poor subzone, defining a northeast-side-down sense of displacement. Displacement on the fault dies to the northwest, so that one can walk on the pumice-poor subzone around the fault tip. To the southeast, the fault trends downslope towards Drill Hole Wash; two splays of this fault can be mapped through the base of the mixed-pumice subzone and the base of the crystal-rich member. The cumulative stratigraphic throw across the two fault splays totals 5 m; one of these splays can be mapped farther downslope where it cuts the top of the lower lithophysal zone. There are several west-northwest-striking faults lower on this slope, but the relation of these faults to the longer northwest-striking fault is not clear.

The north-northeast-striking fault is defined on the Little Prow by a juxtaposition of the vitrophyre subzone with the pumice-poor subzone; this fault loses displacement along strike to the north-northeast, and does not continue beyond its brecciated intersection (or near-intersection) with the northwest-trending fault previously discussed. South of that brecciated intersection, the vitrophyre occupies a thin (5-8 m wide) discontinuous strip of outcrop that commonly is bounded on its east side by breccia. The north-northeast-striking fault bounds the east side of the vitrophyre. It is an east-side-down fault that clearly has undergone strike-slip displacement, as it offsets a northeast trending fault by 30 m in a left-lateral sense near the southwest corner of Plate 3. Both of these faults merge with the Solitario Canyon fault west of the map area (fig. 3), so this is a case of one splay of the Solitario Canyon fault cutting another.

The vitrophyre-bounding fault tracks the west side of Yucca Crest for about 800 m (Plates 2 and 3). Southwest of the map area, this fault is identified as one of the principal splays of the Solitario Canyon fault (Scott and Bonk, 1984); it forms the most significant break in the cliff-forming, resistant part of the crystal-rich member on the west-facing slope of Solitario Canyon, producing about 30 m of stratigraphic throw, and merges with the Solitario Canyon fault near the base of the slope. "PRELIMINARY DRAFT"

A third splay of the Solitario Canton fault strikes northeast and intersects the top of the Little Prow at elevation 4850 ft (Plate 3). Displacement dies out near the top of the ridge, such that the pumice-poor subzone is only partially cut by this fault.

The main strand of the Solitario Canyon fault zone crosses the saddle separating the Little Prow (to the southeast) from Ammo Ridge (to the northwest), and produces 21-24 m of west-side-down stratigraphic throw on the southwest-facing slope just south of that saddle. Three hundred meters north of the saddle between the Little Prow and Ammo Ridge, the west-side-down stratigraphic throw on the Solitario Canyon fault is 11 m. By comparison, the east-northeast-trending "splay" discussed above has about 30 m of displacement, on the west-facing slope of Solitario Canyon. It is clear that the northward decrease in displacement on the main strand of the Solitario Canyon fault (evident in Scott and Bonk, 1984) is accomplished, at least in part, as significant components of the displacement leave the main fault strand via northeast-trending splays.

There is a 4-10 - m - wide breccia zone along the main strand of the Solitario Canyon fault in the map area. Abundant brecciated basalt is exposed in an unnamed trench excavated across the Solitario Canyon fault on the Little Prow - Ammo Ridge saddle. On the southwest-facing slope just south of the saddle, brecciated basalt as well as apparently intact, unbrecciated outcrops of basalt occur in the breccia zone. The basalt must have intruded the fault zone, then was brecciated as parts of the fault zone were reactivated. Isotopic ages of correlative basalts are 9-10 Ma (Scott, 1990), and samples of brecciated basalt from the trench on the Little Prow - Ammo Ridge saddle have recently been dated at 10-11 Ma (E. Smith, oral communication, 1995). Thus, the intrusion of these basalts into the fault zone and their subsequent brecciation is consistent with the generally-accepted timing of deformation at Yucca Mountain (e.g., Scott, 1990): largest-magnitude extension between 13 and 11.5 Ma, with displacement on some faults (such as the Solitario Canyon fault) continuing into the Quaternary.

This study included partial geologic mapping of the next ridge north of Ammo Ridge (Plate 3), although this is northwest of the original study area (the northwestern limit of which was defined by the Department of Energy as a point 1000 ft beyond the projected intersection of the Sundance and Solitario Canyon faults). On top of this ridge, 650-700 m northwest of the Little Prow - Ammo Ridge saddle, there is a north-northwest-trending fault that juxtaposes the mixed-pumice and pumice-poor subzones of the crystal-rich member of the Tiva Canyon Tuff. On the southwest-facing slope below the ridge, there appears to be about 18 m of east-side-down displacement of the base of the mixed-pumice subzone, although it is impossible to precisely locate the bases of the mixed-pumice and crystal-transition subzones on the east side of the fault due to limited bedrock exposure on this slope. We mapped 3 m of displacement of the base of the upper lithophysal zone, lower in the slope, along the probable continuation of this fault. Fault displacement on the north-northwest-trending structure appears to diminish rather abruptly to the south on this slope. There are several discontinuous breccia bodies exposed, suggesting the possibility of distributed brittle strain that may have accommodated the displacement mapped on the discrete fault at the top of the ridge.

The north-northwest-trending fault mapped on the ridge north of Ammo Ridge continues to the northwest of the study area, based on the mapping of Scott and Bonk (1984). It is almost certainly a more significant structure, in both extent and offset, than the Sundance fault zone. Its nature and extent will be investigated as part of regional mapping to be carried out by the USGS in the Fall of 1995.

DISCUSSION

The preceding presentation of the geologic mapping emphasizes that east-side-down dip-slip displacements characterize the Sundance fault zone. Spengler and others (1994) discussed east-side down motion on faults in the Sundance fault zone, and suggested that this stratigraphic displacement is associated with dextral strike-slip faulting. The present study produced no firm evidence for strike-slip motion along the Sundance fault zone. No slickenlines were found, and the crude subhorizontal mullion-like structures found near the base of the south slope of Live Yucca Ridge do not constitute compelling strike-slip evidence. On Dead Yucca Ridge and "Purgatory Ridge," where the Sundance fault zone is best developed, the outcrop patterns of the zones of the Tiva Canyon Tuff show that the strata dip easterly to east-southeasterly (Plate 2). With these stratal dips, the northeast-side-down offset along the northwest-striking Sundance fault zone would be inconsistent with dextral strike-slip motion, but such stratal offset could hypothetically be produced by sinistral strike-slip motion. Significant amounts of pure strike-slip displacement could not have occurred in the places (on Live Yucca Ridge and the ridge north of Dead Yucca Ridge) where stratigraphic throw across the Sundance fault zone diminishes to zero; in these places there is a divergence of 30°-45° between the strike of the strata and the strike of the fault zone, so strike-slip motion would have produced stratal displacement. Hypothetically, oblique slip along the Sundance Fault, in the unique direction that lies in the plane of the dipping strata, could be invoked to explain zero stratigraphic throw at the ends of the mapped Sundance fault, but this singular situation is highly unlikely, and there is no evidence for it. We do not interpret a significant component of strike-slip motion on the Sundance fault zone, for the reasons recounted above.

An important theme in the deformation of the Tiva Canyon Tuff at Yucca Mountain, as found in this study, is the discontinuous nature of faulting along minor fault zones such as the Sundance and perhaps even the Ghost Dance, which are not block-bounding structures. A simple comparison of the Solitario Canyon fault and the Sundance fault illustrates pertinent points. The Solitario Canyon fault is one of the principal block-bounding faults of the Yucca Mountain area, and is marked (in the study area) by a breccia zone that is at least 4 m wide. It is a continuous structure that can be mapped for many kilometers, and also has long continuous splays (Christiansen and Lipman, 1965; Lipman and McKay, 1965; Scott and Bonk, 1984). The Sundance fault zone, on the other hand, consists of fault strands that commonly have little lateral or vertical continuity, even on the scale of a single ridge.

The south slopes of "Purgatory Ridge" and Dead Yucca Ridge (Plate 2) provide several examples of the vertical and lateral variability of the geometry of the Sundance fault zone. On both ridges, several fault strands comprise a 25- to 70-m-wide zone at the top of the middle nonlithophysal zone, low on the south-facing slopes. On both ridges, only one fault strand is mapped up into the crystal-rich member at the top of the ridge, but the displacement accomplished by this single strand is somewhat less than the cumulative displacement across the broader fault zone that cuts the top of the middle nonlithophysal zone.

These map patterns along the Sundance fault zone exemplify a stratigraphically-controlled faulting style. A zone of discrete, discontinuous faults affects a broader area in the crystal-poor member than in the overlying crystal-rich member of the Tiva Canyon Tuff. This geometry appears to contrast with the upward-splaying, or "horsetailing" pattern commonly observed along the Ghost Dance fault zone (Day and others, 1995), yet we emphasize that the upward-splaying geometry along the Ghost Dance fault zone is documented within the crystal-poor member of the Tiva Canyon Tuff. The upward-splaying geometry along the Ghost Dance fault zone may not continue up through the crystal-rich member. In this study, only one strand of the Ghost Dance fault was mapped in the crystal-rich member of the Tiva Canyon Tuff across the tops of Antler Ridge and Live Yucca Ridge. Thus, both the Sundance and Ghost Dance fault zones may be characterized by a similar stratigraphic control of faulting style.

This stratigraphic control of faulting reflects a fundamental contrast in strength between the crystal-rich and crystal-poor members of the Tiva Canyon Tuff. Because the Sundance fault zone is wider, with more individual faults, in the crystal-poor member relative to the crystal-rich member, the crystal-poor member appears to have been less competent (weaker). Such a strength contrast may be related to inherent physical properties, as measured in experimental deformation of unjointed samples, or it may be related to mesoscopic characteristics, such as the number and distribution of cooling joints, which were produced before significant tectonism affected the welded tuff. The available experimental data suggest that the sampled zones of the crystal-poor member (cll, cmn, cul) and the crystal-transition subzone (cr1) at the base of the crystal rich member have significantly greater tensile and ultimate strengths than the overlying subzones (cr2, cr3) of the crystal rich member (Boyd and others, in press). However, we observe a greater abundance of cooling joints (which have preferential northwest and northeast-striking orientations) in the crystal-poor member than in the crystal-rich member. Thus we attribute the broad distributed deformation of the crystal-poor member to the availability of pre-existing cooling joints in that member for exploitation by the Sundance fault zone. We attribute the narrower, more restricted deformation in the crystal-rich member to the lower frequency of cooling joints there.

The lack of vertical continuity for individual fault strands through the different stratigraphic levels requires a mechanism for lateral accommodation of strain in the Tiva Canyon Tuff. The accommodation probably occurred in a distributed fashion along locally exposed, gently-dipping breccia zones that acted as zones of decoupling (fig. 4). As such, the faulted crystal poor member exhibits numerous irregular small blocks that have slipped and/or rotated along pre-existing joints and synkinematic breccia zones. In contrast, the relative paucity of cooling joints in the overlying crystal rich member has confined the offset to a fewer number of discrete faults between larger, undeformed blocks (fig. 4).

The most striking contrast in deformational styles of the crystal-rich and crystal-poor members is present where faults cut the crystal-poor member but no faults can be mapped through the overlying crystal-rich member. The best example is on the south slope of Antler Ridge, where numerous northwest-striking faults (and a few north- and northeast-striking faults) produce minor offsets in the top and bottom of the middle nonlithophysal unit (Plate 1). The cumulative displacement due to minor faults offsetting the top of the middle nonlithophysal zone is 13 m (east-side-down) across a 210-m-wide domain east of the Ghost Dance fault. In this domain, a single mapped fault produces 2 m of west-side-down displacement of the base of the crystal-rich member. The degree of resolution afforded by the spotty outcrop control allows the possibility of several unmapped faults with 1-2 m displacement of this contact; however, no mapped faults cut the better-exposed base of the mixed-pumice subzone near the top of the slope. As discussed previously, the discontinuous nature of faulting on this slope requires lateral accommodation of strain, probably by distributed brittle deformation manifested by diffusely-distributed breccia zones in the upper part of the crystal-poor member (upper lithophysal zone). Because discrete faults do not appear to continue up through the crystal-rich member on this slope, the crystal-rich member must be draped above the faults that cut the lower part of the section. Perhaps because of a relative scarcity of cooling joints in the crystal-rich member, it behaved as a competent beam that resisted faulting, and in this case simply was gently tilted above the fault blocks that affect the lower units. Such tilting above dominantly northwest-striking faults may account for the northeasterly dip that characterizes these units on Antler Ridge.

Lateral accommodation of displacement is required in places where the Sundance fault zone appears to "jump" across strike. An example is on Dead Yucca Ridge, where the position of the fault on the ridge top is 35 m east of the projected trace of the east edge of the fault zone mapped near the base of the slope. This may be similar to the places where the Ghost Dance fault steps normal to strike to a new location (north slope of Antler Ridge, top of Live Yucca Ridge). We infer that the two fault strands meet at depth in each of these cases; the shallow step-over may occur along a pre-existing cooling joint, or along a zone of distributed brittle deformation. In a well-exposed area, one should be able to test these two hypotheses, but none of these "step-over" areas are particularly well-exposed.

This discussion has focused on the discontinuous nature of individual minor faults that cut the Tiva Canyon Tuff in surface exposures above the potential repository. The Sundance fault zone and other minor faults probably exhibit similar discontinuous characteristics at depth in the Topopah Springs Tuff, which contains the potential repository horizon and is stratigraphically and petrologically similar to the Tiva Canyon Tuff (Buesch and others, in press). In particular, faulting styles in the Topopah Springs Tuff may be stratigraphically controlled in a fashion similar to that described herein for faults that cut the Tiva Canyon Tuff.

CONCLUSIONS.

(1) The Sundance fault zone has a mapped length of 750 m, extending from Dead Yucca Ridge to Live Yucca Ridge. Across Dead Yucca Ridge and "Purgatory Ridge" the fault zone is up to 75 m wide, cutting both the crystal-poor and crystal-rich members of the Tiva Canyon Tuff with a maximum cumulative northeast-side-down displacement of about 11 m. Displacement diminishes to the south, within Live Yucca Ridge. The faults in the Sundance fault zone are almost exclusively characterized by northeast-side-down displacement.

(2) Individual faults within the Sundance fault zone (and elsewhere) are laterally and vertically discontinuous. The Sundance fault zone comprises numerous discontinuous faults that occupy a broad zone in the crystal-poor member of the Tiva Canyon Tuff, and a narrower, more discrete zone in the crystal-rich member; not all faults in the crystal-poor member can be mapped continuously up into the crystal-rich member. This apparent upward-narrowing geometry probably results from variations in strength within the section. Discontinuous faults require accommodation of displacement in the unfaulted parts of the Tiva Canyon Tuff, apparently by

distributed brittle deformation and locally, by minor movements along pre-existing cooling joints.

(3) The Ghost Dance fault can be projected as a continuous structure across Split Wash and is not offset by the Sundance fault zone.

(4) Abundant minor faults in the crystal-poor member of the Tiva Canyon Tuff on the south slope of Antler Ridge are not continuous through the crystal-rich member, which is essentially draped as a monocline above the lower faults.

(5) Abundant breccia on the Little Prow can be attributed to intersecting northeast- and northwest-striking faults that are unrelated to the Sundance fault; the Sundance fault does not cut the Solitario Canyon fault.

(6) A prominent northwest-trending fault is mapped at the northwest end of the map-area, between the Little Prow and The Prow; regional mapping will shed more light on this structure.

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"PRELIMINARY DRAFT"

Figure Captions.

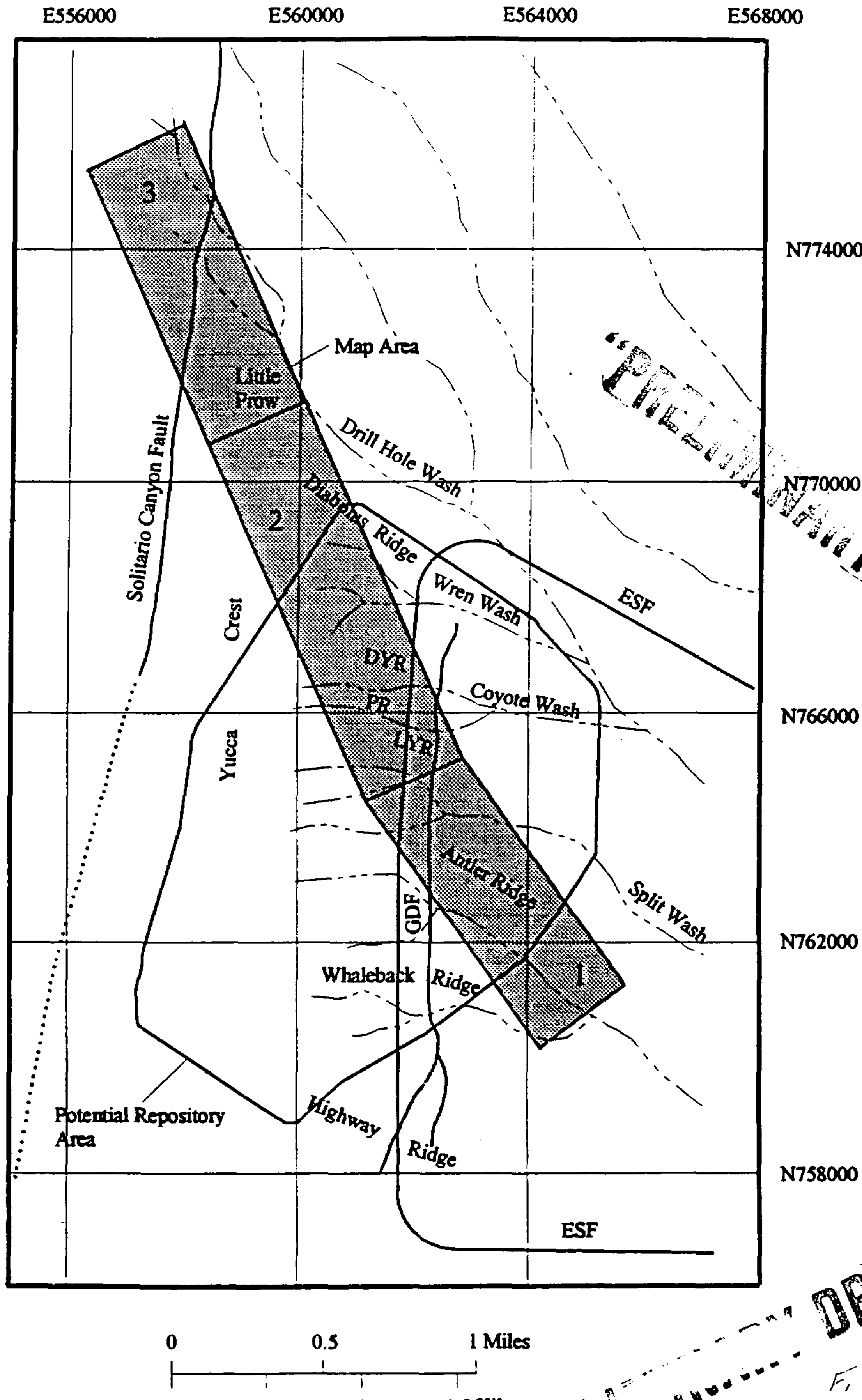
Figure 1. Index map of the study area on Yucca Mountain, Nevada. Stippled area shows area of Sundance geologic map (Plates 1, 2, and 3). ESF, Exploratory Studies Facility; GDF, Ghost Dance fault; DYR, Dead Yucca Ridge; LYR, Live Yucca Ridge; PR, "Purgatory Ridge." Location coordinates are Nevada State Coordinate System.

Figure 2. Detailed geologic map showing minor faulting on the south slope of Antler Ridge near coordinates 762,500 N., 563,350 E. (Nevada State Coordinate System). Reference coordinates (Nevada State Coordinate System) are shown at map border. Refer to Plate 1 for geologic and geographic context of this small area on Antler Ridge. Stippled lines are topographic contours, labeled in feet above sea level. Bold black lines, faults; narrow black lines, stratigraphic contacts. Triangles denote breccia exposures. Wavy lines are an inferred zone of distributed brittle deformation that accommodates strain between discrete faults that are not collinear. Stratigraphic units cr1, cul, cmn3, and cll are explained on Plate 1. "PRELIMINARY DRAFT"

Figure 3. Map showing splays of the Solitario Canyon fault and other faults in the Little Prow area. This map illustrates how fault splays shown on Plate 3 tie into the Solitario Canyon Fault. Geology from this study and from Scott and Bonk (1984). Solid lines, faults. Dashed gray lines, topographic contours, labeled in feet above sea level. Location coordinates are Nevada State Coordinate System.

Figure 4. Cartoon cross-section showing a general model for deformation in the Tiva Canyon Tuff, based on observations made during geologic mapping along the Sundance trend. This cartoon illustrates a discrete, larger-displacement fault cutting the crystal-rich member, and numerous faults with smaller displacement in the crystal-poor member, as observed in the field. Strain compatibility within the section requires movement along subhorizontal planes, including gently dipping breccia zones (which are observed), layer-parallel slip (which appears to locally produce gouge and breccia along partings in the strata) and minor discrete gently dipping faults (not documented, but locally inferred

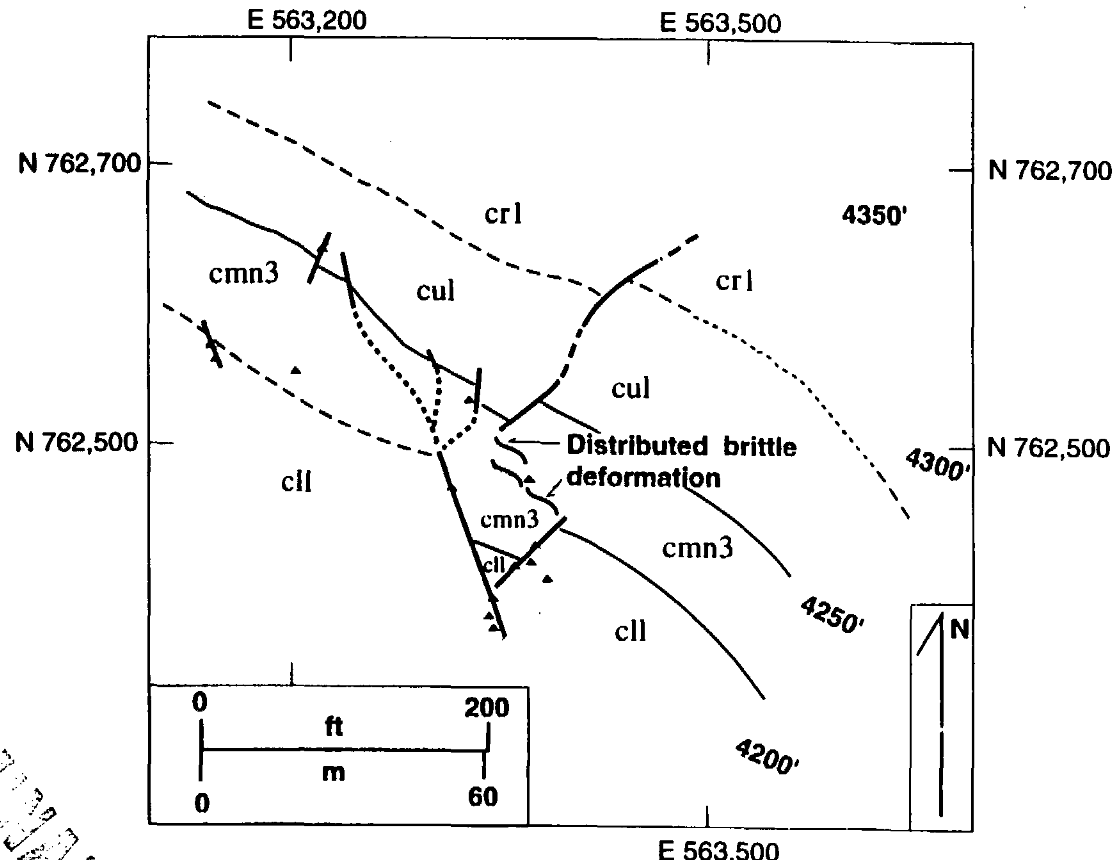
based on map patterns). The scale is purposely omitted form this cartoon drawing, but in the case of the Sundance fault zone, the maximum total displacement measured across the fault zone is 11 m.



"PRELIMINARY DRAFT"

"PRELIMINARY DRAFT"

Fig 1


E 563,200
E 563,500
N 762,700
N 762,700
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N 762,500
crl
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4350'
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Distributed brittle deformation
cll
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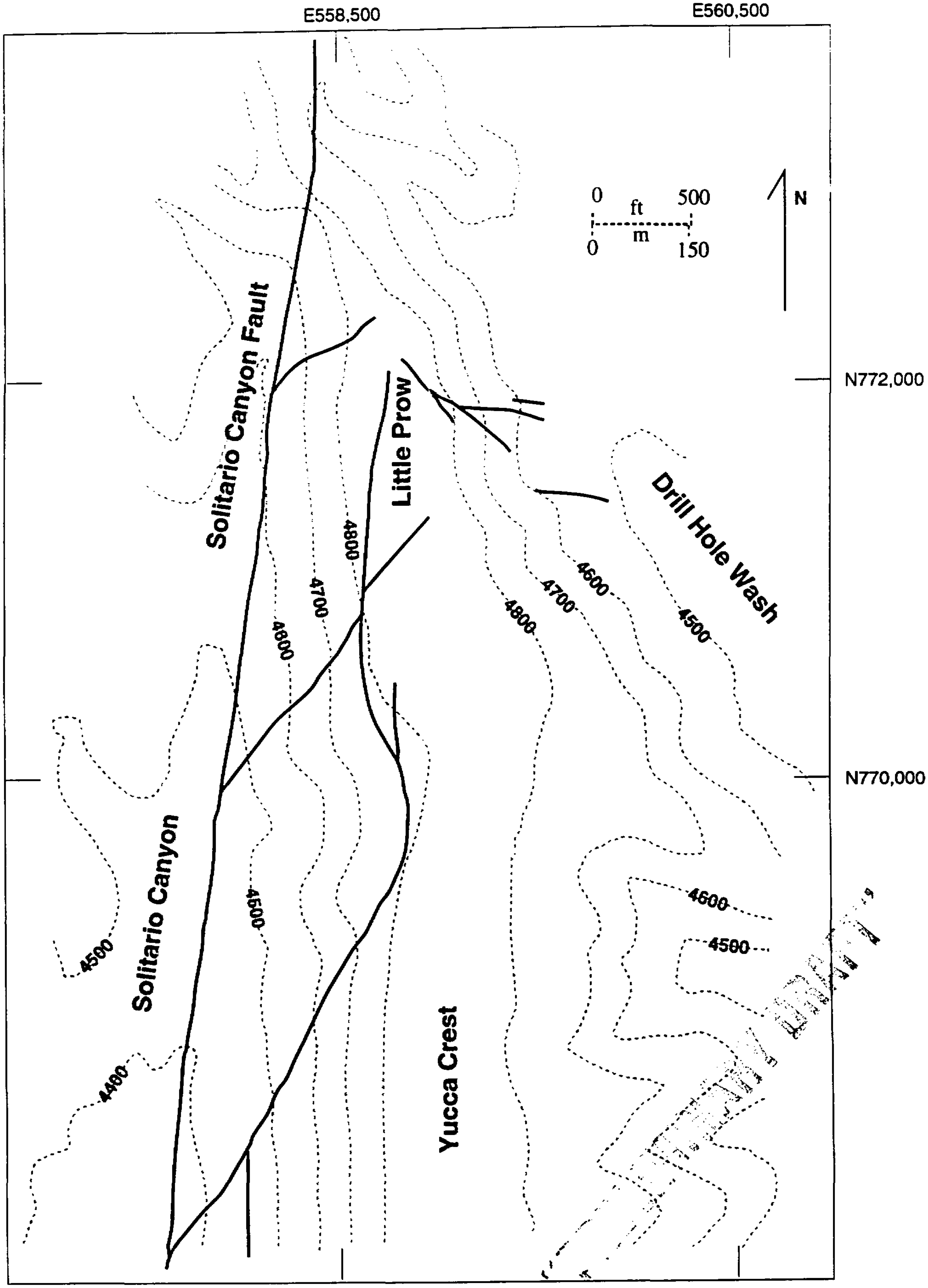
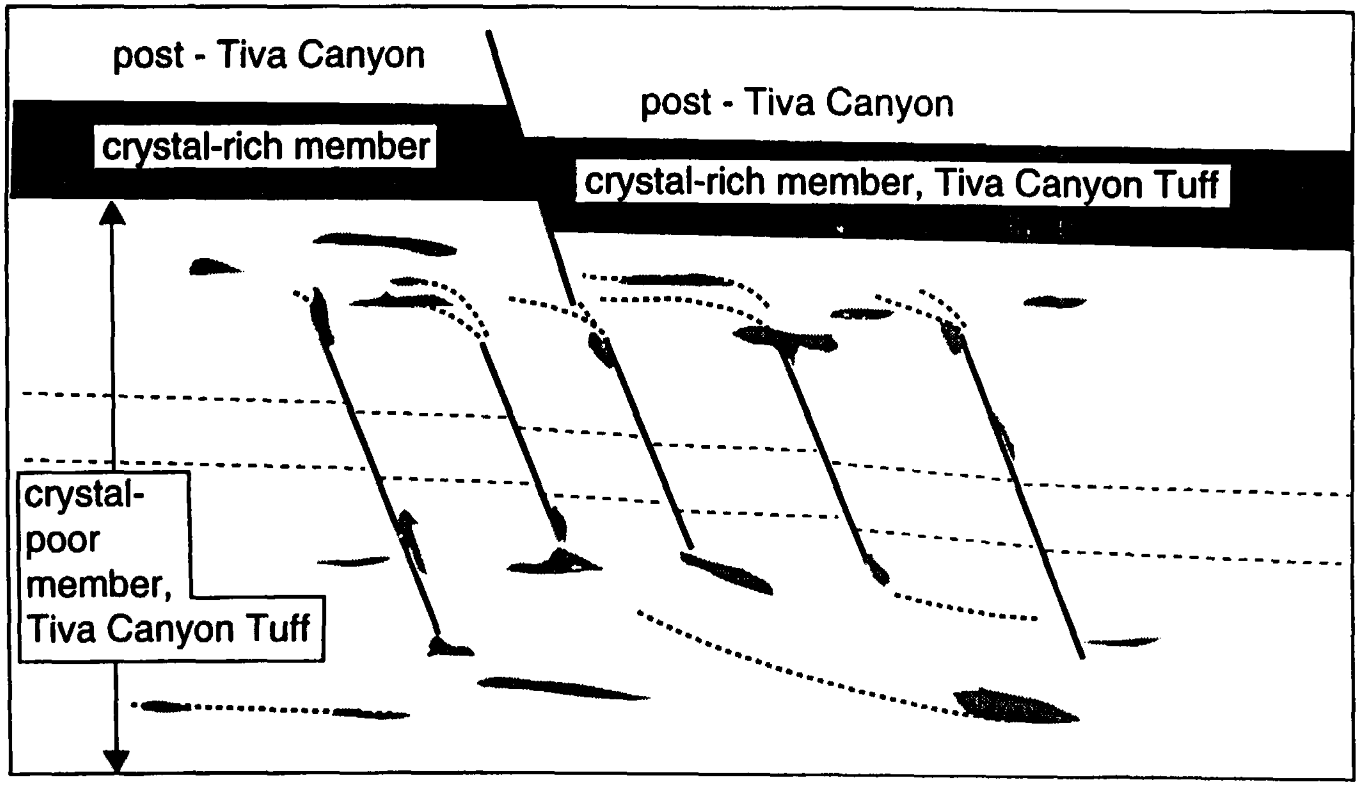
Figure 2.

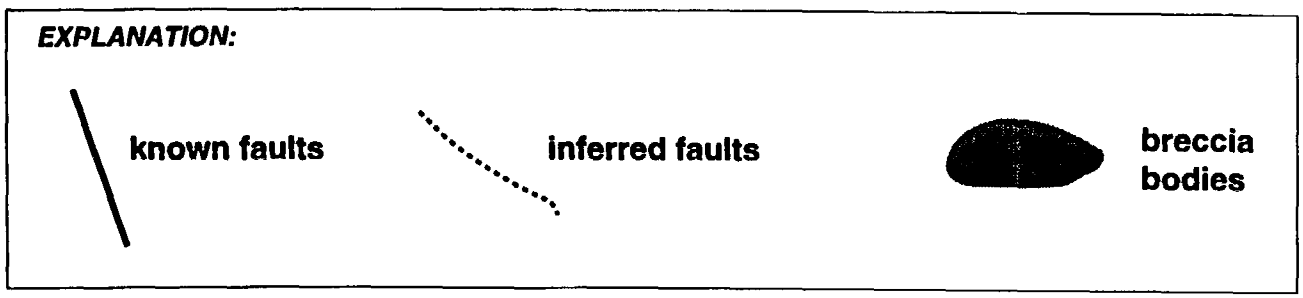


E558,500
E560,500
N772,000
N770,000
0 ft 500
0 m 150
N
Solitario Canyon Fault
Little Prow
Drill Hole Wash
Solitario Canyon
Yucca Crest
4800
4700
4600
4500
4400

Figure 3



post - Tiva Canyon
post - Tiva Canyon
crystal-rich member
crystal-rich member, Tiva Canyon Tuff
crystal-poor member, Tiva Canyon Tuff



EXPLANATION:
known faults
inferred faults
breccia bodies

Figure 4

Participant USGS
Database - USGS
Prepared - 2-DEC-94:14:59:26

Yucca Mountain Site Characterization Project
Planning and Control System (PACS)
Participant Planning Sheet (PSA03)

Page - 1
Inc. Dollars in Thousands (Unesc.)

J. Timothy Sullivan 12/8/94

P&S Account - 1.2.3.2.2.1.2 USGS

P&S Account Title - Structural Features within the Site Area

PWBS Element Number - 1.2.3.2.2.1.2

PWBS Element Title - Structural Features within the Site Area

Baseline Start - 03-oct-1994
Baseline Finish - 28-jun-1996

QA - YES

Fiscal Year Distribution

	Prior	FY1995	FY1996	FY1997	FY1998	FY1999	FY2000	FY2001	FY2002	FY2003	FY2004	Future	At Complete
Annual Budget	0	2887	2418	0	0	0	0	0	0	0	0	0	5305

Statement of Work

Direct observation of geologic features in the field and recording of data on aerial photographs and in notebooks. Transfer field data onto a stable topographic base using a mechanical analytical plotter in the photogrammetry laboratory. Collect additional field data with assistance of completed map. Measure and analyze fracture characteristics (abundance, orientation, aperture, roughness, fracture-fill minerals) from uncleared outcrops to furnish the bulk of fracture data for this activity. Clear surficial material on pavements, map and photograph fractures, and record fracture characteristics (density, orientations, apertures, roughness, trace length, spatial distribution, degree of connectivity, fracture-filling minerals). Compile 2-D fracture network models from fracture trace maps and data set. Determine attitudes of fractures and faults by oriented core and paleomagnetic techniques. Integrate characterization of core fractures with surface studies. Analyze Borehole fracture by borehole video-camera and acoustic televiewer. Perform geologic mapping of the exploratory shaft facility (ESF) and drifts, including in situ fracture and geologic mapping and photogrammetric geologic mapping; perform prototype geologic experiments for studying the ESF which involve the development of methods for field data collection and photogrammetric mapping for the repository block at Yucca Mountain. Mark, survey and photograph shaft walls. Collect oriented samples. Map fracture roughness, aperture, direction of movement and lithostratigraphic features. Select and define structural and fracture domains with similar properties in exploratory shaft. Install sensors in shaft wall drillholes. Conduct VSP. Conduct laboratory analysis of core samples for seismic propagation effects.

QARD applies to this effort.

Deliverables will be reviewed and accepted in accordance with the YMSCO Procedure for acceptance of contract deliverables unless otherwise specified.

DELIVERABLES

Deliv ID	Description/Completion Criteria	Due Date
3GGF500M	LTR RPT: ENHANCEMENT OF SCOTT & BONK Criteria - This level 3 milestone will consist of a Letter Report summarizing the evaluation of the internal consistency of the 1:12,000 scale map Scott and Bonk (1984) and the data and interpretations from a photo lineament study for the central block of Yucca Mountain. This area was mapped at a scale of 1:12,000, but recent revisions in stratigraphy and the increased detail of scrutiny of stratigraphic and structural relations necessitates enhancement and possible verification of parts of the Scott and Bonk map. Data collected for this investigation will consist of (1) evaluation of map and cross section relations based on geometric consistency and compatibility with borehole data, and (2) map of dominant structures (1:12,000) and evaluation of lineaments identified on areal photographs and remote sensing images. This activity does not evaluate the stratigraphy and will provide only limited data on the amounts of separation on selected faults.;;This level 3 milestone will be met when a publication package segment has been submitted to the TPO in compliance with YMP-USGS-QMP-3.04 and the TPO has forwarded the information to DOE-YMSCO for concurrence and USGS Director's Office for approval.;;TEXT WAS TRUNCATED.	30-jun-1995

0G32212 Structural Features within the Site Area (continued)

DELIVERABLES

Deliv ID	Description/Completion Criteria	Due Date
3GGF510M	LTR RPT: GEOMETRY & CONTINUITY - SUNDANCE FAULT Criteria - This Level 3 milestone will provide an analysis report of the Sundance Fault within the study area that includes a map, conclusions on the character of the fault, and recommendations for future study.;;This milestone will be met when a Letter Report package segment has been submitted to the TPO in compliance with YMP-USGS-QMP-3.04 and the TPO has forwarded the information to DOE-YMSCO for concurrence and USGS Director's Office for approval.	31-aug-1995
3GGF530M	RPT: STRUCT/STRAT OF THE ESF - NORTH RAMP Criteria - This Level 3 report will provide full-periphery maps, generalized cross-section of the North Ramp, and discussion of significant geologic and structural features. The report will provide an assessment of mapping techniques applied in study, and recommendations for future ESF mapping study technique. February 1, 1995 milestone will include data collected through November 1, 1994. Mapping data will be submitted to LRC and available upon request to the project office and the participants. This milestone will be met when a publication package segment has been submitted to the TPO in compliance with YMP-USGS-QMP-3.04 and the TPO has forwarded the information to DOE-YMSCO for concurrence and USGS Director's Office for approval.	31-jan-1995
3GGF540M	RPT: STRUCT/STRAT OF THE ESF - NORTH RAMP Criteria - This Level 3 report will provide full-periphery maps, updated generalized cross-section of the North Ramp, and discussion of significant geologic and structural features. The report will provide an assessment of mapping techniques applied in study, and recommendations for future ESF mappingstudy technique. The milestone will include data collected through April 1, 1995. Mapping data will also be submitted to LRC and available upon request to the project office and the pahrticipants. This milestone will be met when a publication package segment has been submitted to the TPO in compliance with YMP-USGS-QMP-3.04 and the TPO has forwarded the information to DOE-YMSCO for concurrence and USGS Director's Office for approval.	30-jun-1995
3GGF550M	LRT RPT: VERT CONT/FRAC CHAR PAINTBRUSH GRP Criteria - This level 3 Milestone will be met with a Letter Report containing maps, tabular fracture attributes, stereographic projections and histograms, overlays, a computer file of the fracture data, and a evaluation of significant textural features in the thin sections. The report will include the results and conclusions of the study and recommendations for further investigations.;;This milestone will be met when a Letter Report package has been submitted to the TPO in compliance with YMP-USGS-QMP-3.04 and the TPO has forwarded the information to DOE-YMSCO for concurrence and USGS Director's Office for approval.	31-aug-1995
3GGF560M	LETTER REPORT: PAVEMENT MAPPING AT FRAN RIDGE Criteria - This milestone will be met by a Letter Report, containing maps, data, conclusions, and recommendations for further work. Produced by detailed mapping of fractures and tabulation of fracture attributes at the Fran Ridge Pavement. The Letter Report shall have been completed in compliance with YMP-QMP-3.04.;;This milestone will be met when a publication package segment has been submitted to the the	30-jun-1995

0G32212 Structural Features within the Site Area (continued)

DELIVERABLES

Deliv ID	Description/Completion Criteria	Due Date
	TPO in compliance with YMP-USGS-QMP-3.04 and the TPO has forwarded the information to DOE-YMSCO for concurrence and USGS Director's Office for approval.	

Approvals

Technical Reviewer 12/8/94 Date

QA Reviewer 12/18/94 Date

Records Package Table of Contents

QA: L	Traceability Designators: DAR #0281A Deliverable ID #3GGF510M WBS #1.2.3.2.2.1.2	Record Pkg. Date: 10-26-95

Title/Description: Deliverable ID #3GGF510M, Ltr Rpt: Geometry/Continuity of Sundance Fault, WBS #1.2.3.2.2.1.2, DAR #0281A

"PRELIMINARY DRAFT"

Record Date	Individual Titles/Groups of Records	Pages
09/05/95	Document Action Request #0281A	1
09/05/95	Deliverable Transmittal for Acceptance Review, JEZ:bkt:0281A, Zimmerman to Jones, for #3GGF510M, without enclosures	1
09/22/95	Approved Deliverable Transmittal, JEZ:bkt:0281A, Zimmerman to Jones, for #3GGF510M, without enclosures	1
09/22/95	Approved Deliverable Transmittal, JEZ:bkt:0281A, Zimmerman to Craig, for #3GGF510M, without enclosures	1
08/31/95	Letter, Craig to Jones, Transmittal of Deliverable 3GGF510M - LTR RPT: Geometry/Continuity of Sundance Fault, WBS 1.2.3.2.2.1.2, without enclosures	2
08/31/95	Completed Deliverable Package	41

NOTE: Blanks are intentional on the Deliverable Transmittal for Acceptance Review

Subtotal Page Count	47
Total Page Count	47

Complied By: Linda M. Mantor	**Signature:** Linda M. Mantor	**Date:** 10-26-95
Authenticated By: Sandra L. Moore	**Signature:** Sandra L. Moore	**Date:** 10-26-95

102.2
WM-11
NH03

delete all distribution except: CF + PDR

YMP-108-R4 YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT Page 1 of 1
04/03/95 DOCUMENT ACTION REQUEST (DAR) DAR No. 0391A /Date PPD DAR No. /Assigned: 9-5-95

Signatures on this document represent signers' acknowledgement that the applicable procedure has been read, understood, and complied with.

SECTION I - ACTION REQUEST

1. DOCUMENT TITLE: LTR RPT: Geometry/Continuity of Sundance Fault	2. CURRENT DOCUMENT NO: N/A	3. REV/ICN: (current) N/A

4. SCP REF. NO.: 8.3.1.4.2.2.1 QARD SECTION: See RTN Matrix

5. TYPE OF ACTION REQUIRED: ☐ Develope New Document ☐ Change Existing Document ☐ Cancel Document ☐ Review Only ☒ Deliverable

6. DESCRIPTION OF ACTION REQUESTED:

Acceptance of contract deliverable no. 3GGF510M

7. DOCUMENTS AFFECTED:

N/A

8. REASON FOR ACTION REQUESTED:

Acceptance of deliverable in accordance with YAP 5.1Q, Rev. 2

☐ Additional Material Attached

9. DELIVERABLE DUE DATE: 8/31/95

10. RELATED REPORT NUMBER:
TDIF GS950808314221.004

11. REQUESTED BY:
for ROBERT W. CRAIG
Print Name
U.S. GEOLOGICAL SURVEY (702) 794-7142
Organization Phone No.
Kaye E Ritchey 8-31-95
Signature Date

SECTION II - ACTION INITIATION

12. REQUEST/ NON-Q CONTRACT DELIVERABLE: ☒ Approved ☐ Rejected

13. EDITORIAL CHANGES ☐ YES ☒ NO

14. DOCUMENT TYPE: ☒ Q ☐

15. CHANGE METHOD: ☐ ICN ☐ Revision ☐ Cancel ☒ N/A

16. CCB ACTION: ☐ YES ☒ NO

17. TRAINING RECOMMENDATION: ☐ Self-Study ☐ Classroom Trng. ☒ N/A ☐ Other

18. COMMENTS: None.

19. PREPARER ASSIGNED: NA

20. RESPONSIBLE ASSISTANT MANAGER/DIRECTOR
Signature 9/14/95
Date

DELIVERABLE: N/A ☐
21. DAR copy with deliverable to Contracting Officer Representative: 9-22-95
Date
22. DAR copy to RO: 9-22-95
Date

SECTION III - ACTION REVIIEW

23. TRAINING REQUIREMENTS: ☒ N/A* ☐ YES - Number of Days Required for Trng:
COMMENTS: not applicable for deliverables. *Requires Justification in Comment Section

24. Training Officer/Training Manager
NA NA
Signature Date

25. PLANS AND PROCEDURES DEPARTMENT (DAR Completion)
Judith E Zimmerman 10/12/95
Signature Date

PLANS AND PROCEDURES DEPARTMENT
DELIVERABLE TRANSMITTAL FOR ACCEPTANCE REVIEW

****

DATE: September 5, 1995 — JEZ:slg:0281A
FROM: Judith E. Zimmerman, Manager — WBS #1.2.9.3.3
Plans and Procedures Department — QA: N

mn for

****

Description: Ltr Rpt: Geometry/Continuity of Sundance Fault
Deliverable ID: 3GGF510M
WBS: 1.2.3.2.2.1.2
Due Date: October 5, 1995

****

Reviewing Organization:
AMSP, YMSCO, NV

AM/DDir.:
S. B. Jones

The <u>original</u> DAR and deliverable package <u>must</u> be returned to the **Plans and Procedures Department, Data Coordinators Office, Room 704, Mail Stop 423,** by the due date of **10/5/95**.

Should you have any questions concerning the review process, please contact Mary Ann Nusbaum, PPD Production Coordinator at (702) 794-5325 or Sandi Moore at (702) 794-5327.

Enclosures:

1. DAR #0281A
2. Deliverable Package

"PRELIMINARY DRAFT"

DELIVERABLE RECEIVED FOR REVIEWING BY:

****

Signature — Date

PLANS AND PROCEDURES DEPARTMENT
APPROVED DELIVERABLE TRANSMITTAL

****

DATE:	September 22, 1995	JEZ:bkt:0281A
TO:	Susan B. Jones	WBS #1.2.9.3.3
FROM:	Judith E. Zimmerman, Manager	QA: N
	Plans and Procedures Department	

****

Enclosed is a copy of the approved DAR and deliverable 3GGF510M, WBS #1.2.3.2.2.1.2, Ltr Rpt: Geometry/Continuity of Sundance Fault. The approval of this deliverable closes DAR #0281A.

PPD will file a record package associated with this DAR in the Records Processing Center.

If you have any questions regarding the information contained herein or concerns about the document coordination process, please contact Mary Ann Nusbaum, PPD Production Coordinator at 794-5325 or Sandi Moore at 794-5327.

Enclosures:

1. Copy of DAR #0281A
2. Copy of completed Deliverable Package

"PRELIMINARY DRAFT"

PLANS AND PROCEDURES DEPARTMENT
APPROVED DELIVERABLE TRANSMITTAL

****

DATE:	September 22, 1995	JEZ:bkt:0281A
TO:	Robert W. Craig	WBS #1.2.9.3.3
FROM:	Judith E. Zimmerman, Manager Plans and Procedures Department	QA: N

****

Enclosed is a copy of the approved DAR for deliverable 3GGF510M, WBS #1.2.3.2.2.1.2, Ltr Rpt: Geometry/Continuity of Sundance Fault. The approval of this deliverable closes DAR #0281A.

PPD will file a record package associated with your DAR in the Records Processing Center. If you have any associated records regarding this deliverable, submit a records package according to records source responsibilities defined in YAP-17.1Q and include the DAR number in the records package title.

If you have any questions regarding the information contained herein or concerns about the document coordination process, please contact Mary Ann Nusbaum, PPD Production Coordinator at 794-5325 or Sandi Moore at 794-5327.

Enclosures:

1. Copy of DAR #0281A

"PRELIMINARY DRAFT"

United States Department of the Interior

U.S. GEOLOGICAL SURVEY
Box 25046 MS 425
Denver Federal Center
Denver, Colorado 80225

IN REPLY REFER TO:

WBS: 1.2.9.2.2
QA: N

August 31, 1995

Susan Jones
Assistant Manager for Scientific Programs
Yucca Mountain Site Characterization Office
U. S. Department of Energy
P.O. Box 98608
Las Vegas, NV 89193

Attn: Plans & Procedures, M&O/TRW, MS423, Las Vegas, NV

SUBJECT: Transmittal of Deliverable 3GGF510M - LTR RPT: Geometry/Continuity of Sundance Fault, WBS 1.2.3.2.2.1.2

Enclosed are two copies of the subject U. S. Geological Survey report for acceptance review processing in accordance with YAP 5.1Q, Rev. 2. This report is being submitted to satisfy Milestone 3GGF510M.

This report has been reviewed in accordance with YMP-USGS-QMP-3.04.

Technical data for this report have been submitted in accordance with YAP-SIII.3Q. The tracking number for the TDIF associated with these data is GS950808314221.004.

If you have any questions or need further information, contact Raye Ritchey at (303) 236-0516, ext. 282.

PRELIMINARY DRAFT

Raye E. Ritchey
for Robert W. Craig
Acting Technical Project Officer
Yucca Mountain Project Branch
U. S. Geological Survey

Enclosures
cc w/DAR only:
T. Sullivan, DOE, Las Vegas, NV
D. Williams, DOE, Las Vegas, NV
S. Simms, M&O/TRW, Las Vegas, NV
T. Statton, M&O/WCFS, Las Vegas, NV
R. Williams, USGS, Denver, CO
M. Chornack, USGS, Denver, CO
W. Day, USGS, Denver, CO
R. Ritchey, USGS, Denver, CO
T. Williams, USGS, Denver, CO