USGS
science for a changing world

Rec'd 2/1/00 (corrected title page inside report) MaB

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

U.S. GEOLOGICAL SURVEY

Open-File Report 98–266

Prepared in cooperation with the
NEVADA OPERATIONS OFFICE,
U.S. DEPARTMENT OF ENERGY, under
Interagency Agreement DE–A108–97NV12033

Nature and Continuity of the Sundance Fault, Yucca Mountain, Nevada

By Christopher J. Potter[1], Robert P. Dickerson[2], *and* Warren C. Day[1]

[1]U.S. Geological Survey, Denver, Colorado,[2]Pacific Western Technologies, Ltd., Lakewood, Colorado

U.S. GEOLOGICAL SURVEY OPEN-FILE REPORT 98–266

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code

Prepared in cooperation with the Nevada Operations Office, U.S. Department of Energy, under Interagency Agreement DE-AI08-97NV12033

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1999

CONTENTS

PLATES (in pocket)

FIGURES

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD) of 1929)—
a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Nature and Continuity of the Sundance Fault, Yucca Mountain, Nevada

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

ABSTRACT

Detailed geologic mapping (1:2,400 scale) was done in the northern part of the potential nuclear waste repository area at Yucca Mountain, Nevada, to determine the nature and extent of the Sundance Fault zone and to evaluate structural relations between the Sundance and other faults. The mapping shows that the Sundance Fault zone can be traced for about 2,500 feet, from Dead Yucca Ridge to Live Yucca Ridge. The term Sundance Fault zone is applied, in this report, to a northwest-striking fault zone that cuts the crystal-poor and the crystal-rich members of the Miocene Tiva Canyon Tuff. This fault zone was mapped across Dead Yucca Ridge and the unnamed ridge that lies between Dead Yucca Ridge and Live Yucca Ridge, and it continues to the southeast across Live Yucca Ridge where its displacement diminishes and it is less prominent. At its northwest end, the Sundance Fault zone terminates 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 230 feet, and the cumulative northeast-side-down vertical displacement across the fault zone does not exceed 35 feet. Substantial strike-slip displacement along the Sundance Fault zone is not indicated by the field relations.

Southeast of the mapped extent of the Sundance Fault zone, the Ghost Dance Fault can be projected along a virtually straight trend beneath the Quaternary surficial deposits in Split Wash with no apparent offset along the Sundance Fault zone. On the south slope of Antler Ridge near the projected trend of the Sundance Fault zone, several northwest-striking faults occur within a 550-foot-wide area, but they are mapped only locally in the crystal-poor member of the Tiva Canyon Tuff.

The Sundance Fault zone does not continue north of Dead Yucca Ridge, and faults that have similar trend and displacement patterns were not mapped on the Little Prow. Abundant breccia float on the Little Prow is related to a north-northeasterly striking 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 Fault zone trend. A prominent northwest-striking, northeast-side-down fault cuts both members of the Tiva Canyon Tuff about 2,000 feet 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 may have affected the Tiva Canyon Tuff to accommodate displacements in the rock volume between the discontinuous discrete fault segments. Two probable mechanisms are distributed brittle deformation, which is associated with diffuse breccia bodies, and minor offsets along numerous preexisting cooling joints.

INTRODUCTION

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

Spengler and others (1994) proposed the existence of the northwest-striking Sundance Fault system within the potential repository area, and of a continuation of the Sundance Fault system to the northwest of the potential repository area. In this report, the term Sundance Fault zone is used, rather than the term Sundance Fault system, because the specific geometric and kinematic relations among the individual fault strands are obscure. Because the age and extent of the Sundance Fault zone were unknown prior to this study, it was necessary to document its length and to evaluate possible cross-cutting relations with other faults, especially those of known or suspected Quaternary age.

In 1995, the U.S. Geological Survey, in cooperation with the U.S. Department of Energy (DOE), under Interagency Agreement DE-AI08-92NV10874, investigated the geometry and continuity of the Sundance Fault along a 1,500 ft-wide northwest-trending corridor from Antler Ridge to 1,000 feet northwest of the Solitario Canyon Fault (U.S. Department of Energy, written commun., 1994). In the Spring of 1995, the USGS mapped and studied a 2.5-mi-long, 1,850-ft-wide northwest-trending area of north-central Yucca Mountain.

Purpose and Scope

This report summarizes the geologic mapping of the 2.5-mi-long, 1,850-ft-wide area that includes the Sundance Fault zone and its proposed continuation to the northwest of the potential repository (fig. 1). The mapping was done at a scale of 1:2,400, and the mapped area is shown in figure 1 and on plates 1, 2, and 3.

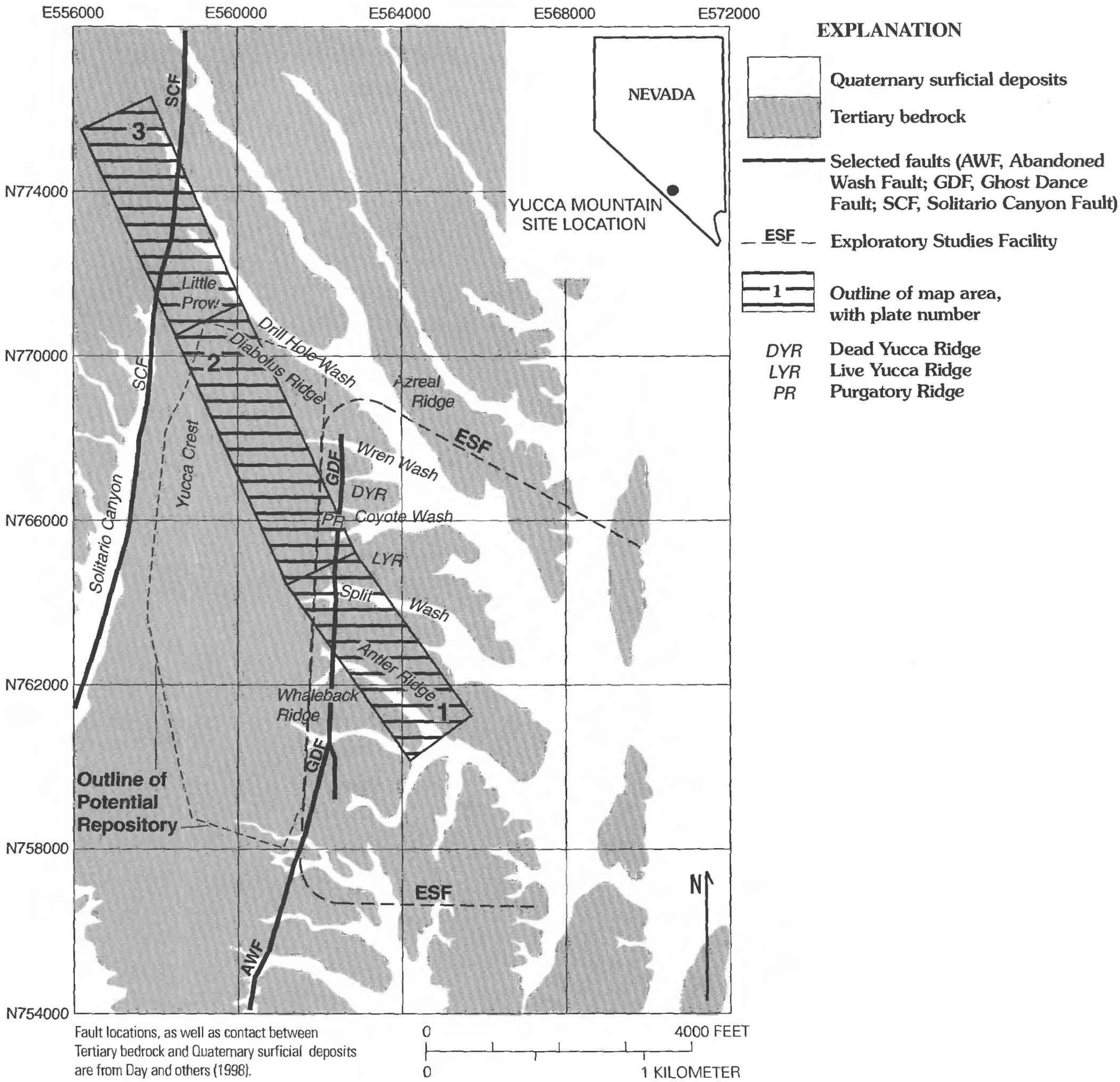
A geologic map was produced to characterize the structure of the study area. In some places several contacts remained unmapped because of poor exposure. Because the defined geographic boundaries of the study area are not necessarily related to the Sundance Fault zone, numerous faults were mapped that are not apparently related to the Sundance Fault zone, particularly in the northwestern part of the map. The southeastern end of plate 1 and the northwestern end of plate 3 are beyond the limits of the study area, and the geologic map is less complete in those areas.

Nevada State Coordinates (in feet) are used to specify locations in this report. These coordinates are for the central zone of Nevada and are based on a Transverse Mercator projection. The origin of this projection for the central zone of Nevada is latitude 34°45′N., and the central meridian is at longitude 116°40′W.

Previous Work

The Sundance Fault system of Spengler and others (1994) was identified as a zone of almost vertical, 320°- to 330°-striking faults, at least 900 ft wide, in the northern part of the potential repository area at Yucca Mountain. Many of the faults within the Sundance Fault system had minor northeast-side-down offset, and Spengler and others (1994) also inferred substantial 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 150 ft.

C.A. Braun and L.G. Martin (Science Applications International Corporation, written commun., 1995) prepared a detailed 1:480-scale map along the Ghost Dance Fault and adjacent parts of the potential repository block at Yucca Mountain. The northern part of their map overlaps the map in this report (parts of pls. 1 and 2), and in this area, the map in this report was based on the same survey control that Braun and Martin established with permanent survey markers on a 200-ft spacing, based on the Nevada State Coordinate system. C.A. Braun and L.G. Martin (Science Applications International Corporation, written commun., 1995) mapped the Sundance Fault on the south flank of Live Yucca Ridge, based principally on a 3-ft-wide northwest-trending breccia zone. They inferred the presence of the Sundance Fault beneath colluvial cover of Quaternary age in Split Wash and mapped a 20-ft stratigraphic offset along the Sundance Fault on the southeast flank of Antler Ridge. In addition, they mapped numerous minor northwest-striking faults within 500 ft of the proposed Sundance Fault; these minor faults are the faults included in the Sundance Fault system of Spengler and others (1994).



Fault locations, as well as contact between Tertiary bedrock and Quaternary surficial deposits are from Day and others (1998).
Nevada State Plane coordinates (in feet) are for the Central zone of Nevada and are based on Polyconic projection.

Figure 1. Study area on Yucca Mountain, Nevada.

As originally proposed by Spengler and others (1994), the Sundance Fault system was about 1 mi long, extending from southeast Antler Ridge, across Split Wash to Live Yucca Ridge. They suggested that the system may continue for an unspecified distance (at least 1.9 mi) to the southeast and northwest, based on observations of structural lineaments, concentrations of brecciated rock, and other northwest-striking fault sets. On the basis of geologic reconnaissance, C.A. Braun and L.G. Martin (Science Applications International Corporation, written commun., 1995) reported that the Sundance Fault could be traced for at least 2.8 mi, from the southeastern flank of Antler Ridge, across the northern part of the potential repository area, and into a northwest-striking 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 compose a

2,500-ft-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 system as defined by Spengler and others (1994).

MAP UNITS

The bedrock in the map area is entirely in the 12.7-Ma Tiva Canyon Tuff (Sawyer and others, 1994). In this report, map units were used that are based on the informal stratigraphic nomenclature of Geslin and others (1995) and Buesch and others (1996) and are, in general, separated by boundaries that can be mapped at a scale of 1:2,400. Plates 1 through 3 indicate the correlation between the map units used in this report and those of Buesch and others (1996).

Map units used in this report for the crystal-poor member of the Tiva Canyon Tuff (vitric, lower nonlithophysal, lower lithophysal, middle nonlithophysal, and upper lithophysal) are similar to zones informally defined in that member by Buesch and others (1996). The middle nonlithophysal map unit (cpmn3 on plates 1–3) corresponds to the upper subzone (Tpcpmn3) of the middle nonlithophysal zone of Geslin and others (1995) and Buesch and others (1996). The lower lithophysal map unit in this report includes the lower lithophysal zone and the two lower subzones of the middle nonlithophysal zone as defined by Buesch and others (1996). A map unit described as upper lithophysal, middle nonlithophysal, undifferentiated is used in the northwestern part of the map area (Wren Wash, Diabolus Ridge, Little Prow area; pls. 2 and 3) because the contact between the middle nonlithophysal and the upper lithophysal zones is difficult to recognize because of the abundance of lithophysae in the upper part of the middle nonlithophysal zone in this area. Although the map units in the crystal-poor member largely are 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 Tuff correspond to four subzones (crystal-transition, mixed-pumice, pumice-poor, and vitrophyre) informally defined in that member (Geslin and others, 1995; Buesch and others, 1996). The first three of these map units cr1, cr2, and cr3 on pls. 1–3) are primary depositional units, in contrast to the zones in 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, 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 3 ft where they are well exposed in the field. The base of the crystal-transition subzone is somewhat more difficult to pinpoint because it is characterized by a more gradual change and usually is determined by the use of a hand lens. Where the subzone is well exposed, it can be accurately identified within 3 feet.

RESULTS OF GEOLOGIC MAPPING

This study was done to test a hypothesis that a single, throughgoing, northwest-striking Sundance Fault zone occupies the area included in the map (fig. 1). Although the geologic mapping revealed numerous faults in the map area (pls. 1–3), a continuous zone of northwest-striking faults that cut the crystal-poor and the crystal-rich members of the Tiva Canyon Tuff could be traced for only 0.3 mi along strike, crossing Dead Yucca Ridge and the unnamed ridge (informally named Purgatory Ridge in this report) that is between Dead Yucca Ridge and Live Yucca Ridge (pl. 2). The faults in this zone are almost exclusively characterized by northeast-side-down displacement. The maximum width of this zone is 230 ft, and the cumulative northeast-side-down vertical displacement across the fault zone does not exceed 35 ft. The term Sundance Fault zone is applied herein only to the zone where both the crystal-poor and the crystal-rich members of the Tiva Canyon Tuff are displaced by faults and to fault strands that are directly along strike where displacement is diminishing. The Sundance Fault zone extends from Dead Yucca Ridge to the south flank of Live Yucca Ridge and is about 2,500 ft long.

Several northwest-striking faults occupy a 550-ft-wide area on the south flank of Antler Ridge to the east of the Ghost Dance Fault (pl. 1), but they can be mapped only locally in the crystal-poor member of the Tiva Canyon Tuff and do not seem to be throughgoing structures because they do not cut the crystal-rich member. Thus, although the presence of minor northwest-striking faults in the ridges to the south of Split Wash can be recognized, the southeastern extent of the Sundance Fault zone is inferred to be north of Split Wash, on Live Yucca Ridge. The Ghost

Dance Fault can be projected along a virtually straight trend beneath the Quaternary colluvial cover in Split Wash and is not offset by the Sundance Fault zone. Details are discussed in the section of this report entitled "Ghost Dance Fault Zone."

The Sundance Fault zone does not seem to continue north of Dead Yucca Ridge, and faults that have the Sundance Fault zone trend and displacement patterns were not mapped on the Little Prow (pl. 3). Abundant breccia float on the Little Prow is related to a north-northeasterly striking splay of the Solitario Canyon Fault and to a northwest-striking fault that continues downslope into Drill Hole Wash (not on the Sundance trend). A prominent northwest-striking, northeast-side-down fault, previously mapped by Scott and Bonk (1984), cuts both members of the Tiva Canyon Tuff about 2,000 ft northwest of the Little Prow, but this fault cannot be traced southeast to the Little Prow.

The results of this report differ significantly from those of Spengler and others (1994). In this report, the Sundance Fault zone has a mapped length of 2,500 ft, compared to 1.9 mi or greater suggested by Spengler and others (1994). On plate 1, the Sundance Fault zone is absent on Antler Ridge and on the ridge that separates the two main tributaries of Split Wash, whereas Spengler and others (1994) mapped the Sundance Fault zone on these ridges. On plate 1, the Ghost Dance Fault is projected to continue straight beneath Quaternary surficial deposits in Split Wash, whereas Spengler and others (1994) interpreted 150 ft of dextral displacement of the Ghost Dance Fault by the Sundance Fault beneath Split Wash. Spengler and others (1994) presented their interpretations of the Sundance fault based on observations made during detailed mapping of the Ghost Dance Fault, whereas this report summarizes comprehensive mapping of the Sundance Fault zone. In this report, consistent stratigraphic and structural criteria were used in the recognition of faults, including clear offset of stratigraphy and the presence of breccia. In several places where faults are reported by Spengler and others (1994), no breccia or stratigraphic offsets were recognized by the authors of this report.

Sundance Fault Zone

The Sundance Fault zone, as mapped on Live Yucca Ridge, Purgatory Ridge, Dead Yucca Ridge, and in the intervening washes (pl. 2), has 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 exposed on the south flank of Live Yucca Ridge as a 2-ft-wide tabular breccia body that strikes 340°, dips vertically, and can be traced in outcrop in the lower lithophysal zone of the Tiva Canyon Tuff for about 30 ft up from the base of the slope (pl. 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 5 ft; this is interpreted as the trace of the Sundance Fault. This trace projects across a saddle at the top of Live Yucca Ridge, but the outcrop pattern of the base of the crystal-rich member of the Tiva Canyon Tuff on either side of the saddle does not require an intervening fault (that is, an unfaulted cross section can be drawn across this saddle). Thus, the northwest-striking fault mapped on the south flank of Live Yucca Ridge may not actually cross the top of the ridge. This fault is included in the Sundance Fault zone because it projects into the area where the Sundance Fault zone is well exposed in the next wash to the north, as described in the following paragraphs.

Much of the bedrock on the north slope of Live Yucca Ridge is obscured by colluvial cover, including several large talus fans, making mapping of small fault offsets difficult. 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-striking Sundance Fault mapped on the south side of the ridge.

Northwest-striking faults exposed on Purgatory Ridge, and in the washes to the north and south of Purgatory Ridge, are on trend with faults on Live Yucca Ridge described in the preceding paragraphs and compose the most prominent part of the Sundance Fault zone. These faults 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-striking faults define a 230-ft-wide fault zone that produces a cumulative 30 ft 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 across the wash to the south of Purgatory Ridge 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 25 ft apart, produce 22 ft 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 is just one mapped fault that produces 20 to 25 ft of displacement of the base of the mixed-pumice subzone in the crystal-rich member. This displacement can be mapped on the north and on the south sides of the saddle. Lower contacts on the north side of Purgatory Ridge are difficult to map because the slope is mostly mantled by talus, and Sundance Fault zone 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 compose an 80-ft-wide, northwest-striking fault zone and together produce about 35 ft of northeast-side-down displacement of the top of the middle nonlithophysal zone. This contact is sporadically exposed between thick Quaternary deposits, 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 25 ft (northeast side down). If the trend of this fault, mapped high on Dead Yucca Ridge (pl. 2), were continued down the ridge to the south, its projected position would be about 115 ft east of the east edge of the fault zone mapped low on Dead Yucca Ridge. This fault is one of the most prominent examples of the discontinuous nature of individual faults in 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 Fault projects. This contact is subparallel to the top of the ridge. The contact projects across the saddle with an easterly dip of 4° to 6°, which is actually slightly less than typical dips in this part of Yucca Mountain. Thus, the map pattern seems to eliminate any fault displacement in excess of a few feet across this saddle. No fault was mapped on the south slope of this ridge, although there is a prominent northwest-striking joint set exposed in the upper lithophysal zone on that slope.

Presence of the Sundance Fault zone south of Split Wash is not verified because the mapping does not indicate the presence of a throughgoing, northwest-striking fault zone that cuts the crystal-rich and the crystal-poor members of the Tiva Canyon Tuff on Antler Ridge (pl. 1). Although several minor northwest-striking faults are mapped in the crystal-poor member on the south slope of Antler Ridge, unfaulted, northeast-dipping contacts were mapped 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. C.A. Braun and L.G. Martin (Science Applications International Corporation, written commun., 1995) mapped the Sundance Fault on this slope, with about 20 ft 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 160 ft east of drill hole USW H-4 in the wash south of Antler Ridge. The mapping for this report, which used 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 seems to narrow to a single strand in the overlying crystal-rich member. The implications of this unusual structural pattern are presented in the section, "Discontinuous Nature of the Sundance Fault Zone and other Minor Faults."

Ghost Dance Fault Zone

A part of the north-striking Ghost Dance Fault zone is exposed in the southern part of the study area on Antler Ridge, Live Yucca Ridge, and Purgatory Ridge (pls. 1 and 2). (For a broader discussion of the Ghost Dance Fault over its entire mapped extent, see

Day and others (1998)). On the south slope of Antler Ridge, the Ghost Dance Fault, which herein is the fault that has maximum displacement in the Ghost Dance Fault zone, is exposed near 763,000 N., 562,350 E. (Nevada State Coordinate system; pl. 1) and is marked by a 3- to 6-ft-wide breccia zone along which contacts have been displaced about 40 ft down to the west. The fault strikes 5° low in the slope and bends to a 0° (due north) strike in the middle of the slope. A 345°-striking fault, which is about 65 ft west of the Ghost Dance Fault at the top of the Antler Ridge Pavement (ARP-1, pl. 1) pavement (low on the slope), is marked by a prominent breccia zone and produces 10 ft of west-side-down offset of the top of the middle nonlithophysal zone. The displacement diminishes upsection; there is about 3 ft of displacement of the base of the crystal-rich member, and the unnamed fault cannot be identified above that contact.

The Ghost Dance Fault crosses Antler Ridge to the north of ARP-1, about 360 ft east of a pronounced saddle, and produces about 40 ft of west-side-down displacement of the base of the crystal-rich member of the Tiva Canyon Tuff on the north slope of Antler Ridge (pl. 1). However, the Ghost Dance 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. Fifty feet to the east, a north-striking fault occupies the middle of the slope and produces about 40 ft of west-side-down displacement of the base of the upper lithophysal zone. This latter fault strand has all the attributes of the Ghost Dance Fault, including its orientation, the presence of a 3-ft-wide breccia zone, and the amount and sense of displacement. The locus of the Ghost Dance Fault, therefore, steps across 50 ft to the east on this slope. This relation was originally shown on an unpublished map by C.A. Braun and L.G. Martin (Science Applications International Corporation, written commun., 1995).

The continuity of the top of the middle nonlithophysal zone of the Tiva Canyon Tuff beneath the upper, westerly Ghost Dance Fault strand indicates 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 zone. 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 preexisting discontinuity, such as a northwest-striking cooling joint or a set of closely spaced northwest-striking cooling joints. In such a case, the preexisting cooling joint would be the site of intense brecciation and dip-slip displacement compatible with the displacement of the Ghost Dance Fault strands.

Fifty feet east of the topographically higher, westerly Ghost Dance strand on the north slope of Antler Ridge, a northwest-striking fault offsets the base of the crystal-rich member by 15 ft (west side down). This fault projects into the brecciated area between the two Ghost Dance Fault strands and may be related to the accommodation of displacement across the discontinuous Ghost Dance Fault.

In the vicinity of the overlap of the two Ghost Dance Fault strands on the north slope of Antler Ridge, the presence of several other northeast- and northwest-striking faults was inferred. On the Ghost Dance Fault hanging wall, two northeast-striking faults offset the base of the crystal-rich member of the Tiva Canyon Tuff by a total of 35 ft; these faults are not exposed but are based on 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. Because the northeast-striking fault may merge with the Ghost Dance Fault, and because the northeast-striking fault has an east-side-down sense of displacement and seems to be confined to the footwall, the fault intersection has the effect of reducing the total displacement across the Ghost Dance Fault by about 35 ft. This effect may, in part, explain the decreased displacement observed across the Ghost Dance Fault on the north side of Split Wash.

The northwest-striking faults mapped east of the topographically lower, easterly Ghost Dance strand are based on offsets of the top of the middle nonlithophysal zone and are somewhat speculative because they cannot be traced more than a few feet on the outcrop-poor, talus-covered slope. Therefore, it is not known whether the northwest-striking faults merge with the Ghost Dance Fault downslope beneath the covering deposits.

If the northwest- and northeast-striking faults formed synchronously with the movement on the main splay of the Ghost Dance Fault, these faults may be part of a larger upward-widening (horsetailing) of the Ghost Dance Fault zone. This geometry was documented by Day and others (1998) 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. The sparse bedrock exposure on the north slope of Antler Ridge along the Ghost Dance Fault zone, however, restricts further conjecture.

Low on the north slope of Antler Ridge, the Ghost Dance Fault is marked by a persistent 010°-striking 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 of the Tiva Canyon Tuff (in the footwall) near the base of the south slope of Live Yucca Ridge (pl. 1). The Ghost Dance Fault was not mapped on the nose of the ridge separating the two main tributaries of Split Wash. The fault contact proposed in that location (Spengler and others, 1994) was mapped in this report as a normal transition between 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. Because the Ghost Dance Fault does not seem 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. The Ghost Dance Fault projects beneath the Quaternary surficial deposits straight across Split Wash.

On the south slope of Live Yucca Ridge (pls. 1 and 2), the Ghost Dance Fault trends due north to slightly west of north and has about 10 ft of west-side-down displacement. A second fault, about 35 to 65 ft to the east, strikes 020° and offsets the upper and lower contacts of the middle nnonlithophysal unit of the Tiva Canyon Tuff by 10 ft (west-side-down). This latter fault does not seem to continue up or down the slope for any 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 10 ft) across the breccia zone associated with the main trace of the Ghost Dance Fault. At the top of the ridge (pl. 2), the mapped location of the Ghost Dance Fault steps eastward by about 55 ft; the two splays do not connect in map view but may connect at depth. On the north slope of Live Yucca Ridge and on the eastern nose of Purgatory Ridge, there is about 15 ft of west-side-down displacement along the Ghost Dance Fault (pl. 2). North of this location, the Ghost Dance Fault continues beyond the map area, and displacement diminishes to zero in the Wren Wash vicinity (Scott and Bonk, 1984).

Character of Faulting in the Southern Part of the Map Area

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

On the south slope of Antler Ridge (pl. 1), for 1,300 ft east of the Ghost Dance Fault, numerous northwest-striking faults and several north- and northeast-striking faults offset contacts in the crystal-poor member of the Tiva Canyon Tuff but do not continue up into the crystal-rich member. 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 also are pods of breccia distributed across the slope that have no apparent relation to faults. On this slope, displacement of the base of the crystal-rich member was mapped 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—there could be additional minor concealed offsets (with 3 ft or less of displacement) of this contact. Stratigraphic throw across the mapped minor faults ranges from 1 to 20 ft, with most displacements in the 3 to 10 ft range. Almost all of these faults have a mapped length of less than 150 ft, and none of them have a mapped length in excess of 300 ft. These limited fault lengths do not seem to be an artifact of poor bedrock exposure. In almost every place, the mapped extent of fault strands is constrained by unfaulted contacts that cross the projected location of known faults that are mapped either upslope or downslope.

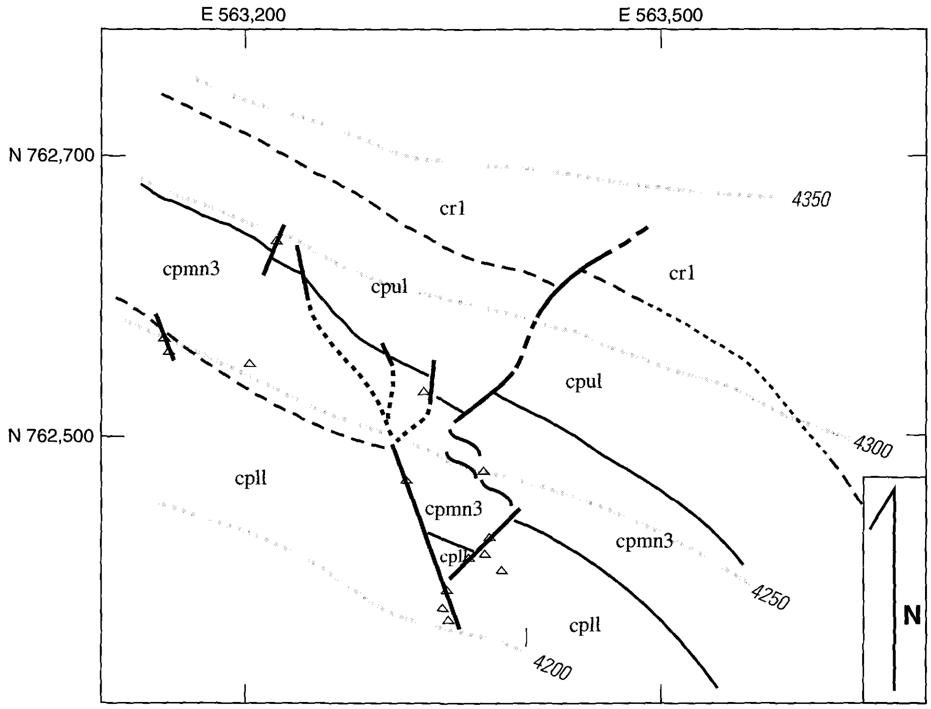
The discontinuous nature of faulting requires that fault displacements be balanced by some sort of distributed deformation in the rock mass between the mapped discrete faults. Much of the breccia on this slope, most of which is only in float, may have developed as part of a distributed brittle deformation that operated in concert with the discontinuous discrete faults to accommodate strain in the 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 shown at a larger scale in figure 2. In this area, a small graben is bounded by a northeast-striking fault that has 16 ft of displacement and by a northwest-striking fault that has 22 ft of displacement. Displacements were determined from the map pattern of the lower lithophysal/middle nonlithophysal contact. Downslope (to the south), the northwest-striking fault seems to truncate the northeast-striking fault (or the northeast-striking fault merges into the northwest-striking fault), based on the trends of breccia mapped on the slope. Neither the northeast- nor the northwest-striking fault can be traced an appreciable distance upslope. The breccia zone that marks the northeast-striking 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-striking fault located 65 ft to the west offsets this contact by 15 ft. Pods of breccia occupy the middle nonlithophysal unit between the two noncontinuous northeast-striking faults. These breccia pods may have originated as a zone of distributed brittle deformation accommodating the displacement on the two northeast-striking faults. The northwest-striking fault that bounds the west side of the small graben cannot be traced upslope as a single discrete fault, but seems to branch into several smaller northwest-striking splays that offset the top of the middle nonlithophysal zone. Thus, the upsection continuation of one of the graben-bounding faults jumps laterally through an accommodation zone that has 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. The Little Prow area was mapped and no evidence could be found that the Sundance Fault crosses Yucca Crest near the Little Prow. Instead, 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 540 ft north of drill hole UZ-N27 (pl. 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 of the Tiva Canyon Tuff, defining a northeast-side-down sense of displacement. Displacement on the fault diminishes to the northwest, so that the pumice-poor subzone is exposed around the fault tip. To the southeast, the fault trends downslope toward 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 15 ft; 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 of the Tiva Canyon Tuff, this fault loses displacement along strike to the north-northeast and does not continue beyond its brecciated intersection (or near-intersection) with the northwest-striking fault discussed in the preceding paragraph. South of that brecciated intersection, the vitrophyre occupies a thin 15- to 25-ft 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 has undergone strike-slip displacement because it offsets a northeast-striking fault



Topographic base map from the 1:6,000-scale topographic contour data produced from the orthophoto mission flown in 1990 by EG&G for the U.S Department of Energy. Nevada State Plane coordinates (in feet) are for the Central zone of Nevada and are based on Polyconic projection.

0 — 200 FEET
0 — 60 METERS

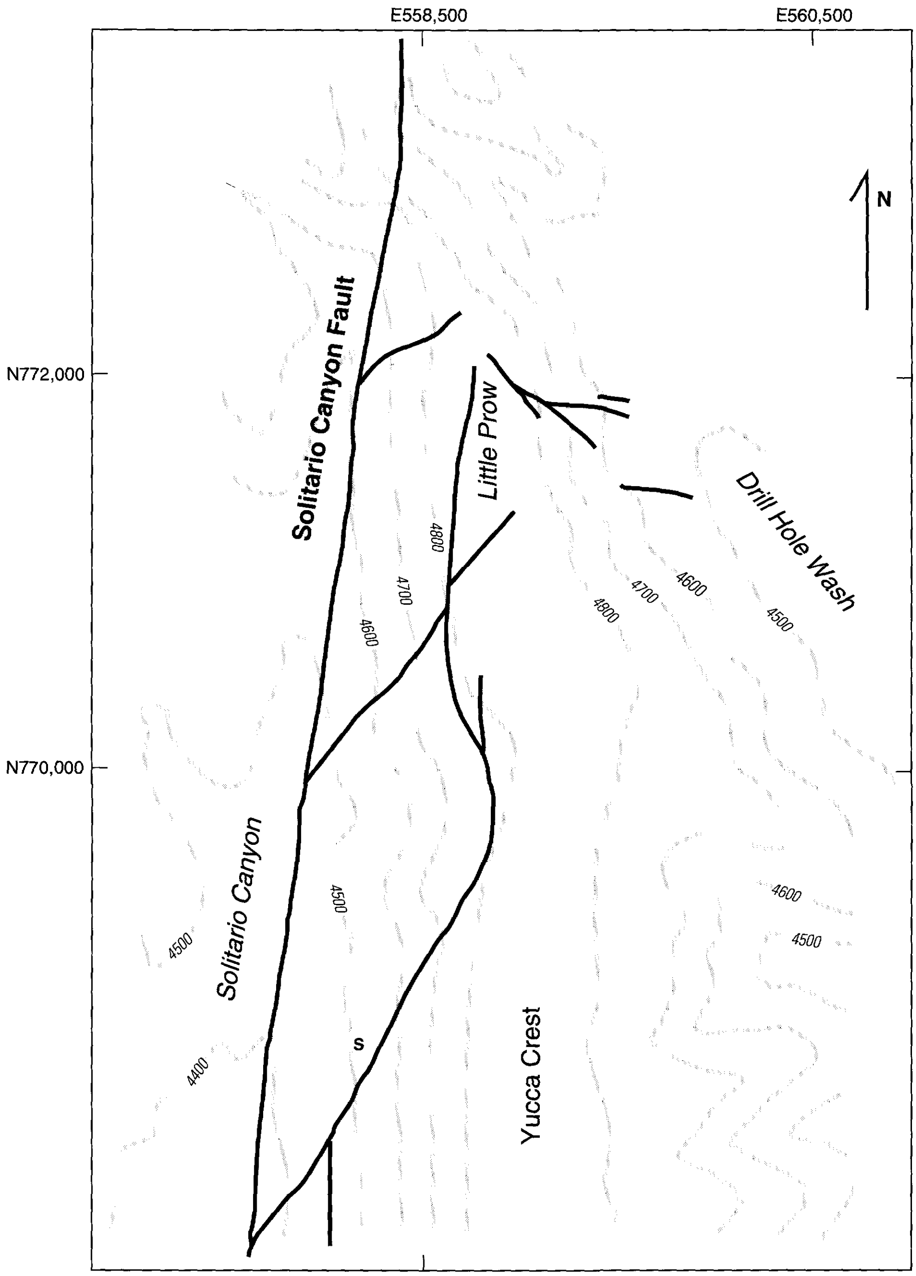
EXPLANATION

- **crl** — Crystal-transtion subzone, crystal-rich member of the Tiva Canyon Tuff
- **cpul** — Upper lithophysal zone, crystal-poor member of the Tiva Canyon Tuff
- **cpmn3** — Upper subzone of the middle nonlithphysal zone, crystal-poor member of the Tiva Canyon Tuff
- **cpll** — Middle and lower subzones of the middle nonlithphysal zone, and the lower lithophysal zone, crystal-poor member of the Tiva Canyon Tuff
- *4200* — Topographic contours, 50-ft contour interval, elevation in feet above sea level
- **Faults**—Solid where exposed, dashed where approximate, dotted where inferred
- **Stratigraphic contacts**—Solid where exposed, dashed where approximate
- Zone of distributed brittle deformation that accommodates displacement between faults that are not collinear
- Fault breccia

Figure 2. 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.

by 100 ft 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). 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 2,600 ft (pls. 2 and 3). Southwest of the map area, this fault (designated by S, fig. 3) is identified as one of the principal splays of the Solitario Canyon Fault (Scott and Bonk, 1984; Day and others, 1998); it forms the main break in the cliff-forming, resistant part of the crystal-rich member of the Tiva Canyon Tuff on the west-facing slope of Solitario Canyon, producing about 100 ft of strati-



Topographic base map from the 1:6,000-scale topographic contour data produced from the orthophoto mission flown in 1990 by EG&G for the U.S. Department of Energy. Nevada State Plane coordinates (in feet) are for the central zone of Nevada and are based on Polyconic projection

0 500 1000 FEET
0 150 300 METERS

EXPLANATION

4500 **Topographic contour, 100-ft contour interval, elevation in feet above sea level**

Mapped fault

S **Principal northwest-striking splay of the Solitario Canyon Fault**

Location of faults is based on this study and on Day and others (1998)

Figure 3. Splays of the Solitario Canyon Fault and other faults in the Little Prow area. This map illustrates how fault splays shown on plate 3 relate to the Solitario Canyon Fault.

graphic throw, and merges with the Solitario Canyon Fault near the base of the slope (fig. 3).

A third splay of the Solitario Canyon Fault strikes northeast and intersects the top of the Little Prow at elevation 4,850 ft (pl. 3). Displacement diminishes near the top of the ridge so that the pumice-poor subzone is only partly cut by this third splay of the Solitario Canyon 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 70 to 80 ft of west-side-down stratigraphic throw on the southwest-facing slope just south of that saddle. One thousand feet north of the saddle between the Little Prow and Ammo Ridge, the west-side-down stratigraphic throw on the Solitario Canyon Fault is 35 ft. By comparison, the northeast-striking splay (designated by S, fig. 3) has about 100 ft of displacement on the west-facing slope of Solitario Canyon. 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 large components of the displacement are transferred from the main fault strand by northeast-striking splays.

There is a breccia zone that is 12 to 30 ft wide along the main strand of the Solitario Canyon Fault in the map area (pl. 3). 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 and apparently intact unbrecciated outcrops of basalt are present in the breccia zone. The basalt likely intruded the Solitario Canyon Fault zone, then was brecciated as parts of the fault zone were reactivated. Isotopic ages of correlative basalts are 9 to 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 to 11 Ma (E.I. Smith, University of Nevada, Las Vegas, oral commun., 1995). Thus, the intrusion of these basalts into the Solitario Canyon Fault zone and their subsequent brecciation is consistent with the generally accepted timing of deformation at Yucca Mountain (Scott, 1990); the largest magnitude extension was between 13 and 11.5 Ma, and displacement on some faults (such as the Solitario Canyon Fault) continued into the Quaternary Period.

This study included partial geologic mapping of the next ridge north of Ammo Ridge (pl. 3), although this ridge is northwest of the original study area (the northwestern limit of which was defined by the DOE as a point 1,000 ft beyond the projected intersection of the Sundance and Solitario Canyon Faults). On top of this ridge, 2,100 to 2,300 ft northwest of the Little Prow–Ammo Ridge saddle, there is a north-northwest-striking 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 seems to be about 60 ft of east-side-down displacement of the base of the mixed-pumice subzone, although the bases of the mixed-pumice and the crystal-transition subzones cannot be located precisely on the east side of the fault because of limited bedrock exposure on this slope. Ten feet of displacement of the base of the upper lithophysal zone, lower in the slope, was mapped along the probable continuation of this fault. Fault displacement on the north-northwest-striking structure seems to diminish rather abruptly to the south on this slope. There are several discontinuous breccia bodies exposed on low on the slope, indicating the possibility of distributed brittle deformation that may have accommodated the displacement mapped on the discrete fault at the top of the ridge.

The north-northwest-striking 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) and Day and others (1998). Its extent and offset are larger than the extent and offset of the Sundance Fault zone.

SENSE OF DISPLACEMENT ON THE SUNDANCE FAULT ZONE

The geologic mapping in this report indicates that east-side-down dip-slip displacements characterize the Sundance Fault zone. The 1995 mapping included in this report produced no firm evidence for strike-slip motion along the Sundance Fault zone. No slickenlines were found, and the crude subhorizontal mullion-like structures near the base of the south slope of Live Yucca Ridge were too poorly defined to 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 indicate that the strata dip easterly to east-southeasterly (pl. 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. Large 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° to 45° between the strike of the strata and the strike of the Sundance Fault zone, so strike-slip motion would have produced stratal displacement. Hypothetically, oblique slip along the Sundance Fault, in the unique direction defined by the intersection of the strata and the fault, could be invoked to explain zero stratigraphic throw at the ends of the mapped Sundance Fault, but this singular situation is unlikely, and there is no evidence for it.

DISCONTINUOUS NATURE OF THE SUNDANCE FAULT ZONE AND OTHER MINOR FAULTS

An important aspect in the deformation of the Tiva Canyon Tuff at Yucca Mountain, as determined in this study, is the discontinuous nature of faulting along minor fault zones, such as the Sundance Fault and perhaps even the Ghost Dance Fault, which are not block-bounding structures. A 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 12 ft wide. The fault is a continuous structure that can be mapped for many miles and also has long continuous splays (Christiansen and Lipman, 1965; Lipman and McKay, 1965; Scott and Bonk, 1984; Day and others, in press). The Sundance Fault zone, however, consists of fault strands that commonly have little lateral or vertical continuity, even on a single ridge.

The south slopes of Purgatory Ridge and Dead Yucca Ridge (pl. 2) provide several examples of the vertical and lateral variability of the geometry of the Sundance Fault zone. On both ridges, several fault strands compose a 75- to 230-ft-wide zone at the top of the middle nonlithophysal zone of the Tiva Canyon Tuff, 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 along this single strand is somewhat less than the cumulative displacement across the broader Sundance 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 of the Tiva Canyon Tuff than in the overlying crystal-rich member. This geometry seems to contrast with the upward-splaying, or horsetailing pattern commonly observed along the Ghost Dance Fault zone (Day and others, 1998); yet, the upward-splaying geometry along the Ghost Dance Fault zone is documented in the crystal-poor member. 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 across the tops of Antler Ridge and Live Yucca Ridge. Thus, the Sundance and the Ghost Dance Fault zones may be characterized by a similar stratigraphic control of faulting.

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 and has more individual faults in the crystal-poor member compared to the crystal-rich member, the crystal-poor member seems to have been less competent (weaker) than the crystal-rich member. 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 substantial tectonism affected the welded tuff. The available experimental data indicate that the sampled zones of the crystal-poor member (cpll, cpmn, and cpul) and the crystal-transition subzone (cr1) at the base of the crystal-rich member have greater tensile and ultimate strengths than the overlying subzones (cr2 and cr3) of the crystal-rich member (Boyd and others, 1996). However, a greater abundance of cooling joints (which have preferential northwest- and northeast-striking orientations) were observed in the crystal-poor member than in the crystal-rich member. Thus, the broad distributed brittle deformation of the crystal-poor member is attributed to the availability of preexisting cooling joints in that member for exploitation by the Sundance Fault zone. The narrower, more restricted deformation in the crystal-rich member is attributed to the lower frequency of cooling joints in that member.

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. A diagrammatic cross section in figure 4 shows a discrete, larger displacement fault cutting the crystal-rich member and shows numerous faults that have smaller displacement in the crystal-poor member, as observed in the field. Strain compatibility in the stratigraphic section requires movement along subhorizontal planes, including gently dipping breccia zones (which are observed), layer-parallel slip (which seems to have locally produced gouge and breccia along partings in the strata), and minor discrete gently dipping faults (not documented, but locally inferred on the basis of map patterns). The accommodation probably occurred in a distributed fashion along locally exposed, gently dipping breccia zones that functioned as zones of decoupling (fig. 4). As such, the faulted crystal-poor member has numerous irregular small blocks that have slipped or rotated, or both, along preexisting joints and synkinematic breccia zones. In contrast, the relative paucity of cooling joints in the overlying crystal-rich member has confined the offset to fewer discrete faults between larger, undeformed blocks (fig. 4).

The most striking contrast in deformation of the crystal-rich and the crystal-poor members of the Tiva Canyon Tuff 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 (pl. 1). The cumulative displacement due to minor faults offsetting the top of the middle nonlithophysal zone is 40 ft (east side down) across a 700-ft-wide domain east of the Ghost Dance Fault. In this area, a single mapped fault produces 6 ft 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 up to 6 feet of displacement of this contact; however, no mapped faults cut the better exposed base of the mixed-pumice subzone near the top of the south slope of Antler Ridge. As discussed in the section entitled "Character of Faulting in the Southern Part of the Map Area," 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 seem to continue up through the crystal-rich member on this south 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 functioned 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 predominantly northwest-striking faults may account for the northeasterly dip that characterizes these units on Antler Ridge.

Lateral accommodation of displacement is needed in places where the Sundance Fault zone seems to jump across strike. An example is on Dead Yucca Ridge, where the position of the fault on the ridge top is 115 ft east of the projected trace of the east edge of the Sundance Fault zone mapped near the base of the slope (pl. 2). This map pattern is similar to the places where the Ghost Dance Fault steps normal to the strike to a new location (north slope of Antler Ridge and top of Live Yucca Ridge; pls. 1 and 2). The two fault strands may meet at depth in each of these places; the shallow step-over may occur along a preexisting cooling joint or along a zone of distributed brittle deformation. Detailed analyses of the step-over areas were prevented by the poor exposures of bedrock there.

CONCLUSIONS

The principal conclusions regarding the Sundance Fault zone and other faults in the map area are as follows:

1. The Sundance Fault zone has a mapped length of 2,500 ft, extending from Dead Yucca Ridge to Live Yucca Ridge. Across Dead Yucca Ridge and Purgatory Ridge, the Sundance Fault zone is as much as 230 ft wide, cutting the crystal-poor and the crystal-rich members of the Tiva Canyon Tuff, and has a maximum cumulative northeast-side-down displacement of about 35 ft. Displacement diminishes to the south on Live Yucca Ridge. The faults in the Sundance

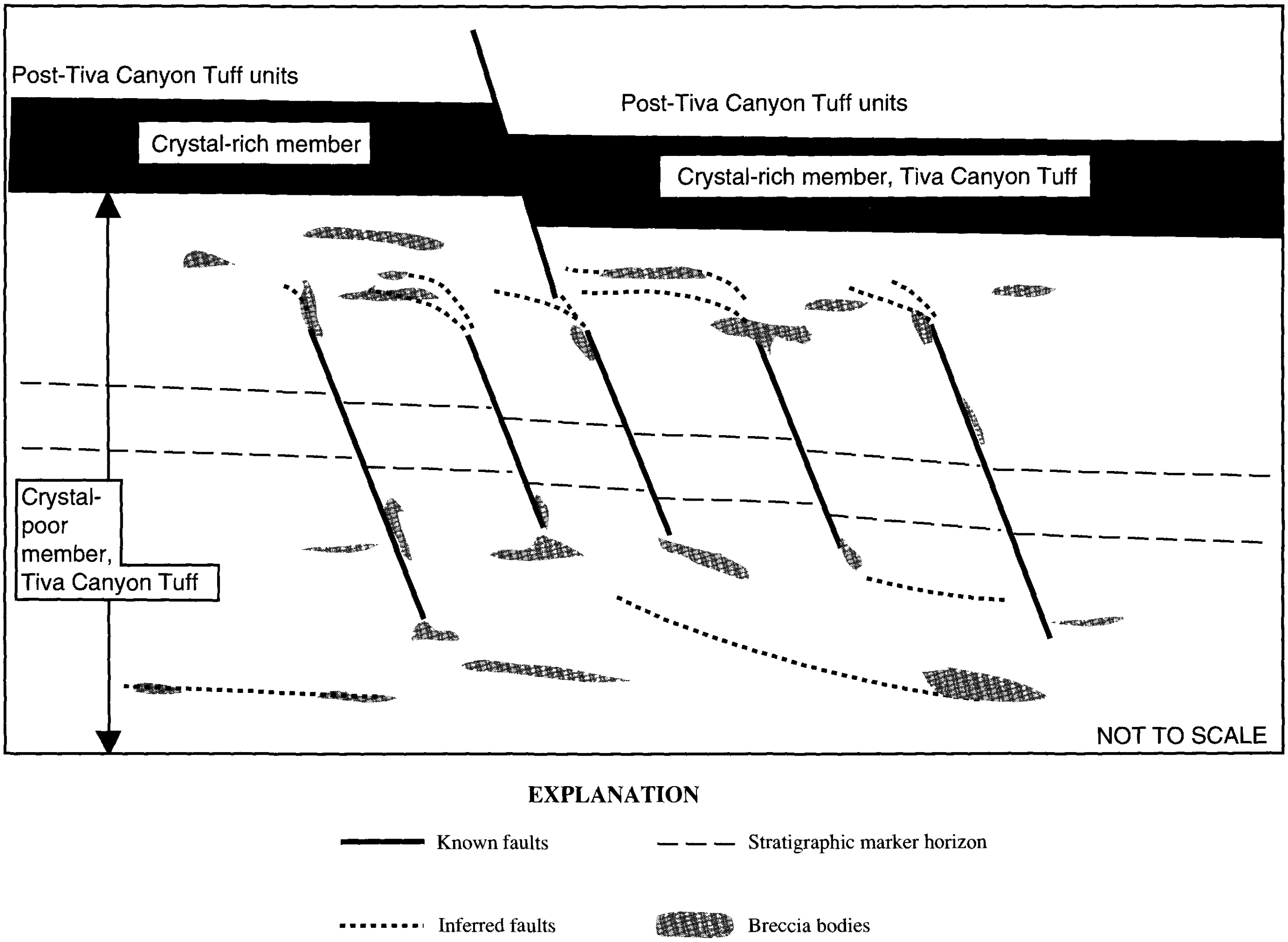


Figure 4. Diagrammatic cross section showing a general model for deformation in the Tiva Canyon Tuff, based on observations made during geologic mapping along the Sundance Fault zone.

Fault zone are almost exclusively characterized by northeast-side-down displacement.

2. Individual faults in the Sundance Fault zone and elsewhere are laterally and vertically discontinuous. The Sundance Fault zone consists of 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 in the Tiva Canyon Tuff 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 preexisting 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 may be 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 zone; the Sundance Fault zone does not cut the Solitario Canyon Fault.
6. A prominent northwest-striking fault is mapped at the northwest end of the map area, between the Little Prow and The Prow; this fault is distinct from, and seems unrelated to, the Sundance Fault zone.

REFERENCES CITED

Boyd, P.J., Price, R.H. Noel, J.S., and Martin, R.J., 1996, Bulk and mechanical properties of the Paintbrush Tuff recovered from borehole USW NRG-2, 2A, 2B, and 3—Data report: Albuquerque, N.M., Sandia National Laboratories Report SAND94-1902, 88 p.

Buesch, D.C., Spengler, R.W., Moyer, T.C., and Geslin, J.K., 1996, Proposed stratigraphic nomenclature and macroscopic identification of lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain, Nevada: U.S. Geological Survey Open-File Report 94-469, 45 p.

Christiansen, R.L., and Lipman, P.W., 1965, Geologic map of the Topopah Spring Northwest quadrangle: U.S. Geological Survey Geologic Quadrangle Map GQ-444, scale 1:24,000.

Day, W.C., Dickerson, R.P., Potter, C.J., Sweetkind, C.A., San Juan, C.A., Drake, R.M., II, and Fridrich, C.J., in press, Geologic map of the Yucca Mountain area, Nye County, Nevada: U.S. Geological Survey Miscellaneous Investigations Series map I-2627, scale 1:24,000.

Day, W.C., Potter, C.J., Sweetkind, D.S., Dickerson, R.P., and San Juan, C.A., 1998, Bedrock geologic map of the central block area, Yucca Mountain, Nye County, Nevada: U.S. Geological Survey Miscellaneous Investigations Series map I-2601, 2 sheets, scale 1:6,000.

Geslin, J.K., Moyer, T.C., and Buesch, D.C., 1995, Summary of lithologic logging of new and existing boreholes at Yucca Mountain, Nevada, August 1993 to February 1994: U.S. Geological Survey Open-File Report 94-342, 39 p.

Lipman, P.W., and McKay, E.J., 1965, Geologic map of the Topopah Spring Southwest quadrangle: U.S. Geological Survey Geologic Quadrangle Map GQ-439, scale 1:24,000.

Sawyer, D.A., Fleck, R.J., Lamphere, M.A., Warren, R.G., Broxton, D.E., and Hudson, M.R., 1994, Episodic caldera volcanism in the Miocene southwestern Nevada volcanic field—Revised stratigraphic framework, $^{40}Ar/^{39}Ar$ geochronology, and implications for magmatism and extension: Geological Society of America Bulletin, v. 106, no. 10, p. 1304–1318.

Scott, R.B., 1990, Tectonic setting of Yucca Mountain, southwest Nevada, *in* Wernicke, B.P., ed., Basin and Range extensional tectonics near the latitude of Las Vegas, Nevada: Boulder, Colo., Geological Society of America Memoir 176, p. 251–282.

Scott, R.B., and Bonk, Jerry, 1984, Preliminary geologic map of Yucca Mountain, Nye County, Nevada, with geologic sections: U.S. Geological Survey Open-File Report 84-494, scale 1:12,000.

Spengler, R.W., Braun, C.A., Martin, L.G., and Weisenberg, C.W., 1994, The Sundance Fault—A newly recognized shear zone at Yucca Mountain, Nevada: U.S. Geological Survey Open-File Report 94-49, 11 p.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1999 — 773-051 / 20135 Region No. 8

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
U.S. DEPARTMENT OF ENERGY

OPEN-FILE REPORT 98–266
ANTLER RIDGE AREA—PLATE 1
C.J. Potter and others, 1999, Nature and continuity of the Sundance Fault, Yucca Mountain, Nevada

EXPLANATION

Geologic Units

Quaternary

Qu	Quaternary surficial deposits, undifferentiated

Tertiary

Tiva Canyon Tuff

Crystal-rich member

cr2	Mixed-pumice subzone (Tpcrn2, Tpcrl2)*
cr1	Crystal-transition subzone (Tpcrn1, Tpcrl1)*

Crystal-poor member

cpul	Upper lithophysal zone (Tpcpul)*
cpmn3	Upper nonlithophysal subzone of middle nonlithophysal zone (Tpcpmn3)*
cpll	Lower lithophysal zone (including Tpcpll, Tpcpmn1, Tpcpmn2)*
cpln	Lower nonlithophysal zone (Tpcpln and locally includes Tpcpv)*

* Abbreviation of informal stratigraphic nomenclature by Buesch and others (1996)

cpll / cpln Contact—Solid where exposed or tightly constrained, dashed where approximately located, dotted where concealed beneath Quaternary surficial deposits, queried where inferred or uncertain

? Fault—Solid where exposed or tightly constrained, dashed where approximately located, dotted where concealed beneath Quaternary surficial deposits, queried where inferred or uncertain

Breccia

Surface trace of breccia zone

Prominent concentration of fault breccia float

Cleared exposure

UZ-N32 Drill hole and name

Reference cited:
Buesch, D.C., Spengler, R.W., Moyer, T.C., and Geslin, J.K., 1996, Proposed stratigraphic nomenclature and macroscopic identification of lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain, Nevada: U.S. Geological Survey Open-File Report 94–469, 45 p.

Geologic map showing the Sundance Fault zone and adjacent areas, Antler Ridge area

By
C.J. Potter, R.P. Dickerson, and W.C. Day, 1999

14°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1994

400 200 0 200 400
SCALE IN FEET

120 60 0 60 120
SCALE IN METERS

SCALE 1:2,400
CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Topographic base map from the 1:6,000-scale topographic contour data produced from the orthophotographic mission flown in 1990 by EG&G for the U.S. Department of Energy. Nevada State Plane coordinates (in feet) are for the central zone of Nevada and are based on polyconic projection.

Mapping done spring 1995 by
C.J. Potter[1], R.P. Dickerson[2], W.C. Day[1], and Karl Kellogg[1].
Digital cartography by R.L. Blackburn[2] and A.J. Donatich[1].

[1]United States Geological Survey, Denver, Colorado
[2]Science Applications International Corporation, Denver, Colorado

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
U.S. DEPARTMENT OF ENERGY

OPEN-FILE REPORT 98–266
DIABOLUS RIDGE TO LIVE YUCCA RIDGE—PLATE 2
C.J. Potter and others, 1999, Nature and continuity of the Sundance Fault, Yucca Mountain, Nevada

EXPLANATION

Geologic Units

Quaternary

Qu	Quaternary surficial deposits, undifferentiated

Tertiary

Tiva Canyon Tuff

Crystal-rich member

Vitric zone

crv	Vitrophyre subzone (Tpcrvl)*

Nonlithophysal zone and (locally present) lithophysal zone

cr3	Pumice-poor subzone (Tpcrn3)*
cr2	Mixed-pumice subzone (Tpcrn2, Tpcrl2)*
cr1	Crystal-transition subzone (Tpcrn1, Tpcrl1)*

Crystal-poor member

cpul	Upper lithophysal zone (Tpcpul)*
cpum	Upper lithophysal zone and middle nonlithophysal zone, undifferentiated (Tpcpmn, Tpcpul)*
cpmn3	Upper nonlithophysal subzone of middle nonlithophysal zone (Tpcpmn3)*
cpll	Lower lithophysal zone (including Tpcpll, Tpcpmn1, Tpcpmn2)*
cpln	Lower nonlithophysal zone (Tpcpln)*
cpv	Vitric zone (Tpcpv)*
bt	Bedded tuff beneath the Tiva Canyon Tuff

* Abbreviation of informal stratigraphic nomenclature by Buesch and others (1996)

cpll cpln Contact—Solid where exposed or tightly constrained, dashed where approximately located, dotted where concealed beneath Quaternary surficial deposits, queried where inferred or uncertain

85 Strike of dip of prominent joint or joint set

Strike of vertical joints

? Fault—Solid where exposed or tightly constrained, dashed where approximately located, dotted where concealed beneath Quaternary surficial deposits, queried where inferred or uncertain

Breccia

Surface trace of breccia zone

Prominent concentration of fault breccia float

Reference cited:
Buesch, D.C., Spengler, R.W., Moyer, T.C., and Geslin, J.K., 1996, Proposed stratigraphic nomenclature and macroscopic identification of lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain, Nevada: U.S. Geological Survey Open-File Report 94–469, 45 p.

Geologic map showing the Sundance Fault zone and adjacent areas, Diabolus Ridge to Live Yucca Ridge

By
C.J. Potter, R.P. Dickerson, and W.C. Day, 1999

14°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1994

400 200 0 200 400
SCALE IN FEET

120 60 0 60 120
SCALE IN METERS

SCALE 1:2,400
CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Topographic base map from the 1:6,000-scale topographic contour data produced from the orthophotographic mission flown in 1990 by EG&G for the U.S. Department of Energy. Nevada State Plane coordinates (in feet) are for the central zone of Nevada and are based on polyconic projection.

Mapping done spring 1995 by
C.J. Potter[1], R.P. Dickerson[2], W.C. Day[1], and Karl Kellogg[1].
Digital cartography by R.L. Blackburn[2] and A.J. Donatich[1].

[1]United States Geological Survey, Denver, Colorado
[2]Science Applications International Corporation, Denver, Colorado

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
U.S. DEPARTMENT OF ENERGY

OPEN-FILE REPORT 98–266
LITTLE PROW AREA—PLATE 3
C.J. Potter and others, 1999, Nature and continuity of the Sundance Fault, Yucca Mountain, Nevada

EXPLANATION

Geologic Units

Quaternary

Qu	Quaternary surficial deposits, undifferentiated

Tertiary

Tiva Canyon Tuff

Crystal-rich member

Vitric zone

crv	Vitrophyre subzone (Tpcrvl)*

Nonlithophysal zone and (locally present) lithophysal zone

cr3	Pumice-poor subzone (Tpcrn3)*
cr2	Mixed-pumice subzone (Tpcrn2, Tpcrl2)*
cr1	Crystal-transition subzone (Tpcrn1, Tpcrl1)*

Crystal-poor member

cpum	Upper lithophysal zone and middle nonlithophysal zone, undifferentiated (Tpcpmn, Tpcpul)*
cpll	Lower lithophysal zone (including Tpcpll, Tpcpmn1, Tpcpmn2)*
cpln	Lower nonlithophysal zone (Tpcpln, and locally includes Tpcpv)*
cpv	Vitric zone (Tpcpv)*
bt	Bedded tuff beneath the Tiva Canyon Tuff

* Abbreviation of informal stratigraphic nomenclature by Buesch and others (1996)

cpll / cpln — Contact—Solid where exposed or tightly constrained, dashed where approximately located, dotted where concealed beneath Quaternary surficial deposits, queried where inferred or uncertain

? — Fault—Solid where exposed or tightly constrained, dashed where approximately located, dotted where concealed beneath Quaternary surficial deposits, queried where inferred or uncertain

Strike-slip fault—Arrows show sense of movement

Breccia

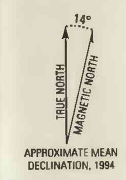
Surface trace of breccia zone

Prominent concentration of fault breccia float

Reference cited:
Buesch, D.C., Spengler, R.W., Moyer, T.C., and Geslin, J.K., 1996, Proposed stratigraphic nomenclature and macroscopic identification of lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain, Nevada: U.S. Geological Survey Open-File Report 94–469, 45 p.

Geologic map showing the Sundance Fault zone and adjacent areas, Little Prow area

By
C.J. Potter, R.P. Dickerson, and W.C. Day, 1999



400 200 0 200 400
SCALE IN FEET

120 60 0 60 120
SCALE IN METERS

SCALE 1:2,400
CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Topographic base map from the 1:6,000-scale topographic contour data produced from the orthophotographic mission flown in 1990 by EG&G for the U.S. Department of Energy. Nevada State Plane coordinates (in feet) are for the central zone of Nevada andl are based on polyconic projection.

Mapping done spring 1995 by
C.J. Potter[1], R.P. Dickerson[2], W.C. Day[1], and Karl Kellogg[1].
Digital cartography by R.L. Blackburn[2] and A.J. Donatich[1].

[1]United States Gaological Survey, Denver, Colorado
[2]Science Applications International Corporation, Denver, Colorado