"PRELIMINARY DRAFT"

VERIFICATION AND ENHANCEMENT OF BEDROCK GEOLOGIC MAPS FOR YUCCA MOUNTAIN, NEVADA

Edited by Warren C. Day and Cynthia D.M. Corbett

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ADMINISTRATIVE REPORT

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By Warren C. Day and Cynthia D. M. Corbett

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PREFACE

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High-level nuclear waste may be stored at the potential repository site at Yucca Mountain in Nevada. Therefore, it is critical that the potential repository site be mapped in sufficient detail and at the highest possible confidence level to identify and characterize geologic hazards, as well as hydrologic and pneumatic pathways. Geologic maps are a vital underpinning for geoscience research for the Yucca Mountain Project (YMP) in Nevada. They are the foundation for the site characterization studies, such as the potential seismic hazards assessment, the tectonic, and hydrologic studies, and the performance assessment for overall site suitability. Moreover, geologic mapping is an integral part of the framework for the geoengineering associated with design and construction of the exploratory studies facility (ESF) and the potential repository.

The preliminary geologic map published by Scott and Bonk (1984), combined with a more recent article by Scott (1990), has provided the framework for all geologic research at the mountain. The work was more detailed than previous 1:24,000-scale mapping by Christiansen and Lipman (1965) and by Lipman and McKay (1965), who first delineated the major faults and lithostratigraphic units for the Yucca Mountain area. However, the mapping done by Scott and Bonk (1984) was conducted from a detailed reconnaissance viewpoint and was never meant to be extrapolated to the levels of detail currently (1995) needed for the three-dimensional geologic computer modeling nor for the final design of the ESF or the potential repository site.

The chapters in this administrative report describe the results of the work to verify the

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Scott and Bonk (1984) geologic map and cross sections and to determine if the preliminary map is adequate for the site analyses now (1995) required. In progress work to enhance the preliminary map is also discussed.

Chapter A by R.P. Dickerson is a review of the internal consistency of the work by Scott and Bonk (1984) and of the agreement between the geologic sections and drill-hole log data from other sources (see Chapter A). Dickerson found that there are several areas of divergence between the geologic map and cross sections.

Chapter B by C.W. Weisenberg describes the photolineament investigation to identify any previously unknown structures in the potential repository area that may affect the design of the potential repository facility, seismic hazard analyses, or performance assessment studies. Weisenberg reported that most of the photolinears were attributable cooling joints and previously delineated faults. Further photolineament investigations are not warranted at this time.

Chapter C by W.C. Day and others is a map with discussion of the predominant faults in the potential repository area and is part of an ongoing mapping effort and, as such, is viewed as preliminary. However, Day and others document the complex geometry of the dominant fault and fault zones. Many of the faults branch at their terminations near the ground surface, creating a "horse-tail" geometry that opens up toward the surface. One of the conclusions is that some of the fault and associated breccia zones, like the Ghost Dance fault zone, may become narrower at depth as the individual splays of the fault zone converge.

Chapter D by D.C. Buesch and others briefly describes their work to enhance the stratigraphic nomenclature used by Scott and Bonk (1984) by providing a consistent nomenclature following the work of Geslin and others (1994) and Buesch and others (in press) for the predominant formations at Yucca Mountain, the Tiva Canyon Tuff and the Topopah Springs Tuff. Stratigraphic horizons in the Topopah Spring Tuff, which are structural datums critical for the design of the repository and the three-dimensional geologic model, are best exposed on the in Solitario Canyon on the west flank of Yucca Mountain. Buesch and others flagged key stratigraphic horizons on the west flank of Yucca Mountain and provided a detailed control on variations of stratigraphy and location of faults. They delineated the base of the Tiva Canyon Tuff, which is the prime lithostratigraphic and structural control for the three-dimensional lithostratigraphic model (Buesch, Nelson, and others, in press).

This body of work highlights the need for a new geologic map at a scale sufficient for the needs of the entire YMP. The new generation of mapping needs to incorporate the new stratigraphic nomenclature used project-wide in all subsurface activities such as drilling and in the ESF. The new geologic mapping must also integrate the results of recent and ongoing geophysical studies which were not available at the time of Scott and Bonk's (1984) work. The complex nature of the fault zones as well as the location of minor faults within the repository is not presented in the published map of Scott and Bonk (1984). A 1:6,000 scale seems to be a suitable compromise between the need for detailed information useful for the design and the construction phases at YMP, which could benefit from even more detailed mapping, and the effort to produce a more regional perspective needed for the geologic, hydrologic, and performance assessment investigations.

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CHAPTER A

EVALUATION OF THE PRELIMINARY GEOLOGIC MAP AND GEOLOGIC SECTIONS OF YUCCA MOUNTAIN, NYE COUNTY, NEVADA, AND ITS COMPATIBILITY WITH DRILL-HOLE LOGS

By **Robert P. Dickerson**

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EVALUATION OF THE PRELIMINARY GEOLOGIC MAP AND GEOLOGIC SECTIONS OF YUCCA MOUNTAIN, NYE COUNTY, NEVADA, AND ITS COMPATIBILITY WITH DRILL-HOLE LOGS

By Robert P. Dickerson

ABSTRACT

The 1984 preliminary geologic map for Yucca Mountain has been the primary source of surface geologic data and includes data about subsurface stratigraphy and structure for the Yucca Mountain Project site. Therefore, this map and accompanying geologic sections were evaluated for internal consistency and consistency with other technical information sources. The results of this office-based evaluation are summarized in this chapter. Although much of the geology portrayed on the preliminary geologic map is found to be reasonably consistent, some differences were found between the attitude of Tiva Canyon Tuff subunits as mapped and the dip and strike data. Other inconsistencies were found between drill-hole subsurface data and map data on Yucca Crest. A comparison between the Yucca Mountain Project Technical Data Base Geographic Information System data base and the preliminary geologic map reveals some differences in drill-hole locations. Some inconsistencies exist between the preliminary geologic map and the accompanying geologic sections and include the number and locations of faults as well as the stratigraphic nomenclature. Differences also exist between subsurface drill-hole data and the geologic sections in regards to structural and stratigraphic information. Field checks, reevaluation of available drill-hole logs, consistent adherence to current (circa 1995) stratigraphic nomenclature, and local remapping are necessary to resolve the differences found during this evaluation, and to provide a geologic

map data base that incorporates the last decades-worth of information not available at the time the 1984 preliminary map was prepared.

INTRODUCTION

During development of the U.S. Geological Survey's three-dimensional, computer-assisted, lithostratigraphic model (Buesch and others, 1995) of the potential high-level nuclear waste repository at Yucca Mountain, Nevada (fig. 1), certain inconsistencies were discovered between and within the various data sets. The primary data sets used were the 1984 preliminary geologic map of Yucca Mountain (Scott and Bonk, 1984) for the surface geologic data, and drill-hole lithologic logs (table 1) and geologic sections (Scott and Bonk, 1984) for the subsurface data. The inconsistencies prompted a detailed study of the various data sets concerned. This chapter is an evaluation of the internal geologic consistency between the preliminary geologic map and the accompanying geologic sections from the report by Scott and Bonk (1984). Hereafter the preliminary geologic map (Scott and Bonk, 1984, sheet 1) will be referred to as the preliminary geologic map, and the geologic sections (Scott and Bonk, 1984, sheet 2) will be referred to as the geologic sections. Table 2 shows the stratigraphic nomenclature used on the geologic sections (Scott and Bonk, 1984) and in drill-hole lithologic logs. The consistency between the preliminary geologic map and geologic sections, and the published (Spengler and others, 1979; Spengler and others, 1981; Bentley and others, 1983; Maldonado and Koether, 1983; Rush and others, 1984;

FIGURE 1. NEAR HERE

TABLE 1. NEAR HERE

Figure 1. Index Map and locations of geographic features and drill-holes.

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APPENDIX B-I. Description of photolineaments in the study area.

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APPENDIX B-1

DESCRIPTION OF PHOTOLINEAMENTS IN THE STUDY AREA

(Note: credit for the identification of faults in the study area goes to the authors of Chapter C of this report).

P-1. A 450 m long, N10°W alignment of broadly spaced east facing benches (seen best on 5-9a-8 pm) marks this weak lineament, along with a small saddle on the north side of Broken Limb Ridge and a sharp bend in the wash north of highway Ridge. A faint tonal anomaly is found on top the ridge.

Field Check A short, down-to-the-west N20°E fault with less than 3 m of offset was mapped on the south flank of Broken Limb Ridge near the south end of the lineament, along with an area of brecciation. On the north flank of the ridge, a N10°W, down-to-the-west fault with less than 3 m offset was found. The lineament may represent a zone of minor faulting parallel to the N10°W fault, but no other evidence that P-1 is due to a fault was found.

P-2. This 600 m long, N15°W striking feature (the zone of parallel aligned features is wide and the lineament could be interpreted to strike N25°W is on the edge of the study area, but is of interest because it lines up at a distance with the southern end of the Sundance fault and the lineament (P-6) associated with it. It is best expressed as a pronounced white band on 5-9a-7 am and as a linear ledge on 5-9a-7 pm which trends into a saddle at the top of the north end of Boundary Ridge. Parallel tonal anomalies are slightly offset to the west on the east end of Whaleback Ridge. This lineament corresponds substantially to a north-northwest fault mapped by Scott and Bonk along which a small elongate graben occurs.

Field Check Much of the lineament was confirmed to represent the Scott and Bonk Fault. A breccia zone along the fault contains much white, probably caliche-coated breccia and overlying rubble. An east facing straight and planar scarp about 2 m high forms the west boundary of the breccia zone and accounts for a strong shadow seen on the late afternoon photographs. Faulting here is indicated on the photographs by the benches and the white tonal anomaly.

P-3. Best observed on 5-9a-8 am, this 1000 m long, N35°W lineament is one of the more prominent features on that photos. It is expressed rather differently along strike. On Whaleback Ridge, near its center, the lineament is marked by a broad saddle, the termination of a ridge-crest cliff, and numerous thin and closely spaced north-northwest linear dark tonal anomalies. To the north-northwest is an aligned broader dark tonal anomaly and a steep ravine diversion which abruptly turns to a semi-aligned orientation. To the south-southeast is a broad aligned saddle on the small ridge between Broken Limb and Whaleback ridges. On Broken Limb Ridge, an aligned dark tonal band is present on the north facing slope, and a small aligned step on the top of the ridge (best seen on 5-9a-8 pm). The thin aligned dark tonal anomalies are also present in surrounding areas. They add to the visual impression of a long linear feature when present between widely spaced saddles and ravine bends. The features are not perfectly aligned, and expanding the width of the lineament has the effect of adding more features.

Field check A significant area of probable fault breccia was found along the trace of

P-3 in the wash on the north side of Broken Limb Ridge. However, the trend of these breccias is about N10-15°W. On Whaleback Ridge, two down-to-the-west faults were mapped near P-3 but they strike about N5°E. At the NW end of the lineament, at the above mentioned abrupt bend in the wash, a steep bank of massive Tiva Canyon Tuff forms the bend. No evidence of faulting was found. A probable fault breccia is found here about 30 m west of the lineament, but trends north-south. The thin north-northwest tonal anomalies seen on the photos along the lineament are probably alignments of brush which are parallel to steep, north-northwest cooling joints seen in nearby outcrops.

It appears that P-3, while it forms an eye catching lineament on photo 5-9a-8 am, is a fortuitus alignment of different features. While the saddles are probably due to differential erosion along faults, the faults have a different strike than the lineament. Vegetative alignments parallel to north northwest cooling joints in the general area add to the visual effect of aligned saddles.

P-4. On the south flank of Antler Ridge, just west of the Ghost Dance Fault, is a previously recognized zone of scattered breccia, fractures, and slickensides. A very subtle N30°W, 800 m lineament identified. Several short, narrow, dark NNW tonal anomalies mark the Antler Ridge part of the feature. They align with the western termination of the cliff on the ridge crest, and fracture-bounded blocks trend parallel to the lineament. It could not be traced to the northwest, although parallel features are present nearby. The wash south of Antler Ridge makes a sharp bend to the southwest at the intersection with the lineament. Several aligned relatively wide north-northwest dark tonal anomalies are found on the two ridges to the south between Antler and Whaleback Ridge and align with a rather dark band on the NE side of Whaleback Ridge.

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<u>Field Check.</u> Examination revealed that the largest breccia zone has about a N10W trend, and that the slickensides consist of light grooving on probable sheared north-northwest cooling joint surfaces, but that these shear zones cannot be traced more than 2-3 m and do not appear to have significant offset. The wash diversion is due to a landslide. N30°W striking cooling joints cut nearby small outcrops.

The cause of the tonal anomalies on ridges south of Antler Ridge is difficult to determine on the ground. They appear to be zones of slightly denser vegetation than surrounding areas present where soil is composed of relatively smaller rock fragments. The dark band on Whaleback Ridge appears to be a line of dark talus (rock strip) at a small angle to the slope direction. Evidence suggests that P-4 is not a significant fault zone.

P-5. A series of N30°W trending anomalies are seen on the photos on the short middle ridges of Split Wash, and on western Live Yucca Ridge to the north and Antler Ridge to the south. The trend is best seen on 5-9a-9 (am). This group of features includes tonal anomalies, benches, and cliff terminations. Two wash diversion are aligned with the trend. The strongest features on each ridge are generally not perfectly aligned, but together the area displays an impressive broad zone of parallel short lineaments.

P-5, a N30°W, 1200 m long feature, is the best single alignment within this zone, and was selected for study.

On north Antler Ridge a thin dark tonal anomaly marks the lineament along with small NNW scarps or fissures in the upper Tiva cliff. A dark tonal anomaly is aligned on the south middle ridge of Split Wash. On the north middle ridge a thin cliff of upper Tiva terminates in a NE facing bench, adjacent to a slight tonal anomaly on the ridge flanks. On west Live Yucca Ridge a small ravine slope is aligned with the trend, and an upper Tiva cliff termination is approximately aligned at the top of the ridge. Slightly offset from the trend are some sharp, steep-sided wash diversions to a NNW orientation in the south branch of Coyote Wash.

Field Check. Several closely spaced north-south faults on Antler Ridge are the only faults mapped on P-5. Cooling joints observed in outcrop form a usually rectilinear network of very steep, northwest and northeast striking joints. Joints can be easily traced by alignments of brush on the hillsides, these are often over 50 m long. It is likely that some of the north northwest dark anomalies are sheared cooling joints, but many of the photo anomalies are longer and wider than the lines of brush growing in joints seen in the field.

Most of the short, dark tonal anomalies of P-5 seen on the photos are not visible on the ground, but along at least two the soil was observed to be thicker and composed of small rock fragments, as opposed to a thin cover of larger rock fragments resting on bedrock seen in adjacent areas. The areas of thicker soil support a denser growth of grass and small brush, compared to a few sparse large bushes which grow in fractures in the very shallow bedrock nearby. Closely spaced fractures are present along P-5 in areas of outcrop, but their extent is unknown. These zones may be minor shear zones or represent swarms of closely spaced cooling joints, sheared or unsheared. The term "fracture zone" is a nonspecific description of P-5 and anomalies like it.

In the south branch of Coyote Wash, steep N30°W joints can be observed along the sharp stream diversions found on P-5, suggesting the diversion is due to joint control. Arguably, north-northwest zones of weakness could control the diversions, and now be covered in the wash or by landslides, but the lack of fault offsets or breccias in the nearby slope does not support this model. Some evidence of faulting on P-5 exists in the form of fracturing and broken rock, but there is little reason to believe the long lineament marks a significant fault zone.

P-6. This lineament is in part coincident with the main Sundance fault trace where it was mapped on Live Yucca Ridge (Spengler and others, 1994). As discussed in chapter C of this report, the Sundance Fault zone has can be traced about 0.5 km and has 6-8 m of down-to-the-east offset. Field study of the Sundance structure is presently being conducted by Chris Potter and others of the USGS staff.

The N30°W lineament is 1200 m long and can be traced as a prominent feature north from Live Yucca Ridge to the western part of Wren Wash. Thus, the photolineament associated with the Sundance fault is longer than the fault as mapped. P-6 is expressed primarily as aligned saddles, sharp stream diversions, and cliff terminations. The best expression is on 5-9a-9(am).

Starting on Live Yucca Ridge, and continuing three more ridges two the north, the lineament is marked by aligned saddles. In the three intervening washes of these four ridges, including the branches of Coyote Wash, are three aligned sharp southward stream diversions. At the north end, several short ridges in upper Wren wash have upper Tiva cliffs that terminate near the lineament. Along the south slope of Dead Yucca Ridge east of the Sundance is a remarkable set of well exposed rectilinear cooling joints which show up nicely on 1-22-14. The distinct pattern of thin joint formed lineaments stops at the saddle of the Sundance lineament, suggesting structural disruption. light tonal anomalies marks known breccias on Live Yucca ridge and the Ridge to the north in Coyote Wash.

Field Check. Details of the Sundance Fault are currently being studied by C.J. Potter of the U.S.G.S. The rock in the saddles is broken, and no cooling joints extend across it, suggesting a fault. A prominent N30W breccia a few m wide is found on the south flank of Live Yucca Ridge; the next two south-facing slopes to the north have some less impressive breccia. The photolineament supports the existence of the Sundance Fault as a significant fault. The length of the lineament suggests the fault may be somewhat longer than the mapped trace.

P-7. This is a vague N30°W, 700 m lineament on Antler Ridge which is close to alignment with P-6. It consists of a modest northeast facing ledge in the gently sloping upper Tiva Canyon Tuff surface at the top of the ridge, best seen on 5-9a-9 pm, and continues as aligned narrow north northwest tonal anomalies on both north and south slopes of Antler Ridge.

Field Check Spengler and others (1994) show several north-northwest down-to-the-east faults with greater than 3 m of vertical displacement on south Antler Ridge approximately aligned with P-7. The faults form a low angle with the offset contacts, so that a slight change in attitude could account for the map patterns. Mapping reported in chapter C of this report found no fault offsets along the trend of P-7. The nature of the tonal anomalies could not be determined.

P-8. This is the Ghost Dance Fault zone, which is included here as a known fault for which our methods of locating possible faults on air photos can be checked. Plate C-1 shows shows a west and east boundary of P-8 because it is a wide feature. The lineament is divided into three segments which bend from north-south in the south to near N5°E in the north.

The steep slope on the east side of the fault produces shadowing on the early morning photos, and several anomalous steep ravines on the flanks of the ridges add to this shadowing effect. Tonal anomalies are interestingly not prominent along the Ghost Dance Fault. The fault has a lack of small linear tonal anomalies aligned to it, compared to features like P-4 or P-5.

Field Check Mapping reported in Chapter C of this report shows that the Ghost Dance Fault has number of smaller faults associated with it. This may be one reason why the fault appears as a wide anomaly on the photographs. Many of the breccia zones are cemented with thin silica coatings instead of calcite. These breccias are hardly visible on the photos, while in comparison calcite-cemented breccias are often quite obvious.

P-9. On photos 1-19-17 and 18, obvious offset of several layers of the Tiva Canyon Tuff are seen along the base of the west face of Yucca Crest (east slope of Solitario Canyon). A small ravine trends about N40°W through this offset, and aligns with the apparent fault. These features align approximately with a straight narrow incised ravine just on the east side of Yucca Crest. Lining up the two features suggests a possible continuous fault with an average strike of about N30°W and a length of 700 m. The northwest and southeast end of this trend are mapped as two separate short fault segments by Scott And Bonk.

<u>Field check.</u> A clear down to the southwest offset was found on the lineament where it crosses Yucca Crest, juxtaposing the nonlithophysal zone of the crystal-rich unit of the Tiva Canyon Tuff with the stratigraphically lower lithophysal zone of the crystal-rich unit.. About 5-6 m of offset is indicated. Some breccia is present, but the fault zone is remarkably subtle on the ground at Yucca Crest compared to the photolineament.

P-10. This N30°E, 800 m long feature is located along a down-to-the-northwest fault Scott and Bonk mapped on the west flank of Yucca Crest along Solitario Canyon. It is best expressed on photo 1-19-20, on which an alignment of gullies and small rock scarps is found. However, an apparent large down-to-the-northwest offset of a resistant ledge of the top of the Topopah Springs Tuff occurs across P-10.

<u>Field Check</u> A small offset of about 1 m is found along P-10 on Yucca Crest, but the base of the Tiva Canyon Tuff is offset about 3 m. The top of the Topopah Springs Tuff, however, is offset about 13 m. The field check confirms the impression of a larger offset on the Topopah Springs derived from the photographic study.

P-11. This N35°E, 650 m long feature corresponds with a north-northeast striking down-to-the-west normal fault on Scott and Bonk. The lineament is composed mostly of a narrow ravine on the south side of Diabolus Ridge, but also as a narrow saddle on the ridge crest where upper Tiva Canyon Tuff appears uplifted. Bedding lineations approaching from the east terminate at the lineament. It continues a short distance to the south as a thin light tonal anomaly.

<u>Field Check</u> A substantial breccia zone and obvious down-to-the-west fault can be found at the site of P-11. However, examination suggests the narrow ravine does not follow the trend of the fault exactly. The fault on the south slope of Diabolus Ridge may strike more to the north and be out of alignment with P-11. The ledges to the southwest probably are related to P-10, if of structural origin.

LOCALITIES OF INTEREST

A number of linear features which are confined to one ridge, are very faint, or otherwise where not considered worthy of listing as lineaments, yet deserved field checking for some reason, were listed as L features.

L-1,L-2, L-3, L-4. These are paired steep northwest or north-northwest trending or NE trending meander banks on either sides of bends in the wash north of Highway Ridge. They may mark structural features or simply be random results of meander entrenchment. Interestingly, the only well developed entrenched meanders in the area of the central block seem to be on this wash and the wash to the south of Highway Ridge.

<u>Field check</u> The meander bends are typically bounded by steep slopes cut in welded Tiva Canyon Tuff. The rock at these localities was found to be typically relatively competent. Faults and brecciated areas are present on nearby slopes of ridges, but there is no regular relationship between these zones of weakness and the locations of sharp meander bends. While some of the bends may be due to fault control, it can not be established at these localities.

L-5. This is a short but steep, narrow, and straight ravine on the south side of Broken Limb Ridge.

Field Check Mapping presented in chapter C of this report suggests L-5 is the area of the north end of the large offset Dune Wash Fault of Scott And Bonk. The ravine is not parallel to the fault mapped here. The ravine indicates a possible fault, but does not indicate its true orientation.

L-6, L-7. A pair of north-south trending ledges on the east facing slope west of P-9 produce straight of shadows on the late afternoon photos. L-7 corresponds closely to a N-S fault of Scott and Bonk.

Field Check . L-7 is confirmed as a fault by mapping in Chapter C of this report. L-6 was not mapped as a fault, but similarity to L-7 suggests it may be a fault that was not mappable because of cover or some other reason.

L-8. This a feature just east of and parallel to P-2. It forms a straight shadow on the late afternoon photos.

Field Check . The feature forms a low ledge, but colluvial cover prevents confirmation as a fault.

L-9,10,,12,13,14,17,18,20. These features are all steep, straight, but short northeast-trending segments of washes that form near parallel shadows, mostly in the southwest part of the study area (similar features are present elsewhere). Because northeast striking faults have been recognized in nearby areas on the Scott and Bonk map and regionally as well, they were selected for study. They usually do not align with other types of features to form long lineaments, although in a few cases short NE tonal anomalies and vegetation alignments on probable NE cooling joints can be seen on the photos. No northeast alignment significant enough to be given a P rating was recognized, but a poorly defined northeast fabric of the photos is certainly present.

Field Check There was no convincing evidence of faulting of northeast trend found on any of these features. Nearby breccias were found and small fault offsets in places, but where the strikes of these features could be determined they were between N20°W and N10°E. There do exist numerous straight, near vertical northeast oriented cooling joints, some in the exposed rock of the ravines and wash banks and some in nearby outcrops. The best explanation for these short northeast lineaments is that they are due to structural control of erosion by these joints.

L-11. This is a straight bank section of the south flank of Whaleback Ridge where it abuts the braided wash segment to the south.

Field Check No evidence for faulting was found at this locality, although the contacts on the ridge above are poorly exposed.

L-15. This is a dark tonal lineament present on the east end of Whaleback Ridge.

Field Check. A small north-south fault was found on the south flank of the ridge, but is not parallel with the N30°W trend of L-15.

L-16. This feature is similar to the nearby P-7.

Field Check . See discussion of P-7. No fault was mapped on this trend in the present study.

L-19. Found nearby the similar P-5, it consists of a narrow dark tonal anomaly.

Field Check See discussion of P-5.

L-21. This feature is a short N15°W trending steep ravine on the south flank of highway

Ridge. On Photo 1-22-11 it appears to mark a pronounced offset of bedding lineations on the hillslope.

Field Check. The offset on a fault at this location on Scott and Bonk is about 6 m. Mapping for this study revealed an offset of about 14 m. The fault can be mapped northward, but not in alignment with the photolineament.

"PRELIMINARY DRAFT"

Figure 1A. Uninterpreted copy of aerial photograph no. 5-9a-9 pm, an early morning low-sun-angle view, showing the center of the study area. Scale is about one cm = 120 m. Compare with figure 2.

Figure 1B. The aerial photograph shown in figure 1A, with photolineaments marked. Compare with Plate B-1.

Table 1

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TABLE 2. NEAR HERE

Scott and Castellanos, 1984; Spengler and Chornack, 1984; Thordarson and others, 1984; Whitfield and others, 1984; Carr and others, 1986) drill-hole data and the unpublished, preliminary and unreviewed drill-hole data from R. Spengler (U.S. Geological Survey, written commun., 1984) is reviewed. This chapter does not incorporate a complete field check, although some field observations have been useful in interpreting some of the compaction foliation data and Tiva Canyon Tuff subunit contacts recorded on the map. Users of this chapter will benefit by having a copy of the preliminary geologic map of Yucca Mountain, Nye County, Nevada, with geologic sections (Scott and Bonk, 1984) available to them for reference.

Since the preliminary geologic map was published, the Tiva Canyon and Topopah Spring Members of the Paintbrush Tuff have been formally redesignated to formational status as the Tiva Canyon Tuff and the Topopah Spring Tuff within the Paintbrush Group (Sawyer and others, 1994). Much of this chapter is focused on attitudes and structures within the Tiva Canyon Tuff because it composes the largest part of the bedrock exposed at the surface in the central block of Yucca Mountain, the region of primary interest for site characterization studies.

EVALUATION OF PRELIMINARY GEOLOGIC MAP

Subunit Contacts

Local strike lines were constructed along the various ridges for the part of the preliminary geologic map located between Solitario Canyon to the west and Midway Valley to the east,

Table 2

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Table 2 continued

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and between Yucca Wash to the north and Abandoned Wash to the south (hereafter referred to as the central block). See figure 1 for the location of the ridges. For a given Tiva Canyon Tuff subunit contact, the local strike lines were constructed by connecting two points of equal elevation. The local strike lines were then compared to one another. Local dip was calculated from the differences in elevation and distance between the local strike lines. The elevation difference between the local strike lines is commonly 20 feet, but may be more because of incomplete bedrock exposure along subunit contacts. The discussion that follows refers to the attitudes of the subunits based on the orientation of subunit contacts and does not refer to the attitudes as shown by the strike and dip symbols on the preliminary geologic map.

Of particular interest is a comparison of the basal contacts for the lower rhyolitic portion and the upper crystal-rich quartz latite portion of the Tiva Canyon Tuff. The base of the Tiva Canyon Tuff and the base of the crystal-rich quartz latite represent two different depositional boundaries. The base of the Tiva Canyon Tuff mimics the paleotopographic surface upon which this pyroclastic flow was deposited; this pre-existing surface may or may not have local relief. However, because the lower thick rhyolite portion of the Tiva Canyon Tuff would have previously filled in paleotopographic low areas, the depositional surface for the overlying quartz latite may represent a surface that was originally flat and approximately horizontal.

The base of the Tiva Canyon Tuff is represented on the preliminary geologic map by the base of the columnar subunit (cc). The crystal-rich quartz latite is represented by Scott and Bonk (1984) as a caprock subunit (ccr), and the upper cliff subunit (cuc) is described by Scott and Bonk (1984) as a crystal-rich rhyolite. However, subsequent stratigraphic studies based primarily on drill-hole lithologic data (Buesch and others, in press) have included the crystal-rich transition zone in with the overlying crystal-rich quartz latite. In addition, current mapping efforts have discovered that the actual base of the crystal-rich quartz latite generally occurs below the mapped upper cliff subunit (cuc) contact, and that the cliff that characterizes the upper cliff subunit may correspond to part of the crystal-rich transition or to the mixed pumice subzones of the quartz latite as they are described in Buesch and others (in press). When this comparison was initiated it was determined that the base of the upper cliff subunit (cuc) was the closest approximation of the base of the crystal-rich quartz latite on the preliminary geologic map. For the purposes of this study it is assumed that the base of the upper cliff subunit (cuc) is near to, and parallel with the base of the crystal-rich quartz latite. This assumption is probably not correct in detail, although it may be a reasonable approximation. The overlying quartz latite caprock subunit (ccr) cannot be used because it does not represent the base of the crystal-rich quartz latite.

The base of the Tiva Canyon Tuff is exposed in the northern part of the central block at Yucca Mountain (fig. 2), whereas the base of the upper cliff subunit (cuc) is exposed on ridge tops throughout the central block (pl. 1). As a result, any comparison between these two surfaces is confined to the northern part of the central block, the only area where both surfaces are extensively exposed (fig. 3).

Figure 2. NEAR HERE

Figure 3. NEAR HERE

Figure 2. Base of Tiva Canyon Tuff local strike like map.

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Figure 3. Base of Tiva Canyon Tuff compared with inferred base of crystal-rich quartz latite.

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Southwest of Sever Wash the strike of both surfaces is approximately parallel (N 10° E to N 35° E), though the strike of the upper cliff subunit (cuc) exhibits more variability than does the strike of the base of the Tiva Canyon Tuff. The base of the Tiva Canyon Tuff has a more uniform dip (2.5 to 7.6 degrees to the southeast) than does the base of the upper cliff subunit (0 to 12.9 degrees to the southeast for cuc). Areas where strike lines for these two surfaces overlap are shown in figure 3. The data indicate that changes in dip in one surface are reflected, in part, by changes in dip in the other surface. The dip of the base of the Tiva Canyon Tuff is commonly, but not always, marginally steeper than the dip of the base of the upper cliff subunit (cuc). At Isolation Ridge northeast of Sever Wash, variability of both strike and dip is much greater, and the dip is steeper for the base of the upper cliff subunit (cuc) than it is for the base of the Tiva Canyon Tuff.

The contacts for the other subunits within the Tiva Canyon Tuff represent surfaces based on processes of welding, cooling, devitrification, vapor-phase alteration, and erosion. Although these processes may or may not yield surfaces that are parallel to primary contacts, inspection of aerial photographs of Yucca Mountain indicated that subunit contacts within the Tiva Canyon Tuff are mostly parallel.

Strike lines for subunit contacts ccr/cuc, cuc/cul, cul/crs, and crs/cll are shown on plate 2. Areas around the central part of Azreal Ridge, Live Yucca Ridge, and to a lesser extent, around Isolation Ridge and Diabolus Ridge on plate 2 lack parallelism between the subunit contacts; both the strike and the dip of subunit contacts vary greatly between the subunits. In contrast, these subunit contacts are mostly parallel to sub-parallel in other parts of the preliminary geologic map. The differences in the orientation of the various subunit contacts vary nonsystematically at Isolation Ridge, central Azreal Ridge, and Live Yucca Ridge. At Diabolus Ridge, however, the lower subunit contacts (cul/crs and crs/cll) are sub-parallel to one another, but are different in strike by as much as 80 degrees from the upper subunit contacts (ccr/cuc and cuc/cul). These and other smaller differences are shown on plate 2 and listed in table 3.

TABLE 3. NEAR HERE

The differences in orientation of subunit contacts at the four locations discussed above may result from several causes. The differences may accurately portray the geology as it exists, or they may indicate places where the geology may have been inaccurately mapped. On-going mapping activities at Yucca Mountain suggest that some subunit boundaries, principally the upper cliff subunit (cuc) and the caprock subunit (ccr) were not used in a fashion consistent with the present understanding of the stratigraphy of the Tiva Canyon Tuff. For example, the upper cliff subunit (cuc) on Scott and Bonk (1984) commonly refers to the mixed pumice subzone of the crystal-rich quartz latite (Buesch and others, in press) but in many places actually corresponds to the underlying crystal-rich transition subzone of the crystal-rich quartz latite (Buesch and others, in press). Similarly, the caprock subunit (ccr) may correspond to either the mixed pumice subzone (Buesch and others, in press) or the pumice-poor subzone (Buesch and others, in press) of the crystal-rich quartz latite. If the stratigraphy is accurately portrayed on the preliminary geologic map at the four

Table 3

"PRELIMINARY DRAFT"

locations discussed above, then perhaps welding, cooling, devitrification, and vapor-phase alteration phenomena are not constrained within parallel zones at these locations. Alternatively, perhaps the nonparallelism of the subunit contacts within these four locations indicates the presence of structures that are incompletely exposed.

Strike and Dip Data

Strike and dip symbols on the preliminary geologic map denote attitudes of beds of nonwelded tuff and of compaction foliation within the welded tuff. A foliation symbol is used to show the attitude of flow foliation within lava flows. Flow foliation of lava flows was not analyzed in this chapter because of the contorted nature of the flow foliation, and because lava flows do not crop out within the central block of Yucca Mountain. The following discussion refers to the foliation that is imparted to the tuff by the compaction of pumice clasts during welding of the thick, densely welded, pyroclastic flow deposits of the Tiva Canyon Tuff.

Foliation

The foliation referred to on the preliminary geologic map (Scott and Bonk, 1984, page 8) for welded tuff probably is the foliation defined by pumice flattening, although pumice swarms and lithic-clast trains may locally define the foliation as well. However, how these types of foliation in the welded part of the Tiva Canyon Tuff relate to the true attitude of the tuff as defined by an originally horizontal surface (such as the base of the crystal-rich quartz latite), or how the foliation relates to the subunit contacts within the Tiva Canyon Tuff is not entirely clear. Because foliation attitude and structural attitude of the formation may be based on different planar features, their measurements may legitimately yield different results. If thick welded tuffs are deposited on a surface of low relief and modest incline, then compaction foliation would mimic the true attitude of the bed. Alternatively, if the basal contact has a large amount of local relief, compaction foliation in the lower part of the tuff may be subparallel to the basal contact, and compaction foliation in the upper part of the tuff may be subparallel to the top of the unit (Chapin and Lowell, 1979). Additionally, confining pressure is greater in the lower part of the tuff than in the upper part of the tuff, creating greater local uniformity of foliation orientation in the lower part of the tuff and allowing for more random orientation in the upper part of the tuff (Chapin and Lowell, 1979). This spacial relationship of the compaction foliation with stratigraphic position within the tuff has recently been confirmed, in part, by field observations at Yucca Mountain in the Tiva Canyon Tuff where flattened pumice clasts are more uniformly oriented in the basal vitrophyre than they are in the mixed pumice zone in the upper part of the crystal-rich quartz latite. Additionally, the orientation of compaction foliation within parts of the Tiva Canyon Tuff appear to be more variable at some localities, such as near the Ghost Dance fault, than at other localities that are away from major structures. However, this is probably more indicative of structural rotation near faults than of primary foliation orientation.

Bedding Attitudes

The following discussion addresses the agreement between foliation attitudes as recorded by the strike and dip symbols displayed on the preliminary geologic map and the attitude of the subunits as determined by their contacts. A map was prepared (plate 3) that contains local strike line data for the subunits, and strike and dip data from the preliminary geologic map. For a given Tiva Canyon Tuff subunit contact, local strike lines were constructed by connecting two points of equal elevation with a straight line. The strike lines were drawn through unfaulted ridges and not across alluvium-filled valleys that might contain hidden structures. Two or more such strike lines were then used to calculate the dip of the bed. The attitude of beds determined in this way was then compared to the attitude shown on the preliminary geologic map by strike and dip symbols. Additionally, those strike and dip symbols that are incompatible with the outcrop pattern that is shown on the preliminary geologic map but whose pattern does not lend itself to the construction of local strike lines are shown in red.

Five areas where the strike and dip symbols differ from the attitudes of beds by 30 degrees or more in strike, or by 5 degrees or more in dip are shown on plate 3. These areas are Isolation Ridge, central Azreal Ridge, Antler Ridge, upper Highway Ridge, and Boundary Ridge. Boundary Ridge also is the area of greatest concentration of strike and dip symbols that indicate subunit orientations that are incompatible with the bedrock outcrop patterns shown on the preliminary geologic map. Other locations in the central block shown on plate 3 may contain minor differences in subunit attitude (less than 30 degrees in strike and 4 degrees in dip) compared to the attitude shown by the strike and dip symbols on the preliminary geologic map. These locations also are listed in table 4.

TABLE 4. NEAR HERE

Table 4

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Drill-hole Stratigraphic Data and Mapped Geology on Yucca Crest

Differences in the location of stratigraphic unit contacts became evident during an attempt to correlate data from drill-holes USW G-3, USW H-3, and USW H-5 (fig. 2), all located along the top of Yucca Crest, with surface structural data and surface stratigraphic contact data shown on the preliminary geologic map.

When contacts in the drill-holes USW G-3, USW H-3, and USW H-5 were projected westward to the surface of Solitario Canyon at the inclination indicated by structural data on the preliminary geologic map, the contacts intersected the surface at elevations higher and lower than the elevations of the contacts shown on the preliminary geologic map. Moreover, contacts projected from the slope above Solitario Canyon to the east and below Yucca Crest at the dip shown on the preliminary geologic map intersect the drill-holes at elevations different from the elevations recorded in the lithology logs for drill-holes USW G-3, USW H-3, and USW H-5. This particular problem has affected the three-dimensional lithostratigraphic model since the first model was developed. It also affects the design engineers' calculations for the volume of rock available in this part of Yucca Mountain that does not contain lithophysal cavities. A comparison between the projected contacts from the drill-holes and the actual contacts as shown on the preliminary geologic map is listed in table 5.

TABLE 5. NEAR HERE.

Table 5

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Drill-Hole Location on Geologic Map

Seventeen drill-holes are shown on the preliminary geologic map, eleven of which are used to construct the geologic sections that accompany the preliminary geologic map. To verify the drill-hole locations on the preliminary geologic map, the locations were checked against a drill-hole-location data base for all the drill-holes at Yucca Mountain; the data base was obtained from the project Technical Data Base (GENISES/Geologic Information System (GIS)) maintained by EG&G in Las Vegas, Nevada. There are an additional 59 drill-holes in the vicinity of Yucca Mountain that are not shown on the 1984 preliminary geologic map, but are listed in the recent (1994) drill-hole data base.

The GIS data base provides the official drill-hole locations to be used for all Yucca Mountain work (R. Nelson, U.S. Department of Energy, written commun., 1994). A comparison of this authorized drill-hole location data base to a second drill-hole location data base acquired from Raytheon Services Nevada in Las Vegas, Nevada (who provided survey location support to the Yucca Mountain Project) indicates that all differences for X and Y position coordinates for the two data bases are less than one foot. Therefore, the GIS data base was confidently used to compile a scale-stable drill-hole-location map. This map was printed at the same scale (1:12,000) as the preliminary geologic map. The GIS data-based map and the preliminary geologic map were then overlaid on one another and a comparison of the seventeen drill-hole locations was made. The best agreement between the authorized drill-hole locations provided by EG&G and the drill-hole locations on the preliminary map occurred by using drill-holes USW G-2, USW G-3, and UE-25a #4 as the registration points. These three drill-holes showed almost perfect location agreement on the two maps. Locations for eight other drill-holes on the preliminary geologic map differed by 20 to 50 feet. Four other drill-hole locations differed by 55 to 130 feet (table 6).

TABLE 6. NEAR HERE

EVALUATION OF GEOLOGIC SECTIONS

Drill-Hole Stratigraphic Data on Geologic Sections

Scott and Bonk (1984, sheet 2) constructed geologic sections A-A', B-B', and E-E' based on stratigraphic data provided from drill-holes USW G-1, USW G-2, USW G-3, USW G-4, USW H-3, USW H-4, USW H-5, UE-25 WT-5, UE-25 WT-14, UE-25a #1, and UE-25P #1. The geologic sections were constructed to pass through the drill-hole locations. In addition, geologic section AA' shows drill-hole J-13, but this drill-hole is not shown on the preliminary geologic map. Although Scott and Bonk (1984) referenced published reports only for drill-holes USW G-1 and USW G-2 (Spengler and others, 1981; Maldonado and Koether, 1983), they may have had access to unpublished lithologic descriptions for the other drill-holes. To verify the validity and locations of the stratigraphic the units shown on the geologic sections, these units were compared to the lithologic logs for all eleven drill-holes (Spengler and others, 1979; Bentley and others, 1983; Rush and others, 1984; Thordarson and others, 1984; Whitfield and others, 1984; Spengler and Chornack, 1984; and Carr and others, 1986; and a preliminary/unreviewed lithologic description for UE25 WT-5). A comparison with drill-hole J-13 was not made because this drill-hole is not shown on the preliminary geologic map. The comparison between the stratigraphic data from the geologic sections and from the

Table 6

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drill-hole lithology logs is summarized in table 7. Stratigraphic intervals on the geologic sections were measured with an engineering scale. The line thickness on the geologic sections resulted in a limit of uncertainty of about 20 feet for the values reported in this chapter. Differences between the geologic sections and the drill-hole lithology logs are listed in table 8.

TABLE 7. NEAR HERE.

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The agreement between the lowermost stratigraphic unit portrayed on the geologic sections and the equivalent stratigraphic unit in the drill-hole lithologic logs is within 35 feet or less. The most common differences between the geologic sections and the drill-hole lithologic logs are summarized as follows:

- Scott and Bonk (1984, sheet 2)) include faults at several locations (UE25 WT-5, USW H-3, USW H-4, and USW G-4) that are not indicated in the drill-hole lithologic logs. (Data for UE25 WT-5 from preliminary/unreviewed lithologic log.)
- At several sites, one or more sequences comprising welded and nonwelded tuff are described only in the drill-hole lithologic logs, or only in the geologic sections, but not in both.
- The nonwelded tuff is the unit most commonly missing in correlations.

In the geologic sections the moderately and densely welded parts of the pyroclastic-flow deposits are shown as welded, but the nonwelded and partly welded zones of these deposits

Table 7

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Table 8

are included with the subjacent or superjacent nonwelded bedded deposits. This may be the reason that the nonwelded tuff is the unit most commonly missing in the correlations of the stratigraphic units. Five of the eleven drill-holes on the geologic sections do not appear to show all existing stratigraphic units or faults indicated in the drill-hole lithologic logs. Drill-hole lithologic logs also do not describe stratigraphic units portrayed on the geologic sections at five of the eleven drill holes. Three of the geologic sections show differences at the same drill-hole locations where three of the drill-hole lithologic logs indicate stratigraphic sequences that may be incorrectly logged.

Structures on the Preliminary Geologic Map, the Geologic Sections, and in Drill-hole Logs

A comparison of the geologic sections with the preliminary geologic map reveals that the geologic sections display many more faults than are shown on the preliminary geologic map.This may be because Quaternary surficial deposits obscure numerous faults at Yucca Mountain. Geologic section AA' shows 24 faults between the Solitario Canyon fault and the Bow Ridge fault. The preliminary geologic map, however, only shows seven faults that intersect the line of section for AA"; another 15 faults are shown adjacent to the line of section. The fault 500 feet west of the Bow Ridge fault, as shown on both the preliminary geologic map and geologic section AA', is entirely buried by alluvium of Quaternary age, and there is no geophysical evidence cited nor bedrock geology shown to indicate that this particular fault even exists. Where geologic section AA' traverses Fran Ridge, 15 faults are shown, but the line of section on the preliminary geologic map shows only six faults. Geologic section BB' shows 30 faults that are not shown on the preliminary geologic map; one of the faults is the central Midway Valley fault, replete with a west-dipping breccia zone.

This feature has been detected by ground magnetic and gravity surveys, but is not shown on the preliminary geologic map. Geologic section CC' shows eight faults that are not shown on the preliminary geologic map. Geologic section EE' shows shallow-dipping subsurface faults that terminate abruptly and may or may not offset any beds. There are no surface or drill-hole data to support the existence of most of these faults, and the faults that are recorded in the drill-hole lithologic logs are located on the geologic sections at a different position by 100 feet or more.

The southeast-northwest geologic sections of Scott and Bonk (1984, sheet 2) all show a 200- to 700- feet wide zone of west-dipping strata west of all major block-bounding faults (13 west-dipping zones on geologic sections AA', BB', and CC'). The preliminary geologic map shows west-dipping strata at only four of these 13 locations. The wide zones of west-dipping strata shown on the geologic sections are an interpretation of a structural style that is not constrained by the geologic data shown on the preliminary geologic map.

The attitudes of the strata change across many of the faults, of which many are portrayed as steeply-dipping planar features. It is difficult to reconcile these changes in attitude of the strata as they cross the steeply-dipping planar faults that are shown on the geologic sections. The strata cannot be restored to their original configuration across these faults, and the geologic sections cannot be balanced unless there is significant internal deformation within the fault blocks. If zones of distributed brittle deformation within the fault blocks are invoked to account for the change in the dip of the strata across the faults, then there may be no need for the large number of faults that are shown on the geologic sections.

The geologic sections of Scott and Bonk (1984) are an interpretation of a style of brittle deformation that may be present at Yucca Mountain; however, the geologic sections are not necessarily rigorous sections based solely on the surface geologic map data and subsurface drill-hole data. Additionally, the geologic sections representation of drill-hole lithologic and structural data do not totally represent the data that were first published for the drill-holes. Many of the differences between depths reported in the drill-hole lithologic logs and the depths shown on the geologic sections are minor, and may represent nothing more than very small drafting deviations whose magnitude has been exaggerated by the 1:12,000 scale of the finished product. However, other units are shown as having several hundred feet of difference regarding their true stratigraphic depth.

DISCUSSION OF SOME FACTORS OF THE EVALUATION

The differences on the preliminary geologic map noted herein may arise from the assumptions made for reviewing the map as much as they may lie with the preliminary geologic map itself. In particular, the differences between the attitudes of subunit contacts and the attitudes of compaction foliation may be affected. It is possible that the differences reported in this chapter reflect the actual geology, but our understanding of the structural and stratigraphic subtleties of Yucca Mountain is incomplete. It also is likely that the combination of incomplete bedrock exposure and subtle, vertical and lateral variation within the subunits have resulted in local inaccuracies in the location of contacts, producing the differences noted here. In particular, the relationship at Yucca Mountain between the attitude of compaction foliation and the attitude of subunit contacts is unclear, but may involve the local rotation of blocks within the Tiva Canyon Tuff.

Differences and similarities between the attitude of the base of the Tiva Canyon Tuff and the base of the crystal-rich quartz latite may be real; interpretations of the data shown on the preliminary geologic map do not yield geologically unreasonable observations or conclusions. The base of the crystal-rich quartz latite as it is understood today is not represented on the preliminary geologic map, nor is the mapped contact for the base of the upper cliff subunit (cuc), which most closely approximates the base of the crystal-rich quartz latite on the preliminary geologic map, consistently applied on the map. The observed greater variability of the base of the crystal-rich quartz latite, relative to the base of the Tiva Canyon Tuff, is due, in part, to the inconsistent application of the upper cliff subunit (cuc) contact. Additionally, the greater amount of exposed bedrock for the upper cliff subunit (cuc) contact relative to the amount of bedrock exposed at the base of the Tiva Canyon Tuff may accentuate the apparent differences between these two contacts. The affect of local relief on the paleotopographic surface is difficult to isolate in this instance. Furthermore, bedrock exposures on Yucca Mountain are predominantly better developed on the south-facing slopes than they are on the north-facing slopes, which are commonly covered with talus. Small differences in locating subunit contacts, which are often transitional over a vertical extent of several feet, can result in the kinds of nonparallelism of subunit contacts shown on the preliminary geologic map. Finally, inaccuracies in the topographic base map used for compiling the data could introduce the types of differences reported in this chapter.

As mentioned in the section on foliation and strike and dip data, differences between foliation attitudes and subunit contact attitudes may not indicate shortcomings in the preliminary geologic map. Recent field observations of compaction foliation at Yucca Mountain have revealed areas where the attitude of compaction foliation is consistent with the attitude of the strata (such as in the basal vitrophyre of the Tiva Canyon Tuff in Yucca Wash and in Solitario Canyon), and areas where there is a great deal of variation of attitudes within the compaction foliation (such as in the lower lithophysal zone and middle nonlithophysal zone of the Tiva Canyon Tuff along the northern part of the Ghost Dance Fault). The nature of the relationship between compaction foliation and subunit attitudes at Yucca Mountain is uncertain, although it appears that local rotation of blocks within the Tiva Canyon Tuff near faults may account for much of the variation in foliation attitudes.

If errors exist in the topographic base map, then errors may be introduced in the calculation of attitudes based on the strike lines constructed for this chapter. The topographic base map used for the preliminary geologic map is the same topographic base map used for earlier geologic maps that were at a scale of 1:24,000 (Lipman and McKay, 1965; Christiansen and Lipman, 1965). This topographic base is quite adequate for 1:24,000 scale maps, but is less useful for 1:12,000 scale maps because of the lack of topographic resolution for smaller features. Recent field studies have shown that small scale features that are useful for locating faults and subunit contacts are not expressed on topographic base maps that use a 20 foot contour interval, but are expressed on maps that use a smaller contour interval (Wu, 1985).

To reconcile the drill-hole data with the surface geologic data along Yucca Crest, the eastward dip of the strata along Solitario Canyon and beneath Yucca Crest would need to be increased. Such an increase in dip is not supported by the structural data shown on the preliminary geologic map by strike and dip symbols or by local strike lines (fig. 2 and pl. 2), nor is it represented on the geologic sections. Either the drill-hole data are incorrect, the stratigraphic contacts are incorrectly located on the slope above Solitario Canyon, or the contacts represented on the preliminary geologic map are different from the contacts recorded in the drill-hole lithologic logs. The steep, west-dipping slope in Solitario Canyon is partly covered with talus, and many of the subunit contacts are obscured. Precise location of subunit contacts in Solitario Canyon is difficult. Additionally, many of the contacts are gradational in nature, and different criteria may have been used to define contacts at the surface than were used to identify contacts in the drill-hole lithologic logs.

A possible source of error in this chapter is the potential for scale instability between the preliminary geologic map and the drill-hole location map prepared from the project Technical Data Base. Although both the preliminary geologic map and the drill-hole location map were produced at a scale of 1:12,000, if both maps are not exactly 1:12,000 in the X and the Y directions, then an apparent location error could appear where no real location error exists. The drill-hole location map contained coordinate lines (Nevada State Coordinate System) at 5,000-ft intervals over the entire map. All coordinate lines were checked with an engineering scale for stability of the plot file. The drill-hole location map was scale accurate in both the X and Y directions at all locations on the map, within the accuracy limits of the engineering scale used. No check was made of the preliminary geologic map because it lacks a similar grid, hence, scale stability for it is not known.

Finally, since the time the preliminary geologic map with geologic sections was published, core samples from drill holes USW G-1, USW G-2, USW G-3, USW G-4, and UE-25a #1 have been reexamined, and some of the stratigraphic horizons below the Topopah Spring Tuff have been reinterpreted. The reinterpreted drill-holes were not used to check the accuracy of the geologic sections, but investigators need to be aware that more current subsurface data are available than the data shown on the geologic sections.

CONCLUSION

This chapter presents the results of a check of the internal consistency of the preliminary geologic map and geologic sections. The check includes a comparison with published drill-hole data for the drill-holes shown on the geologic sections. A rigorous field check of the preliminary geologic map is beyond the scope of this chapter, but field observations are employed to check the nature of subunit contacts and compaction foliation.

Differences exist between the stratigraphy shown on the preliminary geologic map, the stratigraphy shown on the geologic sections, and the stratigraphy recorded in the drill-hole lithologic logs. Furthermore, subunit contacts such as the base of the upper cliff subunit (cuc) and the caprock subunit (ccr), are not used in a consistent fashion on the preliminary geologic map. A unified stratigraphic nomenclature has recently been developed (Buesch and others, in press). Some important contacts defined in the new stratigraphic nomenclature, such as the base of the crystal-rich quartz latite of the Tiva Canyon Tuff, are not portrayed on the preliminary geologic map or the geologic sections. The new stratigraphic framework is the basis for current geologic mapping conducted at Yucca Mountain.

Strike and dip symbols on the preliminary geologic map commonly record the attitude of compaction foliation within the Tiva Canyon Tuff. Some differences are noted between attitudes of the compaction foliation and the attitudes of the subunit contacts on Azreal Ridge, Boundary Ridge, and Isolation Ridge. The difference between compaction foliation attitude and subunit contact attitude may indicate a style of distributed brittle deformation not previously recognized at Yucca Mountain. Foliation attitudes and bedding attitudes should be defined and correctly labelled on geologic maps.

There is a difference along the top of Yucca Crest between the drill-hole subsurface contacts in USW G-3, USW H-3, and USW H-5 and the subsurface projection of contacts shown on the preliminary geologic map. The difference may result from using different criteria to define stratigraphic units in the subsurface in drill-hole lithologic logs and on the surface on the preliminary geologic map, or it may result from imprecisely located subunit contacts. Careful use of a unified stratigraphic nomenclature can resolve differences between surface geologic mapping and subsurface lithologic logging.

A difference is noted between the location of some drill holes on the preliminary geologic map and in the project Technical Data Base. Since the preliminary geologic map was published, additional holes have been drilled at Yucca Mountain. Reliable drill hole location information can be obtained from the Yucca Mountain Project Technical Data Base.

The geologic sections display different stratigraphic subdivisions and more faults than the preliminary geologic map shows. Additionally, there were differences in the location of stratigraphic units and structural features on the geologic sections relative to the positions indicated in the drill-hole lithologic logs. It is understood that all geologic sections employ a certain amount of interpretive geology, but geologic sections should honor the available data.

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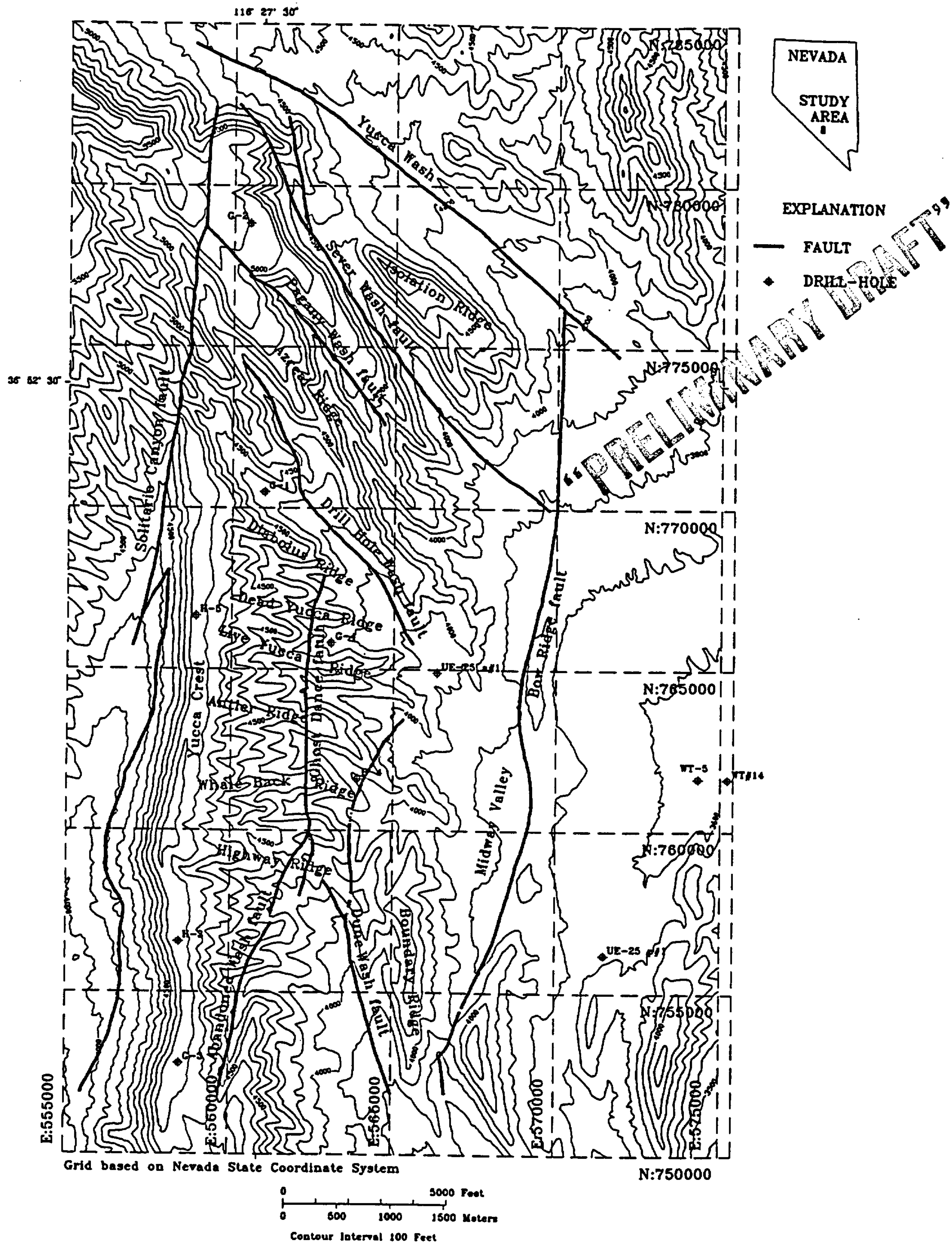
Figure 1


116° 27' 30"
36° 52' 30"
NEVADA
STUDY AREA
EXPLANATION
FAULT
DRILL-HOLE
"PRELIMINARY DRAFT"
N:785000
N:780000
N:775000
N:770000
N:765000
N:760000
N:755000
N:750000
E:555000
E:560000
E:565000
E:570000
E:575000
Yucca Wash
Sever Wash fault
Isolation Ridge
Pagany Wash fault
Azreal Ridge
Solitario Canyon fault
Drill Hole Wash fault
Diabolus Ridge
Dead Yucca Ridge
Live Yucca Ridge
Ghost Dance fault
Antler Ridge
Yucca Crest
Whale Back Ridge
Highway Ridge
Abandoned Wash fault
Dune Wash fault
Boundary Ridge
Midway Valley
Bow Ridge fault
G-2
G-1
H-5
G-4
UE-25 a#1
H-3
G-3
WT-5
WT#14
UE-25 p#1
Grid based on Nevada State Coordinate System
0
5000 Feet
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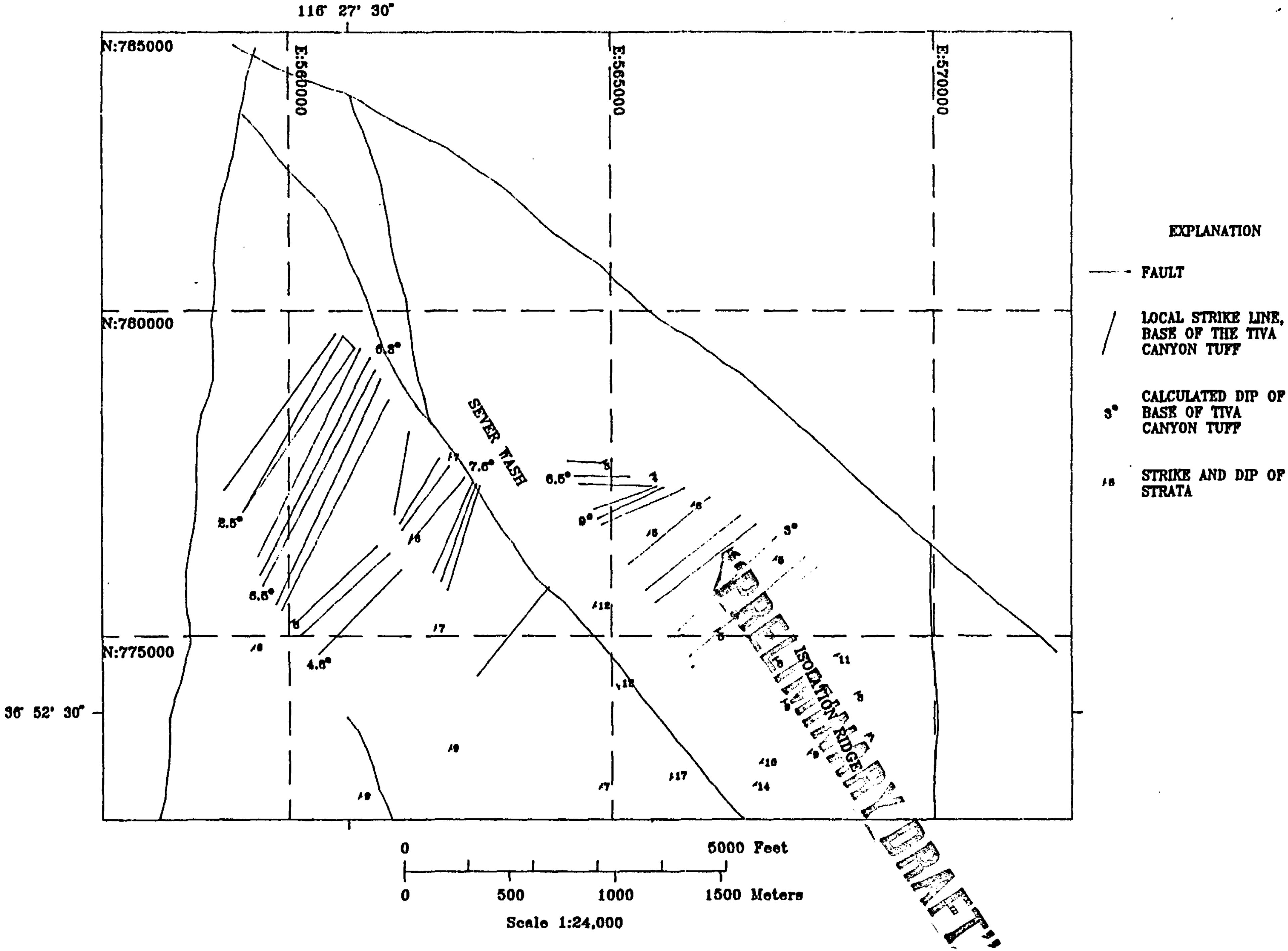
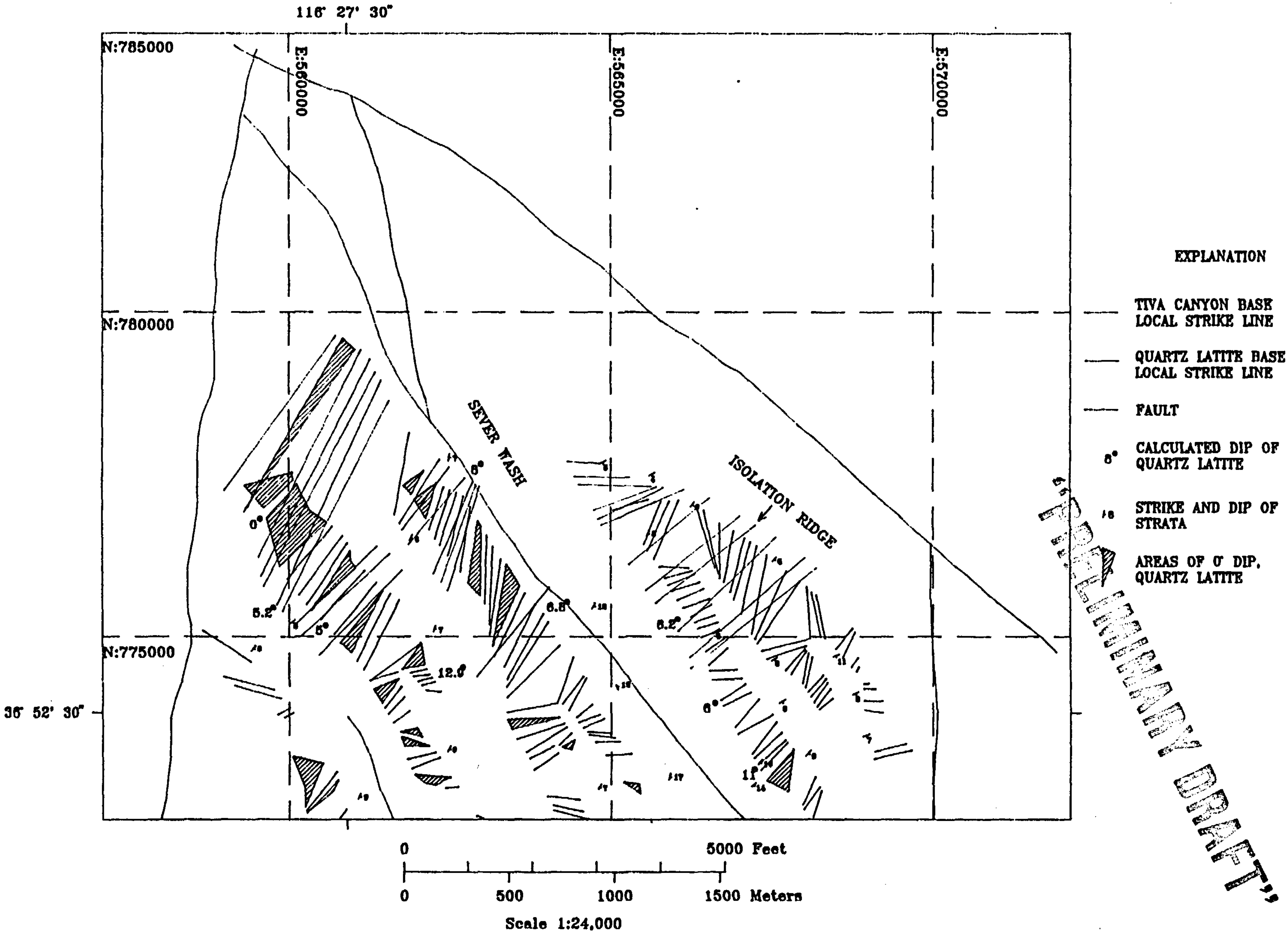
1000
1500 Meters
Contour Interval 100 Feet



THE BASE OF THE TIVA CANYON TUFF LOCAL STRIKE LINE MAP



BASE OF THE TIVA CANYON TUFF COMPARED WITH THE INFERRED BASE OF THE QUARTZ LATITE

Table 1. Drill-hole names used in this report and the names used in the U.S. Geological Survey, Water Resources Division.

U.S. Geological Survey, Water Resources Division drill hole name	Drill hole name used in this report
UE-25p #1	UE25P-1
USW WT-5	USW WT-5
UE-25 WT#14	UE-25WT#14
USW H-3	USW H-3
USW H-4	USW H-4
USW H-5	USW H-5
UE-25a #1	UE 25a-1
USW G-1	USW G-1
USW G-2	USW G-2
USW G-3	USW G-3
USW G-4	USW G-4

Table 2. Explanation of stratigraphic units and correlation between the units from preliminary geologic map[1] and from the drill-hole lithologic logs.

Stratigraphic unit names	Preliminary geologic map stratigraphic unit symbols	Drill-hole stratigraphic unit symbols
Quaternary/Tertiary	QTac	
colluvium		Qc
aluvium		Qa
Rainier Mesa Tuff	Tmr	Tmr
Nonwelded tuff	n	n
Yucca Mountain Tuff, welded	Tpyw	Tpyw
Pah Canyon Tuff, welded	Tppw	Tppw
Topopah Spring Tuff, welded	Tptw	Tptw
Prow Pass Tuff, welded	Tcpw	Tcpw
Bullfrog Tuff, welded	Tcbw	Tcbw
Tran Tuff, welded	Tctw	Tctw
Lithic Ridge Tuff, welded	Tlrw	Tlrw
Flow breccia	Tfb	Tfb
Calcified ash-flow tuff	Tfg	Tfg

Table 2. Explanation of stratigraphic units and correlation between the units from preliminary geologic map[1] and from the drill-hole lithologic logs -- Continued.

Stratigraphic unit names	Preliminary geologic map stratigraphic unit symbols	Drill-hole stratigraphic unit symbols
Older tuff	Totw	Totw

Table 3. Comparison of strike of local strike lines for Tiva Canyon Tuff subunit contacts. [ccr, caprock zone (quartz latite); cuc, upper cliff zone; cul, upper lithophysal zone; crs, rounded step zone; vs, versus].

Location (See fig. 2.)	Subunit contacts compared	Difference in strike orientation
Lower Azreal Ridge	cul/cuc vs cuc/ccr	12 to 70 degrees
	cul/cuc vs crs/cul	12 to 65 degrees
Diabolus Ridge	crs/cul vs cuc/ccr	40 to 90 degrees
Unnamed ridge between Live Yucca Ridge and Dead Yucca Ridge	cul/cuc vs crs/cul	14 to 43 degrees
Live Yucca Ridge	cul/cuc vs cuc/ccr	65 to 72 degrees
	cul/cuc vs crs/cul	70 to 88 degrees
Antler Ridge	cul/cuc vs crs/cul	22 to 44 degrees
Unnamed ridge north of Highway Ridge	cul/cuc vs crs/cul	27 to 90 degrees
	cuc/ccr vs crs/cul	15 to 47 degrees

Table 4. Differences in strike and dip between Tiva Canyon Tuff subunit contacts 1984 preliminary geologic map[1] and from constructed contours at locations along ridges [See fig. 2 for locations].

Location	Difference (degrees)	
	Strike	Dip
Unnamed ridge north of Whaleback Ridge	26	6
Highway Ridge	0	5
Unnamed ridge south of Whaleback Ridge	30	3
Whaleback Ridge	25	3
Unnamed ridge north of	40	3
Highway Ridge	20	10
Antler Ridge	42	4
	22	11
	19	5
Unnamed ridge north of	45	2
Yucca Ridge	23	1
	46	0
	15	3
	10	2
	0	2
Diabolus Ridge	13	3
	11	1

Table 4. Differences in strike and dip between Tiva Canyon Tuff subunit contacts 1984 preliminary geologic map[1] and from constructed contours at locations along ridges [See fig. 2 for locations] -- Continued.

Location	Difference (degreese	
	Strike	Dip
Azreal Ridge	71	5
	45	4
	40	2
	32	6
	25	1
	25	0
	19	7

Table 5. Comparison of stratigraphic unit base from drill-hole logs and the 1984 preliminary geologic map.

[Stratigrpahic nomenclature is from the preliminary geologic map[1]; all units dip 7 degrees.]

Drill hole			Strata	Projected contact in Solitario Canyon	Mapped[1] contact in Solitario Canyon	Elevation difference
Name USW	Total depth (feet)	Surface elevation (feet)		(feet)	(feet)	(feet)
G-3	4,856.5	4,508	ch	4,560	4,595	+35
		4,483	cc	4,538	4,575	+37
		4,433	bt	4,502	4,455	-47
H-3	4,866.4	4,486.5	ch	4,533	4,625	+92
		4,474.3	cc	4,522	4,610	+88
		4,462.5	bt	4,524	4,480	-44
H-5	4,850.8	4,441.0	ch	4,475	4,580	+105
		4,365.9	cc	4,409	4,500	+91
		4,360.6	bt	4,412	4,465	+53

[1]Scott and Bonk, 1984

"PRELIMINARY DRAFT"

Table 6. Offset of drill-hole locations comparing 1984 preliminary geologic map[1] and Geographic Systems Information data base.

Offset = 0 to 50 feet		Offset greater than 50 feet	
Drill-hole	Offset	Drill-hole	Offset
USW G-2	0	UE25-b1	130
USW G-3	0	UE25a-1	60
UE25-a4	0	UE25-P1	55
USW G-1	50	USW H-3	55
USW G-4	20		
USW H-1	45		
USW H-4	40		
USW H-5	50		
UE25-a5	25		
UE25-a6	50		
UE-25WT#14	20		

[1]Scott and Bonk, 1984

Table 7. Depths of stratigraphic horizons determined from drill-hole logs and geologic sections[1].

[--, no data]

Lithology	Lithologic unit depth (feet)		
	Drill-hole log	Geologic section	Difference
		Drill-hole UE25p-1	
Qc	50	85	+35
Qa	128	220	+92
Tpc	255	300	+45
fault	267	300-380	+33 to +113
Tptw	1,158	1,160	+2
n	1,950	1,830	-120
Tcbw	2,150	2,150	0
n	2,265	2,570	+305
Tctw	2,550	3,060	+510
n	3,320	---	---
fault	3,385	3,060	-325
n	3,733	3,810	+77
Tfg	3,844	4,010	+166
n	4,070	4,280	+210
fault	---	4,330	---
		[2]Drill-hole USW WT-5	
Qa	120	180	+60
fault	---	480	---
Tmr	800	840	+40
Tpcw	1,210	1,230	+20
n	1,280	---	---
Tptw	1,330	1,310	-20

Table 7. Depths of stratigraphic horizons determined from drill-hole logs and geologic sections[1] -- continued.

Lithology	Lithologic unit depth (feet)		
	Drill-hole log	Geologic section	Difference
		UE-25WT#14	
Qa	120	120	0
Tptw	1,120	1,120	0
n	1,290	1,290	0
		Drill-hole USW H-3	
Tpcw	350	335	-15
n	442	420	-22
Tptw	1,252	1,310	+58
n	2,000	2,000	0
Tcbw	2,323	2,330	+7
n	2,990	3,005	+15
Tctw	3,118	3,135	+15
n	3,290	3,290	0
fault	---	3,320	---
n	4,000	4,010	+10
		Drilll-hole USW H-4	
Qa	---	45	---
Tpcw	174	180	+6
n	224	270	+46
fault	---	1,100	---
Tptw	1,217	1,230	+13
fault	---	2,000	---
n	2,500	2,520	+20
Tcbw	2,585	2,610	+25
n	2,990	3,020	+30
Tctw	3,230	3,250	+20
n	4,000	4,000	0

Table 7. Depths of stratigraphic horizons determined from drill-hole logs and geologic sections[1] -- continued.

Lithology	Lithologic unit depth (feet)		
	Drill-hole log	Geologic section	Difference
		UE 25a-1	
Qa	30	45	+15
Tpcw	95	190	-5
n	276	280	+4
Tptw	1,317	1,310	-7
n	1,950	1,980	+30
Tcpw	2,014	2,025	+11
n	2,333	2,430	+97
Tcbw	2,500	2,535	+35
		USW G-1	
Qa	60	35	-25
n	270	260	-10
Tptw	1,360	1,345	-15
n	1,867	---	---
Tcpw	1,977	---	---
n	2,074	2,095	+21
Tcpw	2,152	2,175	+23
n	2,447	2,450	+3
Tcbw	2,602	2,575	-27
n	2,639	2,800	+161
Tctw	3,083	2,950	-133
n	3,558	3,565	+7
Tfb	3,920	3,925	+5
n	5,001	4,995	-6
Totw	5,309	5,165	-144
n	5,399	---	---
Totw	5,422	---	---
n	5,582	5,600	+18
Totw	5,646	5,720	+7

Table 7. Depths of stratigraphic horizons determined from drill-hole logs and geologic sections[1] -- continued.

Lithology	Lithologic unit depth (feet)		
	Drill-hole log	Geologic section	Difference
	Drill-hole USW G-1 (continued)		
n	5,688	---	---
Totw	5,891	---	---
n	5,911	5,910	-1
Totw	6,000	6,010	+10
	Drill-hole USW G-2		
Tpcw	220	225	+5
n	260	265	+5
Tpyw	336	350	+14
n	565	565	0
Tppw	666	700	+34
n	762	770	+8
Tptw	1,681	1,700	+19
n	2,704	2,710	+6
fault	2,704	2,710	+6
Tcpw	2,984	2,920	-64
n	3,290	3,320	+30
Tfbw	3,447	3,475	+28
n	3,574	3,590	+16
Tctw	---	4,750	---
n	4,079	4,100	+21
Tfb	4,150	4,180	+30
n	4,195	4,230	+35
Tlrw	4,203	4,230	+27
fault	4,672	4,660	-12
n	4,874	4,900	+26
Tfb	5,637	5,670	+33
n	5,670	5,705	+35
Tfb	5,885	5,935	+50

Table 7. Depths of stratigraphic horizons determined from drill-hole logs and geologic sections[1] -- continued.

Lithology	Lithologic unit depth (feet)		
	Drill-hole log	Geologic section	Difference
	Drill-hole USW G-2 (continued)		
n	5,942	6,015	+73
Totw	6,006	6,040	+34
	Drill-hole USW G-3		
Tpcw	354	350	-4
n	424	420	[illegible]
Tptw	1,299	1,295	-4
n	2,100	2,100	0
Tcbw	2,546	2,550	+4
n	2,565	2,580	+15
Tctw	2,988	3,070	+82
n	3,065	3,130	+65
Tctw	3,234	3,250	+16
n	3,263	3,520	+257
Tctw	3,668	3,680	+12
n	3,747	---	---
Tctw	3,819	---	---
n	3,876	3,885	+9
Tlrw	3,976	3,995	+19
fault	4,296	4,200	-96
n	4,327	4,325	-2
fault	4,600	4,500	-100
Tlrw	4,870	4,870	0
n	4,899	4,900	+1
Totw	5,031	5,030	-1
	Drill-hole USW G-4		
Qa	30	50	+20
Tpcw	118	140	+22

Table 7. Depths of stratigraphic horizons determined from drill-hole logs and geologic sections[1] -- continued.

Lithology	Lithologic unit depth (feet)		
	Drill-hole log	Geologic section	Difference
		Drill-hole USW G-4 (continued)	
n	239	270	+31
Tptw	1,353	1,390	+37
n	---	2,400	---
Tcpw	---	2,430	---
n	2,370	---	---
Tcbw	2,397	---	---
n	2,581	2,590	+9
Tcbw	2,680	2,690	+10
n	2,904	---	---
fault	2,989	---	---
n	2,999	3,020	+21
Tctw	3,001	3,025	+24
		[3]Drill-hole USW H-5	
Tpcw	390	380	-10
n	568	545	-23
Tptw	1,700	1,685	-15
n	2,670	2,610	-60
Tcbw	2,710	2,690	-20
n	---	2,745	---
Tctw	---	2,810	---
n	3,422	3,445	+23
Tfb	4,000	4,000	0
		[4]Drill-hole USW H-5	
Tpcw	390	380	-10
n	568	545	-23
Tptw	1,700	1,680	-20
n	2,670	2,610	-60
Tcbw	2,710	2,685	-25

Table 7. Depths of stratigraphic horizons determined from drill-hole logs and geologic sections[1] -- continued.

Lithology	Lithologic unit depth (feet)		
	Drill-hole log	Geologic section	Difference
	[4]Drill-hole USW H-5 (continued)		
n	---	2,740	---
Tctw	---	2,810	---
n	3,422	3,430	+8
Tfb	4,000	4,000	0
	[5]Drill-hole USW H-5		
Tpcw	390	400	+10
n	568	585	+17
Tptw	1,700	1,730	+30
n	2,670	2,665	-5
Tcbw	2,710	2,715	+5
n	---	2,750	---
Tctw	---	2,810	---
n	3,422	3,435	+13
Tfb	4,000	4,010	+10

[1]Scott and Bonk, 1984

[2]Drill-hole log data is preliminary, unreviewed data

[3]Depth of geologic section is from AA' line-of-section from preliminary geologic map (Scott and Bonk, 1984)

[4]Depth of geologic section is from BB' line-of-section from preliminary geologic map (Scott and Bonk, 1984)

[5]Depth of geologic section is from EE' line-of-section from preliminary geologic map (Scott and Bonk, 1984)

Table 8. Summary of drill-hole log and geologic section comparison.

[AA', BB', and EE' are lines of section from preliminary geologic map[1]; n, nonwelded tuff; Qa, Tpcw, Tptw, Tcpw, Tcbw, Tctw, Tpcw, and Totw, see table 2; ft, feet; "/", contact.]

Drill-hole name	Difference of geologic section horizons from log horizons (feet)	Number of units/ number of units within limit of accuracy	Features in logs missing in geologic sections	Features in geologic sections missing in logs
UE25P-1	0 - 510	12/2	n below Tctw at 3,320 ft	Fault at base (4,330 ft)
[2]USW WT-5	20 - 60	5/3	n below Tpcw at 1280 ft	Fault below Qa at 480 ft
UE-25WT#14	0 - 20	3/3	None	None
USW H-3	0 - 58	10/5	None	n below Tctw at 3,290 ft Fault below n at 3,320 ft
USW H-4	0 - 46	11/5	None	Qa from surface to 45 ft Fault below Tpcw at 1,100 ft Fault below Tptw at 2,000 ft
USW H-5	0 - 60	(AA';BB';EE') 9/4; 9/4; 9/6	None	n below Tcbw at 2,740 ft to 2,750 ft

Table 8. Summary of drill-hole log and geologic section comparison -- continued.

[AA', BB', and EE' are lines of section from preliminary geologic map[1]; n, nonwelded tuff; Qa, Tpcw, Tptw, Tcpw, Tcbw, Tctw, Tpcw, and Totw, refer to table 2; ft, feet.]

Drill-hole name	Difference of geologic section horizons from log horizons (feet)	Number of units/ number of units within limit of accuracy	Features in logs missing in geologic sections	Features in geologic sections missing in logs
UE25a-1	30 - 97	8/5	None	None
USW G-1	3 - 161	23/9	n/Tcpw at 1,867 ft/1,977 ft Totw/n at 5,399 ft/5,422 ft Totw/n at 5,688 ft/5,891 ft	None
USW G-2	0 - 73	26/10	None	None
USW G-3	0 - 26	21/14	n/Tctw at 3,747 ft/3,819 ft	None
USW G-4	9 - 37	14/3	n/Tcbw at 2,400 ft/2,430 ft	n/Tcpw at 2,370 ft/2,397 ft n below Tcbw at 2,904 ft Fault at 2,989 ft

[1]Scott and Bonk, 1984.

[2]Lithologic data for USW WT-5 from preliminary, unreviewed lithologic log.

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Figure 2A. A portion of aerial photograph no. 5-9a-9 pm, a late afternoon low-sun-angle photograph showing essentially the same area (at the same scale) as figure 1.

Figure 2B. The same aerial photograph shown in figure 2A with selected photolineaments marked.

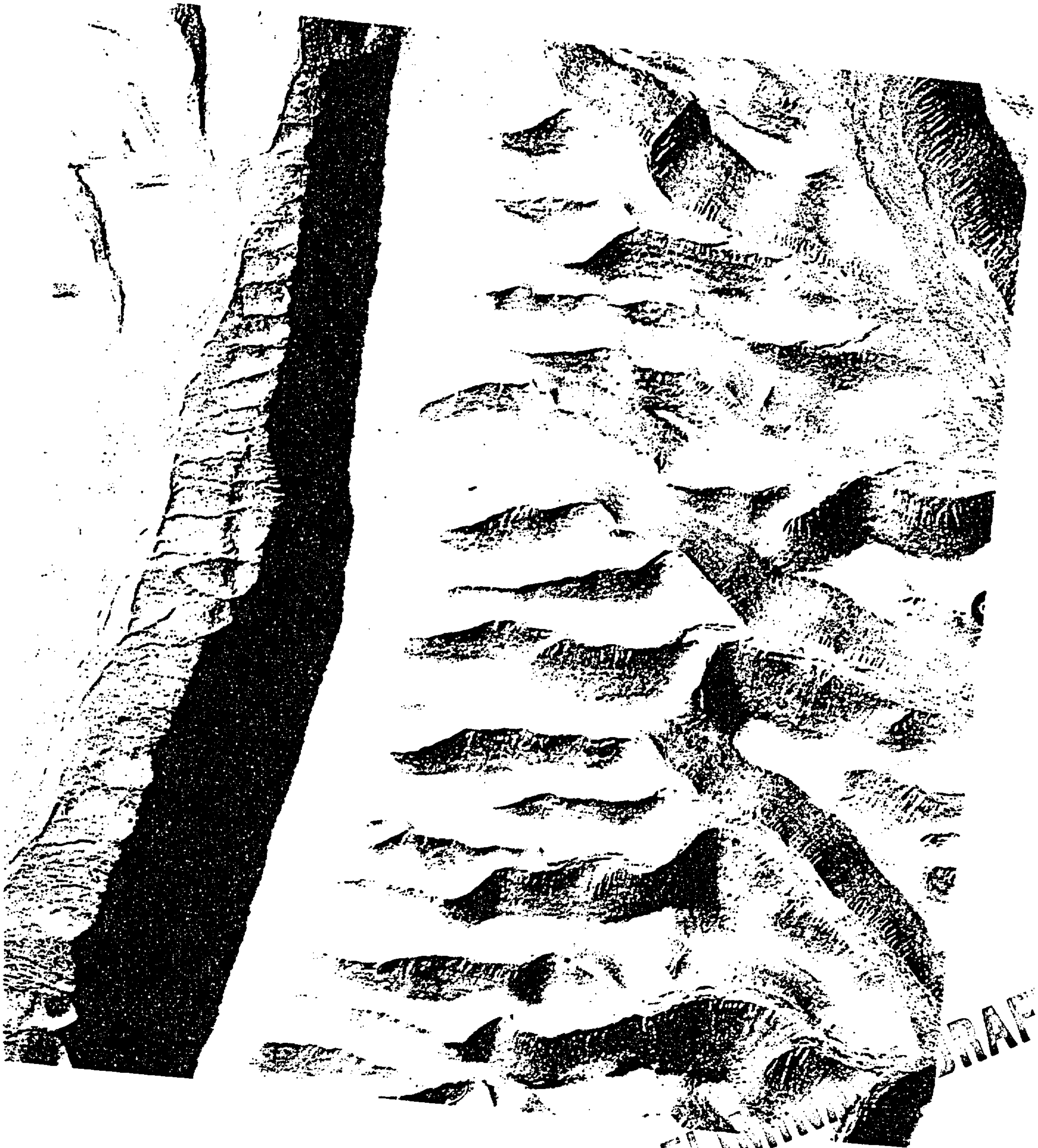
Figure 3A. A portion of aerial photograph no. 1-22-14, a mid-day high-sun-angle view centered on Live Yucca Ridge. The scale is approximately one cm equals 60 m.

Figure 3B. The same aerial photograph shown in figure 3A with selected photolineaments and an area of cooling joints marked. pattern of significant faults.

Figure 4. Zone of brush forming a lineament (beginning in lower left of photograph) on hillside in western Split Wash. Several steep, N30W striking cooling joints, parallel to the lineament, are visible in the lower center of the photograph. The relationship suggests the brush is growing along a cooling joint. The larger bushes in the view are about a meter high.

Figure 5. A N30W cooling joint in welded Tiva Canyon Tuff which shows evidence of shearing. The cooling joint is seen at lower right (in the shadow) parallel to the compass. To the upper left the cooling joint grades into a highly fractured and brecciated area (see close-up in figure 6). Looking north near west Antler Ridge. Scale is indicated by the compass and hammerhead at lower right.

Figure 6. Close-up view of upper right portion of sheared cooling joint in figure 5, showing fractures and breccia along joint. Compass at bottom center indicates the scale.



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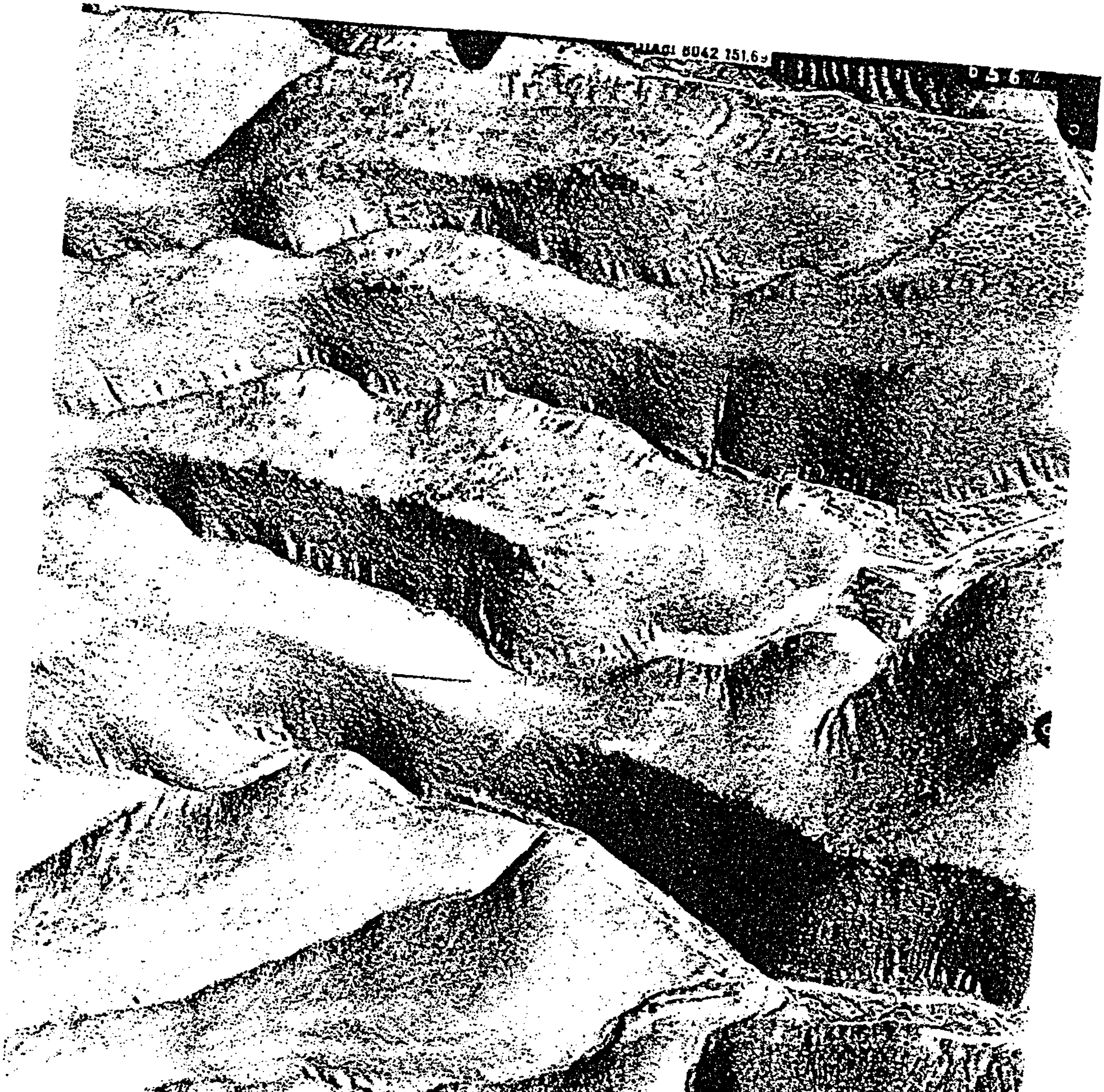

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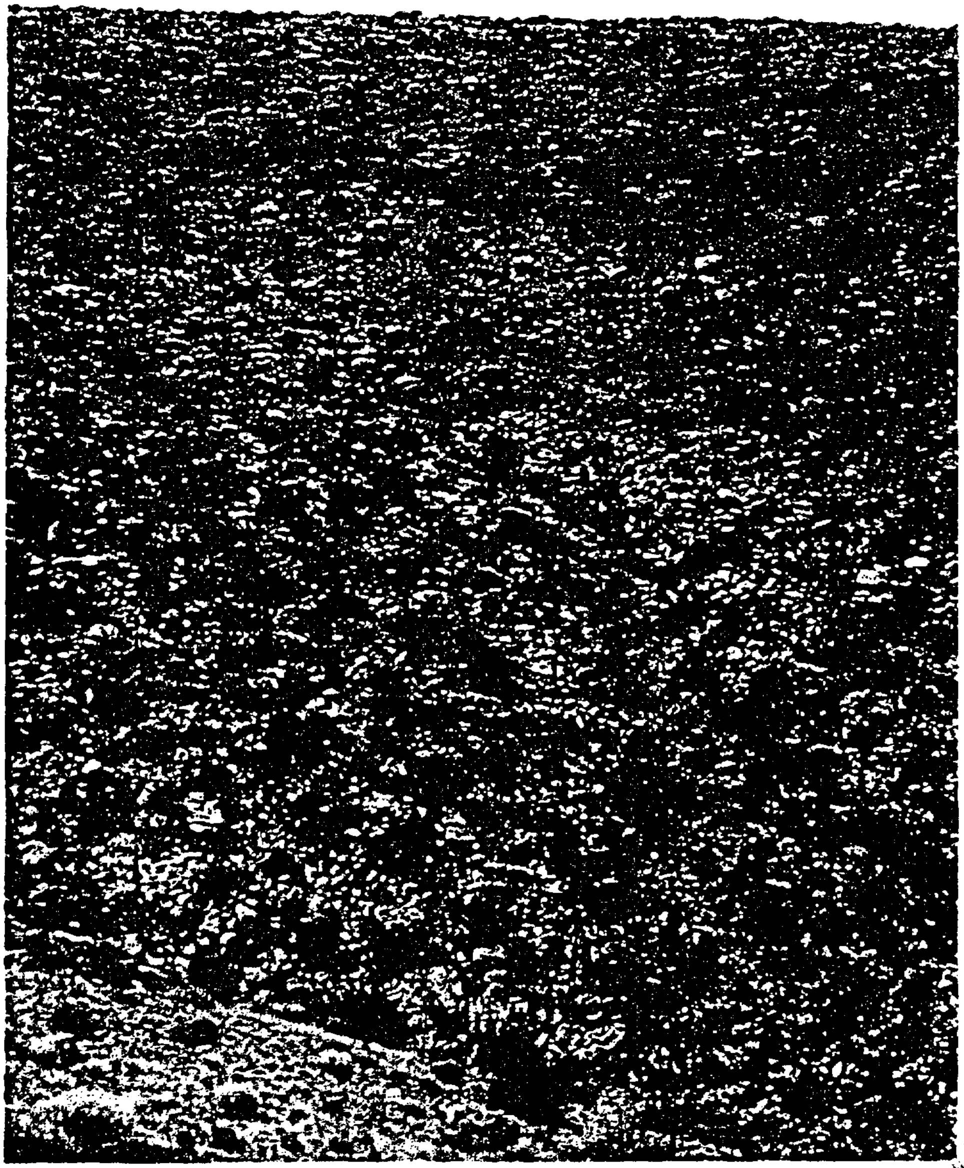

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Table B-1. Aerial photographs of potential repository area used in study

[1] Central block is the general area of the potential repository.

[2] N-S is for North-South.

[3] Two flights, (a) Counter #8290+, and (b) Counter #8432+ have the same series number.

[Photos obtained from Great Basins Aerial Photography, Reno, Nevada]

Series	Print number	Flight area	Date	Time	Scale	Flight line
1-19	-18 to -23	Solitario Canyon	8/15/87	Afternoon	1:6,000	[2]N-S
1-22	-10 to -16	Central block, Highway Ridge	8/15/87	Noon	1:6,000	N-S
2-10a	- 6 to -12	Central block	8/14/87	Noon	1:12,000	N-S
5-9a	-[3]6(a;b) to -10	a) Central block Highway Ridge to Drill Hole Wash	9/24/87	a) Morning b) Afternoon	1:12,000	N-S

CHAPTER B

EVALUATION OF AERIAL PHOTOGRAPHIC EVIDENCE FOR FAULTING IN THE AREA OF THE POTENTIAL REPOSITORY, YUCCA MOUNTAIN, NEVADA

By Charles W. Weisenberg

U.S. GEOLOGICAL SURVEY

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EVALUATION OF AERIAL PHOTOGRAPHIC EVIDENCE FOR FAULTING IN THE AREA OF THE POTENTIAL REPOSITORY, YUCCA MOUNTAIN, NEVADA

By Charles W. Weisenberg

ABSTRACT

Examination of existing aerial photography for evidence of unmapped faults in the vicinity of the potential nuclear waste repository at Yucca Mountain, Nevada, revealed no new faults and resulted in reinterpretation of the map pattern of only three previously mapped faults. Revisions to the preliminary geologic map of Scott and Bonk (1984) based on photolineament analysis consist of an increase in the offsets for two faults and connecting two separate aligned faults into a single longer fault. Photolineaments are not a reliable way to identify faults in the study area because other features tend to overprint lineaments formed by faulting. Field checking of a number of north-northwest striking lineaments suggests they are in part formed by abundant north-northwest cooling joints, some of them sheared, and probable minor north-northwest fracture zones. These zones of weakness impart a pronounced north-northwest fabric to the photographs which tends to overwhelm lineaments formed by faults. However, a prominent lineament lies along, and supports the existence of the Sundance Fault. Known faults do, in general, show a number of features on aerial photographs that possibly could be used to identify faults in nearby areas.

INTRODUCTION

High-sun-angle and low-sun-angle aerial photography was examined for evidence of faults that are not shown on the geologic map of Scott and Bonk (1984). The boundaries of the area investigated are essentially those of the potential repository facility as shown on plate

B-1; however, several significant photolineaments which lie outside, but strike into the proposed repository, also were examined. This work was undertaken as a part of the larger program to verify and enhance the preliminary geologic map of Scott and Bonk (1984). Currently, this map is the basis of geologic research at the potential repository facility. Previous photolineament studies of the Yucca Mountain project (YMP) area were done by O'Neill and others (1993), which was a regional study of the yucca Mountain area, and by Throckmorton (1987), a more detailed study of certain small-scale features. Scott and Bonk (1984) marked photolineaments on their geologic map with a dash-dot line but did no analysis of the lineaments. The present report focuses on aerial photographic interpretation in the area of the potential repository.

This study was conducted as a geologic mapping project using YMP technical procedure GP-1, R2 for geologic mapping. Technical procedure GP-50 R2 for identification of geomorphic features of tectonic significance was a useful reference. Information on the aerial photographs used is summarized on Table B-1. Specific photographic print numbers referred to in the text are identified on this table. Aerial photographic sets were printed by Great Basins Aerial Photography, Reno, Nevada. Some of the negatives were loaned by the Desert Research Institute, University of Nevada, Reno. The photographs were of scales 1:6000 and 1:12,000 and consisted of black and white conventional vertical aerial photographs taken at high sun angle (mid-day) and low sun angle (early morning and late afternoon). Limited special processing was done to enhance contrast on some of the photographs. A standard desk-top stereoscope was used for examination of the photographs.

TABLE 1. NEAR HERE

Features shown on the aerial photographs were plotted on 1:6000 orthophotographic maps of the Yucca Mountain area provided by EG&G, Las Vegas, Nevada. These features were then digitized and reduced onto plate B-1. The more prominent photolineaments are numbered with a P, as in P-6. Less prominent, more local photolineaments that were considered worthy of investigation are numbered with an L (locality) prefix.

This study was designed to identify unrecognized significant faults. To that end longer features, however poorly developed, were considered more important than shorter features, however well developed. Features parallel to regional fault trends were weighted as more important as well.

Field checking involved inspection for the presence of contact offsets and fault breccia, and determining the evidence for the origin of the anomalies. For brevity, in this report photographs means aerial photographs. The term lineament here means the same as photolineament. Distances are in meters (m) or kilometers (km).

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GEOLOGIC SETTING

The geologic setting of Yucca Mountain has been reviewed by Spengler and others (1989, 1993, and 1994), and by Fox and others (1990). The primary unit exposed in the study area is the Tiva Canyon Tuff of the Paintbrush Group, a mostly welded pyroclastic flow deposit of middle Miocene age (Sawyer and others, 1994). Stratigraphic terms for subdivisions of the Tiva Canyon Tuff are from Buesch and others (in press). These terms differ from the older terminology of Scott and Bonk (1984). The Tiva Canyon Tuff is

Table 1.

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noted for the prominent development of primary cooling joints. which typically are long, usually planar joints with very smooth surfaces and local degassing features (tubular structures) (Barton and others, 1984, 1989, 1993). in the study area, the cooling joints commonly form an orthogonal network of steep joints as much as 50 m long. Barton and others (1989), working in an area centered on Live Yucca Ridge east of the Ghost Dance Fault, found the frequency maxima of strike to be 31 to 60 degrees azimuth for the northeast set and 311 to 359 degrees for the northwest set. Field inspection of dozens of outcrops in areas to the west and south of Barton and others (1989) study area suggests that steep cooling joints striking about N 30°-35° W are common.

ANALYSIS OF PHOTOLINEAMENTS

Descriptions of the photolineaments as identified in the office, and the results of the field checks of each lineament are described in appendix 1. Eleven prominent (P) and twenty-one shorter locality (L) lineaments were identified and examined in the field by the author. Final evaluation of the lineaments was also substantially based on the Map of Dominant Structures (plate C-1) provided with Chapter C of this report.

The individual photographs varied in usefulness to this study. The low-sun-angle photographs show more visual lineaments because of the way they accentuate topography. The high-sun-angle photographs are better at disclosing color differences due to mineral coatings or vegetation density. Figures 1, 2, and 3 are interpreted and uninterpreted photocopies of three aerial photographs used in this study. Note the differences in shading between the early morning photograph in figure 1, the late afternoon photograph of essentially the same area in figure 2, and the mid-day view in figure 3.

FIGURE 1-A. NEAR HERE

FIGURE 1-B. NEAR HERE

FIGURE 2-A. NEAR HERE

FIGURE 2-B. NEAR HERE

FIGURE 3-A. NEAR HERE

FIGURE 3-B. NEAR HERE

The P lineaments are mostly composite features consisting of alignments of subtle, short, separated anomalies of different kinds. A number of long, north-northwest trending P lineaments are identified on plate B-1. With the exception of P-6, the length of these north-northwest lineaments is highly interpretive, and the decision to identify them as discrete features is an aggressive attempt to identify any unrecognized significant faults. As discussed below and in appendix 1, field work suggests the north-northwest P features do not represent a pattern of significant faults.

L lineaments typically are chosen because they form a pronounced lineament or because they form a group of parallel features. For example, the area contains numerous

Figure 1-A. Uninterpreted copy of aerial photograph no. 5-9a-9 pm, an early morning low-sun-angle view, showing the center of the study area. Scale is about one cm = 120 m. (Compare with fig. 2-A.)

Figure 1-B. The aerial photograph shown in figure 1-A, with photolineaments marked. (Compare with pl. B-1.)

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Figure 2-A. A portion of aerial photograph no. 5-9a-9 pm, a late afternoon low-sun-angle photograph showing essentially the same area (at the same scale) as fig. 1.

Figure 2-B. The same aerial photograph shown in fig. 2-A with selected photolineaments marked.

Figure 3-A. A portion of aerial photograph no. 1-22-14, a mid-day high-sun-angle view centered on Live Yucca Ridge. The scale is approximately one cm equals 60 m.

Figure 3-B. The same aerial photograph shown in fig. 3-A with selected photolineaments and an area of cooling joints marked.

short steep ravines which form parallel northeast lineaments. The trend is parallel to a regional trend of faulting. So a group of these are identified as L features for further study.

Scott and Bonk (1984) marked numerous photolineaments on their geologic map. Most of the P features in this study correspond at least in part to a Scott and Bonk photolineament, but their's are much shorter. Scott and Bonk's distribution of lineament orientations are about the same as in this study. The differences are probably because the current study used newer low-sun-angle photographs and because this study singles out the longest possible photolineaments, however poorly developed.

The predominate linear features seen on the photographs are related to cooling joints. These photolineaments occur either individually or as closely spaced sets comprised of narrow alignments of prominent brushy vegetation (fig. 4), abrupt diversions of washes, and short wash segments that were anomalously straight or deeply incised. Individually, these lineaments are short. However, any other prominent feature are likely to form an alignment with a cooling joint-formed lineament, creating the visual impression of a longer lineament.

FIGURE 4. NEAR HERE

Although the cooling joints are primary contractional features of the welded tuff, field observation provides many examples of cooling joints which show evidence of shear. Cooling joints sometimes are continuous with small breccia zones and tectonic fractures (an example is shown in figs. 5 and 6). In some places the surfaces of the joints are scored with near-horizontal slickensides. Small fault offsets (less than 0.3-m right-lateral separation) of

Figure 4. Zone of brush forming a lineament (beginning in lower left of photograph) on hillside in western Split Wash. Several steep, N 30° W Zone of brush forming a lineament (beginning in lower left of photograph) on hillside in western Split Wash. Several steep, N 30° W striking cooling joints, parallel to the lineament, are visible in the lower center of the photograph. The relationship suggests the brush is growing along a cooling joint. The larger bushes in the view are about a meter high.

northeast joints are found in a number of places. The large majority of sheared cooling joints have steep, northwest or north-northwest strikes. The number of cooling joints that show evidence of shear is small compared to the large number of unsheared joints. Photolineaments formed by sheared joints appear similar to those formed by unsheared joints, (a relation found elsewhere; Seagall and Pollard, 1983).

FIGURE 5. NEAR HERE

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FIGURE 6. NEAR HERE

A group of north-northwest subtle dark tonal anomalies which are longer and wider than the anomalies formed by cooling joints appear on the photographs. Such features comprise part of the composite lineaments P-3, P-4, P-5, L-15, and L-19. In field checking, the cause of these dark anomalies could usually not be identified. However, along one, P-5, a band of relatively broken rock and thicker soil, covered by a denser cover of grass than nearby areas, corresponds to the anomaly. The lineament is a north-northwest striking zone with no contact offsets or fault breccia, although it has some closely spaced fracturing along it. These features could represent a greater scale of shearing (faulting) on cooling joints than that described above, but no fault offset or fault breccias are found along joints near P-5 to support this. If these subtle dark anomalies are faults, they are probably small. They are considered here probable minor fracture zones.

Figure 5. A N 30° W cooling joint in welded Tiva Canyon Tuff which shows evidence of shearing. The cooling joint is seen at lower right (in the shadow) parallel to the compass. To the upper left the cooling joint grades into a highly fractured and brecciated area (see close-up in fig. 6). Looking north near west Antler Ridge. Scale is indicated by the compass and hammerhead at lower right.

Figure 6. Close-up view of upper right portion of sheared cooling joint in fig. 5, showing fractures and breccia along joint. Compass at bottom center indicates the scale.

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One prominent north-northwest lineament, P-3, is interpreted to be a coincidental alignment of saddles formed by faults closer to a north-south strike, with the visual effect reinforced by short north-northwest cooling-joint lineaments.

Another prominent photolineament, P-6, corresponds in part to the Sundance Fault as mapped by Spengler and others (1994) and as shown on plate C-1 of this report. The photolineament supports the interpretation of the Sundance as a significant structure. It is somewhat longer (1.2 km) than the mapped fault on plate C (0.5 km).

Expression of known faults

Known faults (mapped by Scott and Bonk and confirmed by this report) often form poorly expressed photolineaments. Some exceptions are the Ghost Dance and Sundance faults (see discussion of P-6 in appendix 1) and faults associated with P-2 and L-7. Study revealed that six kinds of features contributed to composite photolineaments along faults:

1. Anomalous narrow, steep ravines along ridge slopes; some of them straight, others irregular.

2. Saddles along ridges, which were often flanked by abrupt terminations of the escarpments commonly present on ridge crests formed by the crystal rich unit of the Tiva Canyon Tuff.

3. Areas of white talus or soil which occur where calcite-coated (caliche) breccia float is present. In some cases, the calcite-coated rock appears to be exposed by landsliding along the zone of weakened bedrock.

4. Straight, low benches or ledges on ridge crests which form shadows on low-sun-angle photographs. They may reflect the tendency of one side of a fault, probably the footwall, to be less fractured than the other side, and therefore resistant to erosion.

5. Places where the hillside lineations formed by layering in the Tiva Canyon Tuff are terminated, disrupted, or appear offset.

6. Aligned shadows due to the fault line scarps on ridge crests along the Ghost Dance Fault.

Modifications to the Scott and Bonk map "PRELIMINARY DRAFT"

Field checks for three photolineaments (P-9, P-10, and L-21), identified three places where a revision of the Scott and Bonk (1984) map to include new structures is warranted. In the area of P-9, Scott and Bonk show two short, aligned faults separated by about 200 m. The photo examination suggested these faults are connected to form one long fault: field checking confirmed this interpretation. At P-10, the Scott and Bonk map indicates a fault with no more than a meter offset: but the layering on the photographs appears to be offset considerably more than that amount, particularly at the southwest end of the fault. Field mapping confirms the impression from the photos. The base of the Tiva Canyon Tuff is offset about 5 m, and the top of the Topopah Springs Tuff is offset about 13 m. At L-21, the lineation formed by bedding along the south slope of Highway Ridge appears to be offset more than the five meters indicated on Scott and Bonk (1984). Field checking revealed that the offset is closer to 14 m. This fault has been traced by field mapping to about 400 meters north of P-1, but the fault does not follow the trend of the lineament.

STRUCTURAL INTERPRETATION OF PHOTOLINEAMENTS

Cooling joints

The large majority of L features (L-1,-2,-3,-4,-5,-9,-10,-11,-12,-13,-14,-17, and -20) are interpreted as a consequence of control of wash erosion by cooling joints. Cooling joints are also an important contributor to the larger composite photolineaments: in fact, without them many of the P features may not have been selected.

North-northwest faulting

The shearing of cooling joints and possible fracture zones like P-5 could be related to north-northwest right lateral faulting found less than 3 km to the north on the Sever Wash, Pagany Wash, and Drill hole Wash faults (Scott and others, 1984). And recognized within the study area along the Sundance Fault by Spengler and Others, 1994. The relative importance of shearing related to this system and the influence of the near parallel cooling joints cannot be easily determined. There is an apparent coincidence of a major cooling joint orientation being near parallel to a regional fault trend, the nature of which is beyond the scope of this study. Features in the study area likely to be faults of the Sever Wash set (besides P-6) include P-2, P-9, and L-8.

North-south faulting

Located at the southern extension of the Basin and Range geologic province, the primary strain at Yucca Mountain is commonly considered to be east-west extension on normal faults oriented nearly north-south. Although the Ghost Dance fault is the major fault system in the area, lineaments of this orientation do not dominate the aerial photographs. Instead, north-northwest and even northeast lineaments are more abundant. Thus the visual fabric of the aerial photographs does not reflect the primary strain pattern in the area.

Northeast structures

Although regional northeast-striking faults occur in areas near the study area, P-10 is the only northeast fault recognized as a photolineament within the study area (it was previously mapped by Scott and Bonk). P-11 is a northeast lineament but field mapping shows the fault has only a 15 degree northeast strike. Little evidence of faulting was found on other northeast lineaments.

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CONCLUSIONS

The major conclusions of this study are:

1. The preliminary geologic map of Scott and Bonk (1984) should be revised to show greater offsets on faults along P-10 and L-21, and connect two separated faults along P-9. No other changes to the map are suggested as a result of the aerial photographic study.
2. Photolineaments were not reliable indicators of the faults in the study area, because other features tend to visually overwhelm lineaments formed by faults. these other features are predominately numerous cooling joints.
3. A group of long, north-northwest striking composite lineaments recognized in this study are mostly formed by cooling joints, sheared cooling joints, and minor fracture zones. With the possible exception of P-6, they are not formed by significant faults.

4. Known faults are characterized by a) anomalous ravines along ridge slopes; b) saddles, often flanked by terminations of ridge crest escarpments; c) white caliche-coated rock fragments which mark breccia or landslide scars along faults; d) straight, low benches or ledges on ridge crests; e) places where bedrock layering was terminated, disrupted, or appeared offset; and f) fault line scarps on ridge crests.

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CHAPTER C

DOMINANT FAULTS IN THE VICINITY OF THE POTENTIAL HIGH-LEVEL NUCLEAR WASTE REPOSITORY, YUCCA MOUNTAIN, NEVADA

By Warren C. Day, Christopher J. Potter, Charles W. Weisenberg, Robert P. Dickerson, Karl Kellogg, Richard W. Spengler, and Mark R. Hudson

U.S. Geological Survey

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DOMINANT FAULTS IN THE VICINITY OF THE POTENTIAL HIGH-LEVEL NUCLEAR WASTE REPOSITORY, YUCCA MOUNTAIN, NEVADA

By Warren C. Day, Christopher J. Potter, Charles W. Weisenberg, Robert P. Dickerson, Karl Kellogg, Richard W. Spengler, and Mark R. Hudson

ABSTRACT

Faults within the proposed high-level radioactive nuclear waste repository at Yucca Mountain, Nevada impact the design and site-characterization studies. Knowing the location and geometry of these faults is necessary to help constrain the position of the potential repository, predict the effects of seismogenic events, understand the controls on surface infiltration and fracture flow hydrology, and evaluate the site through performance assessment studies. This progress report outlines the location of the dominant structures within the perimeter of the potential repository. It is part of an ongoing effort by the U.S. Geological Survey to map the geology of the area encompassed by the exploratory studies facility and potential repository boundary at a scale of 1:6,000. The 1:12,000-scale map presented in this report includes faults identified during ongoing mapping by the authors, as well as faults delineated by previous studies. The location of the major block-bounding faults as defined by previous studies is confirmed. However, there are several differences between this report and previous studies regarding the complexities associated with the Ghost Dance and Sundance Faults as well as the location of minor faults. In addition, the new mapping is delineating the numerous fault splays (where identifiable) associated with the larger fault zones within the potential repository.

This report illustrates that many faults are complex zones of small and, locally,

discontinuous fault splays that branch or "horse-tail" both vertically and along strike. These geometric relationships are important to understanding the zones of breccia between the various fault strands and to interpretations of the vertical continuity of fault zones. The preliminary mapping of this report indicates that the Ghost Dance Fault zone consists of numerous fault splays that "horse-tail" at the surface, but may become narrower with depth, which if true, will have a major impact on the volume of the useful ground at depth in the repository horizon within the Topopah Spring Tuff. Further mapping of this zone, as well as integration of ongoing shallow seismic studies, can help define the geometry of this important structural feature.

INTRODUCTION

The main objective of this report is to delineate the dominant structures within the potential repository at Yucca Mountain. This report directly affects the assessment of seismic hazards, hydrologic studies of infiltration and fracture flow, development of the three-dimensional geologic computer models, as well as performance assessment for site suitability. The faults shown on plates 1 and 2 were identified during our ongoing geologic mapping, in which the 1:6,000-scale topographic and orthophoto base maps developed by EG&G Energy Measurements, Inc., were used. In addition to our mapping, structural information was compiled from Scott and Bonk (1984), Braun and others (written communications, 1995), and from the photolineament study by Weisenberg (this volume). Because a full geologic mapping effort was beyond the scope of this report, only a few stratigraphic horizons were used as structural datums throughout the area. The contacts between the lower lithophysal, middle nonlithophysal, and upper lithophysal zones, of the crystal-poor member of the Tiva

Canyon Tuff are exposed throughout most of the area and were used as structural datums. In addition, the contact between the crystal-rich and crystal-poor members provides a datum that is one of the few primary petrologic breaks in the study area.

This report covers two areas, the central potential repository area and the southeastern end of Azreal Ridge, under which the exploratory studies facility (ESF) is currently progressing (fig 1). The work in the Azreal Ridge area (fig. 2) was beyond the original scope of the study area, but data were needed to help understand why the structures encountered in the ESF could not be correlated with those depicted on the preliminary geologic map by Scott and Bonk (1984).

FIGURE 1. NEAR HERE

FIGURE 2. NEAR HERE

DOMINANT STRUCTURES IN THE VICINITY OF THE POTENTIAL REPOSITORY

In general, the volcanic rocks at Yucca Mountain strike north-northwesterly, dip gently (up to 25 degrees) to the east, and are cut by north-, northwest-, and northeast-trending faults (pl. 1). This report confirms the location of the dominant faults mapped by Christiansen and Lipman (1965), Lipman and McKay (1965), and Scott and Bonk (1984). The faults compiled on plate 1 include only those that could be verified. This chapter identifies several differences in the location and orientation of some of the minor faults and shows the complex nature of the Ghost Dance Fault, which trends north through the central part of the potential repository area (pl. 2).

Figure 1. Generalized fault map of the study area. Yucca Mountain, Nevada.

"PRELIMINARY DRAFT"

Figure 2. Geologic map of the southeastern part of Azreal Ridge. Yucca Mountain, Nevada.

"PRELIMINARY DRAFT"

The northern part of the study area has far fewer faults than the central and southwestern part (pl. 1). There are three dominant faults in the northern part of the study area; the northern termination of the Ghost Dance Fault zone; a north- northeast-trending fault that crosses Diabolus Ridge; and the northwestern extent of the Sundance Fault zone. Only a few minor faults having minimal trace length (less than 100 m) and vertical offset (less than 3 m) were found in the northern part of the study area (pl. 1).

The Ghost Dance Fault is the main thoroughgoing fault in the central part of the potential repository area. The 1:240-scale mapping by Braun and others (written communication, 1995) provided a very detailed view of the zone. The 1:6,000-scale mapping of this report provides an overview of the zone and delineates the width and its primary fault splays. Along the southern end of the Ghost Dance Fault zone, the main fault zone bifurcates along strike and trends both southwest into the Abandoned Wash Fault of Scott and Bonk (1984) and southeast, toward but does not connect with the Dune Wash Fault (pl. 1). The mapped traces on plate 2 do not correspond with those of Scott and Bonk (1984). The main trace of the Ghost Dance Fault zone north of drill hole UZ-7a is approximately 150 m wide at the surface. The zone is made up of numerous fault splays that both parallel the main north-trending trace of the zone, and, locally, branch off the main fault laterally and vertically. Vertical "horse-tailing" is present both on the south side of Whale Back Ridge and on the north-facing slope of Broken Limb Ridge, directly south of the drill hole UZ-7a location. The "horse-tail" geometry resembles that of flower structure faults (Sylvester, 1988), but the latter term is generally reserved for faults of known strike-slip dominant motion, which is not the case for many of these faults.

The vertical separation (west-side down) on the Ghost Dance Fault zone varies along strike. The two faults that branch off of the southern terminus of the Ghost Dance Fault zone have a vertical offset of less than 3 m. Approximately 300 m to the north in the area of drill hole UZ-7a there is about 26 m of vertical offset. Spengler and others (1994) noted that to the north on Antler Ridge there is about 12 m of offset, which decreases northward to only 1.5 m on Live Yucca Ridge. North of Live Yucca Ridge the fault zone narrows to less that 6 m wide and has 4 to 6 m down to the west normal dip-slip displacement. We depict the margins of the fault zone as two parallel fault traces, but, in reality, there are probably numerous splays between these two faults that are not exposed.

Spengler and others (1994) identified the Sundance Fault system in the central part of the repository area as a wide zone of minor northwest-trending faults that commonly show northeast-side down displacement. The Sundance Fault was identified as the "dominant structure" in the middle of the Sundance Fault system, and Spengler and others (1994) inferred a significant component of right-lateral displacement along the fault system.

The projected trend of the Sundance Fault system intersects the Ghost Dance Fault beneath Quaternary cover in Split Wash. Spengler and others (1994) proposed that the Ghost Dance Fault is offset by about 50 m in a right-lateral sense along the Sundance Fault beneath Split Wash. Our mapping does not support this conclusion; we find that the Ghost Dance Fault can be traced along an essentially straight trend beneath the Quaternary cover in Split Wash with no apparent offset along a younger fault. On the north flank of Antler Ridge, near the proposed intersection of the Sundance trend with the Ghost Dance Fault, Spengler and others (1994) and Braun and others (SAIC, USGS. written communication, 1995) proposed that two parallel strands of the Ghost Dance Fault. about 16 m apart. were offset from one another along a younger northwest-trending fault related to the Sundance system. Our mapping confirms that the two Ghost Dance strands overlap in map view, but does not support the existence of a younger strike-slip fault. Details of these relations are documented in a map and report currently in preparation by C.J. Potter and others (USGS, written communication, 1995). We suggest that the two Ghost Dance strands meet at depth, and that the abundant breccia in the colluvium between the two fault tips may be indicative of a broad accommodation zone between the two strands. 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. These latter two hypotheses do not require a separate tectonic event to explain the seemingly discontinuous nature of the Ghost Dance Fault.

We find that the Sundance Fault zone can be mapped for about 0.5 km (across two ridges, Dead Yucca Ridge and the unnamed ridge between Live Yucca Ridge and Dead Yucca Ridge) as a significant fault zone that cuts both the crystal-rich and crystal-poor members of the Tiva Canyon Tuff with a cumulative northeast-side-down displacement of 6 to 8 m. Although we mapped several minor northwest-trending faults cutting parts of the crystal-poor member of the Tiva Canyon Tuff on Live Yucca Ridge, on the unnamed ridge between the tributaries of Split Wash, on Antler Ridge, and on Whaleback Ridge (fig. 1 and pl. 1), these do not appear to be through-going structures and do not define a fault zone or fault system. Details of the faulting along the Sundance trend are addressed in a map and report currently in preparation by C.J. Potter and others (USGS, written communication, 1995). The trace of the faults delineated by their new mapping is incorporated in this report.

In the southwest part of the study area we could not verify the trend and(or) existence of some of the minor faults Scott and Bonk (1984) mapped (pl. 2). However, we did identify other minor faults they did not delineate. Scott and Bonk (1984) mapped three northwest-trending faults with 3 to 6 m down to the west offset. Upon inspection, the evidence indicates that these are part of one north-northeast-trending fault, which has minor down to the west displacement on its northern end. but increases in throw to about 15 m to the south. We were not able to identify some of the minor faults in the southwestern-most part of the area mapped by Scott and Bonk (1984).

GEOLOGY OF SOUTHEASTERN AZREAL RIDGE

The ESF tunnel is currently (June 1995) drifting underneath the southeast terminus of Azreal ridge (fig. 2) within the area outlined by Scott (1990) as the "imbricate fault zone". Scott and Bonk (1984) mapped numerous northeast-trending faults associated with the imbricate fault zone. The ESF tunnel is encountering several northwest-trending faults in this zone, seemingly contradicting the trend predicted on the Scott and Bonk (1984) map. Our subsequent mapping (fig. 2) has shown that there indeed are four northeast-trending faults in this area as well as three previously unrecognized northwest-trending faults. In addition, the northeast-trending fault mapped by Scott and Bonk (1984) near drill hole NRG-4 actually trends northwest (pl. 2), is downthrown to the west, and has a minor splay exposed on the ridge crest. Scott and Bonk (1984) depicted this fault as offsetting the main trace of the Drill Hole Wash Fault, which, if ture, provided a fundamental link in the understanding of the relative timing of faulting in the area. Scott and Bonk's mapping argues that the dominant northwest-trending faults, like the Drill Hole Wash. Pagany Wash. and Sever Wash Faults were, therefore. cut by the faults of the imbricate fault zone. However. because evidence for such a northeast-trending fault near NRG-4 is absent this relationship is equivocal. Unfortunately, the area where the northeast- and northwest-trending faults intersect is covered by Quaternary alluvium.

Many faults have branching or "horse-tailing" terminations throughout the Azreal Ridge area, which increase the area of brecciated and broken bedrock. Two such faults are shown to the east and west of drill hole NRG-4 on plate 1. Although the main traces have minor vertical dip-slip offset (less than 3 m). small splays branch off the main traces, increasing the area of brecciation associated with faulting from about 5 m wide near the main trace at the base of the ridge up to 80 m wide at the terminus of the main trace, over an elevation gain of about 70 to 80 m.

CONCLUSIONS

New geologic mapping integrated with previous studies has delineated the dominant faults inside the potential repository area. The northern part of the study area has few recognized faults, most of which were previously delineated by Christiansen and Lipman (1965), Lipman and McKay (1965), and Scott and Bonk (1984). Our mapping has started to outline the complex nature of the Ghost Dance Fault zone, which has numerous fault splays that branch both vertically and along strike. In addition, the mapped location of the southern splays of the Ghost Dance Fault differ markedly from those depicted by Scott and Bonk (1984). Within the area of the potential repository the major divergence between our work and that of Scott and Bonk (1984) is in the southwestern part of the study area. They depicted numerous minor northwest-trending faults some of which we can not verify. However, we do recognize several minor north-trending faults. Further mapping to the east and south of the potential repository should help constrain the complex faulting related to the imbricate fault zone defined by Scott (1990), through which the ESF traverses.

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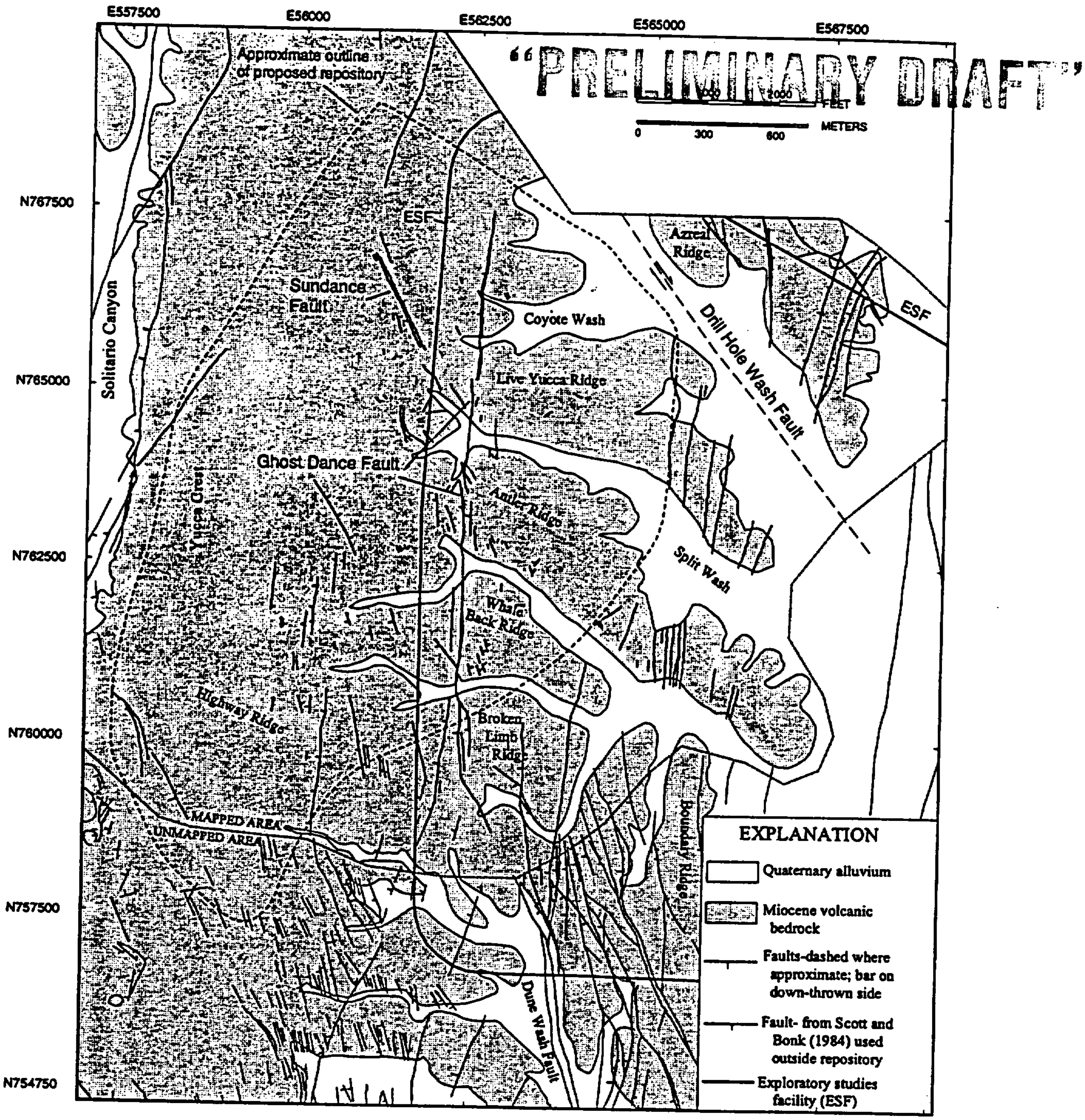

"PRELIMINARY DRAFT"
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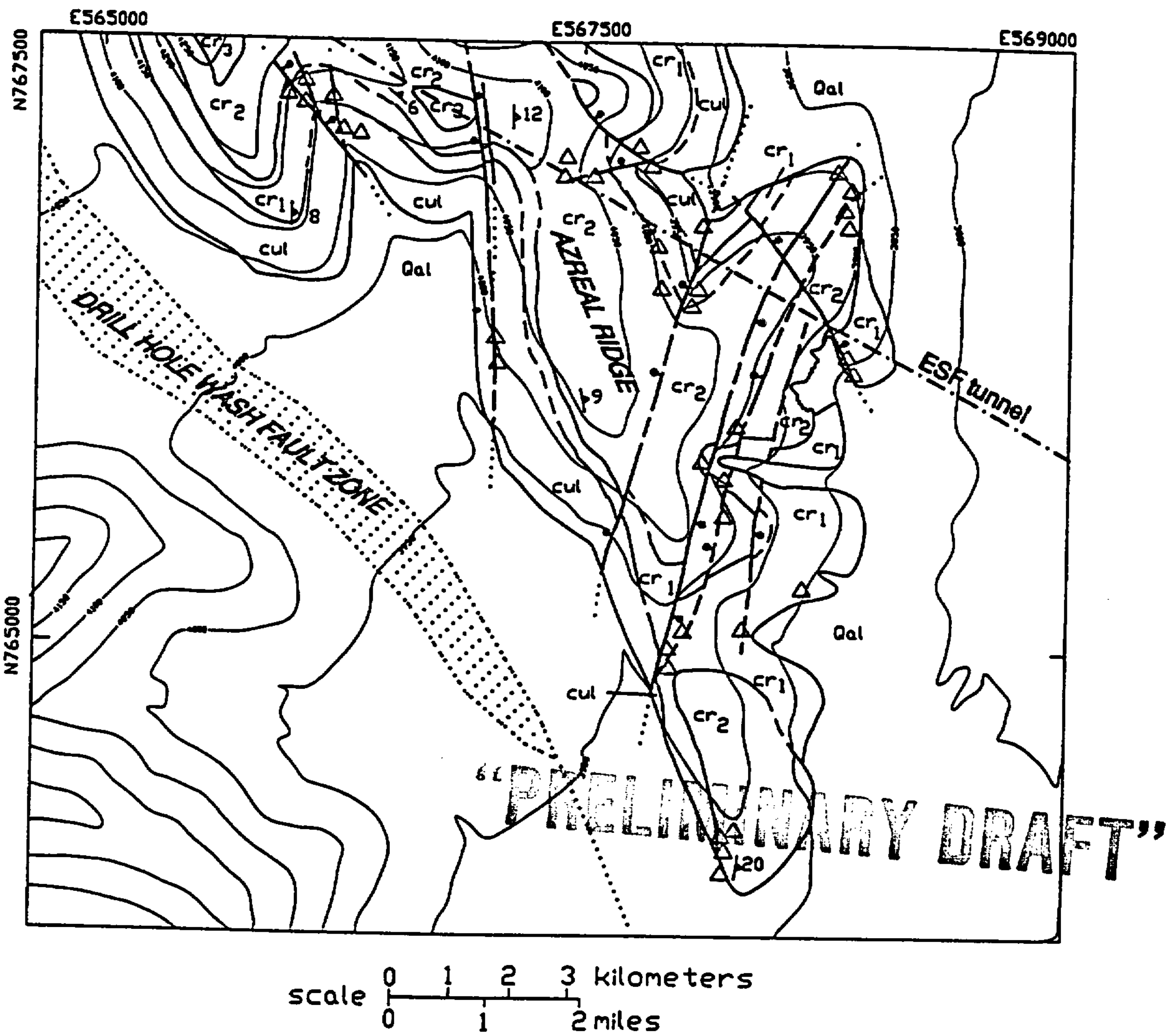
FEET
METERS
0
300
600
Approximate outline of proposed repository
ESF
Sundance Fault
Solitario Canyon
Coyote Wash
Azreal Ridge
Drill Hole Wash Fault
Live Yucca Ridge
Ghost Dance Fault
Antler Ridge
Split Wash
Whale Back Ridge
Highway Ridge
Broken Limb Ridge
Boundary Ridge
MAPPED AREA
UNMAPPED AREA
Dune Wash Fault
EXPLANATION
Quaternary alluvium
Miocene volcanic bedrock
Faults-dashed where approximate; bar on down-thrown side
Fault- from Scott and Bonk (1984) used outside repository
Exploratory studies facility (ESF)

Fig 2



CONTOUR INTERVAL 50 FEET

EXPLANATION

Quaternary

Qal — Alluvium

Tertiary

Tiva Canyon Formation

Crystal-rich Member

cr3 — Punice-poor zone

cr2 — Mixed-punice zone

cr1 — Transition zone

Crystal-poor Member

cul — Upper lithophysal zone

Breccia

Strike and dip of compaction foliation

Contact, dashed where inferred

Fault, dashed where inferred, dotted where concealed (ball and bar on down-thrown side)

Exploratory Studies Facility tunnel (ESF)

Fault zone

CHAPTER D

SURVEY OF THREE LITHOSTRATIGRAPHIC CONTACTS IN SOLITARIO CANYON FOR STRATIGRPAHIC AND STRUCTURAL CONTROL

By David C. Buesch, Carl L. Zimmerman, and Jon R. Wunderlich

U.S. Geological Survey

"PRELIMINARY DRAFT"

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SURVEY OF THREE LITHOSTRATIGRAHIC CONTACTS IN SOLITARIO CANYON FOR STRATIGRPHAIC AND STRUCTURAL CONTROL

by: **David C. Buesch, Carl L. Zimmerman, and Jon R. Wunderlich**

ABSTRACT

Geologic relations at Yucca Mountain, Nevada, are integral to several site-characterization activities of a potential high-level waste repository, and the design of the Exploratory Studies Facility and potential repository. The west flank of Yucca Mountain in Solitario Canyon provides detailed exposures for lithostratigraphic and structural relations, but steep slopes limit the accuracy of location. To provide detailed control for geologic studies, a total of 353 stations have been surveyed to an accuracy of less than 1 foot along three lithostratigraphic contacts with traverses that vary in length from 9,200 to 15,800 ft. Surveyed contacts include (1) the base of the Tiva Canyon Tuff (Tpcpv1), (2) the base of the crystal-rich, vitric, moderately welded subzone of the Topopah Spring Tuff (Tptrv2), and (3) the base of the crystal-poor, upper lithophysal zone of the Topopah Spring Tuff (Tptpul). Tpcpv1 is the primary structural control for the three-dimensional lithostratigraphic model of the central block of Yucca Mountain. Tptrv2 is the base of the nonwelded Paintbrush Tuff hydrogeologic unit. Tptpul corresponds to the contact of the TSw1 and TSw2 thermal-mechanical units and is the conceptual upper boundary for the potential repository. Analyses of survey data and comparison with previously mapped relations are not complete, but initial results (1) help constrain lateral variations along the lithostratigraphic contacts, (2) confirm some of the larger structural features, and (3)

help document features that have not been previously reported.

INTRODUCTION

Lithostratigraphic units are well exposed in Solitario Canyon on the west flank of Yucca Mountain, Nevada, but mapping is typically difficult as a result of steep slopes, gentle east dips of the strata, and the lack of detailed topographic control. For ten years, the 1:12,000 scale map of Scott and Bonk (1984) has been used for stratigraphic and structural relations at Yucca Mountain. The 1984 map, which was enlarged from an original 1:24,000 scale base map with 20-ft topographic contours, has more limitations than implied by the 1:12,000 scale in the depiction of topography and the ability to precisely locate features on the steep west-facing slopes. Although the map of Scott and Bonk (1984) is a reasonably good preliminary representation of the geology of Yucca Mountain (see other chapters), many uses of the map push the limits of what the map can provide. Therefore, an evaluation of the accuracy of the geology depicted on the map of Scott and Bonk (1984) and establishment of surveyed controls of key features exposed in Solitario Canyon has been initiated. A summary of this work is described in this chapter.

Geologic relations on the west flank of Yucca Mountain are integral to several site-characterization activities and the design of the Exploratory Studies Facility (ESF) and potential repository. Site-characterization activities include (1) studies of the variations in lithostratigraphic (Scott and Bonk, 1984; Buesch, Spengler, and others, in press), hydrogeologic (Office of Civilian Waste Management, 1988), and thermal-mechanical (Ortiz and others, 1984) units, (2) studies of faults in the central block (see other chapters), (3) the combination of stratigraphic and structural relations into three-dimensional syntheses and models (Wittwer and others, 1992; Buesch, Nelson, and others, in press), and (4) the folding of results from these studies into performance assessment computations. Design engineers of the ESF and potential repository use three-dimensional models of thermal-mechanical units in the Topopah Spring Tuff to evaluate geometric and thermal-load options (R. Elayer, Yucca Mountain Project Management and Operations, Morrison and Knudson, written commun., 1995).

As an initial evaluation of the stratigraphic and structural accuracy on the map of Scott and Bonk (1984) in Solitario Canyon, three lithostratigraphic contacts have been traced in the field, staked, and surveyed to determine the x, y, and z location. Raytheon Services Nevada (RSN) surveyed the staked locations with Electronic Distance Meter (EDM) instruments to an accuracy of less than 1 ft, and has submitted the data to the Local Record Center, Las Vegas, Nevada (DTN RA950000000001.004). This chapter describes the lithostratigraphic contacts used, how stations were identified, and presents the surveyed station locations. Survey results provide three-dimensional control for studies in progress and previously collected data. Studies in progress include (1) a series of measured sections of lithostratigraphic units (USGS Stratigraphic Studies Project, nonpublished data), (2) correlation of lithostratigraphic units with hydrologic properties in the Paintbrush Tuff hydrogeologic unit (PTn) (T. Moyer and others USGS/SAIC, written commun., 1995), (3) determination of structures in the central block, and (4) documentation of fracture characteristics in the PTn (D. Sweetkind USGS, written commun., 1995). Data supporting previous studies on the hydrologic properties of lithostratigraphic units are presented in Rautman and others (1994), and Flint and others (in press).

LITHOSTRATIGRAPHIC CONTACTS SURVEYED

This study uses the revised lithostratigraphic nomenclature, detailed descriptions of units for rocks in the Paintbrush Group, and the multiple criteria to identify units described in Buesch, Spengler, and others (in press). A summary description of the base of each unit is in Geslin and others (1995). Correlations of the revised names with the names and unit descriptions of Scott and Bonk (1984) are presented in Buesch, Spengler, and others (in press), and the units used in this study are summarized in table D-1. The three lithologic contacts surveyed along the west flank of Yucca Mountain in Solitario Canyon include, from top to bottom, the base of the crystal-poor vitric nonwelded subzone of the Tiva Canyon Tuff (Tpcpv1), the base of the crystal-rich vitric moderately welded subzone of the Topopah Spring Tuff (Tptrv2), and the base of the crystal-poor upper lithophysal zone of the Topopah Spring Tuff (Tptpul). Based on surface exposures and the number of boreholes that penetrate the base of the Tiva Canyon Tuff, the base of Tpcpv1 is one of the main lithostratigraphic and structural controls across Yucca Mountain and forms the primary structural control for the three-dimensional lithostratigraphic model of the central block (Buesch, Nelson, and others, in press). Tptrv2 is equated with the base of the nonwelded Paintbrush Tuff hydrogeologic unit (Buesch, Spengler, and others, in press). Tptpul corresponds to the contact of the TSw1 and TSw2 thermal-mechanical units and is the conceptual upper boundary for the potential repository (Buesch, Spengler, and others, in press). All three contacts have stations labeled sequentially from south to north with the first station in the same main drainage down slope from borehole USW G-3 on the crest of Yucca Mountain.

Crystal-poor vitric nonwelded subzone of the Tiva Canyon Tuff

The base of the crystal-poor vitric nonwelded subzone (Tpcpv1) forms the depositional base of the Tiva Canyon Tuff (Buesch, Spengler, and others, in press). The crystal-poor vitric nonwelded subzone is equivalent to the basal subzone in the columnar zone of Scott and Bonk (1984) (table 1). The base of Tpcpv1 is exposed discontinuously for approximately 15,800 ft northward from the first survey station (plate D-1). Survey stations at the base of Tpcpv1 are designated "cpv1-xxx" where "xxx" are numeric values from 1 to 138.

TABLE 1. NEAR HERE

Crystal-rich vitric moderately welded subzone of the Topopah Spring Tuff

The base of the crystal-rich vitric moderately welded subzone of the Topopah Spring Tuff (Tptrv2), and typically overlies the vitric densely welded subzone that includes vitrophyre (Tptrv1v) (Buesch, Spengler, and others, in press). Locally, rocks of the moderately welded subzone are devitrified, and vapor-phase corroded and lithified, where they overlay the devitrified dense subzone (Tptrn3) of the crystal-rich nonlithophysal zone. The crystal-rich vitric moderately welded subzone is equivalent to the lower part of the nonwelded subzone in the caprock zone of Scott and Bonk

(1984) (table 1). The lithostratigraphic contact of Tptrv2 and Tptrv1 equates to the base of the nonwelded Paintbrush Tuff hydrogeologic unit (PTn) based on the sharp changes in hydrogeologic properties such as the decrease in porosity to less than 10 percent in the densely welded rocks of Tptrv1 (Buesch, Spengler, and others, in press). The base of Tptrv2 is exposed discontinuously for approximately 13,620 ft northward from the first survey station (plate D-1). Survey stations at the base of Tptrv2 are designated "trv2-xxx" where "xxx" are numeric values from 1 to 164.

Crystal-poor upper lithophysal zone of the Topopah Spring Tuff

The base of the crystal-poor upper lithophysal zone of the Topopah Spring Tuff (Tptpul) is located where the (1) amount of lithophysal cavities decrease downward from greater than 10 percent of the rock to less than 1 percent, (2) amount of light gray and red purple decreases and light brown increases in the groundmass, and (3) fracture characteristics change from irregular and rough to planar and smooth (Buesch, Spengler, and others, in press). The upper lithophysal zone is equivalent to the red lithophysal zone of Scott and Bonk (1984) in the central region of Yucca Mountain (table D-1). The base of Tptpul is exposed discontinuously for approximately 9,200 ft northward from the first survey station (plate D-1). Survey stations at the base of Tptpul are designated "tpul-xxx" where "xxx" are numeric values from 01a to 43a. Along the length of the exposure in the upper part of the middle nonlithophysal zone (Tptpmn), there is a lithophysae-bearing interval that typically has less than 2 percent lithophysal cavities . Stations 33e to 42e are located at the based of the lithophysae-bearing interval in Tptpmn where the amount of lithophysal cavities are as much as 2 to 5 percent of the rock. Along the length of the exposure, five flags are located on a traverse perpendicular to the contact. These flags are where, from the top down, the amount of lithophysal cavities decrease below 10, 2, and 1 percent of the rock, with the greater than and less than 1 percent lithophysal cavities marked at the top and bottom of the lithophysae-bearing interval.

CHOICE OF STATION LOCATIONS

There are a total of 353 stations on survey lines along the three lithostratigraphic contacts. Stations along the contacts are located (1) in drainages where contacts are typically better exposed than on interfluves, (2) at locations of measured sections, reference locations for strip maps of the fracture studies in the PTn, and sample transects of boreholes for hydrologic properties, and (3) approximately every 50 to 200 ft along the base of Tpcpv1 and Tptr2, and 75 to 500 ft along the base of Tptpul. Stations on Tpcpv1 and Tptrv2 are identified with yellow or orange flags to indicate the accuracy and confidence in the location. Well exposed contacts have yellow flags and represent a stratigraphic accuracy of less than 1 ft. Contacts in areas of partial cover have orange flags that represent a stratigraphic accuracy of between 1 and 5 ft. Stations with orange flags are identified in appendix D-1. Extra stations are located to constrain separation on faults. Additional stations are located at the base of the lithophysae-bearing interval in Tptpmn at stations tpul-33e to 42e.

PRELIMINARY RESULTS

Survey data (appendix D-II) was delivered shortly before this report was developed; therefore, detailed analyses have not be done. Most of the preliminary results reported herein are inferred from plots of station locations (plate D-1) and a north-south profile of station altitudes (fig. 1). A few preliminary observations were identified during the walking and flagging of station locations.

FIGURE 1 NEAR HERE

Preliminary stratigraphic relations along the surveyed traverses include the variations in thickness and lateral continuity of units. The survey data helps confirm the overall stratiform geometry of depositional units, approximated by comparing the Tpcpv1 and Tptrv2 profiles, and the zones in the Topopah Spring Tuff, approximated by comparing Tptrv2 and Tptpul profiles. Thickness of the fallout and pyroclastic flow deposits between the Tiva Canyon and Topopah Spring Tuffs increases from about 35 ft in the south to about 90 ft in the north (fig. 1). The northward thickening of these units is gradual to about northing N:761500, and increases sharply north of northing N:761500. Several stations on the base of the crystal-rich vitric moderately welded subzone of the Topopah Spring Tuff were located to document the lateral discontinuity of the vitric densely welded subzone (Tptrv1). Tptrv1 is locally a absent for as much as 200 to 300 ft along the surveyed traverse. The contact of the upper lithophysal (Tptpul) and middle nonlithophysal (Tptpmn) zones of the Topopah Spring Tuff has a relatively uniform geometry (fig. 1), and many sharp changes in altitude of the base of Tptpul are probably attributed to faults. Measuring of sections that transect the Tptpul-Tptpmn contact are in progress and the results will help constrain

Figure 1. North-south profile of survey and altitude data for three lithostratigraphic contacts on the west flank of Yucca Mountain, Nevada.

"PRELIMINARY DRAFT"

lateral and vertical variations along this contact. One example of lateral variation is shown by the amount of lithophysae in the lithophysae-bearing interval in the upper part of Tptpmn. This interval is laterally continuous along the traverse and typically has about 1 to 2 percent lithophysae in the rock. Stations where the percent lithophysae are below 2 percent were not surveyed by RSN. North of northing N:759500, there is an increase in the amount of lithophysae in this interval to about 5 percent of the rock, and this increase is indicated by the surveyed locations (fig. 1).

Preliminary results indicate that many faults on the map of Scott and Bonk (1984) have been confirmed, some are not oriented as mapped, and some were not mapped. The general relation of fewer faults north of Highway Ridge, which corresponds to stations cpv1-83 and tpul-111 near northing N:760400, compared to the amount of faults south of this ridge is confirmed (fig. 1). Several of the larger faults are confirmed near stations cpv1-12 (N:753633), 46 (N:756911), 83 (N:760456), 121 (N:764657), and 138 (N:768098) (fig. 1), but some of the surface traces differ from the map of Scott and Bonk (1984). During the walking of contacts, grabens along some of the northwest-trending faults were confirmed. Faults that offset the Tptrv2 and not Tpcpv1 such as those near northing N:759000 are confirmed (fig. 1). Between stations Tptrv2-011 to 024 (N:753323 to N:753982), there are some northwest-trending faults as mapped by Scott and Bonk (1984), but there are several north-trending down-to-the-west faults that repeat the top of Tptrv2 and were not mapped by Scott and Bonk (1984) (fig. 1). A north-trending, down-to-the-west fault zone duplicates Tptpul with about 30 ft vertical separation. This fault zone is between stations Tptpul-11, 12, 13, and 14 (N:754863 to N:755232).

CONCLUSIONS

Detailed survey locations of 353 stations along three lithostratigraphic contacts will provide accurate x, y, z locations for previous and on going site characterization studies and the engineering design of the ESF and potential repository. Preliminary results indicates that many of the features such as lithostratigraphic contacts and faults on the map of Scott and Bonk (1984) are generally confirmed, but may differ in detail from what can be mapped on base maps with scales of 1:6,000 or larger.

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"PRELIMINARY DRAFT"

"PRELIMINARY DRAFT"

APPENDIX D-I. Survey stations arranged by drainage from south to north along the west flank of Yucca Mountain, Nevada

Appendix D-1. Survey stations arranged by drainage along the west flank of Yucca Mountain, Nevada.

[All stations in traverses cpv1 and trv2 are located stratigraphically within less than 1 ft from the contacts: stations with "or" are located within less than 5 ft from the contact. In traverse tpul, station "a" indicates less than 1 percent of the rock is lithophysal cavities, and "e" is the base of a lithophysae-bearing interval. Letters "xxx" are station numbers. "Y" in the Existing Study section indicates that the survey station is close to an area with previous data collected. Blank spaces indicate that some drainages do not have data from all three contacts.]

Station cpv1-xxx	trv2-xxx	tpul-xxx	Existing Study	Comment
001	001	01a	Y	Beginning of traverses
002				
002	003			
003				
004	02a			
004	005 or			
005 or	006 or	03a		
006	007 or			
007	008 or			
009	04a			
008 or &009	010 or			
010	011 & 012			
	013 or &014 &			
	015 or			
016 or	05a			
011				

Appendix D-1. Survey stations arranged by drainage -- Continued

Station cpv1-xxx	trv2-xxx	tpul-xxx	Existing Study	Comment
012	017 & 018			
013	019 & 020	06a		
014	021 & 022			
	023 & 024	07a		
015				
016 or	025	08a		
017	026 or			
018	027	09a	Y	Borehole at trv2-027
	028	10a	Y	Borehole near trv2-028
019	029			
	030 or			
	031 or			
020	032 or			
021	033	11a & 12a		
022	034			
023	035			
024	036			
025	037	13a		
026	038 or			
027	039 or			
028	040 or	14a		
029	041			
030	042			
031	043 or	15a		
032	044			

Appendix D-L Survey stations arranged by drainage -- Continued.

Station cpv1-xxx	trv2-xxx	tpul-xxx	Existing Study	Comment
	045 or			
033	046			
034	047	16a		
035	048 or	17a		
	049			
	050 or			
	051 or			
	052 or			
036	053 or			
037 & 038	054			
	055			
039	056	18a		
	057			
040	058			
041	059 or	19a		
042	060 or	20a		
043	061 or	21a		
044				
	062			
045 or				
046				
047	063			
048	064 or			
	065			
049	066			

"PRELIMINARY DRAFT"

Appendix D-I. Survey stations arranged by drainage -- Continued

Station cpv1-xxx	trv2-xxx	tpul-xxx	Existing Study	Comment
050				
051	067	22a		
052	068		Y	Measured section SC#1
	069 or	23a		
053	070 or	24a		
	071 or			
054 or				
	072			
055	073	25a		
	074			
056	075 or	26a	Y	Measured section PTn#2
057	076			
058	077	27a		
059	078			
060	079			
061	080 or & 081 or			
062	082	28a		
	083			
063	084	29a		
064				
	085			
	086			
065	087	30a		
066	088	31a		
067				

Appendix D-I. Survey stations arranged by drainage -- Continued

Station cpv1-xxx	trv2-xxx	tpul-xxx	Existing Study	Comment
	089			
	090			
	091			
068				
	092	32a	Y	Borehole traverse at tpul-32
069	093	32a	Y	Borehole at trv2-093
070	094		Y	Borehole at trv2-094
	095			
071	096	33a & e	Y	Borehole at trv2-096
	097		Y	SE corner of FS-1
072	098		Y	Borehole at trv2-098, NE corner of FS-1
	099		Y	NE corner of FS-1, base of PTn#3
073	100			
074	101		Y	Borehole at trv2-101
075	102	34a & e		
076	103 or			
077	104		Y	Borehole at trv2-104
078	105	35a	Y	Borehole at trv2-105
	106			
079 or	107	36a & e	Y	Borehole traverse through PTn
080	108		Y	Borehole near cpv1-080
081	109 or	37a & e	Y	Borehole traverse
082	110	38a & e	Y	Borehole traverse
083	111 or		Y	Borehole traverse
084 or			Y	Borehole traverse at cpv1-84

"PRELIMINARY DRAFT"

Appendix D-I. Survey stations arranged by drainage -- Continued

Station cpv1-xxx	trv2-xxx	tpul-xxx	Existing Study	Comment
085	112			
086	113 or	39a & e	Y	Borehole traverse
087	114	41a & c	Y	Borehole traverse
	115			
088	116 or	42a & e	Y	Borehole traverse
089	117		Y	Borehole traverse
090 or	118		Y	Borehole traverse
091	119 or		Y	Borehole at trv2-119
092	120		Y	Borehole traverse at cpv1-92
093	121 or		Y	Borehole traverse
094 or	122 or		Y	Borehole at trv2-122
095	123	43a	Y	Borehole traverse, end of tpul traverse
096	124 or		Y	Borehole traverse at cpv1-96
	125 or		Y	Borehole at trv2-125
097	126 or		Y	Borehole traverse
	127 or			
098	128 or		Y	Bounding FS#3
099	129 or		Y	Borehole traverse, FS#3 & PTn#6
100	130 or		Y	Borehole traverse at cpv1-100
	131		Y	Borehole at trv2-131
101 or	132		Y	Borehole at cpv1-101
	133 or		Y	Borehole at trv2-133
102 or			Y	Borehole traverse
103 or	134 or		Y	Borehole traverse at cpv1-103 & trv2-134
	135 or		Y	Borehole traverse at trv2-135

Appendix D-I. Survey stations arranged by drainage -- Continued

Station cpv1-xxx	trv2-xxx	tpul-xxx	Existing Study	Comment
104 or	136 or		Y	Borehole traverse at trv2-136
105	137		Y	Borehole traverse at cpv1-105
	138 or		Y	Borehole at trv2-138
106 or				
	139		Y	Borehole & PTn#5a
107 or	140 or		Y	Borehole traverse & PTn#5 near cpv1-107
108 or	141 or		Y	Borehole at trv2-141
109	142 or		Y	Boreholes at cpv1-109 & trv2-142
	143 or		Y	Borehole at trv2-143
110	144 or			
	145 or		Y	Borehole at trv2-145
111 or	146 or		Y	Borehole at cpv1-111
112 or	147 or		Y	Borehole at trv2-147
113 or				
	148 or		Y	Borehole with no rv1 at trv2-148
114 or				
115 or	149 or		Y	Borehole with no rv1 at trv2-149
116 or	150 or			
117	151 or			
118	152 or		Y	Borehole at trv2-152
119 or	153 or		Y	Borehole at cpv1-119 & trv2-153
120				
121	154 or		Y	Borehole at trv2-154
	155 or		Y	Borehole at trv2-155

Appendix D-I. Survey stations arranged by drainage -- Continued

Station cpv1-xxx	trv2-xxx	tpul-xxx	Existing Study	Comment
122 or	156 or		Y	Borehole at trv2-156. cpv1-122 near FS#2 south centerpoint
123			Y	Cpv1-122 near FS#2 north centerpoint
124 or	157 or		Y	Borehole at base of PTn#4 at trv2-157
	158 or			
	159 or			
	160 or			
	161 or			
125 or	162 or			
126	163 or			
	164 or			Trv2 faulted out, end of trv2 traverse.
127 or				
128				
129 or				
130				
131 or				
132				
133				
134 or				
135 or				
136 or				
137 or				Base not exposed
138 or				Contact faulted out, end of traverse

"PRELIMINARY DRAFT"

"PRELIMINARY DRAFT"

APPENDIX D-II. Locations of survey stations for three lithostratigraphic contacts along the west flank of Yucca Mountain, Nevada

Appendix D-II. Survey data for the west flank of Yucca Mountain, Nevada.

[Survey data are generated from stations located along three lithostratigraphic contacts. Data are arranged by ascending descriptor numbers and proper stratigraphic position for the three contacts: cpv1, trv2, and tpul. Data file names and point ID values (station designators) are used by Raytheon Services Nevada. Data file names are listed at the first and last entry in each file. Control points used by the Raytheon Services Nevada are added at the end of appendix.]

Descriptor	Northing	Easting	Elevation	Point ID	Data file name
CPV1 - 001	752393.5	557580.0	[illegible]	1000	SOLCAN6
CPV1 - 002	752568.9	557573.7	4536.4	1001	
CPV1 - 003	752659.5	557588.0	4534.9	1002	
CPV1 - 004	752772.5	557634.7	4535.4	1003	
CPV1 - 005	752846.7	557646.3	4530.9	1004	
CPV1 - 006	752974.8	557693.5	4525.2	1005	
CPV1 - 007	753102.6	557726.7	4518.1	1006	
CPV1 - 008	753184.0	557857.4	4536.0	1007	
CPV1 - 009	753173.2	557872.5	4548.4	1008	
CPV1 - 011	753576.3	557973.3	4534.5	1009	
CPV1 - 012	753632.7	558010.7	4551.0	1010	
CPV1 - 013	753728.6	558019.0	4545.6	1011	
CPV1 - 014	753908.4	558040.7	4542.3	1012	
CPV1 - 015	754036.2	558062.8	4542.9	1013	
CPV1 - 016	754117.2	558097.1	4542.3	1014	
CPV1 - 017	754188.3	558122.7	4538.7	1015	
CPV1 - 018	754386.3	558145.7	4533.3	1016	
CPV1 - 019	754553.9	558108.3	4539.3	1017	

Appendix D-II. Survey data for the west flank of Yucca Mountain, Nevada -- Continued.

Descriptor	Northing	Easting	Elevation	Point ID	Data file name
CPV1 - 020	754770.3	558105.5	4534.6	1018	
CPV1 - 021	754889.5	558117.5	4528.2	1019	
CPV1 - 022	755068.2	558097.8	4520.1	1020	
CPV1 - 023	755183.3	558078.7	4521.0	1021	
CPV1 - 024	755291.3	558079.2	4520.0	1022	
CPV1 - 025	755373.0	558094.6	4528.2	1023	
CPV1 - 026	755490.2	558083.3	4527.6	1024	
CPV1 - 027	755576.5	558064.0	4533.6	1025	
CPV1 - 028	755658.8	558024.8	4536.0	1026	
CPV1 - 029	755699.1	557997.5	4535.8	1027	
CPV1 - 030	755773.5	557956.1	4539.9	1028	
CPV1 - 031	755843.0	557937.1	4540.9	1029	
CPV1 - 032	755939.9	557917.4	4543.4	1030	
CPV1 - 033	756094.0	557896.0	4543.1	1031	
CPV1 - 034	756183.8	557858.5	4539.2	1032	
CPV1 - 035	756237.6	557824.2	4541.1	1033	
CPV1 - 036	756385.8	557778.0	4548.9	1034	
CPV1 - 037	756454.4	557740.2	4542.6	1035	
CPV1 - 038	756446.0	557690.2	4516.0	1036	
CPV1 - 039	756536.3	557650.9	4518.8	1037	
CPV1 - 040	756601.2	557630.4	4525.7	1038	
CPV1 - 041	756715.8	557616.7	4531.2	1039	
CPV1 - 042	756775.8	557616.0	4535.0	1040	
CPV1 - 043	756823.0	557619.8	4536.4	1041	
CPV1 - 044	756877.9	557621.1	4522.7	1042	SOLCAN6

Appendix D-II. Survey data for the west flank of Yucca Mountain, Nevada -- Continued.

Descriptor	Northing	Easting	Elevation	Point ID	Data file name
CPV1 - 045	756885.2	557696.4	4552.4	45	SOLCAN8
CPV1 - 046	756911.3	557715.7	4554.0	46	
CPV1 - 047	757030.0	557723.7	4547.3	47	
CPV1 - 048	757076.2	557718.1	4544.9	48	
CPV1 - 049	757170.2	557681.5	4548.5	49	
CPV1 - 050	757259.5	557667.0	4549.9	50	
CPV1 - 051	757332.4	557681.6	4545.0	51	
CPV1 - 052	757420.5	557686.3	4541.7	52	
CPV1 - 053	757555.8	557688.6	4534.9	53	
CPV1 - 054	757713.7	557706.5	4531.5	54	
CPV1 - 055	757893.2	557678.5	4535.3	55	
CPV1 - 056	758039.0	557629.9	4540.8	56	
CPV1 - 057	758179.9	557589.0	4547.3	57	
CPV1 - 058	758265.1	557557.8	4550.6	58	
CPV1 - 059	758349.1	557540.0	4553.0	59	
CPV1 - 060	758396.9	557526.4	4554.8	60	
CPV1 - 061	758520.9	557489.1	4559.0	61	
CPV1 - 062	758639.8	557421.1	4564.5	62	
CPV1 - 063	758801.2	557388.4	4578.0	63	
CPV1 - 064	758859.1	557363.2	4582.4	64	
CPV1 - 065	758970.0	557342.2	4587.2	65	
CPV1 - 066	759057.0	557324.6	4589.7	66	
CPV1 - 067	759125.1	557318.7	4590.2	67	
CPV1 - 068	759214.4	557310.7	4589.5	68	
CPV1 - 069	759321.6	557331.2	4590.8	69	

Appendix D-II. Survey data for the west flank of Yucca Mountain, Nevada -- Continued.

Descriptor	Northing	Easting	Elevation	Point ID	Data file name
CPV1 - 070	759388.3	557358.9	4590.2	70	
CPV1 - 071	759484.2	557391.3	4589.0	71	
CPV1 - 072	759562.7	557410.1	4589.3	72	
CPV1 - 073	759654.2	557427.2	4589.0	73	
CPV1 - 074	759725.4	557443.2	4586.4	74	
CPV1 - 075	759816.3	557434.0	4586.8	75	SOLCAN8
CPV1 - 076	759909.3	557435.7	4585.9	76	SOLCAN4
CPV1 - 077	759990.7	557453.4	4585.1	77	
CPV1 - 078	760065.0	557459.3	4584.4	78	
CPV1 - 079	760133.8	557464.4	4584.7	79	
CPV1 - 080	760171.8	557472.6	4584.7	80	
CPV1 - 081	760265.2	557488.1	4583.5	81	
CPV1 - 082	760354.2	557498.6	4582.7	82	
CPV1 - 083	760456.4	557606.2	4597.7	83	
CPV1 - 084	760521.4	557632.8	4592.1	84	
CPV1 - 085	760578.4	557645.2	4590.6	85	
CPV1 - 086	760622.3	557653.7	4590.4	86	
CPV1 - 087	760702.8	557661.8	4591.7	87	
CPV1 - 088	760805.8	557665.0	4593.0	88	
CPV1 - 089	760892.6	557682.5	4590.2	89	
CPV1 - 090	760966.1	557709.0	4586.5	90	
CPV1 - 091	761030.4	557727.3	4584.2	91	
CPV1 - 092	761123.5	557735.2	4572.3	92	
CPV1 - 093	761223.9	557742.4	4576.5	93	
CPV1 - 094	761285.2	557763.0	4580.7	94	

Appendix D-II. Survey data for the west flank of Yucca Mountain, Nevada -- Continued.

Descriptor	Northing	Easting	Elevation	Point ID	Data file name
CPV1 - 095	761409.1	557779.8	4575.4	95	
CPV1 - 096	761524.2	557778.9	4578.4	96	
CPV1 - 097	761618.2	557790.9	4576.2	97	
CPV1 - 098	761719.4	557826.5	4574.0	98	
CPV1 - 099	761842.4	557881.9	4568.7	99	
CPV1 - 100	761999.4	557864.6	4571.2	100	
CPV1 - 101	762108.5	557881.2	4572.3	101	
CPV1 - 102	762291.0	557904.9	4571.7	102	
CPV1 - 103	762408.3	557948.1	4569.3	103	
CPV1 - 104	762566.5	557986.6	4565.2	104	
CPV1 - 105	762688.0	558024.5	4560.9	105	
CPV1 - 106	762804.8	558029.0	4560.9	106	
CPV1 - 107	762973.4	558065.3	4558.6	107	
CPV1 - 108	763121.2	558074.2	4560.1	108	
CPV1 - 109	763219.2	558092.7	4557.3	109	
CPV1 - 110	763344.9	558099.0	4553.8	110	
CPV1 - 111	763566.6	558152.5	4549.5	111	
CPV1 - 112	763654.4	558166.7	4535.2	112	
CPV1 - 113	763747.9	558177.2	4522.2	113	SOLCAN4
CPV1 - 114	763998.2	558229.7	4510.6	114	SOLCAN3
CPV1 - 115	764078.1	558245.4	4505.1	115	
CPV1 - 116	764169.6	558254.8	4500.1	116	
CPV1 - 117	764289.4	558227.8	4493.5	117	
CPV1 - 118	764372.2	558216.7	4489.6	118	
CPV1 - 119	764436.2	558215.2	4487.8	119	

Appendix D-II. Survey data for the west flank of Yucca Mountain, Nevada -- Continued.

Descriptor	Northing	Easting	Elevation	Point ID	Data file name
CPV1 - 120	764481.7	558166.8	4470.3	120	
CPV1 - 121	764657.1	558162.3	4472.5	121	
CPV1 - 122	764942.1	558162.3	4477.4	122	
CPV1 - 123	764991.9	558159.6	4477.9	123	
CPV1 - 124	765086.7	558151.8	4476.4	124	
CPV1 - 125	765689.3	558166.1	4480.6	125	
CPV1 - 126	765796.9	558163.2	4482.9	126	
CPV1 - 127	766148.1	558176.7	4491.1	127	
CPV1 - 128	766237.0	558170.2	4491.6	128	
CPV1 - 129	766349.9	558150.8	4490.7	129	
CPV1 - 130	766546.1	558143.9	4497.7	130	
CPV1 - 131	766783.9	558187.7	4500.1	131	
CPV1 - 132	766906.7	558196.2	4503.6	132	
CPV1 - 133	767365.9	558234.6	4503.9	133	
CPV1 - 134	767533.3	558230.1	4510.6	134	
CPV1 - 135	767600.6	558230.9	4507.6	135	
CPV1 - 136	767913.0	558191.2	4501.1	136	
CPV1 - 137	768021.4	558181.0	4503.4	137	
CPV1 - 138	768097.7	558190.1	4512.4	138	SOLCAN3
TRV2 - 001	752406.6	557493.6	4505.0	1103	SOLCAN6
TRV2 - 002	752557.4	557504.1	4501.3	1102	
TRV2 - 003	752583.0	557501.2	4500.1	1101	
TRV2 - 004	752738.6	557508.4	4487.4	1100	
TRV2 - 005	752815.4	557527.6	4483.5	1099	
TRV2 - 006	752938.0	557568.6	4478.7	1098	

Appendix D-II. Survey data for the west flank of Yucca Mountain, Nevada -- Continued.

Descriptor	Northing	Easting	Elevation	Point ID	Data file name
TRV2 - 007	752998.3	557606.7	4487.9	1097	
TRV2 - 008	753170.4	557647.0	4479.6	1096	
TRV2 - 009	753233.3	557713.8	4475.3	1095	
TRV2 - 010	753281.6	557741.6	4469.1	1094	
TRV2 - 011	753323.1	557781.2	4474.2	1093	
TRV2 - 012	753319.5	557828.4	4496.0	1092	
TRV2 - 013	753424.7	557772.2	4457.1	1091	
TRV2 - 014	753414.6	557795.6	4467.7	1090	
TRV2 - 015	753417.7	557831.3	4493.5	1089	
TRV2 - 016	753488.5	557768.8	4455.6	1088	
TRV2 - 017	753681.2	557818.3	4454.7	1087	
TRV2 - 018	753699.6	557917.5	4498.6	1086	
TRV2 - 019	753762.0	557881.2	4476.7	1085	
TRV2 - 020	753733.8	557946.4	4510.3	1084	
TRV2 - 021	753943.6	557933.3	4494.4	1083	
TRV2 - 022	753932.1	557969.7	4510.5	1082	
TRV2 - 023	753994.5	557931.0	4493.8	1081	
TRV2 - 024	753982.5	557965.5	4508.1	1080	
TRV2 - 025	754174.3	558023.1	4501.1	1079	
TRV2 - 026	754228.1	558048.2	4493.9	1078	
TRV2 - 027	754369.9	558062.5	4497.0	1077	
TRV2 - 028	754461.2	558052.4	4499.9	1076	
TRV2 - 029	754513.8	558033.1	4501.8	1075	
TRV2 - 030	754574.8	558013.5	4506.7	1074	
TRV2 - 031	754648.4	558003.8	4507.6	1073	

Appendix D-II. Survey data for the west flank of Yucca Mountain. Nevada -- Continued.

Descriptor	Northing	Easting	Elevation	Point ID	Data file name
TRV2 - 032	754789.9	558032.3	4494.0	1072	
TRV2 - 033	754897.8	558035.5	4490.4	1071	
TRV2 - 034	755053.3	558026.5	4487.3	1070	
TRV2 - 035	755226.1	558016.5	4488.1	1069	
TRV2 - 036	755297.9	558010.7	4486.2	1068	
TRV2 - 037	755363.5	558009.0	4483.7	1067	
TRV2 - 038	755464.2	558005.2	4488.2	1066	
TRV2 - 039	755535.2	557985.1	4492.0	1065	
TRV2 - 040	755612.1	557955.5	4496.0	1064	
TRV2 - 041	755662.8	557924.9	4499.3	1063	
TRV2 - 042	755763.7	557879.1	4505.9	1062	
TRV2 - 043	755837.0	557859.3	4500.7	1061	
TRV2 - 044	755910.5	557847.4	4507.8	1060	
TRV2 - 045	755955.5	557829.8	4506.9	1059	
TRV2 - 046	756081.3	557823.3	4508.4	1058	
TRV2 - 047	756157.8	557800.6	4509.5	1057	
TRV2 - 048	756201.9	557761.9	4512.6	1056	
TRV2 - 049	756256.7	557750.0	4514.1	1055	
TRV2 - 050	756278.6	557729.0	4512.8	1054	
TRV2 - 051	756244.7	557681.5	4484.8	1053	
TRV2 - 052	756289.5	557663.4	4490.7	1052	
TRV2 - 053	756361.4	557672.8	4492.8	1051	
TRV2 - 054	756409.3	557639.4	4491.2	1050	
TRV2 - 055	756443.5	557623.6	4491.3	1049	
TRV2 - 056	756487.9	557614.1	4493.4	1048	

Appendix D-II. Survey data for the west flank of Yucca Mountain, Nevada -- Continued.

Descriptor	Northing	Easting	Elevation	Point ID	Data file name
TRV2 - 057	756536.1	557576.4	4488.5	1047	
TRV2 - 058	756580.4	557544.5	4485.1	1046	
TRV2 - 059	756722.8	557501.4	4485.3	1045	
TRV2 - 060	756778.0	557485.7	4484.1	1044	
TRV2 - 061	756900.4	557561.1	4501.0	1043	SOLCAN6
TRV2 - 062	756912.6	557647.0	4521.5	62	SOLCAN8
TRV2 - 063	757015.4	557671.9	4525.2	63	
TRV2 - 064	757055.4	557666.1	4523.1	64	
TRV2 - 065	757101.5	557652.0	4526.4	65	
TRV2 - 066	757169.8	557629.6	4528.7	66	
TRV2 - 067	757326.9	557614.5	4511.7	67	
TRV2 - 068	757436.3	557613.1	4507.9	68	
TRV2 - 069	757508.7	557612.3	4505.9	69	
TRV2 - 070	757588.4	557619.9	4500.3	70	
TRV2 - 071	757647.8	557632.4	4496.5	71	
TRV2 - 072	757804.9	557620.7	4493.6	72	
TRV2 - 073	757853.5	557601.4	4495.7	73	
TRV2 - 074	757942.4	557565.1	4499.0	74	
TRV2 - 075	758020.5	557546.6	4503.0	75	
TRV2 - 076	758159.6	557511.7	4508.7	76	
TRV2 - 077	758234.3	557481.9	4511.2	77	
TRV2 - 078	758318.2	557466.3	4516.0	78	
TRV2 - 079	758354.8	557458.5	4518.3	79	
TRV2 - 080	758462.0	557423.5	4519.0	80	
TRV2 - 081	758478.7	557413.5	4525.5	81	

Appendix D-II. Survey data for the west flank of Yucca Mountain, Nevada -- Continued.

Descriptor	Northing	Easting	Elevation	Point ID	Data file name
TRV2 - 082	758604.1	557338.8	4533.5	82	
TRV2 - 083	758679.1	557328.0	4535.6	83	
TRV2 - 084	758748.4	557320.1	4536.9	84	
TRV2 - 085	758851.6	557273.1	4544.1	85	
TRV2 - 086	758885.7	557271.4	4545.3	86	
TRV2 - 087	758934.1	557263.8	4546.8	87	
TRV2 - 088	759062.3	557240.9	4555.2	88	
TRV2 - 089	759158.4	557244.7	4554.2	89	
TRV2 - 090	759018.0	557175.7	4516.1	90	
TRV2 - 091	759104.8	557180.1	4524.3	91	
TRV2 - 092	759265.6	557230.2	4555.8	92	
TRV2 - 093	759358.1	557248.2	4548.8	93	
TRV2 - 094	759404.5	557281.0	4552.3	94	
TRV2 - 095	759447.8	557298.4	4549.0	95	
TRV2 - 096	759503.6	557318.3	4548.5	96	
TRV2 - 097	759550.4	557326.5	4548.9	97	
TRV2 - 098	759581.6	557331.2	4547.8	98	
TRV2 - 099	759596.0	557339.2	4547.5	99	
TRV2 - 100	759645.5	557342.0	4548.1	100	
TRV2 - 101	759732.3	557365.1	4546.3	101	
TRV2 - 102	759808.4	557351.5	4548.8	102	SOLCAN8
TRV2 - 103	759886.2	557351.6	4548.0	103TV	SOLCAN4
TRV2 - 104	760009.8	557369.4	4545.6	104TV	
TRV2 - 105	760049.3	557380.2	4545.7	105TV	
TRV2 - 106	760083.8	557378.7	4546.4	106TV	

Appendix D-II. Survey data for the west flank of Yucca Mountain, Nevada -- Continued.

Descriptor	Northing	Easting	Elevation	Point ID	Data file name
TRV2 - 107	760143.1	557382.8	4546.1	107TV	
TRV2 - 108	760199.7	557397.9	4545.1	108TV	
TRV2 - 109	760264.5	557398.5	4544.5	109TV	
TRV2 - 110	760364.1	557403.1	4544.9	110TV	
TRV2 - 111	760529.7	557535.4	4549.5	111TV	
TRV2 - 112	760583.9	557554.4	4547.8	112TV	
TRV2 - 113	760669.1	557570.1	4544.7	113TV	
TRV2 - 114	760735.2	557574.0	4546.1	114TV	
TRV2 - 115	760770.1	557573.4	4546.0	115TV	
TRV2 - 116	760862.3	557581.8	4544.4	116TV	
TRV2 - 117	760942.7	557600.4	4542.5	117TV	
TRV2 - 118	761004.0	557621.0	4539.4	118TV	
TRV2 - 119	761086.6	557638.4	4534.3	119TV	
TRV2 - 120	761134.2	557650.3	4531.7	120TV	
TRV2 - 121	761239.8	557635.6	4534.1	121TV	
TRV2 - 122	761356.8	557668.4	4528.3	122TV	
TRV2 - 123	761396.4	557683.8	4527.4	123TV	
TRV2 - 124	761465.1	557675.7	4528.9	124TV	
TRV2 - 125	761562.1	557677.5	4528.1	125TV	
TRV2 - 126	761645.2	557685.1	4524.8	126TV	
TRV2 - 127	761715.8	557697.4	4523.0	127TV	
TRV2 - 128	761769.3	557717.2	4519.3	128TV	
TRV2 - 129	761854.1	557758.2	4515.1	129TV	
TRV2 - 130	762046.1	557748.3	4520.8	130TV	
TRV2 - 131	762084.1	557767.7	4518.1	131TV	

Appendix D-II. Survey data for the west flank of Yucca Mountain, Nevada -- Continued.

Descriptor	Northing	Easting	Elevation	Point ID	Data file name
TRV2 - 132	762126.0	557770.0	4520.5	132TV	
TRV2 - 133	762258.9	557771.3	4519.1	133TV	
TRV2 - 134	762457.9	557824.0	4510.1	134TV	
TRV2 - 135	762554.5	557841.3	4507.6	135TV	
TRV2 - 136	762622.2	557861.6	4502.2	136TV	
TRV2 - 137	762678.7	557884.9	4502.0	137TV	
TRV2 - 138	762730.0	557879.1	4501.9	138TV	
TRV2 - 139	762917.2	557907.1	4497.4	139TV	
TRV2 - 140	763017.1	557911.8	4498.4	140TV	
TRV2 - 141	763113.2	557915.0	4498.2	141TV	
TRV2 - 142	763224.5	557936.3	4496.8	142TV	
TRV2 - 143	763310.5	557945.8	4495.2	143TV	
TRV2 - 144	763417.2	557944.1	4490.7	144TV	
TRV2 - 145	763587.2	557984.2	4485.3	145TV	
TRV2 - 146	763640.8	558001.2	4479.2	146TV	
TRV2 - 147	763738.1	558010.3	4473.5	147TV	SOLCAN4
TRV2 - 148	763889.7	558032.9	4456.3	148	SOLCAN3
TRV2 - 149	764086.1	558050.2	4442.5	149	
TRV2 - 150	764194.8	558058.7	4433.6	150	
TRV2 - 151	764203.4	557868.6	4401.7	151	
TRV2 - 152	764391.4	557890.2	4400.9	152	
TRV2 - 153	764451.6	557914.9	4400.9	153	
TRV2 - 154	764707.2	557852.4	4409.1	154	
TRV2 - 155	764847.1	557872.8	4411.6	155	
TRV2 - 156	764955.7	557877.1	4407.6	156	

Appendix D-II. Survey data for the west flank of Yucca Mountain, Nevada -- Continued.

Descriptor	Northing	Easting	Elevation	Point ID	Data file name
TRV2 - 157	765121.3	557887.0	4405.7	157	
TRV2 - 158	765197.3	557909.1	4400.9	158	
TRV2 - 159	765417.4	557872.8	4394.8	159	
TRV2 - 160	765456.3	557780.2	4365.0	160	
TRV2 - 161	765537.9	557870.6	4394.5	161	
TRV2 - 162	765683.0	557849.0	4391.4	162	
TRV2 - 163	765729.5	557840.4	4389.3	163	
TRV2 - 164	765895.0	557875.1	4394.2	164	SOLCAN3
TPUL - 01a	752564.8	557105.2	4284.0	1104	SOLCAN6
TPUL - 02a	752637.5	557099.0	4286.8	1105	
TPUL - 03a	752846.2	557153.8	4283.4	1106	
TPUL - 04a	753180.9	557233.5	4280.7	1107	
TPUL - 05a	753467.2	557381.8	4273.2	1108	
TPUL - 06a	753702.8	557427.7	4277.4	1109	
TPUL - 07a	753900.1	557455.9	4265.1	1110	
TPUL - 08a	753941.8	557461.3	4267.0	1111	
TPUL - 09a	754370.4	557522.1	4259.1	1112	
TPUL - 10a	754561.4	557550.9	4270.4	1113	
TPUL - 11a	754863.7	557483.2	4259.5	1114	
TPUL - 12a	754944.3	557648.5	4308.9	1115	
TPUL - 13a	755096.3	557673.7	4308.3	1116	
TPUL - 14a	755232.2	557399.4	4262.4	1117	SOLCAN6
TPUL - 15a	755615.9	557507.2	4289.6	1015	SOLCAN7
TPUL - 16a	755754.6	557440.7	4288.1	1016	
TPUL - 17a	755925.1	557375.1	4297.4	1017	

Appendix D-II. Survey data for the west flank of Yucca Mountain, Nevada -- Continued.

Descriptor	Northing	Easting	Elevation	Point ID	Data file name
TPUL - 18a	756388.9	557298.4	4313.2	1018	
TPUL - 19a	756648.1	557202.5	4323.5	1019	
TPUL - 20a	756768.8	557153.4	4331.8	1020	
TPUL - 21a	757053.6	557181.9	4317.4	1021	
TPUL - 22a	757360.1	557243.0	4330.8	1022	
TPUL - 24a	757644.1	557271.0	4347.2	1024	
TPUL - 25a	757843.7	557268.6	4348.1	1025	
TPUL - 26a	758014.5	557210.4	4352.6	1026	
TPUL - 27a	758168.4	557182.9	4354.5	1027	
TPUL - 28a	758306.9	557082.4	4355.1	1028	
TPUL - 29a	758652.2	556940.7	4354.6	1029	
TPUL - 30a	758820.1	556886.4	4351.0	1030	
TPUL - 31a	758912.5	556869.7	4352.4	1031	SOLCAN7
TPUL - 32a	759255.6	556784.4	4328.3	32	SOLCAN8
TPUL - 33a	759622.0	556810.9	4311.1	33A	SOLCAN5
TPUL - 33e	759689.1	556763.7	4292.5	33E	
TPUL - 34a	759796.2	556789.8	4291.0	34A	
TPUL - 34e	759795.8	556788.7	4292.1	34E	
TPUL - 35a	760067.6	556934.8	4325.8	35A	
TPUL - 35e	760089.3	556855.1	4298.2	35E	
TPUL - 36a	760183.5	557005.7	4337.4	36A	
TPUL - 36e	760193.6	556869.6	4297.3	36E	
TPUL - 37a	760282.6	557018.7	4334.5	37A	
TPUL - 37e	760287.3	556871.2	4295.8	37E	
TPUL - 38a	760453.0	557013.7	4335.5	38A	

Appendix D-II. Survey data for the west flank of Yucca Mountain, Nevada -- Continued.

Descriptor	Northing	Easting	Elevation	Point ID	Data file name
TPUL - 38e	760455.1	556967.3	4312.4	38E	
TPUL - 39a	760658.1	557052.8	4331.2	39A	
TPUL - 39e	760667.2	556998.8	4308.0	39E	
TPUL - 40a	760762.0	557097.5	4329.9	40A	
TPUL - 40e	760796.2	557015.9	4304.7	40E	
TPUL - 41a	760828.9	557126.0	4330.2	41A	
TPUL - 41e	760890.7	557018.8	4297.7	41E	
TPUL - 42a	760971.4	557141.3	4318.7	42A	
TPUL - 42e	761003.1	557065.6	4294.8	42E	
TPUL - 43a	761393.1	557207.3	4310.3	43A	SOLCAN8
Control points used by Raytheon Services Nevada					
26TJS	755306.3	553941.0	3904.8	26	SOLCAN7
32TJS001	763332.2	555895.6	4210.6	32	SOLCAN3
30TJS	760522.4	555403.6	4085.3	30	SOLCAN5
CRATER FL	751222.3	529995.8	3698.9	19230	SOLCAN6
IBIS	767921.0	558818.2	4856.8	19395	SOLCAN4
MILE	759939.8	558023.2	4951.3	19505	SOLCAN3&5&8
PELICAN	752469.5	558110.5	4874.5	19530	SOLCAN7&8
SC#1	753088.4	557589.2	4488.6	1	SOLCAN6
SC#2	762314.7	557811.5	4532.4	2	SOLCAN4
SC #3	758606.3	557316.3	4529.7	3	SOLCAN8
SC #4	759296.0	557282.9	4580.4	4	SOLCAN8

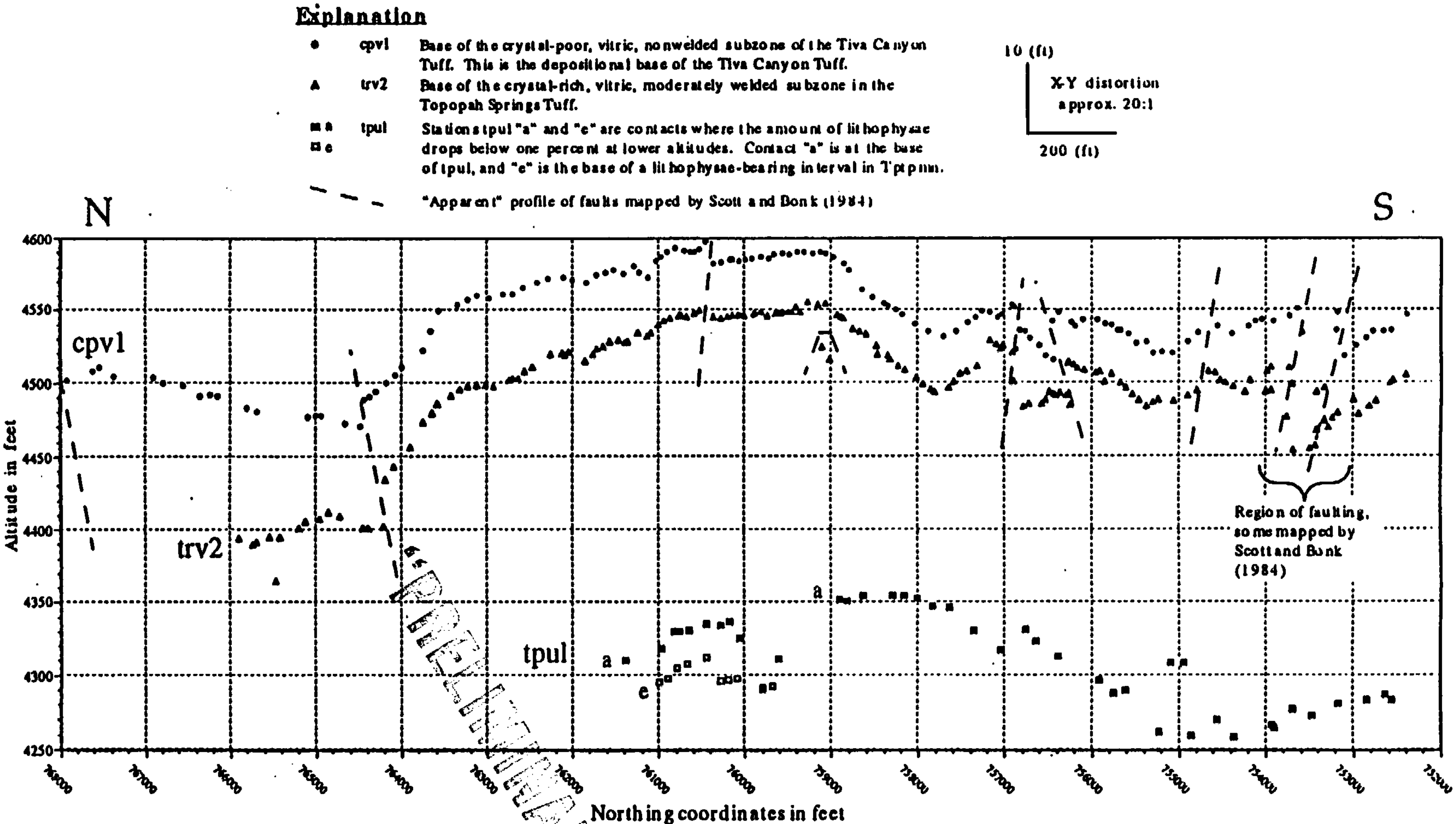

Figure 1. North-South profile of survey and altitude data for three lithostratigraphic contacts on west flank of Yucca Mountain.

Table 1. Table correlating selected nomenclature of Scott and Bonk (1984) and Buesch, Spengler, and others (in press)

[Symbols are for the central region of Yucca Mountain (Scott and Bonk, 1984);

--: no symbol designated; Only formal stratigraphic nomenclature issss capitolized]

Scott and Bonk, 1984		Buesch, Spengler, and others, in press	
Member/zone/subzone	Symbol	Symbol	Formation/member/zone/subzone
Tiva Canyon Member	Tpc	Tpc	Tiva Canyon Tuff
		cp	crystal-poor member
Columnar zone	cc		
		cpv	vitric zone
basal subzone	--	cpvl	nonwelded subzone
Topopah Spring Member	Tpt	Tpt	Topopah Spring Tuf
Caprock zone	tc	tr	crystal-rich member
		rv	vitric zone
nonwelded subzone	--	rv2	moderately welded subzone
		rv1	densely welded subzone
vitrophyre subzone	--	rv1v	vitrophyre interval
		rn	nonlithopysal zone
		rn3	dense subzone
		tp	crystal-poor member
red lithophysal zone	trl	pul	upper lithophysal zone
brick zone	tb	pmn	middle nonlithophysal zone

"PRELIMINARY DRAFT"

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

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) evaulation 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	30-jun-1995

OG32212 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 12/8/94 Date