STRUCTURAL CHARACTERISTICS WITHIN THE POTENTIAL REPOSITORY AREA: RECENT FINDINGS--FUTURE STUDIES

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U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING
APRIL 12, 1994

SIGNIFICANCE OF SURFACE STRUCTURAL STUDIES WITHIN THE POTENTIAL REPOSITORY AREA

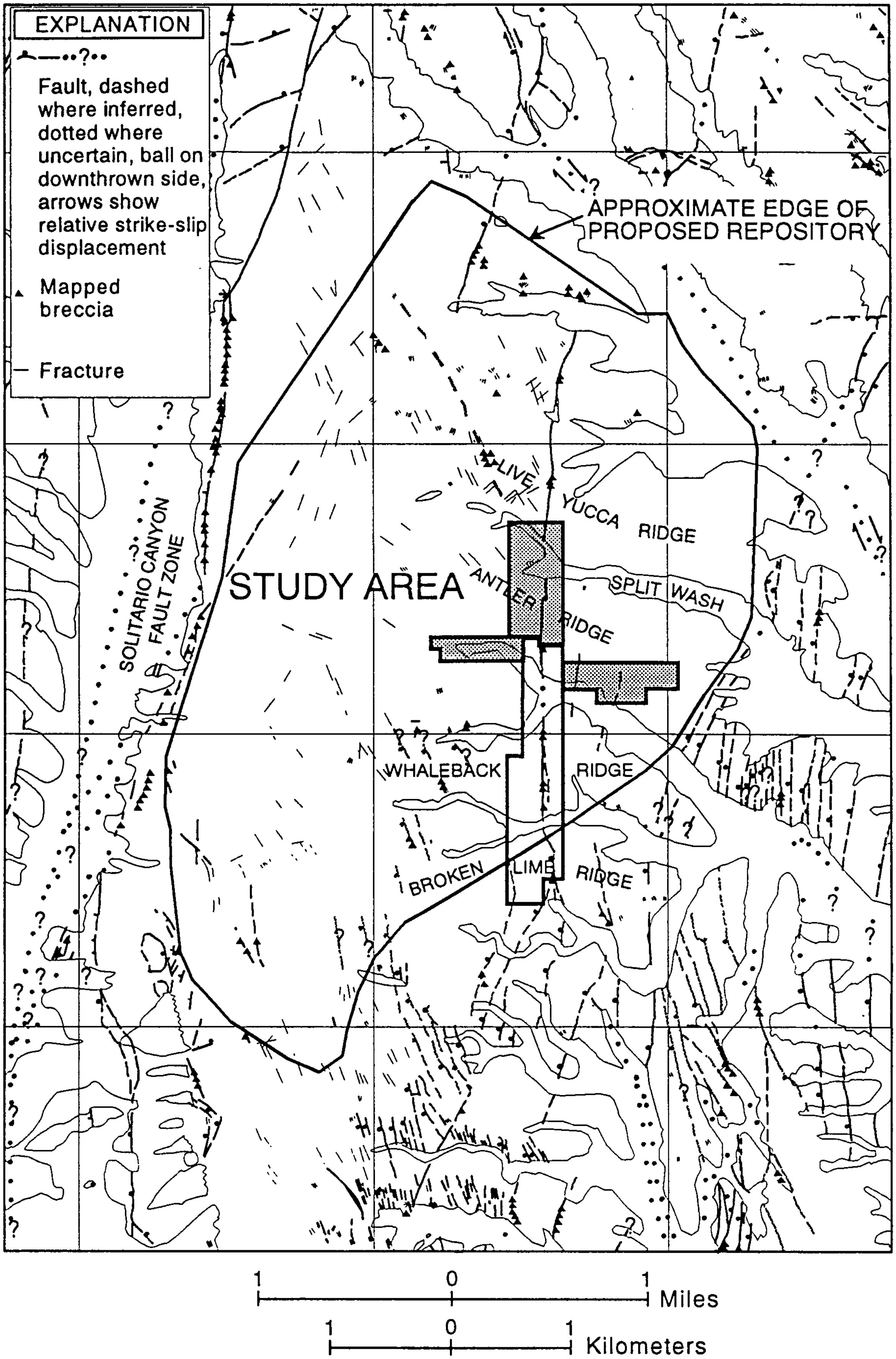
UNSATURATED ZONE MODELING

INVESTIGATIONS OF POTENTIAL FAST PATHWAYS

DEVELOPMENT OF TECTONIC MODELS

DESIGN AND CONSTRUCTION OF ESF

DESIGN OF REPOSITORY LAYOUT


EXPLANATION
Fault, dashed where inferred, dotted where uncertain, ball on downthrown side, arrows show relative strike-slip displacement
Mapped breccia
Fracture
APPROXIMATE EDGE OF PROPOSED REPOSITORY
STUDY AREA
SOLITARIO CANYON FAULT ZONE
LIVE
YUCCA RIDGE
SPLIT WASH
ANTLER RIDGE
WHALEBACK RIDGE
BROKEN LIMB RIDGE
1 0 1 Miles
1 0 1 Kilometers

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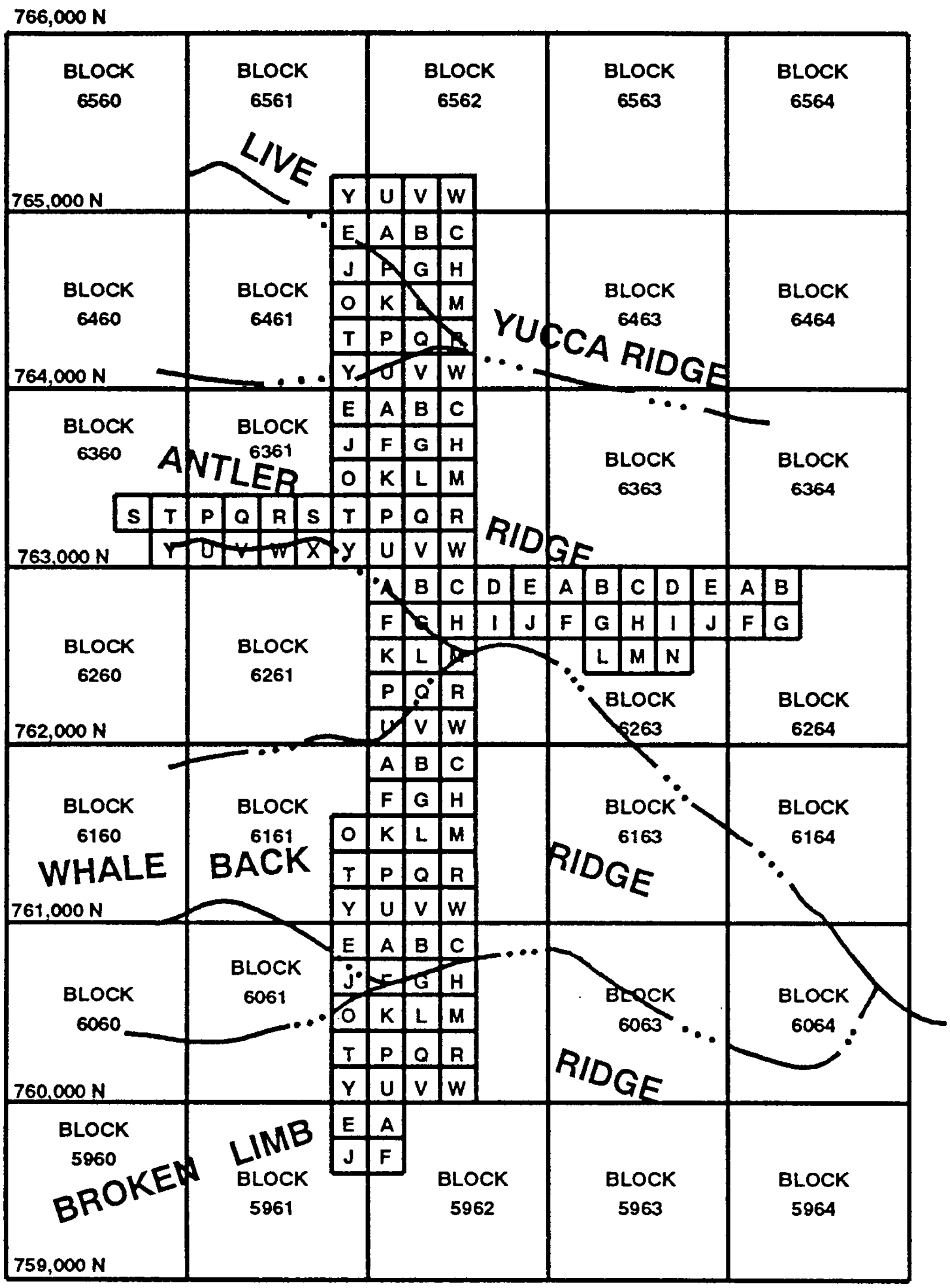

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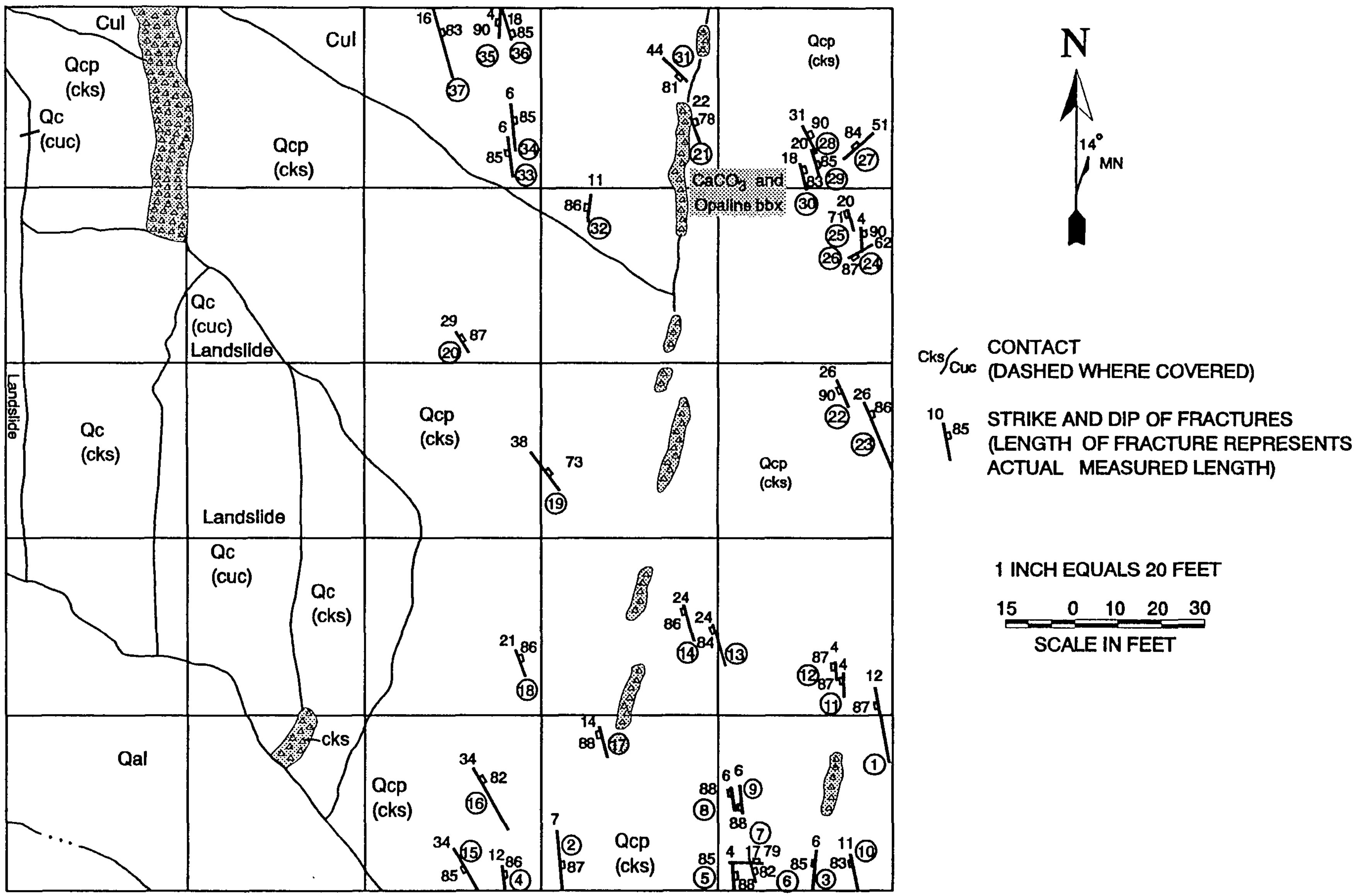
PHOTOGRAPH OF CHARACTER OF TYPE I BRECCIA COMMONLY MAPPED ALONG TRACE OF GHOST DANCE FAULT.

PHOTOGRAPH SHOWING WIDTH OF BRECCIA ALONG GHOST DANCE FAULT AT BASE OF ANTLER RIDGE.

Map Area: 6262B



PHOTOGRAPH OF ANTLER RIDGE PAVEMENT-1.

PHOTOGRAPH OF EASTERN PART OF ANTLER RIDGE PAVEMENT-1.

PHOTOGRAPH OF NORTHWEST-TRENDING STRUCTURE ALONG EASTERN PART OF ANTLER RIDGE PAVEMENT.

PHOTOGRAPH OF EAST FAULT ALONG EASTERN PART OF ANTLER RIDGE PAVEMENT.

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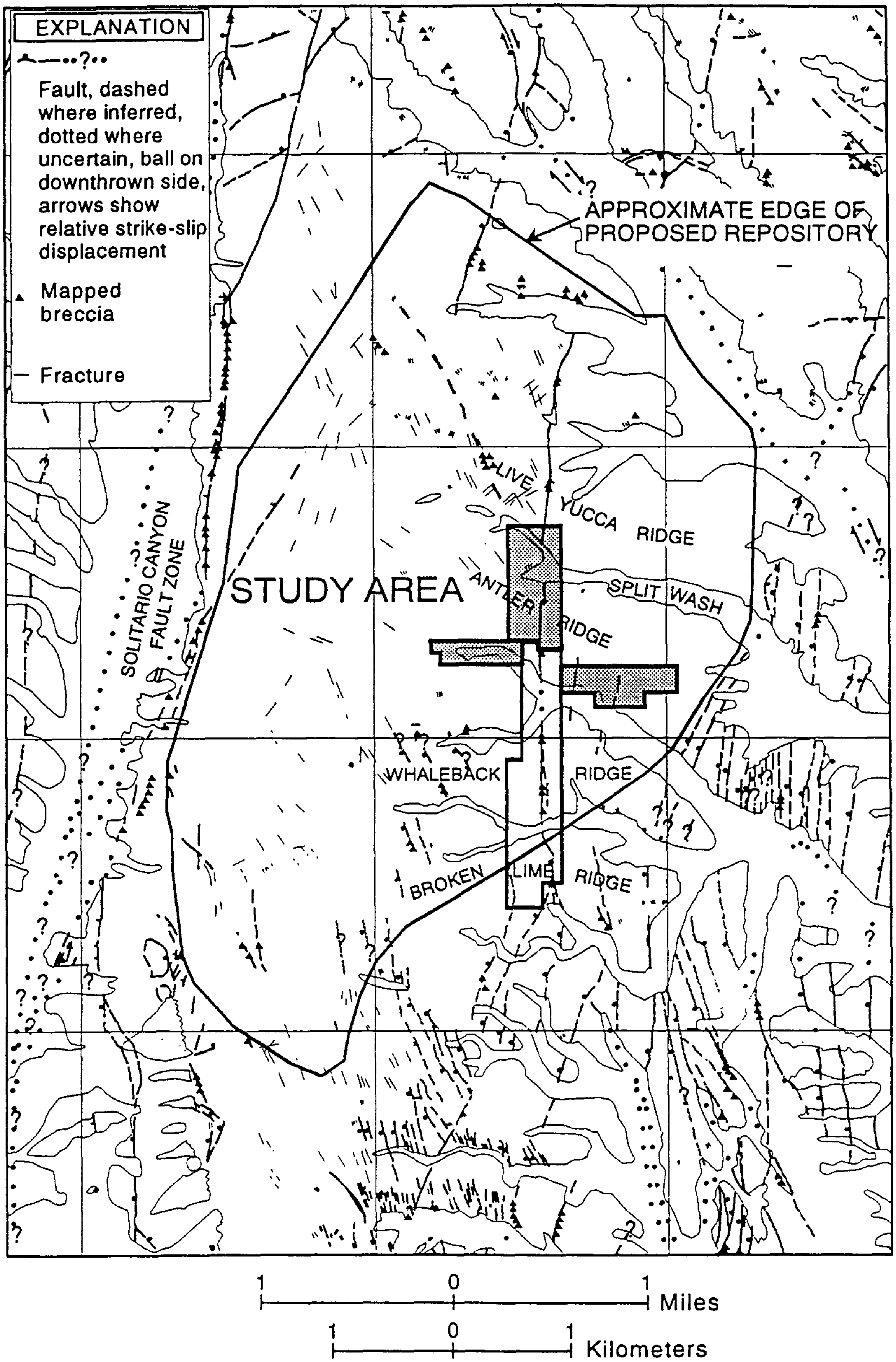
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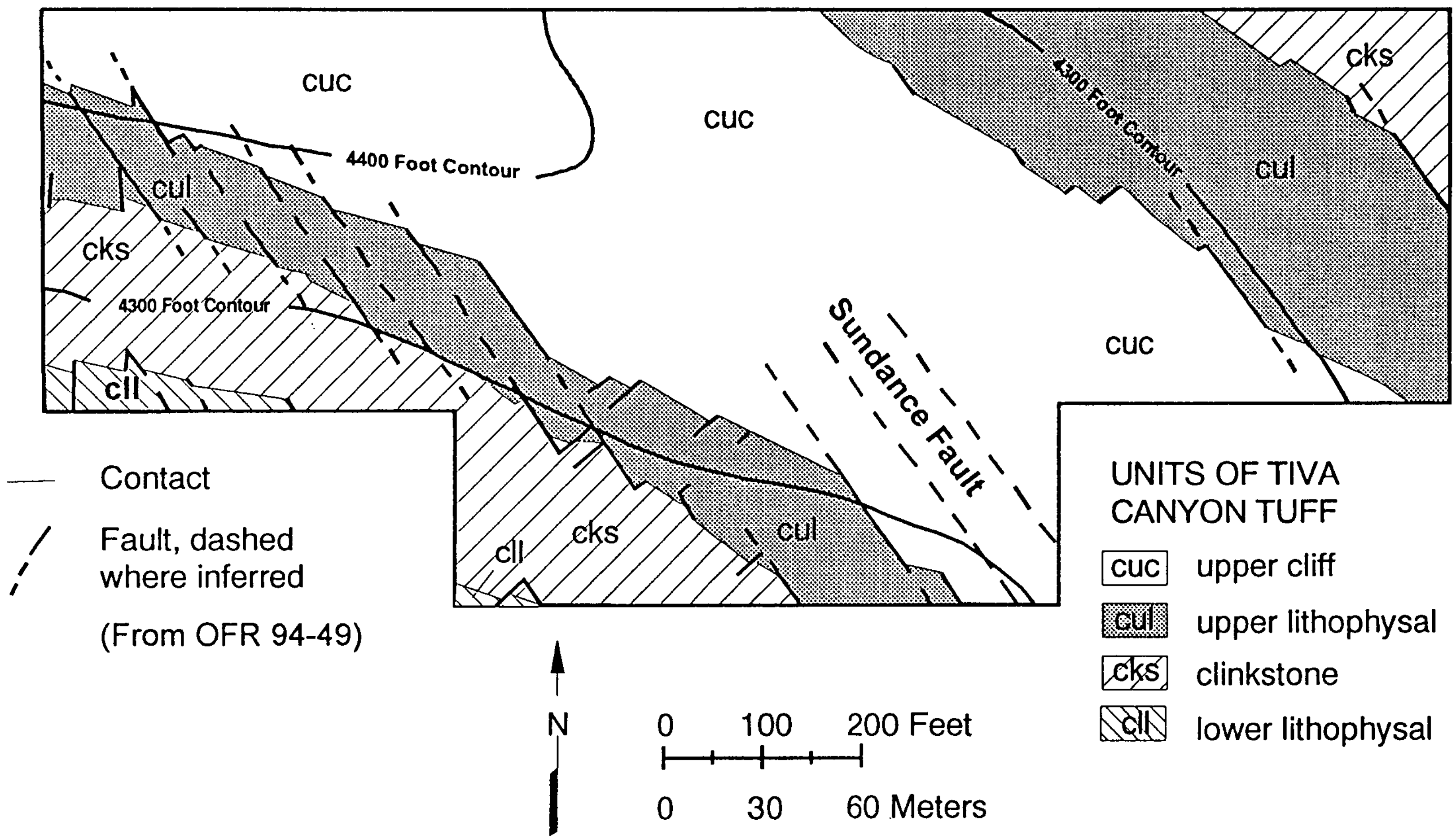

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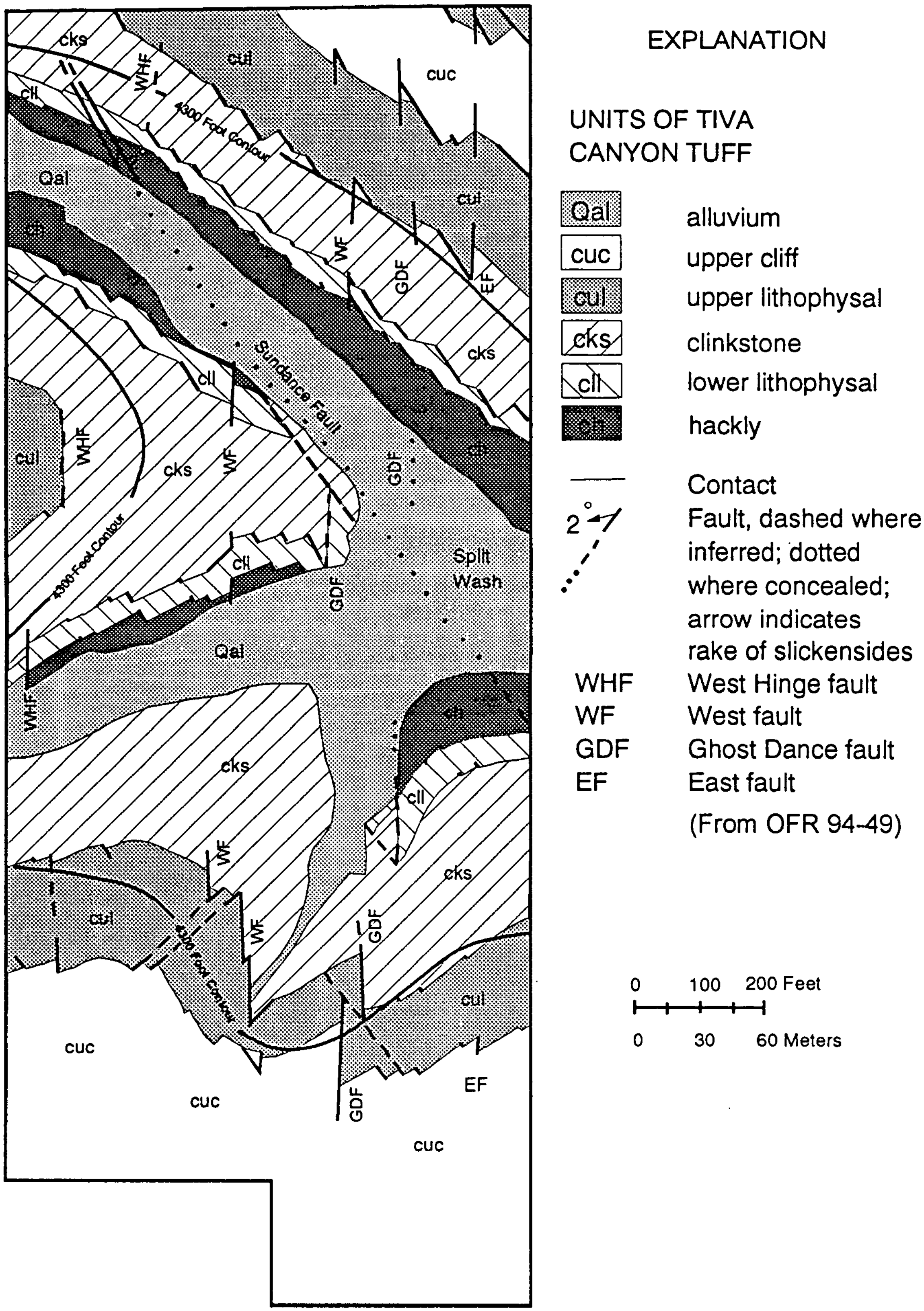

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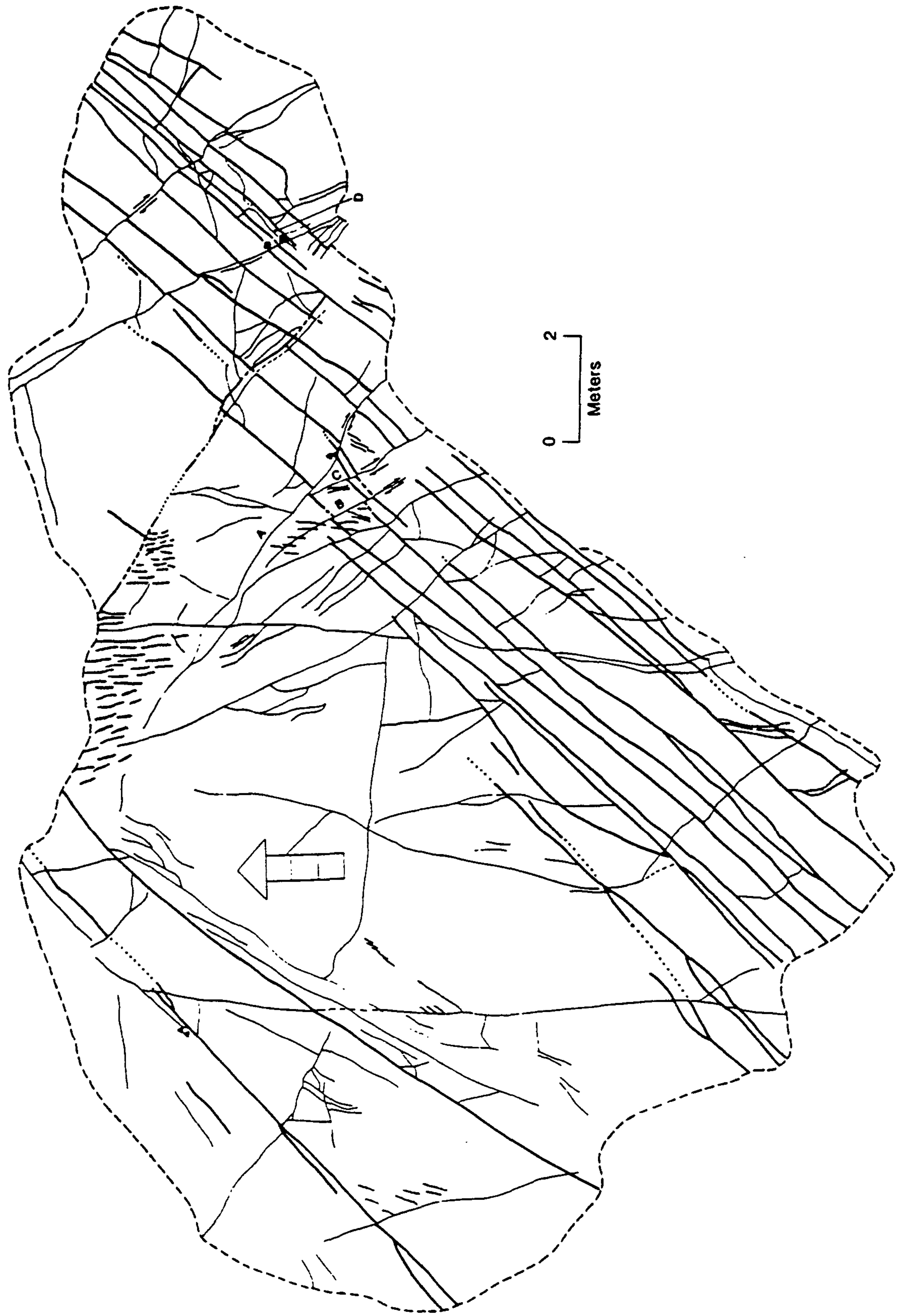

Fracture-trace map of pavement 100, Live Yucca Ridge, Yucca Mountain, Nevada (from C. C. Barton and P. A. Hsieh, "Physical and hydrologic-flow properties of fractures", in International Geological Congress field trip guidebook T385, 1989.

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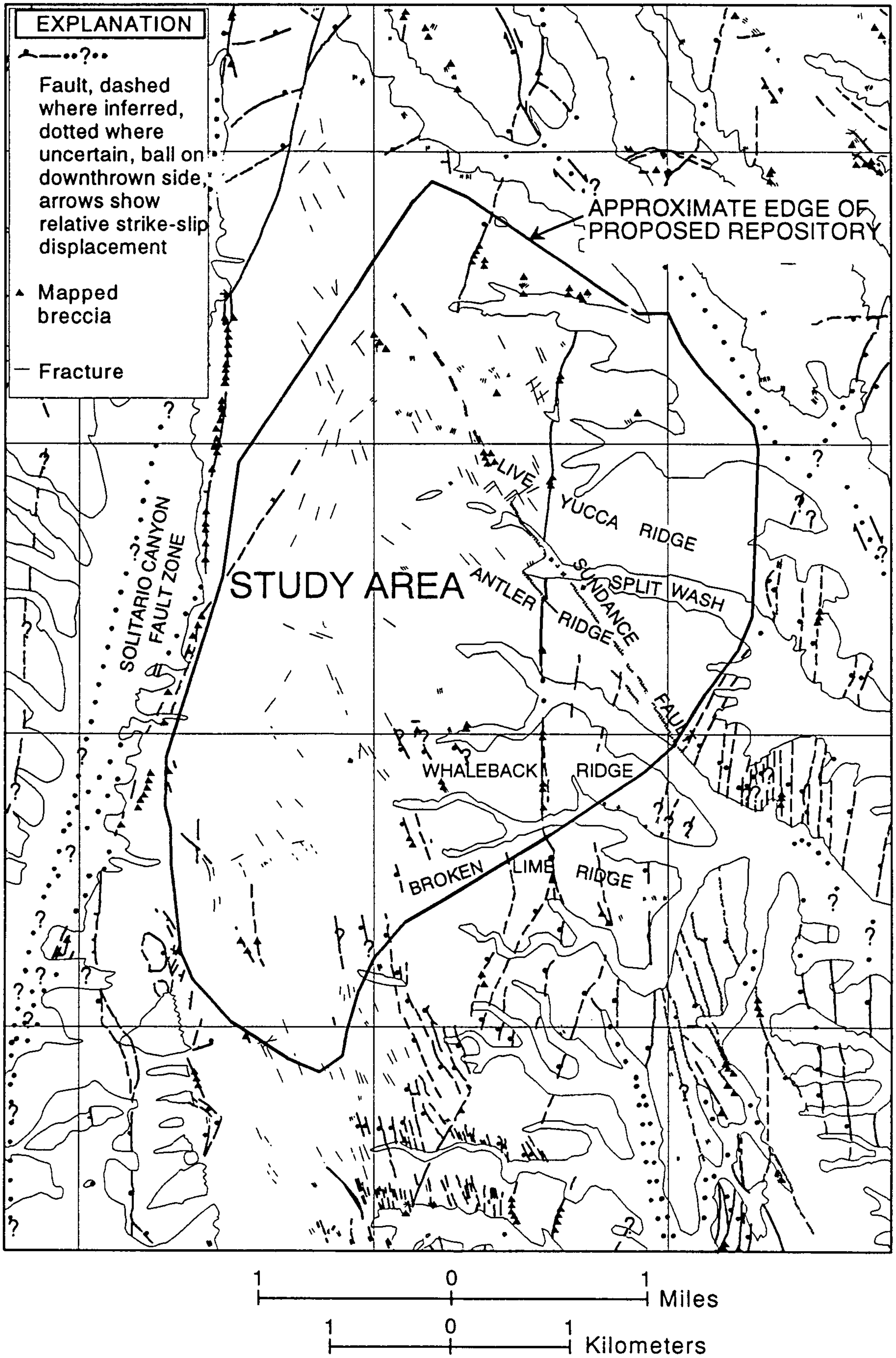

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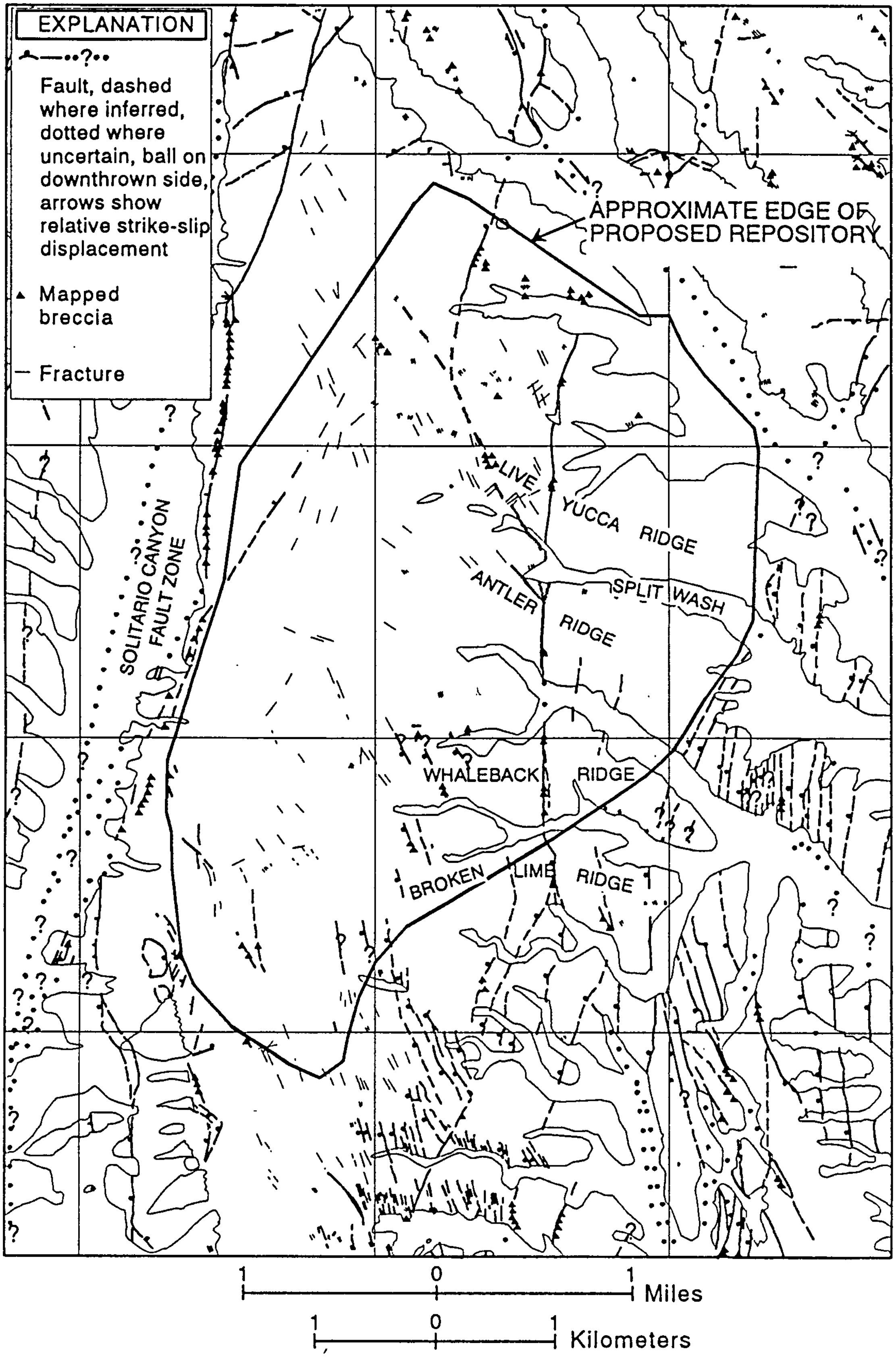

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THE SUNDANCE FAULT: A NEWLY RECOGNIZED SHEAR ZONE AT YUCCA MOUNTAIN, NEVADA

U.S. GEOLOGICAL SURVEY

Open-File Report 94-49

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THE SUNDANCE FAULT: A NEWLY RECOGNIZED SHEAR ZONE AT YUCCA MOUNTAIN, NEVADA

By R.W. Spengler[1], C.A. Braun[2], L.G. Martin[2], and C.W. Weisenberg[2]

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[2] Scientific Applications International Corporation, Golden, CO

Denver, Colorado
1994

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ABSTRACT

Ongoing detailed mapping at a scale of 1:240 of structural features within the potential repository area indicates the presence of several previously unrecognized structural features. Minor north-trending west-side-down faults occur east and west of the Ghost Dance fault and suggest a total width of the Ghost Dance fault system of nearly 366 m (1200 ft). A zone of near-vertical N30°-40°W-trending faults, at least 274 m (900 ft) wide, has been identified in the northern part of our study area and may traverse across the proposed repository area. On the basis of a preliminary analysis of available data, we propose to name this zone the "Sundance fault system" and the dominant structure, occurring near the middle of the zone, the "Sundance fault". Some field evidence suggests left-stepping deflections of north-trending faults along a pre-existing northwest-trending structural fabric. Other field observations suggest that the "Sundance fault system" offsets the Ghost Dance fault system in an apparent right lateral sense by at least 52 m (170 ft). Additional detailed field studies, however, are needed to better understand structural complexities at Yucca Mountain.

INTRODUCTION

Yucca Mountain consists of a series of north-trending, east-tilted, 1- to 4-km (0.6 to 2.5-mi)-wide structural blocks. These blocks are bounded by north-trending westward-dipping high-angle fault zones that displace volcanic strata of Tertiary age by 100 m (330 ft), and locally to as much as 400 m (1300 ft; Scott and Bonk, 1984). The potential area for long-term storage of high-level nuclear waste is situated within the central block of Yucca Mountain, which is bounded on the west by the Solitario Canyon fault zone and on the east and southeast by numerous closely spaced northwest- and northeast-trending faults (fig. 1). From north to south, we divide the central block into three distinctive structural domains on the basis of fault intensity and orientation, topography, and attitude of volcanic strata. Strata in the northern structural domain dip 5° to 10° southeastward and are cut by a series of linear northwest-trending washes, most of which are underlain by, or coincident with, zones of right-lateral strike-slip faulting (Scott and Bonk, 1984). The southernmost strike-slip fault is suspected to underlie Drill Hole Wash, directly north of the northeastern margin of the potential repository area (fig. 1; Scott and others, 1984). In large part, the potential repository area encompasses the central structural domain, where strata commonly dip eastward from 6° to 9° and are dominantly cut by east-trending washes. Here, the Ghost Dance fault is considered the dominant structural feature, as it is the only through-going fault that offsets the exposed 12.5-m.y.-old Tiva Canyon Member of the Paintbrush Tuff. It has recently been proposed to elevate the Tiva Canyon Member to Formation status (D. A. Sawyer and others, written communications, Feb. 10, 1993), and therefore, we will provisionally refer to it as the Tiva Canyon Tuff. The southern domain is characterized by an abundance of closely spaced northwest-trending and ancillary northeast-trending faults with vertical separations on the order of several meters. As mapped by Scott and Bonk (1984), some discontinuously exposed northwest-trending

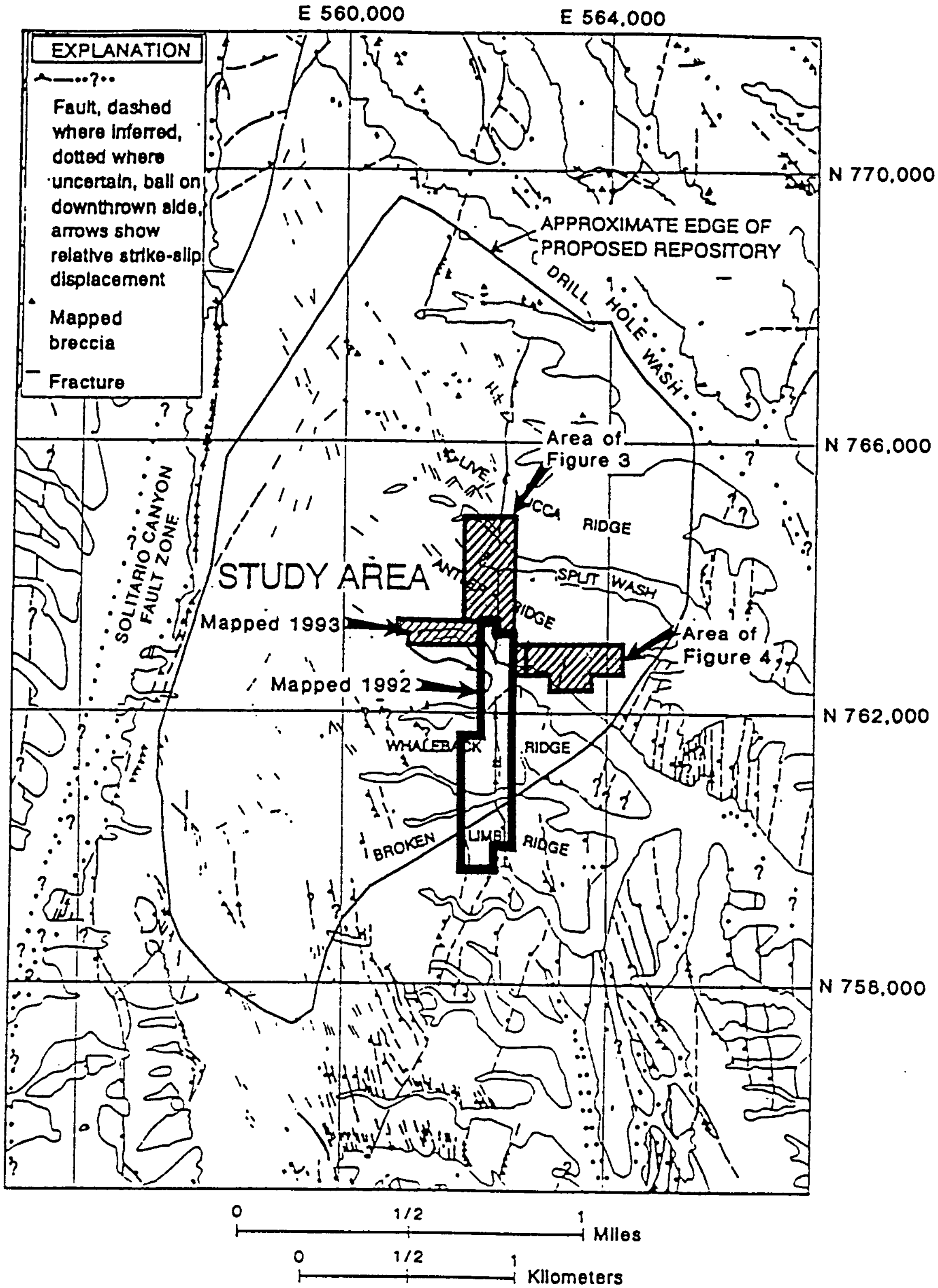

Figure 1.--Map of Yucca Mountain showing the distribution of structural features within and surrounding the proposed repository area and the location of study areas along the southern and central parts of the Ghost Dance fault (structural features from Scott and Bonk, 1984). Nevada State Coordinates are shown in feet.

faults extend northward well into the proposed repository but details of their character have not been studied (fig. 1). This paper summarizes salient structural features that have been identified from detailed field mapping of parts of the central structural domain.

ACKNOWLEDGMENTS

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PREVIOUS MAPPING

In 1992, we initiated a project to map fractures and other observable structural features such as zones of brecciation and separations of lithostratigraphic units on either side of the surface trace of the Ghost Dance fault (Spengler and others, 1993). We first established an internal grid system, composed of 61 m by 61 m (200 ft by 200 ft) areas within the framework of the Nevada State Coordinate System. Field mapping is at a scale of 1:240 and subsequently compiled at a scale of 1:600 (Spengler and others, 1993). The mapped area straddles the surface trace of the Ghost Dance fault, bounded on the north by Antler Ridge and on the south by Broken Limb Ridge (fig. 1). The length of the study area was 1158 m (3,800 ft). For the most part, the southern and northern halves of the study area were, respectively, 244 m (800 ft) and 183 m (600 ft) in width (fig. 1). Based on detailed mapping in 1992 and 1993 (fig. 1), we found that the Ghost Dance fault is the dominant fault in a previously unrecognized structural system, composed of minor north-trending faults and near-horizontal lithostratigraphic units that extend over a width of at least 213 m (700 ft). This structural system, referred to as the Ghost Dance fault system, was also found to exhibit a preferential north- to northwest-trending fracture orientation with isolated occurrences of north- to northwest-trending breccia (Spengler and others, 1993). The thickest and most intensely crushed breccia is found along the Ghost Dance fault. The character of this breccia and the significantly larger vertical separation of lithostratigraphic units are key features that are currently used to distinguish the Ghost Dance fault from other north-trending faults within the system.

STRATIGRAPHY

The uppermost 60 to 75 m (200 to 250 ft) of moderately to densely welded zones of the Tiva Canyon Tuff are moderately to poorly exposed along steep-sided east- to southeast-trending drainages. Some localities are almost completely covered with thick talus deposits. Lithostratigraphic units of the Tiva Canyon Tuff, as originally described by Scott and Bonk (1984), are based on the macroscopic variations in groundmass devitrification, degree of welding, shape of eroded slopes, texture of weathered surfaces, lithophysal cavity abundance, lithic fragment abundance, and phenocryst abundances. These zones, which include, from bottom to top, the hackly, lower lithophysal, clinkstone, upper lithophysal, and upper cliff, and locally, the upper vitrophyre, provide the detailed lithostratigraphic framework for the recognition of offsets of lithostrata on the order of a few meters at a scale of 1:12000 (Scott and Bonk, 1984).

During our detailed mapping in 1992, we increased the number of criteria for recognizing subtle contacts between units of the Tiva Canyon Tuff. These criteria include roughness coefficients of freshly broken surfaces (Barton and Choubey, 1977), working hardness (Hunt, 1984), size and shape of lithophysal cavities, orientation and abundance of foliated pumice clasts, and initial appearance of diagnostic lithic fragments and accessory minerals such as bronze-colored biotite. Our systematic development and use of multiple criteria for each contact between units, currently allow us to recognize apparent offsets of less than a meter (fig. 2).

RESULTS OF MAPPING IN 1993

In 1993, we extended our detailed mapping north, east, and west of the our previously mapped area to include an additional 70 areas. As in previous mapping each area measures 61 m by 61 m (200 ft by 200 ft). Our 1993 mapping extended approximately 550 m (1800 ft) northward along the Ghost Dance fault to include the northern flank of Antler ridge and southern flank of Live Yucca Ridge. Two east-west strip maps were also completed. The two strip maps, for the most part, are 120 m (400 ft) wide, extending to distances of 549 m (1800 ft) east and 366 m (1200 ft) west of the mapping completed in 1992 along the southern flank of Antler Ridge (fig. 1). The primary objective for mapping the strips was to establish the full width of the area where north-trending faults could be detected along the Ghost Dance fault system.

Our detailed mapping indicates that the width of the area, containing as many as six through-going but discontinuously exposed north-trending structures, is almost 366 m (1200 ft). This width appears relatively uniform from Broken Limb Ridge northward to at least the south side of Antler Ridge; a distance of about 1 km (0.6 mi). The Ghost Dance fault, which maintains a position near the middle of the system, remains the dominant structural feature. Almost all ancillary north-trending faults indicate down-to-the-west offset that commonly range between 3 m and 6 m (10 ft and 20 ft). From Broken Limb Ridge to Live Yucca Ridge, ancillary faults maintain a fairly uniform map spacing from the Ghost Dance fault of 114 to 198 m (375 to 650 ft) for the West Hinge fault, 30 to 76 m (100 to 250 ft) for the West fault, and 24 to 69 m (80 to 225 ft) for the East fault. Within the structural system dips of lithostratigraphic units are near-horizontal.

The width of the Ghost Dance fault system is consistent with the width of the area where north- to northeast- trending faults had been previously mapped on either side of the Ghost Dance fault by Scott and Bonk (1984). These ancillary faults were previously interpreted to have northern terminations near the crest of Broken Limb Ridge at the southeastern margin of the proposed repository area (fig. 1; Scott and Bonk, 1984). In contrast to mapping at a scale of 1:12000, our mapping indicates that these faults extend northward well into the proposed repository area.

Northward progression of our structural mapping has led to the recognition of numerous northwest and northeast trending structures north of Whale Back Ridge (fig. 1). Most of these structures indicate apparent offsets of lithostratigraphic units of the Tiva Canyon Tuff by only a few meters. Geometrical relationships of many diffusely spaced northeast- and northwest-trending faults are incompletely understood.

A conspicuous variation in structural style appears to occur north of Antler Ridge and along the southeastern flank of Antler Ridge, which suggests the existence of a previously unrecognized shear zone. The existence and character of this shear zone are based on the appearance of the following structural complexities: 1) abrupt increase in northeastward dip of foliation in lithostratigraphic units, 2) closely spaced northwest-trending shears with apparent right lateral separation, 3) intensely brecciated rock in close proximity to northwest-trending fractures, 4) abrupt decrease in vertical separation along the Ghost Dance fault, and 5) apparent right lateral offset of the Ghost Dance fault system. These field observations have been documented at three critical but isolated exposures along the northern flank of Antler Ridge, along southern flank of Live Yucca Ridge, and along the southeastern flank of Antler Ridge (fig. 1, 3, 4).

Meters	Feet	Zones of Tiva Canyon Tuff	Diagnostic Minerals (Decreasing Order)	Roughness Coefficient for Fresh Surface	ISRM Hardness Classification	Texture and Fractures Features
0	0	vitrophyre (cv)	Sanidine Sphene Biotite	10 to 12	IV	Spherulites as large as 4mm in diameter and perlitic fragments up to 2cm occur in the dark portion. The groundmass varies from glassy to microcrystalline.
25	50 100	upper cliff (cuc)	2-10% Sanidine • Biotite • Hornblende • Sphene	7 to 18	III I	Fresh fracture surfaces vary from subconchoidal in the lower lithic zone, to a rough-blocky break in the more crystal rich upper zone.
	150	upper lithophysal (cul)	1-3% Sanidine • Hornblende • Sphene	6 to 10	II	Fresh fracture surfaces have a saccharoidal (frosted) texture and are commonly subconchoidal.
50 75	200 250	clinkstone (cks)	1-3% Sanidine • Sphene • Hornblende	2 to 8	II to III	Prismatic breakage produces a weathered stairstep pattern at the lower contact and through the middle subzone containing minor (<1%) lithophysae. Freshly broken surfaces have microcrystalline texture and produce a distinctive conchoidal fracture.
		lower lithophysal (cll)	2-3% Sanidine • Sphene • Hornblende • Biotite	8 to 12	I	Prismatic breakage produces a weathered stairstep pattern in outcrop. Lenticular and spherical lithophysae form lineations along foliation planes. Slight lineations of sanidine phenocrysts and eutaxitic textures of collapsed pumice fragments also conform to these foliation planes. Fresh fractures cut directly through lithophysae and spherulitic features. Unit has diagnostic saccharoidal (frosted) texture, and subconchoidal fractures.
100	300 350	hackly (ch)	1-3% Sanidine • Hornblende • Sphene • Biotite	12 to 18	III	Hackly-blocky texture. Fresh fractures break around perimeters of well-developed spherulitic features. Weathering produces a thin scree cover. Phenocrysts in matrix appears randomly oriented. Spheroidal features range from 5mm to 100mm in diameter.
		columnar (cc)	Not Exposed in Map Area			

Note: All diagnostic features are megascope field criteria for 10X or less magnification.
Visible diagnostic features are defined as being greater than 200 microns along the short dimension.
All features are collected from fresh broken surfaces.
Classifications of roughness coefficient and hardness are from Barton and Choubey (1977) and Hunt (1984), respectively.

* Less than 1% of whole rock volume (visible at 10X magnification);
Underline denotes relative importance of mineral for defining the unit in comparison with adjacent zones.

Figure 2.--Stratigraphic column showing diagnostic field characteristics of the units of the Tiva Canyon Tuff (provisional) at Antler Ridge.

Northern Flank of Antler Ridge

Mapping of a 244-m (800-ft)-wide area from the southern flank to the northern flank of Antler Ridge reveals a gradual increase in structural complexity (fig. 3). Small-scale northwest- and northeast-trending faults increase in abundance. For the most part, the north-trending faults are traceable northward, maintaining a similar horizontal spacing and vertical separation as mapped to the south. From the south side of Antler Ridge to the north side of Antler Ridge, a distance of about 168 m (550 ft), vertical separation of lithostratigraphic units along the Ghost Dance fault is relatively uniform, varying from 15 to 12 m (50 to 40 ft). However, the high-angle Ghost Dance fault is offset in an apparent right lateral sense by about 15 m (50 ft) along an inferred northwest-trending shears (fig. 3).

Southern Flank of Live Yucca Ridge

North of Split Wash a conspicuous and abrupt change in structural style occurs. Along the south-facing slope of Live Yucca Ridge (fig. 1, 3), we have mapped numerous parallel N30°-40°W-striking structures, many of which are spaced 5 to 10 m (16 and 33 ft) apart and commonly show less than a few meters of right (or) east-side-down separation of lithostratigraphic contacts. Simple geometric considerations suggest that right slip on northwest-trending faults in an area of gentle eastward dips should result in left separation of contacts along south-facing slopes, which are steeper than the dips. The right separation seen along Live Yucca Ridge (and at some places to the south) may be due to local variations in attitudes of lithostratigraphic units and (or) by a vertical component of slip. Within the Ghost Dance fault system, where lithostratigraphic units are nearly horizontal, near-horizontal fault slip can produce variable outcrop patterns depending on local variations in slip line, attitudes of lithostratigraphic units and topography. Alternatively, some offsets, mapped in poorly exposed areas, may be related to slope movements or zonal variations within the Tiva Canyon Tuff.

The West Hinge, Ghost Dance, and East faults maintain a similar relative horizontal spacing on Live Yucca Ridge as seen to the south. The spacing between the West fault and Ghost Dance fault decreases slightly north of Split Wash. Some of the north-trending structures along Live Yucca Ridge appear to break into left-stepping segments connected by short northwest-trending breccia zones. These deflections from a northerly strike may be due to preexisting northwest-trending structures. However, the locations of identifiable north-trending faults within the Ghost Dance fault system along Live Yucca Ridge suggest an apparent right lateral offset of about 52 m (170 ft) relative to northern Antler Ridge (fig. 3).

The Ghost Dance fault shows a significant decrease in the amount of vertical separation of lithostratigraphic units from 12 m (40 ft) at north Antler Ridge to about 1.5 m (5 ft) near the middle of the south slope of Live Yucca Ridge, which corresponds to a map distance of about 305 m (1000 ft). North of Split Wash, the fault directly east of the Ghost Dance fault that is provisionally referred to as the East fault(?) shows the largest vertical separation of about 3 m (10 ft). If the Ghost Dance fault has been misidentified and is this easternmost fault within our mapped area, a larger amount of right separation can be inferred.

A set of the high-angle N30°W fractures, dipping 85° to 90° to the southwest, is well exposed at drainage level along Split Wash and extends northwestward for several tens of meters along the south slope of Live Yucca Ridge (fig. 3). A breccia zone, 1 m (3 ft) wide, as well as slickensides with a rake of about 2° to the northwest were also found at this exposure. Some fracture surfaces display subtle mullion structures, suggesting a smoother fracture surface in a near-horizontal direction. Internal layering within the clinkstone zone is well developed at this

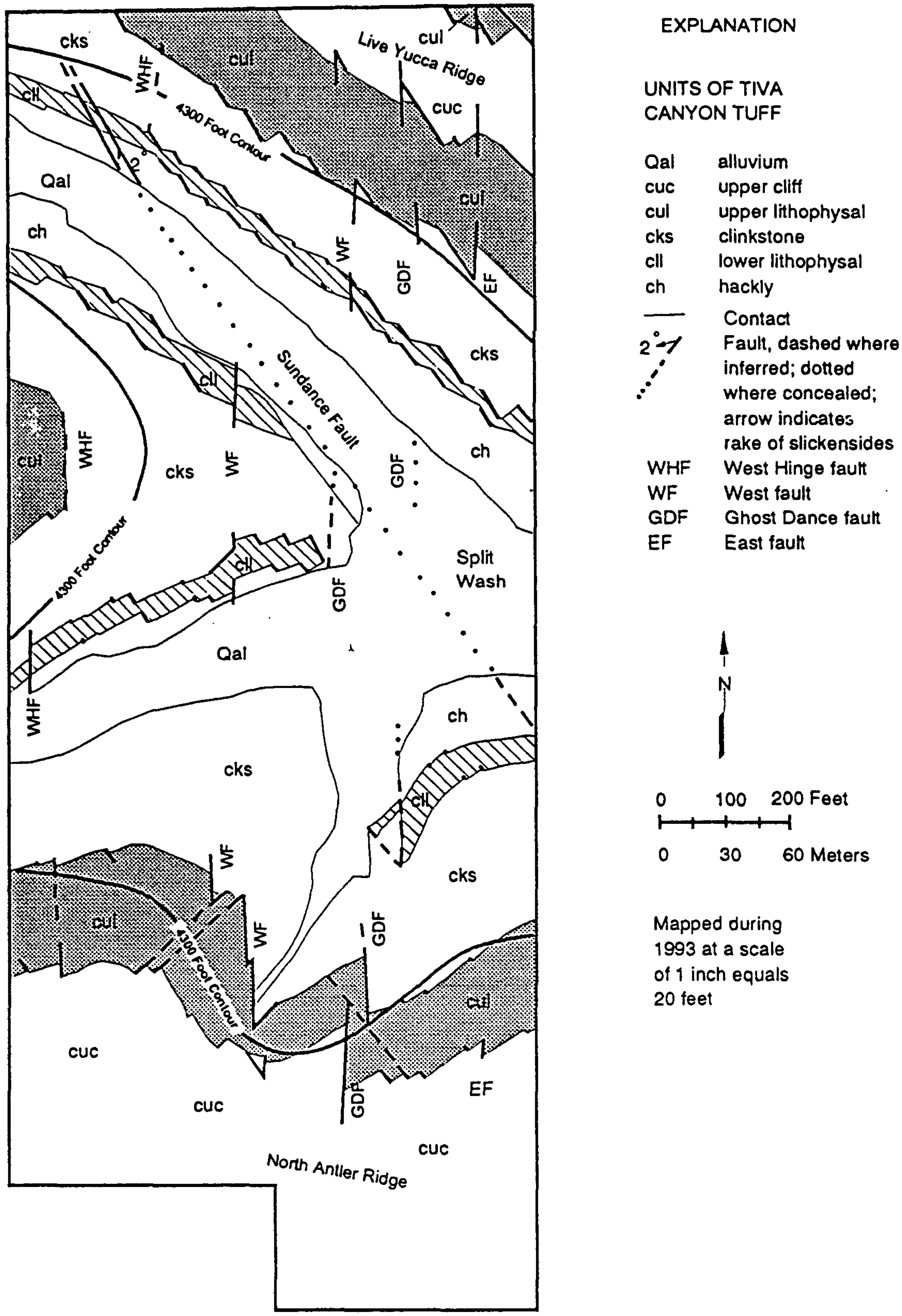

Figure 3.--Generalized geologic map of the Split Wash area showing offset of lithostratigraphic units along the Ghost Dance fault and Sundance fault systems.

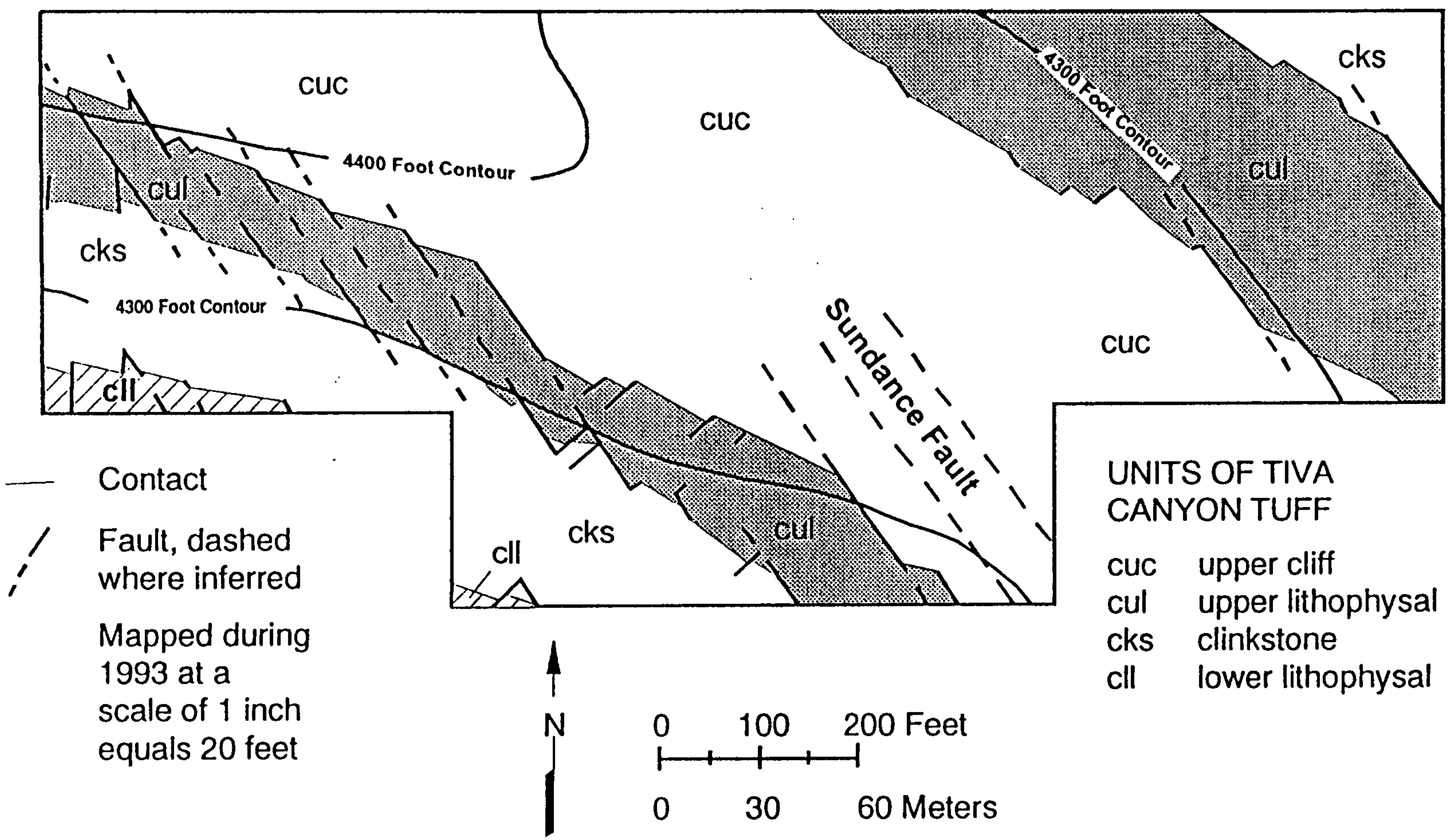

Figure 4.--Generalized geologic map of the eastern part of Antler Ridge showing offset of lithostratigraphic units along the Sundance fault.

locality, appears horizontal on the west side of the fault, dips gently eastward on the east side of the fault, but shows no recognizable vertical separation. As discussed, the inability to detect any vertical separation may be a combination of nearly vertical faults, nearly horizontal lithostratigraphic units, and horizontal slip. The fracture set can be traced northwestward across Live Yucca Ridge as a lineament on aerial photographs, where it appears to project into area of intense brecciation and into a northwest-trending lineament, depicted on Scott and Bonk (1984; fig. 1). Inferred from available preliminary data, we believe that this structure is the most conspicuous through-going feature near the middle of the shear zone and refer to it as the "Sundance fault".

Southeastern flank of Antler Ridge

The uppermost part of the upper cliff unit of the Tiva Canyon Tuff commonly forms a ridge-capping cliff several meters thick over much of Yucca Mountain. This cliff is conspicuously absent along the ridge crest of Antler Ridge directly northwest of drill hole USW UZ-16. Close examination of exposures of the upper cliff unit indicate that it is about 14 m (45 ft) thick to the west and about 23 m (75 ft) thick to the east of this geomorphic feature. Measurement of foliation attitudes in the upper cliff unit along the crest of Antler Ridge indicates an attitude of about N20° W 3°NE directly below this geomorphic feature, which increases to about N40°W 15°NE east of the feature. Mapping along the south-facing slope of Antler Ridge directly below the geomorphic anomaly indicates the presence of multiple apparent right separations of the contact between the upper cliff and the upper lithophysal units (fig. 4). Although this locality is poorly exposed and no discrete fault planes are observable, more than ten apparent right separations of contacts, commonly spaced 15 to 20 m (49 to 66 ft) apart, have been documented within a zone that is at least 274-m (900-ft) wide and trends in a N30°-40°W direction. These apparent right lateral separations in an area of anomalous northeasterly dips of foliation are consistent with right lateral slip and suggest an apparent cumulative right separation of as much as 107 m (350 ft; fig. 4). Alternatively, map patterns may suggest anomalous down-to-the-east displacements. On the basis of reconnaissance mapping, this structurally disrupted zone has been traced southeastward to the base of exposures at Antler Ridge. In the area directly south of drill hole USW UZ-16 numerous northwest-trending structures and (or) conspicuous lineaments have been mapped by Scott and Bonk (1984; fig.5).

INTERPRETATIONS

The Ghost Dance fault is the dominant fault in a structural system composed of minor north-trending west-side-down steeply dipping faults that extends over a width of nearly 366 m (1200 ft). Northward extension of our mapping at a scale of 1:240 reveals localities where closely spaced northwest-trending fractures, northwest-trending separations of lithostratigraphic units, near-horizontal slickensides, subtle mullion structures, and northwest-trending breccia appear to dominate the structural style. Preliminary analysis of the eastward extension of our mapping suggests the presence of a northwest-trending zone that shows either anomalous right lateral or anomalous east-side-down displacements, an abrupt increase in dip of foliation, and abrupt variation in the erosional thickness of the upper cliff zone. These relationships occur within a northwest-trending structural zone that is at least 274 m (900 ft) wide and is herein referred to as the "Sundance fault system". We propose to name the most conspicuous through-going structure, located near the middle of the system, the "Sundance fault" (fig 5). The "Sundance fault system" documents the presence of northwest-trending strike-slip structural features within the central structural domain of the central block. On the basis of structural lineaments and concentrations of

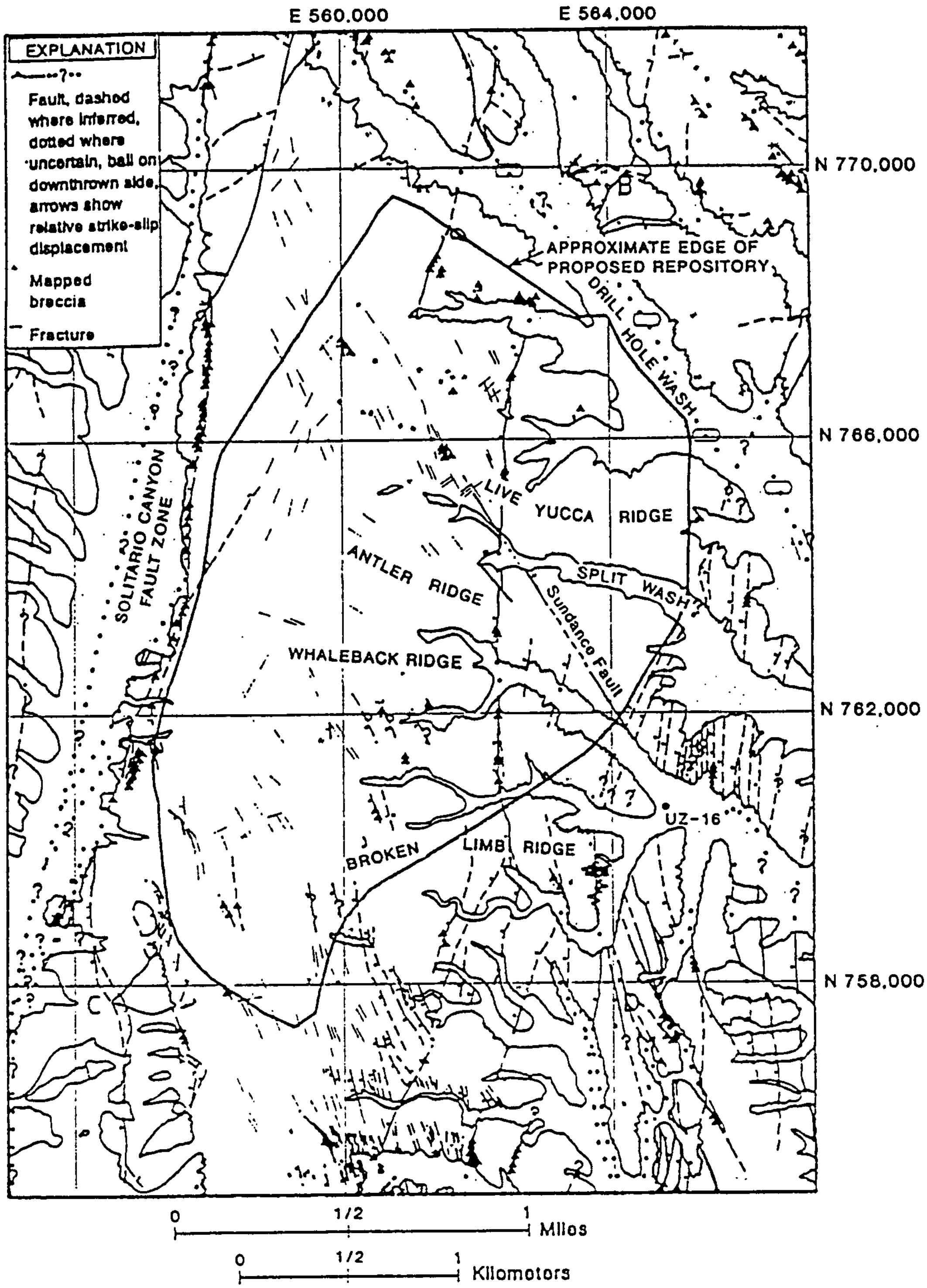

Figure 5.--Map of Yucca Mountain showing the location of the Sundance Fault relative to structural features mapped by Scott and Bonk (1984), and location of USW UZ-16 drill hole.

brecciated rock (initially identified by Scott and Bonk(1984); fig. 5), our detailed mapping, and reconnaissance observations made outside of our mapped area, this zone appears to extend northwestward across the potential repository area. To the southeast, the Sundance fault system appears to project into a conspicuous set of northwest-trending faults that occurs directly southeast of the southeastern margin of the potential repository area (fig. 5). If these previously mapped structural features are the northwestern and southeastern extensions of this same northwest-trending system, it may extend over a distance of at least 3 km (1.9 mi, fig. 5).

Geometric relations between attitudes of lithostratigraphic units, fault slips, and topography have resulted in map patterns that are incompletely understood. Relative age relations between the "Sundance fault system" and the Ghost Dance fault system also remain unresolved. Some field relations suggest that the strike of the north-trending fault system was locally influenced by a pre-existing northwest structural fabric. Other field observations suggest that steeply dipping faults of the Ghost Dance fault system may be displaced in an apparent right lateral sense by at least 52 m (170 ft).

Additional detailed mapping, particularly along east-west trending profiles, in concert with reconnaissance mapping along inferred northwest and southeast extensions will significantly help clarify map patterns, relative age relationships of fault systems, and terminations of the "Sundance fault system".

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