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Structure of the Tshirege Member of the Bandelier Tuff at Mesita del Buey, Technical Area 54, Los Alamos National Laboratory

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STRUCTURE OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF AT MESITA DEL BUEY, TECHNICAL AREA 54, LOS ALAMOS NATIONAL LABORATORY

by

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ABSTRACT

The geological structure of the Tshirege Member of the Bandelier Tuff at Mesita del Buey, Technical Area 54, was examined using precise surveying of the contact between tuff units 1v and 2 for 3.5 km along the north wall of Pajarito Canyon and 0.6 km along the north wall of a tributary to Cañada del Buey. Estimated structure contours on this contact indicate typical strikes of N40E to N70E along this part of Mesita del Buey, although the apparent strike of the tuff is E-W at the western part of the survey. Typical dips are 1.0° to 2.0° to the east or southeast, with an estimated maximum dip of 3.2° near the west end of Material Disposal Area G. Thirty seven faults with vertical displacements of 5 to 65 cm were observed in outcrops along the Pajarito Canyon traverse, and, due to the incomplete exposure of the contact between unit 1v and unit 2, many more faults of this magnitude undoubtedly exist. The faults have a wide range in strike and have either down-to-the-west or down-to-the-east components of offset, although about 65% of the observed displacement is down-to-the-west or northwest. The general absence of larger-scale offsets or inflections along the contact between units 1v and 2 in areas where the small-scale faults were observed suggests that they are not associated with major fault zones. Instead, these faults may record distributed secondary deformation across the Pajarito Plateau associated with large earthquakes on the main Pajarito fault zone 8 to 11 km to the west, or perhaps earthquakes on other faults in the region. The survey data also suggest that a 150 to 250 m wide zone of greater magnitude faulting is present near the west end of the traverse associated with a horst-and-graben structure displaying about 1.5 to 3.5 m of offset on individual faults, although the total amount of offset across this structure and its orientation are not known.

INTRODUCTION

Technical Area (TA) 54 on Mesita del Buey (Fig. 1) has been a primary waste disposal site for the Los Alamos National Laboratory (LANL) since 1956, and is currently used for both storage and disposal of radioactive, hazardous, and mixed waste. Material Disposal Area (MDA) G, located on the eastern part of the mesa, is an active landfill that contains low level radioactive waste in a series of pits and shafts excavated into the Tshirege Member of the Bandelier Tuff. MDA L, to the west, contains various nonradioactive hazardous wastes in pits and shafts. Farther west, MDA H contains classified waste in a series of shafts, and MDA J contains nonhazardous and classified waste in pits and shafts (LANL, 1992).

This study focused on determining the elevation of a key stratigraphic contact in the Tshirege Member at TA-54, including variations in the strike and dip and possible structural deformation of this contact along the length of Mesita del Buey. Discontinuous volcanic surge beds mark the contact between units 1v and 2 as defined by Broxton and Reneau (1995) and Broxton et al. (1995) (equivalent to the contact between units 2a and 2b of Purtymun and Kennedy, 1971, and units

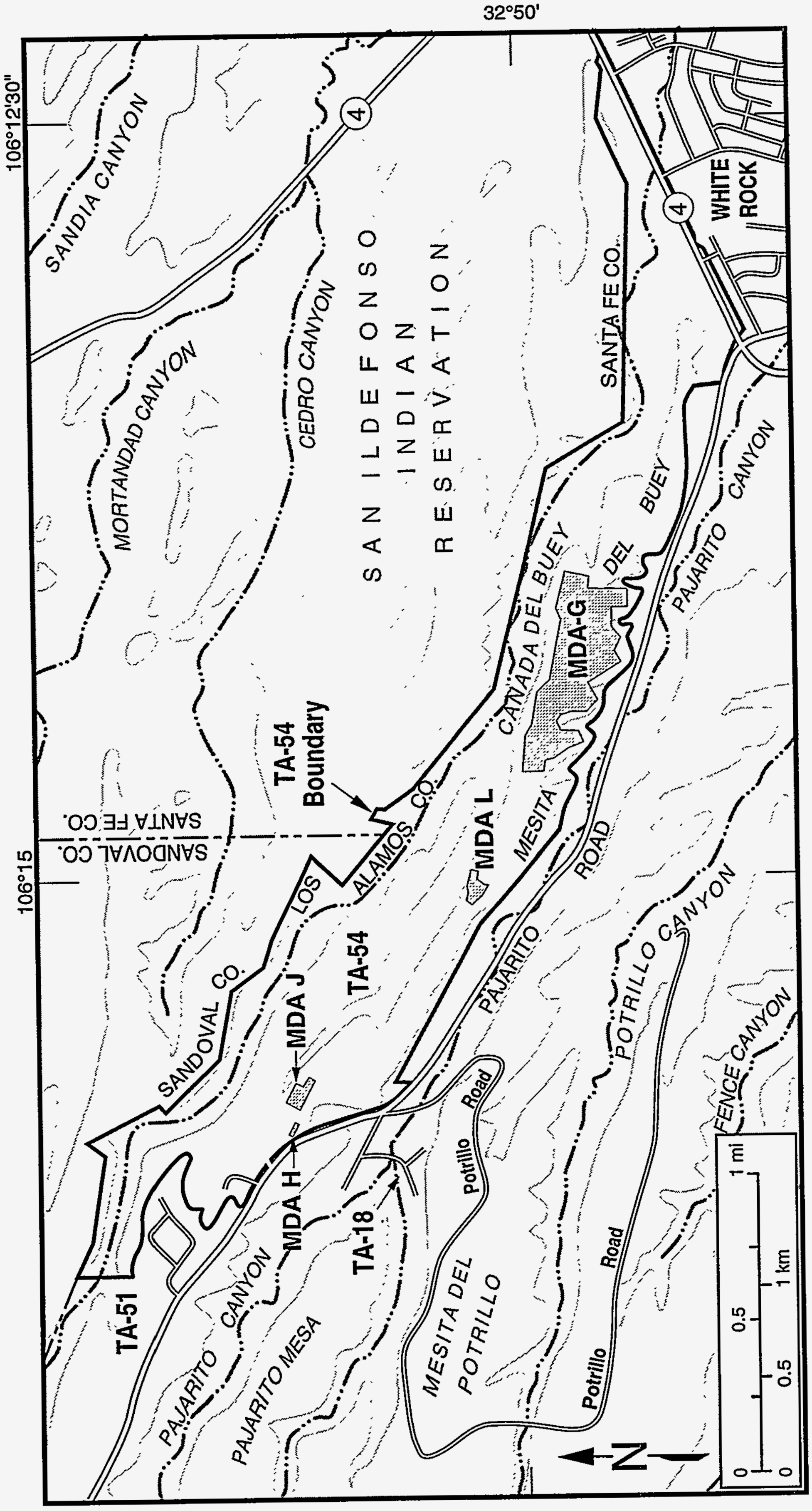

Fig. 1. Location map of Mesita del Buey at TA-54 and vicinity.

B and C of Rogers, 1995). Previous work by Purtymun (1973) documented preferential vapor-phase migration of tritium away from storage shafts at MDA G along this contact. Vapor phase transport is also occurring away from shafts at MDA L, including a variety of volatile organic compounds (VOCs), and away from MDA H, including tritium (LANL, 1992), and stratigraphic influences on subsurface migration may also exist at these MDAs. Recent work at TA-54 suggests that a change in hydraulic properties at the contact between units 1v and 2 produces an important barrier to vertical transport in the vadose zone, leading to lateral moisture flux towards the canyon walls and aiding in drying out the tuff (Rogers and Gallaher, 1995; Neeper and Gilkeson, 1996). The topic of potential surface rupture hazards at LANL during large earthquakes has also been receiving increasing attention recently (e.g., Gardner et al., 1998). Data acquired in this study contributes to an understanding of tectonic deformation at Mesita del Buey over the last 1.2 million years, including the presence or absence of major faults and documentation of widespread small-scale faulting.

METHODS

Structural data were obtained from the Tshirege Member at Mesita del Buey in 1993 by surveying the locations of surge beds and an ash bed that occur in the lower part of unit 2 and the upper part of unit 1v. Surveying was performed using a total station (computerized theodolite), tied to control points whose approximate New Mexico State Plane coordinates and elevations were determined from 1:1200 scale 1991 orthophoto sheets and associated topographic maps with 2-ft contour intervals; base maps were obtained from the Facility for Information Management, Analysis, and Display (FIMAD). This method has also been applied to the mapping of geologic contacts in the Pajarito Mesa area by Reneau et al. (1995) and in the TA-55 area by Gardner et al. (1998), the latter tying into established LANL benchmarks.

All survey points were plotted on FIMAD maps, which provided internal checks on the accuracy of the survey. No systematic errors were noted despite continuous surveying for a distance of over 3 km, and survey points at the far end of the traverse agreed with the topographic base map. We estimate that the survey data have an absolute accuracy of ±10 ft for northing and easting coordinates, relative to true New Mexico State Plane coordinates, and ±2 ft for elevation, with the accuracy being limited by the lack of exact coordinates and elevations for initial control points. Typical precision of instrument setups, as determined in the field during triangulation to temporary benchmarks, is better than 0.05 ft horizontally and 0.02 ft vertically. We estimate the overall precision of our survey, or the internal consistency between measurement points, to be better than 5 ft for coordinate location and better than 1 ft for elevation, similar to that attained by Gardner et al. (1998).

A continuous traverse of the north wall of Pajarito Canyon (Fig. 2) was performed for a distance of 3.5 km, extending from about 0.3 km southeast of MDA G westward to the vicinity of MDA J, and including approximately 390 surveyed points. Additional data on surge beds were obtained for a distance of 0.6 km along the north wall of a tributary to Cañada del Buey near MDA L (54 points), and for a distance of 0.1 km along the south wall of Pajarito Canyon on Potrillo Road (6 points). The surveyed points, plotted according to their easting coordinate (1983 North American Datum, or NAD 83), are shown in Figures 3 to 6 for different parts of the survey. These data were used to construct structure contours on the contact between units 1v and 2, assuming that the lowest surge beds in an area represent the same stratigraphic interval and approximate the base of unit 2. This assumption was verified in many areas by supporting field evidence, including the observation that the base of unit 2 is commonly a sharp welding break. Additional discussion of the nature of this stratigraphic contact at Mesita del Buey is presented in Broxton and Reneau (1995) and Broxton et al. (1995).

The structure contours indicate the approximate strike and dip of the tuff and allow estimates to be made of the elevations of this stratigraphic contact

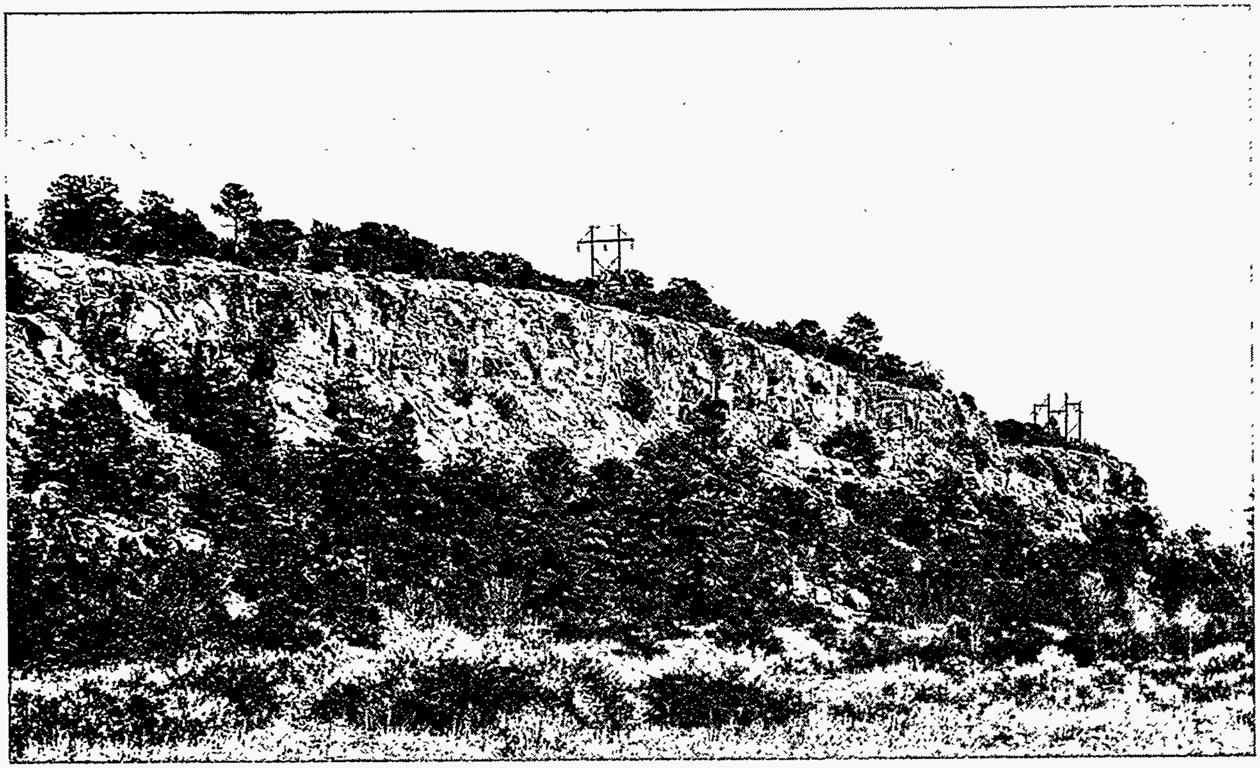

Fig. 2. Photograph of south wall of Mesita del Buey along Pajarito Canyon, east of MDA L. The cliffs forming the upper canyon wall are composed of Tshirege Member unit 2, and the lighter, lower slopes are composed of unit 1v. Volcanic surge beds are common at the contact between units 1v and 2 in this area.

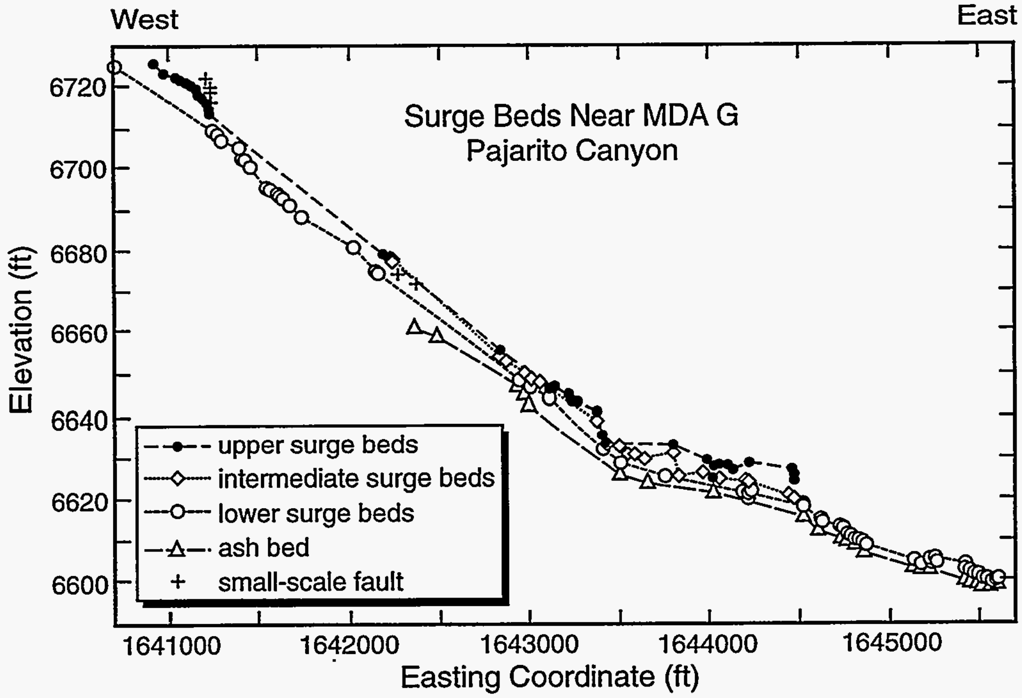

Fig. 3. Elevation of surveyed points on surge beds along the north wall of Pajarito Canyon near MDA G. The lower surge bed approximates the base of unit 2. Note that some points that are located in embayments in the mesa north of the main transect line are not shown on this figure but were used to constrain structure contours. Crosses indicate small-scale faults observed in outcrops and are plotted 5 ft above the surveyed point. All data points are projected to an east-west line. Coordinates are in NAD 83.

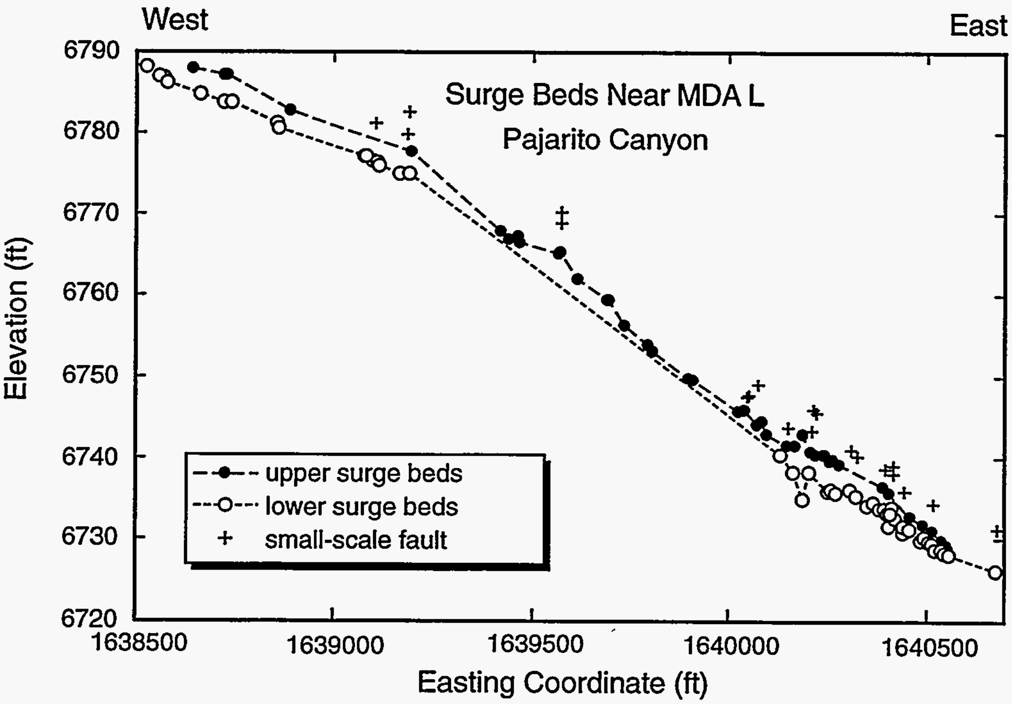

Fig. 4. Elevation of surveyed points on surge beds along the north wall of Pajarito Canyon near MDA L. The lower surge bed approximates the base of unit 2. Crosses indicate small scale faults observed in outcrop and are plotted 5 ft above the surveyed point. All data points are projected to an east-west line. Coordinates are in NAD 83.

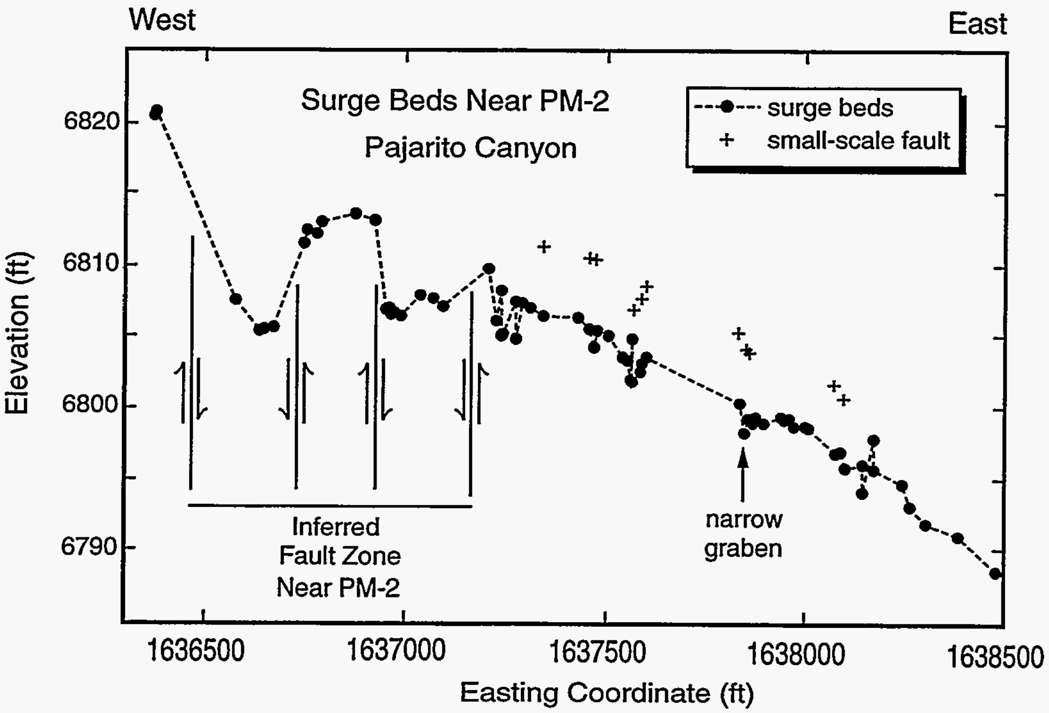

Fig. 5. Elevation of surveyed points on surge beds along the north wall of Pajarito Canyon near well PM-2. Crosses indicate small-scale faults observed in outcrop and are plotted 5 ft above the surveyed point. The zone of larger-scale faults with horst-and-graben structure is inferred based on anomalously low elevations of surge beds in two areas. All data points are projected to an east-west line. Coordinates are in NAD 83.

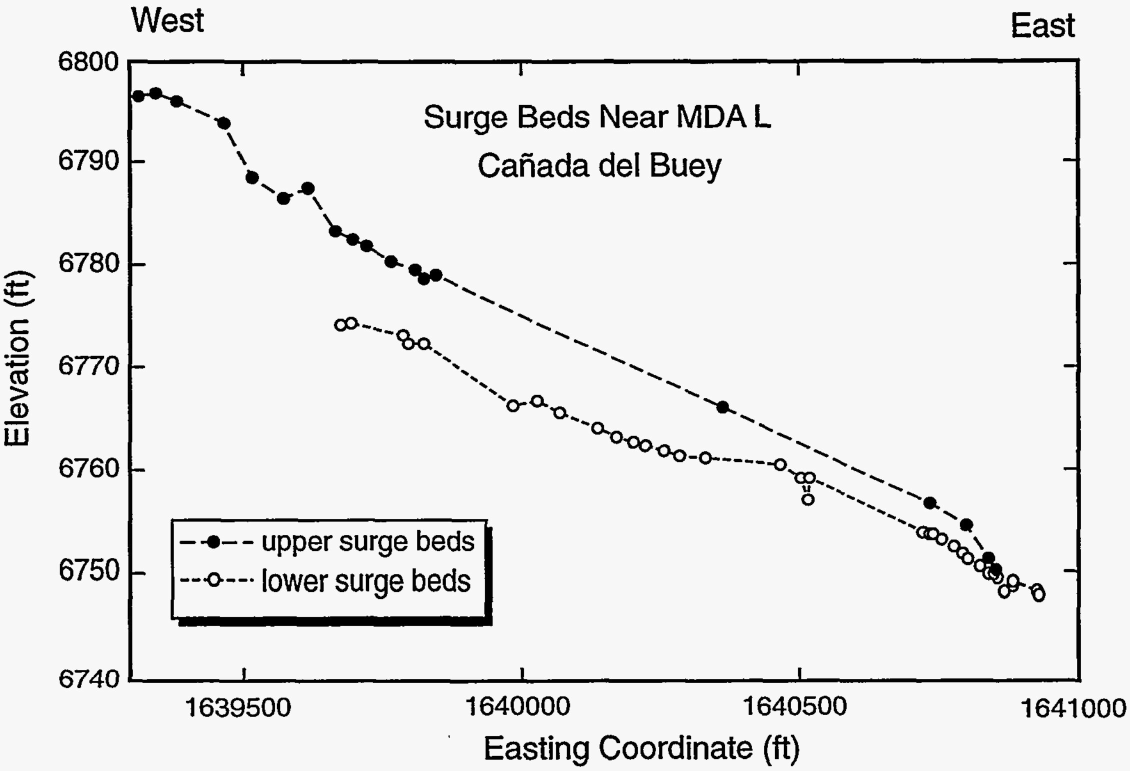

Fig. 6. Elevation of surveyed points on surge beds along the north wall of Cañada del Buey near MDA L. The lower surge bed approximates the base of unit 2. All data points are projected to an east-west line. Coordinates are in NAD 83. Along the length of this survey, a flow unit in the lower part of unit 2 thins rapidly from about 3 m in thickness to the west, pinching out to the east. This pinching out of flow units leads to lateral variations in the abruptness of the chemical transition across the contact between units 1v and 2 (see Broxton et al., 1995).

beneath TA-54. The survey data also provide insight into tectonic deformation of the Bandelier Tuff. In addition, many faults with small amounts of displacement were observed along the north wall of Pajarito Canyon, and their orientation and the amount and direction of displacement were recorded, providing further data on the structural conditions at Mesita del Buey.

STRUCTURE CONTOURS AND STRIKE AND DIP

The strike and dip of the boundary between units 1v and 2 of the Tshirege Member at Mesita del Buey were estimated by constructing structure contours on this stratigraphic contact. The locations of the contours were mainly based on constraints provided by surveyed points on surge beds at the base of and within unit 2 and on an ash bed within the upper part of unit 1v. In several areas, points on the contact between units 1v and 2 were surveyed along strike, allowing contours on this contact to be drawn directly. These areas include the west end of the survey along Pajarito Road near MDA J, the area near well PM-2, the vicinity of MDA L, and the east end of MDA G. In several areas the strike determined from surveyed surge beds was nearly parallel to mesa-top contours, indicating that the top of Mesita del Buey is in places a dip slope on the uppermost tuff unit. We thus used topographic contours to project the structure contours into some areas where no surveyed surge points had been obtained, such as beneath the west part of MDA G.

The accuracy of the structure contours is limited by several uncertainties, particularly: (1) uncertainties in the correlation of surge beds between measurement points; (2) possible original depositional undulations in the surveyed contacts; and (3) possible small-scale faulting or other deformation of the tuff. In some areas multiple surge beds were surveyed, generally extending to higher stratigraphic levels within the lower part of unit 2 (Figs. 3, 4, and 6). Where two or three stratigraphic levels with surge beds have been surveyed they generally are within 1 to 2 m vertically of each other, although at the west end of the Cañada del Buey survey, a surge bed is about 3 m above the base of unit 2 (Fig. 6). For a 300 m distance between surveyed lines near MDA L (i.e., between the north wall of Pajarito Canyon and the north wall of the Cañada del Buey tributary), the possible error in strike imparted by a 1 to 3 m uncertainty in stratigraphic position is about 5° to 15°. Nevertheless, because of the large number of points that were surveyed, we believe that we have constrained the general variation in strike and dip of the tuff along the axis of Mesita del Buey.

The estimated strike of the tuff varies along Mesita del Buey between MDA J and the east end of MDA G (Fig. 7). A nearly east-west strike was measured at the west end of the survey area, although strikes of N40E to N70E are more typical farther east (Table 1). In some areas, such as MDA L, the strike of the tuff appears to be perpendicular to the axis of the mesa, and potential subsurface flow paths controlled by stratigraphic breaks may thus similarly follow the axis of the mesa. Elsewhere, however, particularly through the length of MDA G, the strike of the tuff appears to be strongly oblique to the axis of the mesa, so that subsurface transport controlled by stratigraphic contacts would tend to be southeast towards Pajarito Canyon. This observation is consistent with the southeasterly dip previously reported at MDA G by Purtymun and Kennedy (1971) and inferred for this area in a recent LANL 3-D geologic model (Cole et al., 1997). In addition, the southeasterly dip probably explains why the south margin of the mesa at MDA G is deeply embayed, with the embayments eroded by surface runoff draining down the dip slope towards Pajarito Canyon.

The estimated dip of the tuff also varies along the length of TA-54 at Mesita del Buey (Fig. 8, Table 1). A minimum dip of about 1.0° is estimated in the vicinity of well PM-2, in an area where the strike of the tuff is changing significantly (Fig. 7). A maximum dip of about 3.2° is estimated at the west end of MDA G, and average dips elsewhere are generally between 1° and 2° (Table 1). The apparently steep dip of the base of unit 2 at MDA G is consistent with the relatively steep slope of the mesa top in this area (Fig. 8b). Similarly, a decrease in apparent dip of the tuff near PM-2 occurs where there is a major change in slope of the mesa top (Fig. 8b).

The cause of the variations in strike and dip of the Tshirege Member at TA-54 is not certain but may include both the effects of variations in the underlying paleotopography and the effects of post-Tshirege deformation. For example, the southeast dips near MDAs G and L suggest that the pre-Tshirege paleotopography in this area similarly had a general southeast slope. This is consistent with other evidence for southeast-directed pre-Tshirege drainages in this area that are discussed by Broxton and Reneau (1996). Some of the variations in dip may also be due to faulting that is distributed over broad zones. For example, the area where the slope of the tuff is gentlest, near well PM-2, corresponds to an area where distributed faulting is suggested by local variations in the elevations of surge beds, as discussed in a later section.

DEPTH TO CONTACT BETWEEN UNIT 1V AND UNIT 2

The elevation of the contact between units 1v and 2 of the Tshirege Member beneath the crest of Mesita del Buey at TA-54, as estimated using the approximate structure contours of Figure 7, is shown in Figure 8b. The estimated thickness of unit 2 beneath the mesa crest ranges from 16 m near MDA J to perhaps as little as 8 m near the west part of MDA G. These thicknesses are probably affected by erosion, and the original

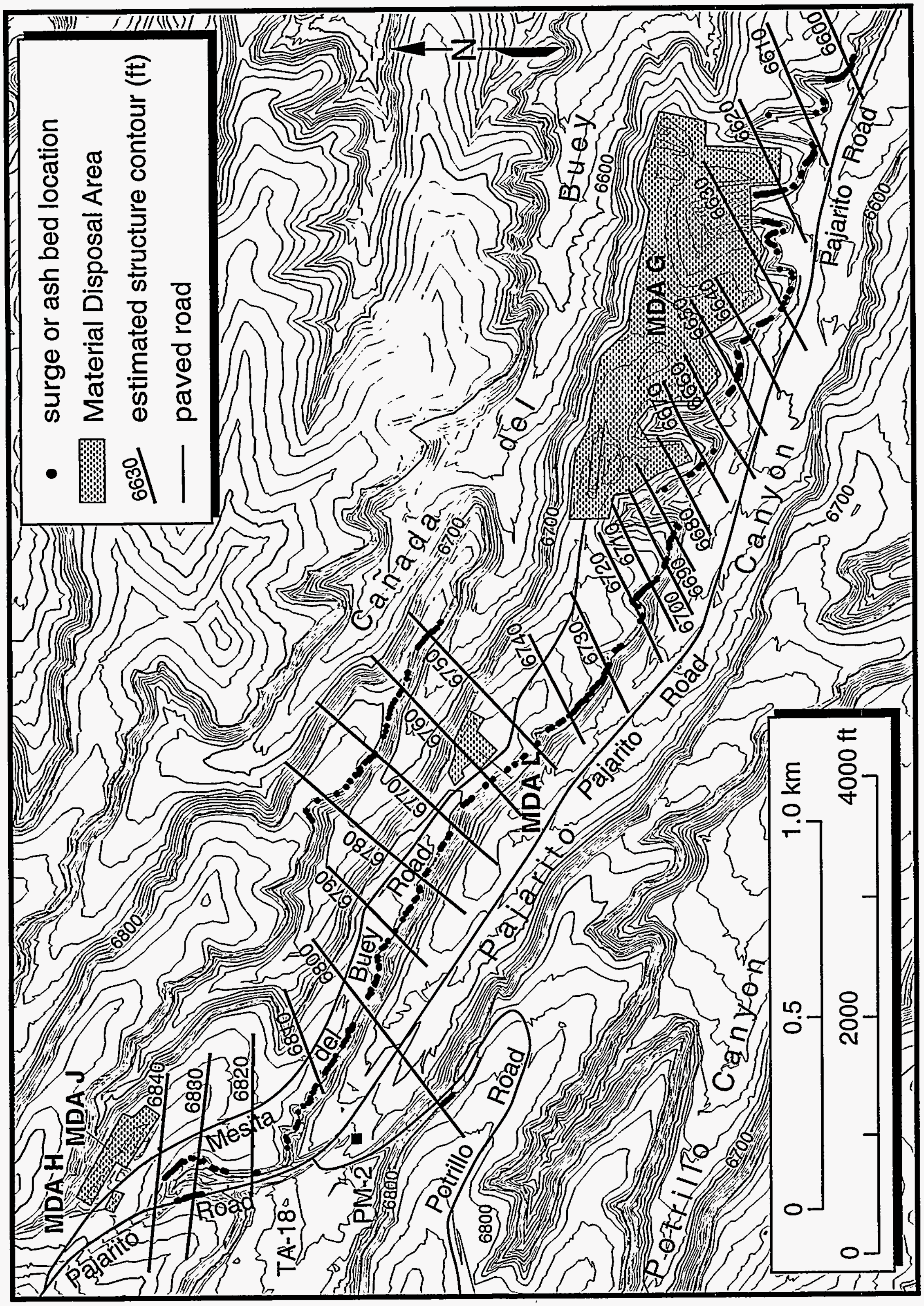

Fig. 7. Map showing location of surveyed points on surge beds and an ash bed near the contact between units 1v and 2 and estimated structure contours on this contact at TA-54. The topographic base is from FIMAD, with 10-foot contour intervals.

Table 1. Estimated strike and dip of the Bandelier Tuff at Mesita del Buey.

Area	Estimated Strike	Estimated Dip
East end MDA J	N85W	1.7°
Near PM-2	N50E-N80E	1.0°
MDA L	N40E-N50E	1.3°
West end MDA G	N60E-N65E	3.2°
Center of MDA G	N55E-N60E	2.1°
East end MDA G	N65E-N70E	1.4°
East of MDA G	N65E-N70E	1.3°

thickness of unit 2 at Mesita del Buey is thus unknown. The estimated average thickness of unit 2 below the mesa crest between MDA J and the east end of MDA G is 10 to 13 m, with average thicknesses of 12 and 11 m at MDAs L and G, respectively.

These estimated depths to the contact between units 1v and 2 can be compared with depths estimated from core hole studies. For descriptions of cores from eight holes near MDA L that were described by Caporuscio (1994), the average difference between the two estimates of the elevation of this contact is 0.5 m, and the maximum difference is 2 m, with the estimates of Caporuscio (1994) tending to be higher than that estimated in this study. This uncertainty is within that expected by Broxton and Reneau (1995), who discuss the difficulty of consistently identifying this contact both in core samples and in outcrop, and the similarity of elevation assignments at MDA L thus supports the general accuracy of both the structure contours of this study (Fig. 7) and the unit designations of Caporuscio (1994).

In contrast to the comparison of the structure contours with the core descriptions of Caporuscio (1994) at MDA L, other descriptions of cores from MDA L typically place the contact between units 1v and 2 at a lower elevation. Descriptions of cores from 16 holes drilled near MDA L in 1985 and 1986 by Kearl et al. (1986; see also Purtymun, 1995) place the contact between units 1v 2 (units 2a and 2b in their original nomenclature) up to 4 m lower than that estimated on Figure 8, averaging 2 m lower. The unit boundary assigned by Kearl et al. (1986) is thus an average of about 2.5 m lower than assigned by Caporuscio (1994). Based on our structure contours, we favor the interpretation of Caporuscio (1994).

FAULTS

Many faults with small amounts of displacement were observed during the surveying of surge beds within the Bandelier Tuff along the north wall of Pajarito Canyon (Fig. 9). A total of 37 faults with measured offsets of from 5 to 65 cm and with a wide range of orientations were recorded. The typical fault offset was 20 to 30 cm (Fig. 10). The locations of these faults are shown on Figures 3 to 5, and data on their locations, orientations, and apparent offsets are presented in Table 2. Because many areas of cliff were covered by colluvial debris or did not display surge beds, the faults in Table 2 undoubtedly do not include all faults present. In addition, many suspected faults with small amounts of offset (<5 to 10 cm) were observed but not measured, and other potential faults were not measured because of the possibility that they represented mass wasting of blocks along the canyon wall. Many of the local variations in surge bed elevations apparent in Figures 3 to 6 may thus reflect faulting that was not recognized during the survey.

The faults were observed across an east-west distance of 1.8 km, extending from the west edge of MDA G to MDA J. It is probable that additional faults exist to the east, but they were not documented during the initial part of the survey. The faults seem to be present along the entire area surveyed and may not be concentrated in any particular area. The highest density of observed

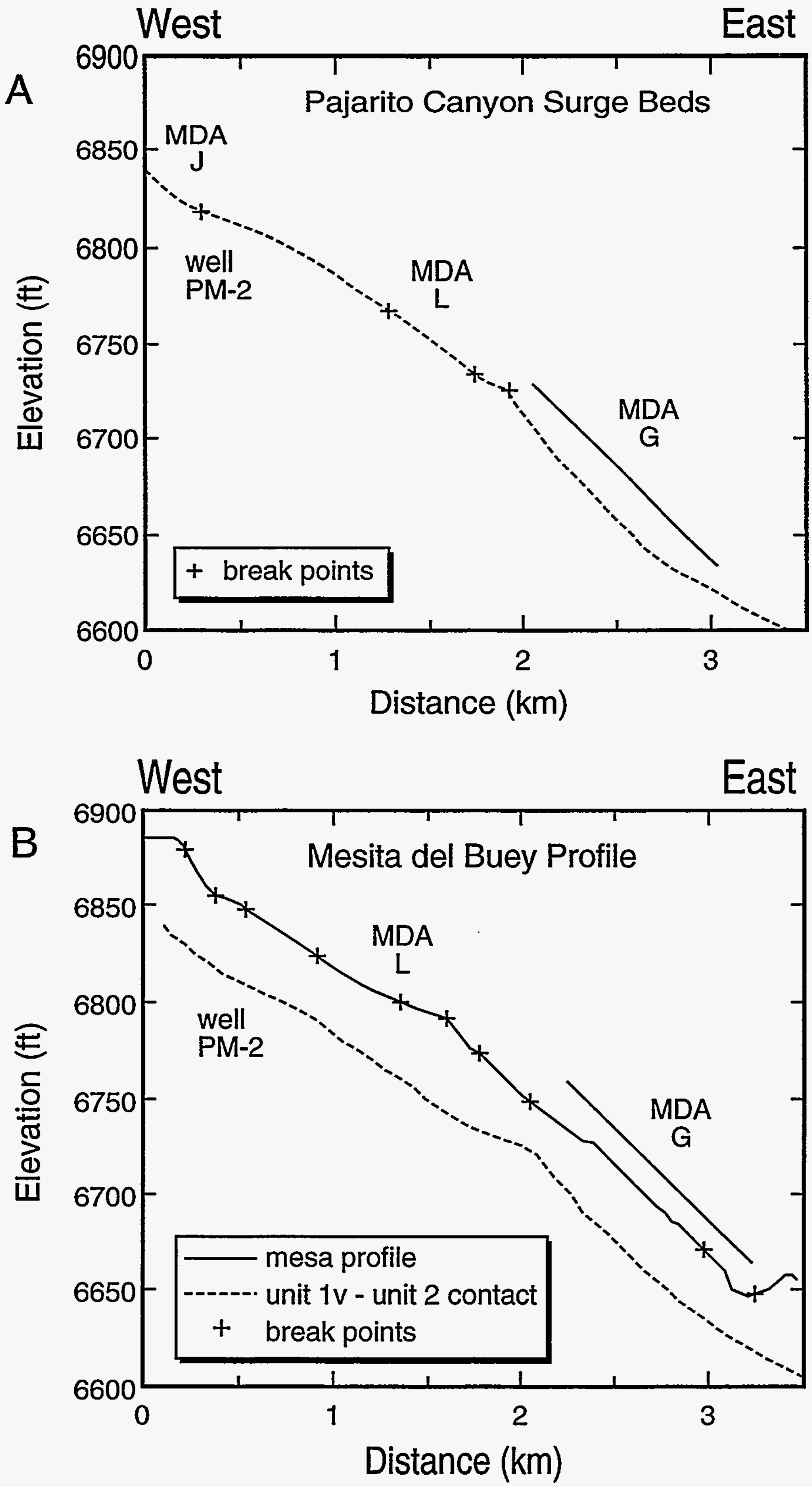

Fig. 8. A. Approximate elevation of base of unit 2 along the north wall of Pajarito Canyon and along Pajarito Road. B. Topographic profile along the crest of Mesita del Buey at TA-54 and projected elevation of base of unit 2 beneath mesa. Both figures are based on structure contours of Figure 7.

Fig. 9. Photograph of fault that displaces contact between units 1v and 2 down-to-the-west along the north wall of Pajarito Canyon at TA-54. The hammer tip is at thin surge bed on west side of fault, and the end of the handle is below surge bed east of the fault. The hammer is 40 cm long.

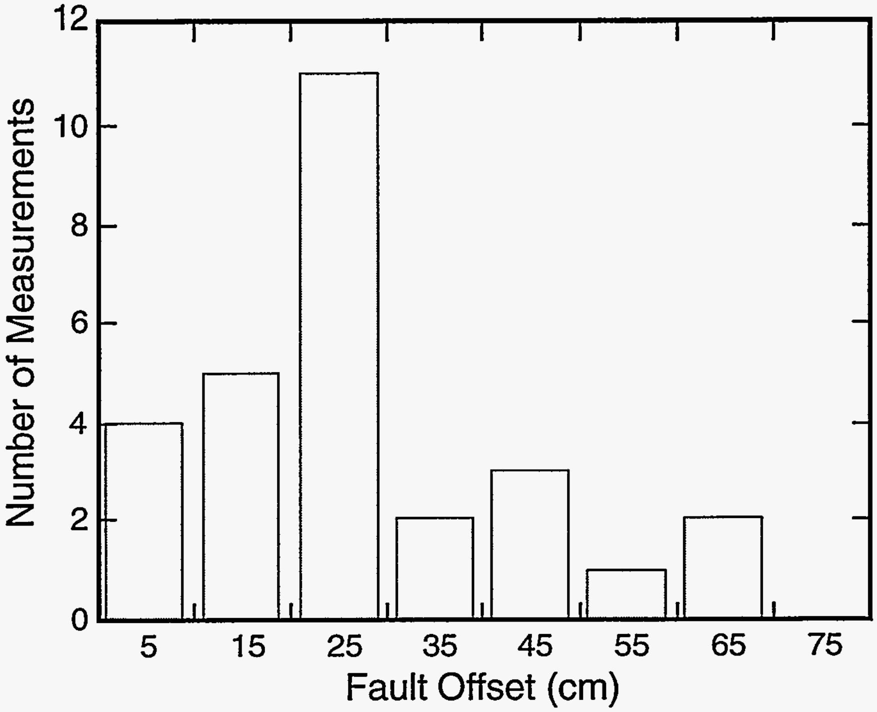

Fig. 10. Histogram of measured offsets on small-scale faults along the south side of Mesita del Buey at TA-54, grouped into 10 cm bins. Many faults with <5 to 10 cm of offset were observed but not measured, and faults of this size are thus underrepresented in this figure.

Table 2. Small-scale faults in surge beds.

Survey Shot	Strike	Offset (cm)	Down-Dropped Side	NAD 83 Coordinates (ft)		Notes
				Northing	Easting	
221	N10E	5 (?)	?	1757474	1642372	
229	N10-55E	20	W (?)	1757543	1642270	
267	N80E	40	N	1757999	1641238	
274	?	65 ?	E	1758019	1641224	fault covered
280	N55E	23	NW	1758037	1641210	
313	N25W	8	NE	1758294	1640682	
324	N35W	25-30	SW	1758363	1640518	possible mass-wasted block (?)
330	N55E	23	?	1758395	1640446	
333	N60E	22	NW	1758417	1640418	
340	N30-62E	5	SE	1758440	1640399	
346	?	15	?	1758494	1640326	
347	E-W	?	N	1758520	1640309	
356	N80W	20	N	1758604	1640223	
358	E-W	?	N	1758609	1640213	
365	N68W	23	NE	1758658	1640151	
373	N65E	11	NW	1758766	1640073	
375	N60E	22	NW	1758791	1640049	
392	N30E	44	NW	1759373	1639571	
408	N50W	25	NE	1759675	1639185	
413	N50-60W	?	NE	1759728	1639103	colluvium; surge difficult to follow
432	N75E	10	N	1760044	1638519	
443	N35W	22	SE	1760265	1638094	
445	N60W?	?	SW?	1760269	1638072	possible fault; offset uncertain
455	?	?	W	1760332	1637861	possible fault; offset uncertain
456	N45E	50	NW	1760342	1637851	E-bounding fault of graben
458	N15W	60	E	1760358	1637830	W-bounding fault of graben
471	N15W	10	W	1760495	1637600	
475	N60W	?	NW?	1760503	1637566	
486	N40E	40	NW	1760553	1637474	
488	N55E	30	NW	1760569	1637455	
491	?	?	S	1760640	1637342	
508	N80E	21	N	1760831	1636963	
514	N70E	30	N	1760930	1636795	
516	N15E	24	W	1760949	1636755	
528	N10W	10	W	1759717	1636947	
556	N-S	7	W	1762010	1636373	
558	N85E	20	N	1762019	1636365	

faults is near MDA L in an area where surge beds were exceptionally well exposed and continuous (Fig. 4), suggesting that the relatively large number of faults recorded there is an artifact of the good exposure. Notably, the surge beds in this area do not display any major changes in elevation or apparent gradient that would suggest the presence of a major fault zone (Fig. 4).

The observed fault planes at Mesita del Buey are steeply dipping, and are inferred to record mainly normal displacement, although no slickensides were found and lateral components of movement are possible. The faults do not display consistent senses of movement and include either down-to-the-west or down-to-the-east components of displacement. Opposing fault displacements partially compensate for each other, reducing the cumulative offset along the surveyed transect. For example, two of the faults with the largest measured displacements, 50 and 60 cm, bound an 8-m wide graben between MDA L and well PM-2 (Fig. 5), and there is little net offset across this feature.

To determine the amount and net sense of offset represented by the observed faults over the east-west extent of the study area, the amount and direction of offset for faults with measured orientation and offset were converted to a vector quantity calculated perpendicular to the fault plane. An easterly component of offset is represented by a positive x value and a northerly component of offset by a positive y value; larger values indicate greater offset (Fig. 11). This procedure gives higher weight to fault planes with greater offset.

The data in Figure 11 indicate a preferred offset to the north and west, with an average fault orientation (weighted to faults with greater offset) of N69E. The northerly component of offset may represent a bias imposed by the exclusion of many potential faults with southerly offsets that were judged to possibly represent mass wasting, and as such the apparent northerly component may not be significant. However, because the surveyed cliffs had a slight westerly aspect, the preferred westerly offset is believed to be real because the exclusion of potential mass-wasted blocks should have given the data set an easterly bias. For the east-west component of offset across the measured faults, 65% was to the west. Because of the possible easterly bias, the true westerly component of offset may be larger. Similar results are obtained when the faults are divided into western and eastern data sets, suggesting that there is no significant change in the style of faulting across the surveyed area. Total net down-to-the-west offset recorded by the measured faults is small, only 1.1 m over an east-west distance of 1.8 km, although many additional faults undoubtedly exist and the total cumulative offset across this part of Mesita del Buey could be significantly larger.

One area of greater magnitude faulting is inferred from the surveyed points at TA-54. In the vicinity of well PM-2, significant changes in the elevation of the surge beds suggest a zone of faulting 150 to 250 m wide that includes two grabens, down-dropped about 1.5 to 3.5 m, that are separated by a horst (Fig. 5). Such a horst-and-graben structure is similar to structures identified at other sites on the Pajarito Plateau (Reneau et al., 1995; Wong et al., 1995; Gardner et al., 1998). The orientation of this fault zone is not known, and the net amount of

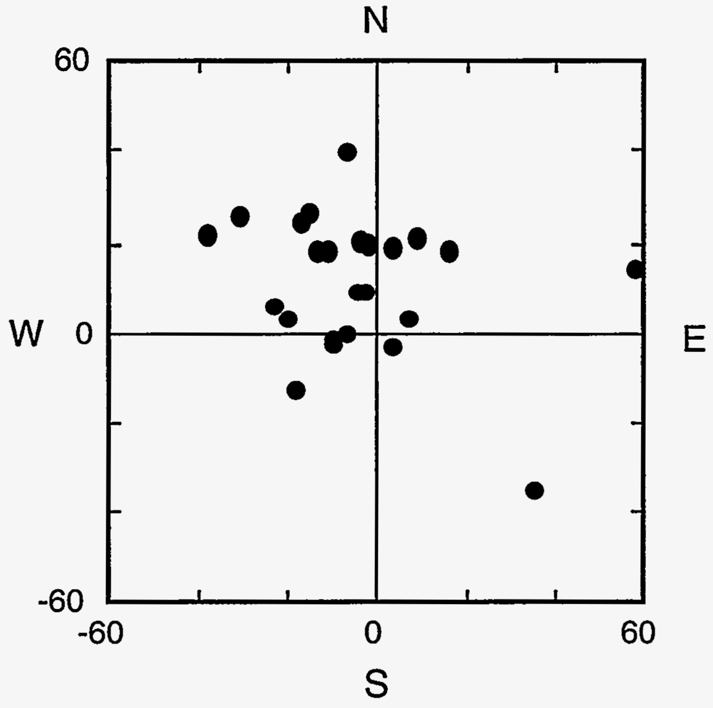

Fig. 11. Fault vector quantities for measured faults at TA-54. Each point indicates the amount and direction of offset along a fault, representing the end point of a line drawn perpendicular to the fault plane, with the line length equal to the amount of offset. Scale is in cm.

offset across it is also uncertain. The fact that this zone corresponds to the area where the apparent slope of the tuff is least, at about 1.0°, indicates the possibility of net down-to-the-west offset, but this cannot be confirmed at present.

The data on faults collected in this study are consistent with previous data collected in this area. In a summary of fracture data collected from pits at MDA G, small magnitude fault offsets were noted in several pits (Rogers, 1977, pp. G-36, G-39, and G-42). In Pit 22, down-to-the-northwest offsets of 7 and 9 cm were measured on two faults. On a larger scale, Dransfield and Gardner (1985) interpreted subsurface data as indicating predominantly down-to-the-west offset on generally north-trending faults beneath the Bandelier Tuff on the eastern parts of the Pajarito Plateau. No data are available on the age of the faults at Mesita del Buey, other than that the faults formed since emplacement of the Tshirege Member of the Bandelier Tuff at about 1.22 million years ago. Other small magnitude faults with similar amounts of offset examined at Pajarito Mesa had their last movements prior to 50 to 60,000 years ago (Kolbe et al., 1994; Reneau et al., 1995), suggesting similar long periods of inactivity at TA-54, farther away from the main Pajarito fault zone.

The characteristics of the faults identified at Mesita del Buey suggest that deformation on this part of the Pajarito Plateau during the past 1.2 million years has generally been dispersed over broad areas and not concentrated in discrete fault zones. It is possible that the faults represent very diffuse adjustments associated with the down-dropping of the Pajarito Plateau relative to the Sierra de los Valles, with small-scale faulting occurring along numerous pre-existing cooling fractures within the tuff. Small-scale faults that are not associated with major fault zones were also observed during a similar survey of surge beds at Pajarito Mesa, 4 to 5 km to the west (Reneau et al., 1995). In other regions, distributed secondary faulting that occurred during historical normal-fault earthquakes has been documented at distances of up to 14 km from the main fault, particularly on the down-dropped side of the fault (Coppersmith and Youngs, 1992; Wells, 1993; Pezzopane and Dawson, 1996). The small-magnitude faulting observed at TA-54, at a distance of 8 to 11 km from the main trace of the Pajarito fault zone, may thus similarly represent secondary faulting associated with surface rupture along the Pajarito fault zone or perhaps other faults in the region, although this hypothesis cannot be tested at this time.

CONCLUSIONS

The strike and dip of the contact between unit 1v and unit 2 of the Tshirege Member of the Bandelier Tuff varies along the length of Mesita del Buey at TA-54. Typical dips are from 1.0° to 2.0° to the east or southeast, with an estimated maximum dip of 3.2° near the west end of MDA G. Estimated strikes are typically N40E to N70E, although the apparent strike of the tuff is east-west near MDA J. The dip of the tuff is nearly parallel to the axis of the mesa at MDA L, and any subsurface movement of liquids or vapor from MDA L that is directed along stratigraphic contacts in the tuff would thus tend to be towards the east beneath the axis of the mesa. However, the dip of the tuff at MDA G is strongly oblique to the axis of the mesa, and stratigraphically controlled transport here would tend to be directed to the southeast towards Pajarito Canyon. The southeast dip of the tuff also influences surface runoff, and the deeply embayed south side of the mesa at MDA G was apparently eroded by surface runoff directed down the dip slope of the tuff.

Small-scale faults are widely distributed at Mesita del Buey, and a total of 37 faults with offsets of from 5 to 65 cm were recorded in this study. The predominant sense of offset is down-to-the-west or northwest, although 35% of the observed offset has a down-to-the-east component. The primary westerly component of offset is consistent with that inferred by other studies on the eastern part of the Pajarito Plateau. These faults are not clearly concentrated in discrete zones, and may represent widespread distributed secondary faulting associated with earthquakes that occurred on the main trace of the Pajarito fault zone 8 to 11 km to the west, or perhaps on other faults in the region. Somewhat larger scale offset is inferred in a 150 to 250 m wide zone near well PM-2 that includes two grabens, 1.5 to 3.5 m deep, separated by a horst. No data on the age of the faults at Mesita del Buey are available, except that movement occurred sometime within the last 1.22 million years.

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