FINAL REPORT

EVALUATION OF THE POTENTIAL FOR SURFACE FAULTING AT TA-63

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EXECUTIVE SUMMARY

The siting, design, and construction of waste treatment facilities, including those at Department of Energy sites, must comply with Environmental Protection Agency regulations for seismic hazards. According to 40 CFR 264.18(a), portions of new facilities where treatment, storage or disposal of hazardous waste will be conducted must not be located within 200 feet (61 m) of a fault which has had displacement in Holocene time. If Holocene faults (including lineations) are present within 3000 feet (914 m) of a facility, a comprehensive geologic analysis of the site is required.

Because the proposed Hazardous Waste Treatment Facility and Radioactive Liquid Waste Treatment Facility at Technical Area 63 (TA-63) will be used for the treatment of hazardous waste, a program of exploratory trenching was performed during the fall of 1992 and summer of 1993 to evaluate the presence of Holocene faulting at TA-63 and to assess the potential for surface faulting. A total of 442 m of trenches were excavated across the full east-west extent of TA-63 oriented perpendicular to the north-south striking Guaje Mountain fault which was suspected to pass within 914 m of the proposed facilities. In addition, a 150 m trench was excavated across the mapped projection of the fault just to the west of Pajarito Road and TA-63. The trenches were logged and samples collected for age-dating. Based on the trench stratigraphy, no evidence of Holocene faulting was observed in the trenches. Fractures in the Bandelier Tuff were pervasive, however, throughout all of the trenches. A structural analysis of the fractures was performed to evaluate the nature and possible relationship with the Guaje Mountain fault. The majority of fractures are very small tensional openings and are not faults. No evidence of repeated movement along the fractures is evident.

Slickensides, which indicate that past movement has taken place, are present within the clay filling of only a few fractures. In general, the slickensides indicate that motion has been nearly horizontal. Our assessment is that the slickensides probably reflect relatively small (less than a few cm) gravitational slip of individual blocks of Bandelier Tuff toward the drainages along the eastern boundary of the site.

Holocene movement along each individual fracture cannot be precluded due to a lack of continuous late Quaternary deposits over the entire site; however, the lack of geomorphic expression, lack of offset along the top of the Bandelier Tuff at fracture locations, and lack of displacement within probable pre-Holocene deposits and soils supports the contention that Holocene faulting at the site is probably absent or possibly too small to detect and hence not significant.

In summary, there is no geomorphic evidence for Holocene active faulting at TA-63. At TA-63, no vertical displacement of the Bandelier Tuff is evident as might be expected if the Guaje Mountain fault were located beneath the site. This suggests that either the fault dies out to the north of the site or that late Pleistocene displacements have been too small to be preserved on the mesa surface in the Bandelier Tuff. Thus, if coseismic rupture does occur along structures adjacent to or within the TA-63 boundary during 1 to 3 m displacement events to the north along the Guaje Mountain fault, the amount of vertical displacement is either negligible along an individual fault plane or the displacement is distributed across a broad zone. Thus, individual fractures or faults would move less than a few mm per event which might not be detectable in the trench exposures.

ACKNOWLEDGMENTS

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INTRODUCTION

This report summarizes our evaluation of potential surface faulting at the proposed sites for the Radioactive Liquid Waste Treatment Facility (RLWTF) and the Hazardous Waste Treatment Facility (HWTF) at TA-63, Los Alamos National Laboratory (LANL). This study was performed by Woodward-Clyde Federal Services (WCFS) at the request of the LANL. Vaniman and Wohletz (1990) mapped projections of both the Guaje Mountain and Rendija Canyon faults in the vicinity of TA-63. Based on results obtained in the ongoing Seismic Hazard Evaluation Program of the LANL (Wong et al., 1993), displacement has occurred on both the Guaje Mountain and Rendija Canyon faults in the past 11,000 years (Holocene time). Thus, in accordance with U.S. Department of Energy (DOE) and Environmental Protection Agency (EPA) guidelines and regulations, the evaluation of the potential for fault surface rupture at TA-63 was required.

1.1 OBJECTIVES

The specific objectives of this study were:

- 1) to assess whether surface faulting is present beneath the proposed footprints of the two facilities; and
- 2) if faulting is present, to evaluate whether such faults moved during the Holocene and, therefore, would need to be considered in siting the facilities to avoid future fault surface rupture.

1.2 SCOPE OF WORK

Our scope of work consisted of three principal tasks:

Task 1 Preliminary Site Analysis - This task included field reconnaissance of TA-63 and coordination with LANL personnel to obtain existing drill hole and foundation data in the site vicinity. This task also included identification of potential trench

localities and associated cultural constraints (e.g., utilities, pipelines, Solid Waste Management Units (SWMUs), and archaeological sites).

Task 2 Subsurface Exploration - Based on information provided by LANL regarding the proposed locations of the RLWTF and HWTF, we excavated four exploratory trenches, totaling 442 m in length, in November 1992. These trenches were designed to extend across the footprints of the facilities with an additional 61 m on either side. Following the recommendations of independent reviewers in March 1993, an additional trench was excavated in June 1993 across the projected trace of the Guaje Mountain fault. All trenches were oriented approximately east-west or normal to the mapped traces of the Guaje Mountain and Rendija Canyon faults. The existence of north-south trending faults through the proposed footprints of the facilities was assessed through such excavations.

Task 3 Data Analysis and Final Report - This task consisted of compilation and analysis of data collected during previous tasks, and completion of this technical report.

1.3 REGULATORY COMPLIANCE

The siting, design and construction of the proposed waste treatment facilities must comply with both DOE and EPA regulations and guidelines for seismic hazards. According to EPA 40 CFR Chapter 1 (7-1-90 Edition) Subpart B (General Facility Standards):

"Portions of new facilities where treatment, storage or disposal of hazardous waste will be conducted must not be located within 200 feet [61 m] of a fault which has had displacement in Holocene time."

If Holocene faults (including lineations) are present within 3000 ft (914 m) of a facility (which is the case at TA-63), a comprehensive geologic analysis of the site is required by the EPA. Specifically,

"Unless a site analysis is otherwise conclusive concerning the absence of faults within 200 feet [61 m] of such portions of the facility, data shall be obtained from a subsurface exploration (trenching) of the area within a distance no less

than 200 feet [61 m] from portions of the facility where treatment, storage, or disposal of hazardous waste will be conducted. Such trenching shall be performed in a direction that is perpendicular to known faults (which have had displacement in Holocene time) passing within 3,000 feet [914 m] of the portions of the facility where treatment, storage, or disposal of hazardous waste will be conducted. Such investigation shall document with supporting maps and other analyses, the location of faults found."

To our knowledge, specific DOE regulations regarding surface faulting do not exist. The existing seismic design criteria, such as UCRL-1590, only address ground-motion hazards to facilities. However, the recently established "Guidance for Evaluation of Seismic Hazard, Systematic Evaluation Program" for DOE Non-reactor facilities states that "studies shall be performed to determine site features such as ground failure under dynamic loading, surface faulting, liquefaction, vibratory ground motion, and site amplification that could influence the design or operation of the facility."

The guidance further stipulates that specific mandatory geologic and seismic factors must be considered in estimating the seismic hazard for facility design:

"Identify all faults greater than about 1000 feet [305 m] long within 5 miles [8 km] of the site and determine whether these faults have evidence of Quaternary movement. This factor is more detailed than factor 1 above to preclude the potential for fault displacement through the facility and to ensure that the Design Basis Earthquake is selected to be consistent with near source estimates of vibratory ground motion, should such a fault exist. The fault specific factors listed above should also be determined for any fault found to have evidence of Quaternary movement."

Although the focus of this study is to evaluate potential surface faulting at the proposed waste treatment facilities, it also provides information on the proximity of the Guaje Mountain and Rendija Canyon faults which is critical for evaluating the ground-motion hazard and determining seismic design criteria. Strong ground motions in the near-field of earthquakes of moment magnitude (M_w) $6\frac{1}{2}$ to 7, which may be possible on the two local faults, can be

quite significant and will need to be considered in the seismic design of the two proposed facilities.

1.4 PREVIOUS STUDIES

Several previous investigations have identified faults exhibiting Quaternary displacement in the LANL area (Griggs, 1964; Smith et al., 1970; Golombek, 1983; Gardner, 1985; Gardner and House, 1987, Wachs et al., 1988). Prominent topographic scarps in the 1.1 Ma Tshirege Member of the Bandelier Tuff within the Pajarito fault zone clearly suggest multiple late-Quaternary displacements. Gardner et al. (1990) found the first direct evidence of Holocene fault activity in the Los Alamos area. They report post-6 ka displacement of strata exposed in a trench across the Guaje Mountain fault in Cabra Canyon. Gonzalez and Gardner (1993) suggested that a 180- to 250- ka- old geomorphic surface is displaced approximately 12 m down-to-the-west along the Guaje Mountain fault. Based on abrupt changes in stream gradients, Wachs et al. (1988) suggest that the Frijoles Canyon fault segment has had Pleistocene or possibly Holocene activity.

In the past few years, an increasing interest in the seismogenic potential of the Pajarito fault zone has motivated several related investigations. Concurrent with this evaluation is an investigation by WCFS to assess the seismic hazard, principally strong ground shaking, posed by the Pajarito fault zone and other significant seismic sources to the LANL. That investigation include detailed paleoseismic studies of the Pajarito fault zone, Guaje Mountain and Rendija Canyon faults. Vaniman and Wohletz (1990) investigated the potential for surface faulting at TA-55 by observing orientations and changes in spacing of bedrock fractures in outcrops crossing projections of the Guaje Mountain and Rendija Canyon Faults. In the initial seismic hazard evaluation of TA-55 performed by Dames and Moore (1972), the local faults were not recognized as seismic sources and, therefore, surface faulting was not considered to be a hazard.

Gardner and House (1987) provide critical reviews of pertinent literature concerning the tectonic setting of the LANL area, field studies of the Pajarito fault zone, and previous seismologic and site-response investigations. Major stratigraphic and structural relations in the LANL region are adequately known from numerous detailed investigations (Doell et al., 1968; Smith et al., 1970; Budding, 1978; Manley, 1979; Golombek, 1983; Gardner and Goff,

1984; Gardner, 1985; Aldrich, 1986; Gardner et al., 1986; Gardner and House, 1987; Aldrich and Dethier, 1990; Gonzalez and Dethier, 1991). These investigations provide stratigraphic and structural information that have been used by WCFS to assess Quaternary faulting and seismic hazards in the LANL area. More detailed geologic maps and analyses of subsurface geology are provided by Gardner and House (1987), Dransfield and Gardner (1985), and Gardner et al. (1990). It is evident from these investigations that the 1.4 to 1.1 Ma Bandelier Tuff provides an excellent stratigraphic marker from which vertical fault displacements can be assessed. In addition, these studies document the locations and amounts of displacements on major late Quaternary faults.

Dransfield and Gardner (1985) provide a structural contour map of the pre-Bandelier surface. This map, which is based on well data, surface outcrops, and interpretations of seismic reflection lines, shows considerable paleotopographic detail where there are few water well or geophysical data and few surface outcrops of the base of the Bandelier Tuff.

Project No.
92C0774

LANL TA-63

LOCATION MAP OF LANL & MAJOR FAULTS

Figure
1

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Map base from FIMAD
Facility for Information Management and Display

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G101319

REGIONAL GEOLOGIC AND SEISMOTECTONIC SETTING

TA-63 is located east of the mapped projection of the Guaje Mountain fault (Vaniman and Wohletz, 1990) (Figures 1 and 2), a north-striking fault with apparent down-to-the-west displacement. The Guaje Mountain fault is part of the north-northeast trending Pajarito fault system, which is comprised of a series of predominantly normal faults that form the active western and northwestern margins of the Española Basin of the Rio Grande rift in north-central New Mexico (Gardner and House, 1987; Gardner and Goff, 1984; Golombek, 1983).

The Rio Grande rift is a north-trending, narrow, extensional province that stretches approximately 1,000 km from Chihuahua, Mexico to central Colorado. The rift forms the eastern margin of the larger extensional Basin and Range seismotectonic province. In New Mexico, the rift separates the Colorado Plateau province to the west from the southern Rocky Mountains and the Great Plains to the east.

Typical rift features of high heat flow, bimodal volcanism, high regional elevation, lithospheric thinning, normal faulting and basin formation are exhibited in the Rio Grande rift (Ingersoll et al., 1990). The central rift, in New Mexico, is characterized by a complex series of *en echelon*, right-stepping, asymmetric, half-graben basins that are up to 60 km wide. They are, from south to north, the Albuquerque-Belen, the Española, and San Luis Basins (Gonzalez and Dethier, 1991). Extension in the rift began about 30 Ma with the formation of broad basins and deposition of synrift sediments (Chapin, 1979). Present structures did not develop until 10 to 15 Ma (Chapin and Seager, 1975; Gardner and Goff, 1984). Basaltic volcanism initiated along the west margin of the Española Basin around 13 Ma and continued sporadically until 5 Ma (Gardner and Goff, 1984). Normal faulting along the western margin of the rift apparently began on the Sierrita fault on the eastern side of the Nacimiento Mountains in late Oligocene time and stepped eastward in the early Miocene to the Cañada de Cochiti fault zone (Aldrich, 1986; Gardner and Goff, 1984; Golombek, 1983). This may coincide with westward tilting of the basin volcanics and sediments (Golombek, 1983). At the end of the Miocene (~5 Ma) the western rift boundary stepped east to the Pajarito fault zone (Aldrich, 1986). The Valles caldera that built the Jemez Mountains was formed primarily during two eruptive episodes at 1.5 and 1.13 Ma

although eruption continued until about 130 ka with the eruption of the El Cajete pumice (Gardner et al., 1986). The poorly defined eastern margin of the rift is marked by a transition from Tertiary-Quaternary rift sediments to Pre-Cambrian to Oligocene rocks that form the western front of the Sangre de Cristo Mountains. The margin is also defined by a belt of north-trending Miocene-Pliocene to late Pleistocene folds and faults (Baltz, 1976).

The Pajarito fault zone forms a 100 km-long discontinuous zone of predominantly down-to-the-west faults. The fault zone may terminate to the north at the Embudo fault or some strain may be transferred from the Pajarito fault zone to the Embudo fault. Sense of slip along the Pajarito fault zone is poorly known. Gardner and House (1987) suggested that in general, predominantly normal slip occurs toward the southern end, oblique slip toward the central section, and a possible increase in horizontal motion occurs to the north. The relatively large component of normal faulting is evident by about 125 m of down-to-the-east displacement of the 1.1 Ma Tshirege member of the Bandelier Tuff. The roughly north-trending Guaje Mountain and Rendija Canyon faults lie to the east-northeast of the Pajarito fault zone. Both of these faults exhibit down-to-the-west displacement with an oblique-slip component (Gardner and House, 1987; Golombek, 1983). The northeast-trending Embudo fault transects the Española Basin separating the Velarde graben to the southeast from the Abiqui embayment to the northwest. It may accommodate different rates of extension and rotation of the two grabens, resulting in complex modes of late Quaternary faulting (Gardner and House, 1987) including predominantly normal displacement to the northeast and reverse displacement to the southwest (Machette and Persinius, 1984; Muehlberger, 1979).

The late Quaternary activity of the local faults of the Pajarito fault zone is of concern to LANL and is being addressed in the current study by WCFS (Wong et al., 1993). In general, based on displacements of the 1.1 Ma Tshirege member of the Bandelier Tuff, geomorphic expression of the faults, and previous paleoseismic studies along the Guaje Mountain fault by Gardner et al. (1990), there has been substantial movement on at least some of the faults since deposition of the tuff. The Guaje Mountain fault has had multiple late Quaternary movements including a possible surface displacement event at about 6 ka (Gardner et al., 1990). As much as 125 m of post 1.1 Ma displacement of the Bandelier Tuff occurred and possibly up to 6 m of undated alluvium has been faulted against Peralta tuff (6.8 Ma) along the Pajarito fault in Bland Canyon to the south of Los Alamos.

SITE DESCRIPTION AND GEOLOGY

LANL is located on the Pajarito Plateau which forms the east flank of the Jemez Mountains, a volcanic complex located along the western margin of the Rio Grande rift (Figure 1). The Plateau lies between the Jemez Mountains and the White Rock Canyon of the Rio Grande and has a gentle regional southeast slope. The plateau was formed during emplacement of Bandelier Tuff, a thick sequence of gently sloping, ash-flow and air-fall pyroclastics which encircle much of the Jemez Mountains. Subsequent erosion of the generally soft tuff created numerous deeply incised canyons that separate narrow, finger-like mesas, which radiate out from the Valles caldera and become progressively narrow and dissected to the southeast. The canyons cut through Bandelier Tuff, basaltic rocks of China Mesa, fanglomerates of Puye Formation, and sediments of the Tesuque Formation.

The TA-63 study area is located on Mesita del Buey, a southeast-trending narrow mesa which separates Mortendad Canyon to the northeast from Pajarito and Twomile Canyons to the southwest (Figure 1). Mesita del Buey is approximately 7 to 8 km long, 300 to 800 m wide and lies about 40 m above Mortendad Canyon to the northeast and 100 m above Pajarito Canyon to the south. Twomile Canyon drains into Pajarito Canyon just west of the study area; Pajarito and Mortendad Canyons both drain southeastward into the Rio Grande. The site occupies approximately 0.12 km² between the elevations of 2170 m and 2200 m (Figures 1 and 2).

Differences in topography and vegetation broadly separate the study site into northwestern and southeastern halves. The northwestern half is predominately grass covered with a 3° to 4° slope to the southeast. It is relatively undissected and supports only scattered, mostly deciduous trees. Aerial photographs taken in 1935 indicate that this area was once under cultivation. In the southeastern half of the site, the south slope increases to approximately 7° to the east and southeast toward the mesa margins. Bandelier Tuff bedrock is commonly exposed and imparts a hummocky appearance to the surface, which supports oak and Ponderosa pine trees.

The study site is underlain by Unit 3 of the Tshirege member of the Bandelier Tuff (Vaniman and Wohletz, 1990). The Bandelier Tuff is a high-silica rhyolitic ignimbrite which is divided into two eruptive phases. The lower ash-flow unit, the Otowi member, was erupted 1.5 Ma from the Toledo caldera and contains a basal air-fall pumice, the Guaje Pumice bed. The Otowi member is highly variable in thickness due to infilling of existing topography and locally can be greater than 200 m thick. The upper ash-flow unit, the Tshirege member, was erupted 1.13 Ma from the Valles caldera and also contains a basal air-fall pumice, the Tsankawi Pumice Bed, which lies disconformably on the Otowi member. The Tshirege member is more uniform in thickness than the underlying member and is typically 35 to 70 m thick on the Pajarito Plateau (Griggs, 1964). Both the Otowi and Tshirege members decrease in thickness eastward. Vaniman and Wohletz (1990) divide the Tshirege member into four units separated by non-welded zones. Unit three, which underlies the site, is described as a non-welded to moderately-welded brown tuff (Vaniman and Wohletz, 1990).

In the northwestern half of the site, thin deposits of silt, silty sand, and sandy silt overlie the Bandelier Tuff and average approximately 0.5 to 1 m in thickness. The steeper southeastern half of the site contains only a thin discontinuous silt cap which overlies localized depressions containing cumulative remnants of one or, possibly more, argillic soil B horizons. The relatively sparse record of surface deposits preserved in the southeastern half is probably because of greater erosion. The record of pedogenesis is more complete in the northwestern part of the site, owing to the stability provided by the flatter surface and its distance away from the mesa margins. Evidence of two buried argillic soil B horizons are preserved in the deposits overlying Bandelier Tuff in Trenches 1 and 4.

Two projected faults are located to the west of the study site. Vaniman and Wohletz (1990) project the Guaje Mountain fault to just west of Pajarito Road, within approximately 61 m of the western terminus of Trench 4, and through the intersection between Twomile Canyon and Pajarito Canyon (Figure 2). They suggest the projection represents the likeliest location of dispersed surface effects rather than a distinct surface rupture. Two splays of the Rendija Canyon fault are projected by Vaniman and Wohletz (1990) to pass approximately 210 m and 300 m, respectively, to the west of TA-63.

GEOLOGIC INVESTIGATION

As part of our evaluation of the potential for surface faulting at the proposed RLWTF and HWTF, we excavated five exploratory trenches to verify the presence or absence of active faults across the site. Of particular interest, was the southern projection of the Guaje Mountain fault, mapped along the western margin of the TA-63 boundary by Vaniman and Wohletz (1990). Their basis for extending the fault south of Los Alamos Canyon was primarily an increase in the number of fractures observed in canyon exposures of the Bandelier Tuff.

4.1 SITE ANALYSIS

Prior to excavation of exploratory trenches, a field reconnaissance was conducted at the site and along the north side of Twomile Canyon (Figure 1). This was done to assess the geologic conditions at the site (including possible depths to bedrock) and to ascertain whether faulting might be geomorphically expressed across the site. In addition, WCFS geologists coordinated with LANL personnel to identify potential trench localities and potential cultural constraints such as utilities, pipelines, SWMU's, archaeological sites, and roads.

4.2 EXPLORATORY TRENCH PROGRAM

We excavated four exploratory trenches across the TA-63 site (Trenches 1-4) with the intent of covering the area of the proposed footprints of the two facilities (Figure 2). Trench 5 was excavated west of the site across the projected trace of the Guaje Mountain fault as mapped by Vaniman and Wohletz (1990). The number of trenches was dictated by cultural and physical constraints and our desire to excavate the trenches perpendicular to the projected trace of the Guaje Mountain fault. The trenches were oriented approximately N80-85°W and are located so that there is overlap between adjacent excavations to maximize the opportunity to expose any fault traces. Due to cultural constraints, Trench 5 was oriented at approximately N 60-65° W. The location of Pajarito Road between Trenches 4 and 5 prohibited overlap between these excavations.

The trenches and their associated lengths are:

- Trench 1   213 m
- Trench 2   51 m
- Trench 3   155 m
- Trench 4   117 m
- Trench 5   149 m.

The purpose of the trenches was to expose Bandelier Tuff and overlying deposits, to evaluate whether evidence of faulting is present, and to constrain the timing of faulting.

4.2.1 Excavation

The trenches were excavated using a track-mounted, Caterpillar hydraulic excavator. Sufficient material was excavated to expose 0.5 to 1 m of representative bedrock (Bandelier Tuff) beneath unconsolidated deposits and rock disturbed by root growth. Trenches averaged 1 to 2 m deep and 1 m wide but were as deep as 3.7 m. Hydraulic shores were installed in areas of the trenches identified by LANL personnel to pose a potential safety hazard.

4.2.2 Trench Preparation and Logging

The south wall of each trench was cleaned by hand-chipping to expose a clean face sufficient to enhance structural, lithologic and textural detail. Color-coded nails were set to delineate fractures, lithologic boundaries and other features of stratigraphic, pedologic or structural significance. A string level line was installed along the flagged wall, and vertical lines marked every 2 m to provide a reference grid for logging. Care was taken to observe the relationships between fractures and geologic materials, especially the upward terminations of fractures against surficial deposits.

Using set nails, vertical meter marks and string level lines as guides, geologic features were logged onto mylar at an original scale of 2.5 cm equals 0.5 m; final report logs were scaled to 2.5 cm equals 2 m. Vertical or near vertical fractures that were traceable across the trench floor to the north wall were numbered, their orientations (strike and dip) measured, and then noted on the trench logs. Slickensides (striae along a fault plane resulting from movement)

were documented on the logs along with associated orientation data. General notes regarding soil development, morphology, composition and texture of geologic units, including bedrock, were noted on trench logs.

4.2.3 Description of Geologic Materials in Trench Exposures

In general, the geologic materials exposed by the excavations consisted of from bottom to top: Tshirege member, Bandelier Tuff; lithified, cross-bedded sand (probably a surge bed?) tuff rubble; sand and silt; and pedogenic soils developed on those deposits.

The preserved record of geologic materials and pedologic processes exposed in the trench walls appear to be related to topography. A gradient change occurs approximately midway through the TA-63 site (and midway along Trench 1) where it separates the predominately grass-covered, gently southeasterly sloping (3° to 4°), northwestern half of the study site from the wooded and more steeply sloping (6° to 7°) southeastern half near the mesa edges. The record is more complete in the gently sloping northwestern half away from the mesa edges. Trench 4 and the western half of Trench 1 expose geologic materials characteristic of the northwestern half, while Trenches 2, 3, 5 and the eastern end of Trench 1 expose materials characteristic of the southeastern half. We consider the differences in the preservation of geologic and pedologic materials across the site to be most strongly influenced by topographic relief, which causes increased erosion near the mesa edges.

4.2.3.1 Trench 1

We identified three stratigraphic units and three pedologic units within Trench 1 (Figures 3a-3l; Table 1). Three of the units are found in a shallow, bedrock depression between 180 and 203 m at the west end of the trench. Trench 1 is located in the gently sloping center of the study area that is overlain by a relatively thick accumulation of unconsolidated sediments (Figure 2; see Table 1 for lithologic descriptions).

Unit 1 Unit 1 is a brown, soft to firm, sandy-silt loess and reworked loess with a thin Ap horizon and comprises the uppermost 40 to 80 cm exposed in Trench 1. It extends from 75 m to the west end of the trench. The upper 10 to 20 cm (soil Ap horizon) contains a distinctive platy structure which is probably due to cultivation. Underlying the platy

structure, the unit is blocky to massive and of slightly higher strength. It has been thoroughly bioturbated and no fractures, bedding or other depositional structures were observed.

Unit 1 unconformably overlies Unit 2 deposits, however in discontinuous zones in the eastern end of the trench and between 130 and 137.5 m it is in contact with Bandelier Tuff. The contact with underlying Unit 2 deposits is typically diffuse probably due to mixing during deposition. An age of 650 +/- 80 yrs BP (sample TA-63 T1 RCS 2) was obtained from a zone of scattered charcoal at the base of the unit (100 m, Figure 3f). Due to evidence of abundant bioturbation through the unit and possibly the introduction of younger carbon, the sample age may be younger than the actual age of the base of the unit.

Unit 2 Between approximately 72 and 180 m, tuff (Unit 6) is unconformably overlain by Unit 2, a sandy silt with clay. Between 180 and the west end of the trench, Unit 2 overlies depression-fill deposits (Units 3, 4 and 5). From the east end of the trench to 72 m, the unit is not preserved due to erosion. Depositional structures observed within Unit 2 include: crude, discontinuous horizontal bedding, mobilization mixing and incorporation of a weathered bedrock rubble within Unit 2 deposits at the bedrock contact, filling of surface irregularities in bedrock and an abrupt smooth erosional contact where it overlies other deposits.

The basal gravel consists predominantly of subrounded to rounded tuff clasts within a light gray silty sand matrix. The gravel appear to be derived from the underlying tuff rubble and include occasional subrounded dacite clasts. One well-rounded quartzite pebble, 6 cm in diameter, was found 74 cm below the surface at the upper boundary of the gravel zone. The basal gravel is missing above deposits within the depression fill. However, the zone occupied by gravel and sandy silt over bedrock appears to continue over depression-fill deposits as a light-gray, sandy silt similar in color and composition to the matrix within the gravel zone. The very fine pebble fraction (2-4 mm) is composed of approximately 40% lithics and 60 % crystals. Most are subangular to surrounded with most crystals showing signs of frosting possibly due to transport. Although the unit has a very stiff to hard consistency it rapidly dissociates (slakes) upon immersion in water. We believe that this unit is a combination of eolian and reworked eolian sediment as slope wash colluvium.

Numerous, narrow (< 5 mm), carbonate and root-filled fracture extend through Unit 2 to the top of the underlying tuff. Occasionally these narrow fractures connect with fractures within the tuff. They are not thought to be contemporaneous and the connection is probably fortuitous at best because of differences in morphology and fill composition (fractures in bedrock typically are wider and contain iron-stained, clayey-sand fill). Additionally, numerous fractures in Unit 2 do not connect with underlying bedrock fractures.

A soil B horizon is developed in Unit 2 deposits. It has a slight reddish hue, light to moderate blocky structure and discontinuous clay films on ped surfaces. The soil is best exposed where Unit 2 overlies depression-fill deposits in the west end of the trench and between 89 and 106 m near the east end. In the midsection of the trench, the soil is poorly defined, possibly due to localized erosion coupled with mixing during the deposition of overlying Unit 1. A very small charcoal fleck (sample TA-63 T1 RCS 1) at the west end of the trench (210 m) from what is thought to be the B horizon equivalent in the north wall, yielded an age of 3050 +/- 70 yrs BP. Although quantitative data on rates of soil development in the laboratory area are unavailable, we believe this age is inconsistent with the time required to develop this B horizon (see discussion in Birkeland, 1984, p. 208).

Unit 3 Extending from 200 to 206 m (Figure 3k), this unit fills a shallow depression cut in underlying Units 4 and 5. It is composed of a very stiff, clayey silty sand. Sand occurs as discontinuous, irregular-shaped lenses and no sedimentary structures were observed. Because the depression boundary truncates Unit 4, a buried soil B horizon, it is probably of erosional construct. Although the unit contains few fractures, one fracture extends down through the underlying unit to coincide with a fracture (T1-66) in the Bandelier Tuff. As discussed above, we believe this fracture is not contemporaneous with the fracture in the underlying tuff due to differences in fill composition and fracture morphology.

Unit 4 Unit 4, extending from 180 to 213 m, is a clayey silt with sand and represents a buried soil B horizon formed in Unit 5 deposits. It is approximately 70 cm thick at 192 m and thins to the east and west in erosional contact with overlying units. Between 200 and 206 m, Unit 4 has been removed by erosion of a shallow channel.

The unit has a reddish-brown hue, strong angular blocky to prismatic structure and thick clay films continuously coat ped surfaces. Narrow (< 5 mm), vertical fractures are abundant in

this unit. Most are carbonate filled and often extend short distances above and below the contacts with other units. No fractures were observed to extend from this unit, through underlying Unit 5 and into tuff bedrock.

Unit 5 Unit 5, the lowermost depression-fill deposit, is a very stiff, brown sand and silt. It contains discontinuous, irregular lenses of fine sand distributed mainly in the lower half of the unit. Gravel, consisting of tuff and dacite clasts, are observed to accumulate near the base of the unit.

Vertical fractures, mainly confined to the silty upper half of the unit, are numerous, narrow (< 5 mm) and carbonate filled. At least two fractures (T1-64 and T1-66, Figure 3k) continue through the unit to coincide with fractures in the underlying tuff. No evidence of displacement, either in the tuff or unconsolidated sediments, is apparent along these fractures and it is unlikely that they are contemporaneous. Manganese oxide-filled horizontal and subhorizontal fractures occur infrequently.

Unit 6 Bedrock beneath all trenches, is composed of Unit 3 of the Tshirege Member of the Bandelier Tuff (Vaniman and Wohletz, 1990). All tuff exposed appears compositionally similar. Differences are mainly in frequency and width of fractures, frequency and intensity of iron oxide staining and, possibly, degree of welding. All may be related to topography.

Most of Trench 1 and all of Trench 4 are located in the gently sloping central part of the study area where the thickness of surface deposits indicate less erosion relative to deposition. In the steeply sloping areas near mesa margins, including Trench 2, 3, 5 and the eastern third of Trench 1, erosion is the dominant surface process. As a probable consequence, tuff near mesa margins has been stripped of the upper several meters of weathered, lower-strength, stained and more frequently-fractured bedrock typically preserved in Trenches 1 and 4.

Vertical fractures predominate in Unit 6, however, in comparison to trenches near the margins of mesas, they are generally narrower, more numerous and the number of near horizontal fractures is greater. An increase of corrected fracture frequency to two standard deviations over the mean occurs in the 15 m segment between 150 and 165 m (see Table 2a and Figure 2). We believe this is not significant and within reasonable background fluctuations since increases of similar magnitude occur in most trenches (e.g., T-3, 110 -125 m; T4, 0 -15 m

and T-5 30-45 m). Fracture fills are predominately iron-stained clayey sand; however fracture fills underlying the depression at the west end of the trench also contain manganese oxide. Iron staining is found along narrow fractures (< 5 mm); however, it also permeates large areas bounded by vertical and horizontal fracture pairs. Approximately 70% of the exposed tuff in the eastern two thirds of Trench 1 is iron stained in this fashion and most of it overlain by relatively thick accumulation of sediments.

In addition to fractures, there are numerous irregular-shaped and pipe-shaped structures (e.g., Trench 1, 100, 126.5, 136.5, 144.5, 145, 153.5 and 160 m) filled with coarse crystals, clay and often surrounded clasts of dacite and welded tuff. Gravel was a less frequent constituent of the pipe-like structures.

The tuff surface beneath Unit 2 deposits is locally irregular and contains a 10 to 20 cm thick rubble zone. The rubble zone typically consists of thin (5 to 10 cm) rough-textured, plate-like slabs that result from weathering along vertical and horizontal partings and a light gray silty sand matrix (pulverized tuff?). The partings become tighter with depth and often terminate at a 2 to 4 cm thick, horizontal, clay-filled fracture of considerable persistence (e.g., 110 to 130 m, Figure 3g). Irregularities at the surface of the rubble zone, along vertical and horizontal fractures within the zone and depressions around fractures which extend through the tuff and into the zone, are filled with Unit 2 deposits. The basal gravel of Unit 2 is derived from this layer and thoroughly mixed at the contact. This zone is distinctive along most of the trench because of its pebbly-like texture and light gray color. No fractures or irregular shaped or pipe-like voids were observed to extend through the rubble zone and into Unit 2 deposits. The accumulation of reddish-brown clay below the rubble zone and probable equivalent of clay found between tuff blocks at the east end of the trench (e.g., Figures 3a and 3b), may represent remnants of one or more overlying soil B horizons that have been, for the most part, eroded off. It is not unreasonable to suggest that Unit 4 may have overlain the entire trench and that this clay accumulation is, in part or wholly, a remnant of Unit 4.

4.2.3.2 Trench 2

We identified one stratigraphic and two pedologic units within Trench 2 (Figures 4a-4c). Trench 2 is located in the more steeply sloping southeastern part of the study area which is overlain by a relatively thin accumulation of unconsolidated sediments (Figure 2). Bandelier

Tuff bedrock is exposed at the surface near the east end of the trench (see Table 7 for lithologic descriptions).

Unit 1 Unit 1 is the probable equivalent of Unit 1 in Trench 1. It is a brown silty sand with a thin (< 10 cm) soil A horizon. Total thickness does not exceed 30 cm and no platy structure indicative of plowing was observed. Below the soil A horizon, the unit has a blocky to massive structure which is in unconformable contact with Unit 2 and Unit 3.

Unit 2 Unit 2 is a soil B horizon that has been partially stripped by subsequent erosion and buried by younger Unit 1 deposits. It is composed of approximately equal percentages of sand, silt and clay. Typically the unit is preserved in shallow depressions and between tuff blocks which form a rubble zone or residuum within the bedrock surface. The accumulation of reddish-brown clay in these zones probably resulted from translocation during one or, possibly, more soil forming intervals. A composite radiocarbon sample (TA-63 T2 RCS 1, Figure 4c) taken at the base of the unit and in contact with tuff bedrock yielded an age of 940 +/- 70 yrs BP. We believe this radiocarbon age is too young for the age of the buried B horizon for three reasons: 1) at the time of sample extraction, we could not determine, with any certainty, that it was not from a burned root (modern roots also follow this contact so that in the event of a surface fire it would be reasonable to find burned roots at the same horizon boundary); 2) pedogenic B horizons are not likely to develop within about a 1000 years (Birkeland, 1984); and 3) radiocarbon samples taken from similar stratigraphic contexts in Trench 5 (TA-63 T5 RCS 1,2 and 4; 980 +/- 60 and 1130 +/- 60, respectively) cluster around the same age, which may suggest they all resulted from the same fire.

Unit 3 Unit 3 is Bandelier Tuff bedrock. It is light to pinkish gray, coarsely crystalline, nonwelded to poorly welded, and contains abundant pumice and few lithic clasts. Pumice clasts are typically undeformed and range between 1 to 20 cm wide. Infrequent pumice clasts are slightly deformed due to light welding. Dacite lithic fragments comprise less than one percent of the tuff volume and are generally less than 2 cm wide, with rare clasts as large as 15 to 20 cm wide.

Iron staining of the tuff is predominantly fracture controlled. Iron staining typically confined to 2 to 4 cm wide "halos" along narrow (< 5 mm) fractures within otherwise unweathered

tuff. The stains commonly occur along narrow, horizontal zones and frequently terminate at vertical fractures.

Vertical to near vertical fractures are relatively few ($< .23$ mm) and wide (average 30 mm) (Table 4). Between 15 and 30 m, corrected fracture frequency increases by two standard deviations over the mean; however, this is not an uncommon occurrence (see discussion under Trench 1, Unit 1 above). Widths range from 0.2 to 8.5 cm and are generally wider than those found in trenches to the west. No fractures in bedrock were observed to extend into overlying younger deposits. Fracture T2-8 connects with a narrow (< 5 mm) carbonate-filled stringer in Unit 2, but differences in fracture morphology and fill composition suggests that they are not temporally related. Slickensides were observed on clay fill within fracture T2-11, however, there was no evidence of slickensides on the tuff surface

Fractures are most commonly filled by reddish-yellow clayey sand and infrequently by reddish-brown to dark reddish-brown sandy clay. Calcium carbonate (CaCO_3) stringers, roots and CaCO_3 root casts are also common within fracture fills. Although the predominant fill morphology is massive, some fills were observed that displayed nearly horizontal bedding and upward segregation of particle sizes; others contained vertical zonation of clay and CaCO_3 . Two fractures (T2-1 and 2) contain well rounded El Cajete pumice as upper fill constituents. El Cajete pumice is thought to be about 150 ky in age (Self et al., 1988) or older (Spell and Harrison, 1993). Unit 2 overlies the pumice in fracture T2-2.

Horizontal and subhorizontal fractures are also common within the tuff. These fractures are typically less than 1 cm wide, but can be up to 5 cm wide and are commonly filled with roots and clayey sand or CaCO_3 . In contrast to the fill within the vertical fractures, zonation and segregation of materials and clayey sand fill were uncommon in the low-angle fractures.

4.2.3.3 Trench 3

We identified one stratigraphic and two pedologic units within the deposits exposed in Trench 3 (Figures 5a-5i). Trench 3 is also located in the more steeply sloping southeastern part of the study area which is overlain by a very thin and discontinuous accumulation of surface sediments. Tuff bedrock is frequently exposed at the surface along the length of the trench (see Table 7 for lithologic descriptions).

Unit 1 Unit 1 is a very thin soil A horizon that has formed in scattered depressions in the humicky bedrock surface. It is composed of a loose, granular silty sand with numerous roots mixed with forest litter. The sand fraction appears to be decomposed tuff and frequently fills voids between rubble tuff blocks at the bedrock surface.

Unit 2 Unit 2 is a buried soil B horizon equivalent to Trench 2, Unit 2 described above. It is preserved in scattered depressions, horizontal fractures and the tops of some vertical fractures. Diminished preservation is probably due to increased erosion at the mesa margin.

Unit 3 Unit 3 is Bandelier Tuff bedrock similar to that described under Trench 2, Unit 3 above. It is uniformly gray, lightly welded and contains few ($< .23$ mm), wide (average 30 mm) fractures. Between 15 and 30 m, corrected fracture frequency increases by two standard deviations, although this is not an uncommon occurrence (see discussion under Trench 1, Unit 1 above). No fractures in bedrock were observed to extend into overlying younger deposits. Fracture T2-8 coincides with a narrow (< 5 mm) carbonate-filled stringer in Unit 2, but differences in fracture morphology and fill composition suggest different ages. Two fractures (T2-1 and 2) contain well rounded El Cajete pumice as upper fill constituents (Tables 5a and 5b).

4.2.3.4 Trench 4

We have identified two stratigraphic units, three pedologic units, including remnants of one possible surge bed within the deposits exposed in Trench 4 (Figures 6a-6g). Trench 4 is located in the gently sloping northwestern section of the study site, which is overlain by 0.5 to 1 m accumulation of unconsolidated sediments (Figure 2). Tuff is not exposed in the Trench 4 area (see Table 6 for lithologic descriptions).

Unit 1 Unit 1 is equivalent to Trench 1, Unit 1 described above, although it covers the length of Trench 4.

Unit 2 Unit 2 is equivalent to Trench 1, Unit 2 described above. This unit is also exposed over the length of Trench 4. The soil B horizon developed within this unit is not as distinct as that observed in the western half of Trench 1; both the reddish hue and structure development have diminished. However, it appears similar to that exposed in the eastern

half of Trench 1 and may also have been partially destroyed by cultivation and/or mixing with overlying Unit 1 deposits. The gravelly zone at the base of the unit is discontinuous and only observed where it is in contact with bedrock tuff. Where the unit overlies Unit 3 deposits, it is generally in clear unconformable contact. Between 109 m and the west end of the trench (Figure 5g), coarse pebble and cobble size gravel (3 to 20 cm) from Unit 4 have become mixed into the base of the unit. Unit 4 is observed to fill deep (+/- 0.5 to 1 m) voids and fractures within the underlying tuff surface (e.g., 73, 107.5 and 116 m).

Unit 3 Unit 3 is a buried and partially stripped soil B horizon. Structurally and compositionally it is similar to the buried soil exposed in Trench 1 (Unit 4) and may be the equivalent. It overlies tuff bedrock nearly continuously from the east end of the trench to 68 m (Figures 6a to 6d). Between 68 m and the west end of the trench it is preserved in only a few shallow depressions (e.g. 77 m and 98 to 100 m). From 48.5 to 51 m (Figure 6c), Unit 1 deposits extend from the surface to bedrock, filling a shallow, irregular depression and truncating Unit 3 deposits to the east and Unit 2 and 3 deposits to the west.

Unit 4 Unit 4 is a unique deposit; no equivalent was observed in any of the other trenches. Extending discontinuously from 88 m to the end of the Trench 4, it is a lithified, well-sorted and cross-bedded sand which probably represents eroded remnants of a surge deposit. Although alluvial origin cannot be ruled out, it looks very similar to a known surge deposit separating Units 3 and 4 of the Tshirege member of the Bandelier Tuff on Pajarito Mesa (uncovered in Trench E1 excavated as part of a current study to evaluate the potential for surface faulting at the proposed site of the Mixed Waste Treatment Facility at TA-67). The surge is most frequently separated from the underlying tuff bedrock by 2 to 4 cm of reddish-brown clay, which is most likely associated with Unit 3. Infrequently it is in abrupt contact with the underlying tuff (e.g. 113 and 116 m) or as clasts mixed with the overlying deposits (e.g., 113 m).

Unit 5 Unit 5 closely resembles the tuff as described in Trench 1, Unit 6 above. The average width of fractures (7.2 mm) is the smallest of the five trenches, but average corrected frequency (5.7/15 m interval) is similar to that of Trenches 1, 2 and 5 (Figure 2; Table 7).

4.2.3.5 Trench 5

We identified one depositional unit and two pedologic units within Trench 5 (Figures 7a-7i). Origin of the depositional unit is most likely eolian or reworked eolian. Trench 5 is located close to the mesa edge above Twomile Canyon (Figure 2). The topography resembles that of the area surrounding Trench 2 and is overlain by a thin, but continuous accumulation of unconsolidated sediments (see Tables 8a and 8b for lithologic descriptions and Table 9 for fracture data).

Unit 1 The upper component of the unit (1a) is a thin, discontinuous soil A horizon. It is composed of a sand with silt, numerous roots and organic debris. A composite charcoal sample (TA-63 T5 RCS 3) from a basal burn layer at 94 m yielded an age of about 60 yrs BP. The lower two-thirds of the unit (1b) is a massive, locally blocky, silty sand that unconformably overlies Unit 2. The probable origin of this unit is loess or reworked loess, which would make it equivalent to Unit 1 in the other four trenches.

Unit 2 Unit 2 is a buried soil B horizon developed, in part, in a sandy silt (2a) and a blocky tuff residuum (2b). Unit 2a is best preserved in the west end of the trench where its reddish hue and angular blocky structure allow it to be easily identified. It becomes less distinctive to the east and is often discontinuous due to partial stripping. Unit 2a contributed to the clay content within Unit 2b, although it may not account for all the clay. The increase in clay within 2b over that in 2a (+/- 80% versus 14%) suggests that it may be a cumulative residual and possibly represents contributions of clay from other soils that formed over the residuum prior to the development of Unit 2a. This seems unreasonable as there are two buried soil B horizons in Trenches 1 and 2.

Unit 2c is somewhat anomalous in that it contains characteristics of both Units 1 and 2. It is part of the tuff residuum, but the matrix does not contain clay like that of Unit 2b and looks more like the loose, sandy silt of Unit 1b. Since it typically does not overlie clayey Units 2a or 2b it may be younger and more accurately a subgroup of Unit 1.

Two charcoal samples, one taken from within Unit 2c at 67 m (TA-63 T5 RCS 4) and a composite (TA-63 T5 RCS 1 and 2) taken at 9 m near the base of Unit 2a, yielded radiocarbon ages of 1160 +/- 60 and 980 +/- 60 BP respectively. These data argue that

Units 2a and 2c are nearly the same age and may be related. However, the ages also cluster with a sample from Trench 2 (940 +/- 70) and, as discussed under Trench 2, Unit 2 above, may reflect only a single event, such as a forest fire, and not the ages of the units.

Unit 3 Unit 3 is Bandelier Tuff bedrock similar to that described under Trench 2, Unit 3 above. It is uniformly gray, lightly welded and contains volcanic glass with quartz and sanidine crystals. Pumice and, less commonly, dacite cobbles are also found within Unit 3. Between 30 and 45 m, corrected fracture frequency increases by two standard deviations; however, this is not an uncommon occurrence (see discussion under Trench 1, Unit 1 above). No fractures in bedrock were observed to extend beyond Unit 2b into overlying younger deposits. Because Unit 2b is a soil developed in tuff residuum, the rubble zone of the bedrock surface, fractures that extend from the underlying tuff into and through this unit would be expected since it is simply the weathered bedrock surface. The clay within the residuum, however, is a product of soil development and postdates fracturing. Evidence of this is the frequent separation of fracture-fill types at the bedrock/residuum contact, pedogenic, reddish-brown clay in the residuum and yellowish-red clayey sand in bedrock.

A wide zone of fractured and stained tuff between 94 and 96 m extends from the base of Unit 2 to the trench floor. We believe it is not fault breccia for the following reasons: 1) there is no apparent offset of the bedrock surface; 2) there is no evidence of shearing or slickensides; 3) boundary fractures do not project to the north wall; and 4) the width decreases to approximately 1 m on the north wall. We believe that it is an anomalous zone of intense weathering and not a product of surface rupture.

Unit 4 Unit 4 is a number of unconnected voids or pipe-like structures filled with coarse sand, clay and frequently gravel that contains approximately 50% dacite clasts. Although similar structures are found in all trenches, their frequency is considerably higher in Trench 5, thus they were given a unit designation. Most are irregularly shaped and do not extend from the surface of the trench to the base nor from one wall to the other. One was pipe-like (24.5 m) and given a fracture designation (T5-9) and others are associated with fractures that do project to the north wall (e.g., T5-14, 15 and 18).

These structures are found within Unit 2b (e.g., 13, 32, 40 and 43 m). We believe, however, this is a fortuitous condition as more will be encountered and become part of a future

residuum or a component of a future soil as the process of weathering, erosion and soil formation continues to lower the tuff surface. Unit 2a soil also develops in these deposits where they are exposed at the surface of the tuff residuum (e.g., meter 32).

4.3 ASSESSMENT OF STRUCTURES

4.3.1 Geologic Observations

Both geologic and structural observations and data were used to assess the nature and age of the fractures exposed in the exploratory trenches. Because of the 1.1 Ma age of the Bandelier Tuff, all structures located within the tuff are Quaternary. The objective of this study, however, was to determine whether any of the fractures are faults and, if so, whether they have had Holocene movement. Because datable materials such as charcoal for ^{14}C analysis were rare and confined to the youngest deposits, estimates of soil development rates as well as the composition of fracture fills were employed to provide broad estimates of timing of fracture formation. Because the age of deposits directly overlying the tuff is unknown, the absence of fractures within that unit does not provide any age constraint on the fractures within the underlying tuff bedrock. Vertical continuity of fractures, continuity of stratigraphic units across fractures and compositions of fracture fills provide insight toward their possible origin and relative age. Fractures that do not continue downward are not faults, but are probably related to weathering or cooling. A lack of apparent vertical or horizontal displacement across the fractures would suggest that they are tensional features and that they cannot be characterized as faults in a strict sense.

The presence of El Cajete pumice as a fill constituent in three fractures as well as the presence of a dense, reddish-brown sandy clay overlying all fractures where preserved (e.g., Figure 3l, T1-1 to T1-4; Figure 5d, T3-21) suggests that all fractures are significantly older than Holocene. This clay probably represents a buried pedogenic Bt horizon and indicates a relatively long period of soil development. No shearing or deformation of the soil or segregation of material was observed within any of the fractures. In addition, if we assume, based on the relatively uniform composition of fill, that all fractures are similar in age, then the presence of El Cajete Pumice (>150,000 yrs BP; Self et al., 1988) preserved in the top half of three fractures (Figure 5h, T3-5 and Figure 4a, T2-1 and 2) suggests a minimum age for fracturing.

Trenches or portions of trenches in the southeastern part of the site expose steps in tuff and tuff residuum above fractures (e.g., Figure 5b, T3-30 and T3-32; Figure 5c, T3-28; Figure 5e, T3-15). The bedrock steps are not present in the opposite wall of the trench and, thus, are not tectonic. Instead, they appear to be related to root throw during tree fall.

In Trench 4 and the west end of Trench 1 where fine-grained deposits and soils developed within those deposits are located, particular attention was paid to the character of the fractures. Within Trench 1, between 72 and 182 m, no fractures within the tuff continue upward into the younger deposits. Narrow (< 5 mm) fractures within younger deposits that coincide with fractures in the underlying tuff are not concomitant in age for the following reasons: 1) younger deposits fill slight depressions at the bedrock contact where the two fractures are coincident; 2) fracture widths, fill composition and morphology are commonly very different; 3) there are more numerous narrow fractures within the younger deposits, all having similar characteristics of width, composition of fill and morphology and only a few are coincident with fractures in the underlying tuff; and 4) the upper contact of the tuff in these locations is undisplaced. It is our contention that these fractures are actually caused by the coincidental location of a weathering- or root-related crack over a preexisting fracture.

Within the depression fill deposits at the west end of Trench 1, few fractures extend upward from fractures in bedrock through and above the buried soil B horizon (Unit 2). The degree of development of this soil suggests that it is pre-Holocene and, thus, almost all of the fractures are also pre-Holocene. Only one fracture could be found that extended through the Unit 4 and into Unit 2, which also contains a soil B horizon. The degree of development of the upper soil B horizon also suggests at least a Holocene age for that soil. It is unlikely that only a single, thin fracture could be the result of tectonic disruption, thus, it is our interpretation that the fracture is actually related to weathering or root migration.

4.3.2 Structural Analysis

A structural analysis of the fractures observed in all four trenches was conducted to better understand the mode of formation and relationship, if any, of the fractures to the Guaje Mountain fault. Appendix A contains a detailed discussion of the methodology and results of the analysis.

Frequency, width, orientation, and characteristics of fracture fill materials were recorded for fractures extending across the trenches and with dips greater than 45°. The fractures were then subdivided into faults and joints based on the presence or absence of shearing and/or slickensides. Fracture frequency and width (within 15 m intervals) were compiled and plotted (Figure 2) with corrections made for bias due to trench orientation (Terzaghi, 1965; see Appendix A). Strikes of steeply-dipping fractures were plotted on a lower hemisphere stereonet projections (Figure 8).

Our results from the analysis show no significant increase in fracture density toward or within the projection of the Guaje Mountain fault (at the west end of the site) as was documented at TA-55 by Vaniman and Wohletz (1990) or toward the cliff edge along the north and east margins of the site (Figure 2). The majority of fractures were vertical with strikes varying from northwest to northeast (Figure 8). There appears to be no strong correlation between fracture width and fracture density (Figure 2). The stereonet plots (Figure 8) indicate a clustering of fracture orientations along a north-northeast strike. Slickenside striae infer probable horizontal motion on some of the fractures.

The structural observations do not support fracture formation due to mass wasting along the canyon margins; fracture frequency does not increase approaching the cliff edge. However, one fracture observed in the east end of Trench 3 had a strike parallel to the cliff edge and slickensides oriented toward the canyon possibly result from gravitational movement toward the canyon. Secondary faulting associated with the projected Guaje Mountain fault to the west could produce strike-slip motion consistent with some slickenside striae. However, fracture frequency does not increase significantly approaching or within the mapped projection of the fault. The possibility that some of the fractures are tectonically derived cannot be precluded. A more extensive analysis of fractures throughout the Bandelier Tuff would be necessary to preclude this possibility.

Average fracture widths did increase toward the mesa edge to the east. This would be away from the projection of the Guaje Mountain fault and in contrast to the results of Vaniman and Wohletz (1990), which suggested fracture widths should have increased near the fault projection. We interpret this widening of fractures to be related to minor settling of tuff blocks canyonward.

Stratigraphic Unit (Color - dry)	Description
1 (7.5 YR 5/4)	<u>Ap Soil Horizon;</u> Sandy Silt; 23% sand, 63% silt, 14% clay; Loess/re-worked loess: moderate fine granular structure; loose dry consistence; nonsticky, nonplastic wet consistence; no clay films; brown structure; loose dry consistence; nonsticky, nonplastic wet consistence; no clay films; no carbonate; many fine irregular pores and few fine tubular pores; lower boundary is clear and smooth and discontinuous; upper 10 to 20 cm has platy structure due to plowing; balance of unit is massive to blocky; lower boundary diffuse smooth; unconformably overlies Unit 2.
2 (7.5 YR 5/3)	<u>Slope wash (?);</u> Sandy Silt with clay; 33% sand, 53% silt, 14% clay; very stiff to hard; slightly sticky and plastic; massive to locally platy structure; silt loam; numerous, very fine, circular and tubular brown pores; clear, irregular boundary; locally, weakly developed horizontal bedding; many, narrow (<5 mm) carbonate-filled fractures. It contains moderately developed buried soil B horizon which is 20 to 25 cm thick; angular blocky and sticky and plastic; a light gray, basal silt where it overlies depression fill deposits (Units 4 and 3), and gravelly silt where it overlies Bandelier Tuff (Unit 6); fractures are common, narrow (< 5 m) CaCO ₃ filaments and few extend beyond the unit boundaries; unconformably overlies Units 3, 4 and 6.
3 (7.5 YR 6/3)	<u>Alluvium (?);</u> Silty Sand with clay; 37% sand, 27% silt, 36% clay; moderate fine granular structure; medium dense; no apparent bedding or other fluvial structures; sand typically confined to lt. brown discontinuous lenses; fill deposit in shallow depression.
4 (5 YR 5/3)	<u>Btb Soil Horizon;</u> Clayey sandy Silt; 16% sand, 50% silt 34% clay; strong angular blocky to prismatic structure; continuous, thick clay films aligned along ped surfaces; few narrow (< 5 mm) CaCO ₃ red brown filaments.
5 (7.5 YR 5/3)	<u>Alluvium;</u> Silty Sand, trace clay and gravel; 50% sand 47% silt 3% clay; medium dense; sand typically confined to discontinuous, irregular-shaped lenses; gavel confined to the base of the unit; few vertical
6 (7.5 YR 7/2)	<u>Bedrock;</u> lightly welded to nonwelded tuff; up to 10 % pumice, occasional dacite cobbles; pumice are predominantly sub-horizontally aligned and some flattened; dacite cobbles are very few, subangular to pinkish to subrounded and up to 10 cm diameter; matrix is massive, coarsely crystalline and contains gray predominantly volcanic glass with quartz and sanidine crystals; Unit 3 of the Bandelier Tuff defined by Vaniman and Wohletz (1990).

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LANL TA - 63

Woodward-Clyde Federal Services

TRENCH 1
LITHOLOGIC DESCRIPTIONS

Table
1

TA-63 TRENCH 1 (data east to west)												
FRACTURE No	METERS	AZIMUTH	DIP	SLICKS	FRACTURE FILL	WIDTH	CORR. FREQ.	15M WIDTH	WIDTH	FRACTURE FREQ	CORR. FRAC. FREQ	V&W
	(log)	(degrees)				(mm)		(INTERVAL)	(AVE/15M)	(/15M INTER.)	(/15M INTER.)	
								(m)	(mm)			
T1-1	5	22	90		S,CL,CA	40	1.02	15	60.0	2	2.06	6
T1-2	10	355	90		S,CL,CA	80	1.04	30	62.5	4	8.91	4
T1-3	16	25	85 SE		S,CL,CA	50	1.04	45	17.8	4	4.27	4
T1-4	17	290	90		S,CL,CA	70	5.76	60	19.4	5	4.43	7
T1-5	23	18	85 NW	HZ (faint)	S,CL	80	1.01	75	22.8	8	9.27	12
T1-6	28	35	90		S,CL	50	1.10	90	10.4	5	7.09	12
T1-7	31	22	90		CL	25	1.02	105	10.6	5	5.72	12
T1-8	35	30	85 NW		CL,S	15	1.06	120	7.3	3	3.89	10
T1-9	37	42	90		CL,S,CA	11	1.18	135	13.3	3	4.08	7
T1-10	45	12	90		S,CL,CA	20	1.00	150	8.0	6	9.93	11
T1-11	45.5	30	90		CL,S	60	1.06	165	10.0	11	14.77	12
T1-12	53	50	90		CA,CL	2.5	1.31	180	4.3	5	7.20	8
T1-13	56	10	90		S,CL,CA	30	1.00	195	11.5	2	2.07	8
T1-14	57	22	90		CL,CA,S	25	1.02	210	39.4	5	7.18	8
T1-15	58	35	90		CL,CA	20	1.10		21.2		6.49	
T1-16	62	7	90		CL	70	1.00		19.1		3.47	
T1-17	64	52	90		CA,CL	15	1.35					
T1-18	66	324	90	shear fab.?	CL,CA,S	50	1.44		LEGEND			
T1-19	67.5	327	85 SW		CL,CA	10	1.37					
T1-20	67.5	352	90		CL,S	10	1.05		CL = CLAY			
T1-21	68	2	85 SE		CL,CA	10	1.01		CA = CALCIUM CARBONATE			
T1-22	71.5	10	77 E		CL,S	7	1.00		S = SAND/GRAVEL			
T1-23	74	29	90		CL,S	10	1.06		R = ROOTS			
T1-24	77	305	90		CL,CA	5	2.37		MnO = MANGANESE OXIDE			
T1-25	80	60	82 N		CL,CA	7	1.56					
T1-26	83.5	40	84 E		CL,S	5	1.15					
T1-27	84	10	90		CL	15	1.00					
T1-28	88	20	90		S,CA	20	1.02					
T1-29	91	40	90		CL,CA	25	1.15					
T1-30	97	348	90		CA,CL	10	1.08					
T1-31	98	341	90		CA	10	1.14					
T1-32	103	12	90		S,CL	4	1.00					
T1-33	104	52	84 E		CL,CA	4	1.35					
T1-34	108.5	55	80 S		CL,S	15	1.41					
T1-35	113.5	38	90		CL	3.5	1.13					
T1-36	118	328	90		CL,CA	3.5	1.35					

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Woodward-Clyde Federal Services

TRENCH 1 FRACTURE DATA

Table
2a

FRACTURE No	METERS (log)	AZIMUTH (degrees)	TA-63 TRENCH 1 CONTINUED (data east to west)				SLICKS	FRACTURE FILL	WIDTH (mm)	CORR. FREQ.			
			DIP										
T1-37	122	30	85 W					CLCA	10	1.06			
T1-38	123	0	85 E					CL	15	1.02			
T1-39	128	70	90					CLCA	15	2.00			
T1-40	136	80	90					SCL	10	2.92			
T1-41	137.5	313	90					CL,S,CA	10	1.84			
T1-42	140	42	90					CA,CL	3	1.18			
T1-43	147.5	68	77 S					CLS	10	1.89			
T1-44	148	10	90					CLCA	5	1.00			
T1-45	149	345	90					CLCA	10	1.10			
T1-46	151.5	347	90					CLCA	15	1.09			
T1-47	152.5	349	75 NE					CLCA	3	1.07			
T1-48	155	35	76 SE					CL,R	10	1.10			
T1-49	156.5	348	90					CLCA	10	1.08			
T1-50	157.5	355.00	90					CL,S,R	20	1.04			
T1-51	158.5	75.00	84 SE					CL	15	2.37			
T1-52	159	330.00	90					CA,CL	2	1.31			
T1-53	161.5	355.00	90					CL,CA,S	12	1.04			
T1-54	162.5	345	90					CL,R	10	1.10			
T1-55	163	45	75 SE					CLCA	10	1.22			
T1-56	163.5	305	82 E					CLS	3.5	2.37			
T1-57	166.5	37	80 NE					CA,CL	3	1.12			
T1-58	173	10	75 W					CL	3	1.00			
T1-59	173.5	10	90					CLS	2.5	1.00			
T1-60	176	340	90					CLS	3	1.15			
T1-61	179.5	80	90					CL	10	2.92			
T1-62	182	350	90					CL	8	1.06			
T1-63	188	5	90					S,MnO	15	1.00			
T1-64	197.5	18	90					S,MnO	30	1.01			
T1-65	200.5	25	90					S,MnO	12	1.04			
T1-66	203	28	90					CL	60	1.05			
T1-67	207.5	40	90					CLS	70	1.15			
T1-68	210	300	90					CL	25	2.92			

LEGEND

CL = CLAY

CA = CALCIUM CARBONATE

S = SAND/GRAVEL

R = ROOTS

MnO = MANGANESE OXIDE

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LANL TA - 63

Woodward-Clyde Federal Services

TRENCH 1 FRACTURE DATA

Table
2b

Stratigraphic Unit (Color - dry)	Description
1 (7.5 YR 5/4)	<u>Ap Soil Horizon;</u> Sandy Silt; 23% sand, 37% silt; Loess/re-worked loess: moderate fine granular structure; loose dry consistence; nonsticky, nonplastic wet consistence; no clay films; brown structure; loose dry consistence; nonsticky, nonplastic wet consistence; no clay films; no carbonate; many fine irregular pores and few fine tubular pores; lower boundary is clear and smooth and discontinuous; massive to blocky structure; lower boundary diffuse smooth; unconformably overlies Unit 2.
2 (5 YR 5/3)	<u>Btb Soil Horizon;</u> Clayey sandy Silt; 30% sand, 36% silt 34% clay; strong angular blocky to prismatic structure; continuous, thick clay films aligned along ped surfaces and around tuff blocks that form a red brown residuum.
3 (7.5 YR 7/2)	<u>Bedrock;</u> lightly welded to nonwelded tuff; up to 10 % pumice, occasional dacite cobbles; pumice are predominantly sub-horizontally aligned and show 3:1 flattening ratio; dacite cobbles are subangular to pinkish to subrounded and up to 10 cm diameter; matrix is massive, coarsely crystalline and contains gray predominantly volcanic glass with quartz and sanidine crystals; Unit 3 of the Bandelier Tuff defined by Vaniman and Wohletz (1990).

Project No. 92C0774A	LANL TA - 63	TRENCH 2 AND 3 LITHOLOGIC DESCRIPTIONS	Table 3
Woodward-Clyde Federal Services			

TA-63 TRENCH 2 (data east to west)												
FRACTURE No	METERS	AZIMUTH	DIP	SLICKS	FRACTURE FILL	WIDTH	CORR. FREQ.	15M WIDTH	WIDTH	FRACTURE FREQ.	CORR. FRAC. FREQ.	V&W
	(log)	(degrees)				(mm)		(INTERVAL)	(AVE/15M)	(/15M INTER.)	(/15M INTER.)	
								(m)	(mm)			
T2-1	1	43	80 W		S,CA,CL	25	1.29	15	41.67	3	5.35	4
T2-2	5	295	82 N		S,CA	85	2.79	30	34.00	4	10.37	6
T2-3	15	42	90		CL,CA	15	1.27	45	37.40	5	6.48	7
T2-4	17	30	75 SE		CL,S,CA	6.5	1.11	60	10.00	1	2.06	2
T2-5	18	15	72 E		S,CL,CA	32	1.02		30.77			
T2-6	23	335	63 SW		CL,CA	25	1.14		12.29	1.71	3.43	
T2-7	29	87	90		CL,CA	45	8.21		13.33	1.63	3.19	
T2-8	31	355	85 W		CL,CA	17	1.01					
T2-9	33	0	90		CL,CA	30	1.00		CL = CLAY			
T2-10	38	58	82NW	8 NE	CL,S	50	1.70		CA = CALCIUM CARBONATE			
T2-11	43.5	45	90		CL,S,CA	10	1.33		S = SAND/GRAVEL			
T2-12	44	318	90	HZ (faint)	CL,CA	80	1.44		R = ROOTS			
T2-13	47	65	70		CL,S	10	2.06					

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TRENCH 2 FRACTURE DATA

Table
4

					TA-63 TRENCH 3 (data east to west)							
FRACTURE No.	METERS	AZIMUTH	DIP	SLICKS	FRACTURE FILL	WIDTH	CORR. FREQ.	15M WIDTH	WIDTH	FRACTURE FREQ.	CORR. FRAC. FREQ.	V&W
	(log)	(degrees)				(mm)		(INTERVAL)	(AVE/15M)	(/15M INTER)	(/15M INTER)	
T3-1	151	5	90		CL,CA	25	1.00	140	20.67	3	3.97	3
T3-2	147	35	90	45 NE	CL,CA	15	1.18	125	25.67	3	4.22	4
T3-3	143	307	90		CL,S	22	1.79	110	23.60	5	6.60	5
T3-4	139.5	50	90		CL,CA	30	1.47	95	24.00	3	3.27	3
T3-5	134	355	90		CL,CA	30	1.01	80	41.67	3	3.41	5
T3-6	127	308	90		S	17	1.74	65	42.50	2	2.01	4
T3-7	123	25	80 S		S	25	1.08	50	18.00	5	6.02	9
T3-8	122	328	90		CL	30	1.22	35	24.50	4	4.34	4
T3-9	121	340	80 E		CL,S	5	1.09	20	14.50	4	5.10	6
T3-10	119	66	85 S		CL,S	13	2.20	5	13.33	3	3.24	3
T3-11	116	355	90		CL,S	45	1.01	0	45.00	1	2.56	1
T3-12	108	336	85 E		S,CL,CA	25	1.12		26.68	3.27	4.07	
T3-13	105	32	90		S,CL	17	1.14		10.75	1.14	1.34	
T3-14	97	10	90		S,CL	30	1.01		LEGEND			
T3-15	91	322	90		S	60	1.33					
T3-16	84	345	90		S	35	1.05		CL = CLAY			
T3-17	81	17	74 E		S	30	1.03		CA = CALCIUM CARBONATE			
T3-18	73	357	90		CL,CA	65	1.01		S = SAND/GRAVEL			
T3-19	71	5	80 E		S,CL	20	1.00		R = ROOTS			
T3-20	64	8	90		CL,S	10	1.00					
T3-21	62	3	41 W		CL	3	1.00					
T3-22	60	12	62 E		S,R	15	1.01					
T3-23	56	303	90	HZ	S	60	2.00					
T3-24	52.5	5	75 E		CL	2	1.00					
T3-25	44.5	353	82 W		CL	13	1.02					
T3-26	43	41	90		CL,CA	45	1.27					
T3-27	40	345	90		CL	25	1.05					
T3-28	35	5	90		CL	15	1.00					
T3-29	34	335	80 E		CL	22	1.13					
T3-30	31	60	85 S		CL	7	1.84					

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TRENCH 3 FRACTURE DATA

Table
5a

TA-63 TRENCH 3 CONTINUED (data east to west)											
FRACTURE No.	METERS	AZIMUTH	DIP	SLICKS	FRACTURE FILL	WIDTH	CORR. FREQ.	15M WIDTH	WIDTH	FRACTURE FREQ.	CORR. FRAC. FREQ.
	(log)	(degrees)				(mm)		(INTERVAL)	(AVE/15M)	(/15M INTER)	(/15M INTER)
T3-31	29	342	90		S,CL	25	1.07				
T3-32	25.5	22	90		CL	4	1.06				
T3-33	19	28	90		S,CL	12	1.10				
T3-34	16	23	90		CL	3	1.06				
T3-35	8	342	90		S,CL	25	1.07		LEGEND		
T3-36	4	70	80 S		S	45	2.56				
									CL = CLAY		
									CA = CALCIUM CARBONATE		
									S = SAND/GRAVEL		
									R = ROOTS		

Project No. 92C0774A	LANL TA - 63	TRENCH 3 FRACTURE DATA	Table 5b
Woodward-Clyde Federal Services			

Stratigraphic Unit (Color - dry)	Description
1 (7.5 YR 5/4)	Ap Soil Horizon: Sandy Silt; 23% sand, 63% silt, 14% clay; Loess/re-worked loess: moderate fine granular structure; loose dry consistence; nonsticky, nonplastic wet consistence; no clay films; brown structure; loose dry consistence; nonsticky, nonplastic wet consistence; no clay films; no carbonate; many fine irregular pores and few fine tubular pores; lower boundary is clear and smooth and discontinuous; upper 10 to 20 cm has platy structure due to plowing; balance of unit is massive to blocky; lower boundary diffuse smooth; unconformably overlies Unit 2; AP soil horizon developed within loess/reworked loess soil horizon.
2 (7.5 YR 5/3)	Slope wash (?): Sandy Silt with clay; 33% sand, 53% silt, 14% clay; very stiff to hard; slightly sticky and plastic; massive to locally platy structure; silt loam; numerous, very fine, circular and tubular brown pores; clear, irregular boundary; locally, weakly developed horizontal bedding; many, narrow (<5 mm) carbonate-filled fractures. It contains moderately developed buried soil B horizon which is 20 to 25 cm thick; angular blocky and sticky and plastic; a light gray, basal silt where it overlies depression fill deposits (Units 4 and 3), and gravelly silt where it overlies Bandelier Tuff (Unit 6); fractures are common, narrow (< 5 m) CaCO ₃ filaments and few extend beyond the unit boundaries; unconformably overlies Units 3, 4 and 6.
3 (5 YR 5/3)	Btb Soil Horizon: Clayey sandy Silt; 16% sand, 50% silt 34% clay; strong angular blocky to prismatic structure; continuous, thick clay films aligned along ped surfaces; few narrow (< 5 mm) CaCO ₃ red brown filaments.
4 (5 YR 5/4)	Surge (?) Lithified Sand; fine to medium grained; well sorted and cross bedded. Brown.
5 (7.5 YR 7/2)	Bedrock: lightly welded to nonwelded tuff; up to 10 % pumice, occasional dacite cobbles; pumice are predominantly sub-horizontally; abundant iron staining; dacite cobbles are subangular to pinkish to subrounded and up to 10 cm diameter; matrix is massive, coarsely crystalline and contains gray predominantly volcanic glass with quartz and sanidine crystals; Unit 3 of the Bandelier Tuff defined by Vaniman and Wohletz (1990).

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Woodward-Clyde Federal Services

TRENCH 4
LITHOLOGIC DESCRIPTIONS

Table
6

					TA-63 TRENCH 4 (data east to west)							
FRACTURE No	METERS	AZIMUTH	DIP	SLICKS	FRACTURE FILL	WIDTH	CORR. FREQ.	15M WIDTH	WIDTH	FRACTURE FREQ	CORR. FRAC. FREQ	V&W
	(log)					(mm)		(INTERVAL)	(AVE/15M)	(/15M INTER.)	(/15M INTER.)	
								(m)	(mm)			
T4-1	3	33	80 W		CL	10	1.09	15	7.25	8	10.81	13
T4-2	6.5	75	65 W		CA	2.5	2.37	30	5.90	5	8.17	11
T4-3	9.5	16	77 W		CA	6.5	1.01	45	3.83	3	3.33	6
T4-4	11	18	90		CL	7.5	1.01	60	9.30	5	5.15	12
T4-5	13	72	90		CL,CA	6.5	2.13	75	15.00	3	3.08	14
T4-6	13.5	336	90		CL,CA	7.5	1.21	90	6.63	4	4.07	9
T4-7	14.5	10	85 E		CL,S	5	1.00	105	2.86	7	7.57	11
T4-8	15	17	85 E		CL,CA	12.5	1.01	120	6.83	3	3.46	13
T4-9	16	295	90		CL,CA	12.5	3.86		7.20	4.75	5.70	
T4-10	20.5	20	80 W		CA	2.5	1.02		3.73	1.91	2.83	
T4-11	22	23	90		CL,S	5	1.03					
T4-12	24	26	90		CL	2	1.04					
T4-13	28	45	90		CL,CA	7.5	1.22		LEGEND			
T4-14	31	35	90		CL,CA	7.5	1.10					
T4-15	33.5	45	90		CL,S	1.5	1.22		CL = CLAY			
T4-16	42.5	5	90		CL	2.5	1.00		CA = CALCIUM CARBONATE			
T4-17	45.5	5	90		CL	4	1.00		S = SAND/GRAVEL			
T4-18	48.5	342	85 W		CL,S	7.5	1.13		R = ROOTS			
T4-19	49.5	11	90		CL,S	12.5	1.00					
T4-20	50	5	90		S,CL	10	1.00					
T4-21	59	16	90		CL	12.5	1.01					
T4-22	67	16	90		CL	27.5	1.01					
T4-23	70.5	355	90		CL,S,CA	12.5	1.04					
T4-24	73	355	90		CL,S	5	1.04					
T4-25	76	355	90		CL,S	5	1.04					
T4-26	80.5	355	85 SW		CL,S	5	1.04					
T4-27	82	10	90		CL	4	1.00					
T4-28	88	12	90		CL	12.5	1.00					
T4-29	92	40	90		CL	2	1.15					
T4-30	95.5	345	85 W		CL,A	4	1.10					
T4-31	96	12	90		CL,CA	2	1.00					
T4-32	97.5	355	76 E		CL,S	1.5	1.04					
T4-33	100	33	90		CL,S	2.5	1.09					
T4-34	102.5	42	90		S,CL	4	1.18					
T4-35	104	3	85 W		S	4	1.01					
T4-36	105.5	352	80 W		CL	7.5	1.05					
T4-37	108.5	340	85 NE		CL	6.5	1.15					
T4-38	113	47	90		CL	6.5	1.25					

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TRENCH 4 FRACTURE DATA

Table
7

Stratigraphic Unit (Color - dry)	Description
1a (7.5 YR 5/3)	<u>A Soil Horizon;</u> silty sand; 2% gravel, 85% sand, 13% silt; moderate fine granular structure; loose dry consistence; nonsticky, nonplastic wet consistence; no clay films; no carbonate; brownmany fine irregular pores and few fine tubular pores; lower boundary is clear and smooth and discontinuous; locally contains worm excreta and finely disseminated charcoal.
1b (7.5 YR 5/3)	<u>Loess;</u> silty sand; trace gravel, 53% sand, 47% silt; locally massive or coarse blocky, also locally laminar; hard dry consistence; sticky, nonplastic wet consistence; no carbonate; no clay films brownfew very fine irregular pores and few fine tubular pores; lower boundary is abrupt and smooth. Unit 1b differs from Unit 1a because it has a blocky, laminar or massive structure and not a fine granular structure, has a hard not loose consistence and does not contain worm excreta.
2a (7.5 YR 5/4)	<u>Btb Soil Horizon;</u> loam; trace gravel, 40% sand, 46% silt, 14% clay; moderate to medium angular blocky; hard dry consistence; sticky nonplastic wet consistence; no carbonate; common thin films on ped brown faces and in pores; few fine irregular pores and common very fine tubular pores; lower boundary is clear and wavy.
2b (5 YR 4/4 & 7.5 YR 5/4)	<u>Residuum;</u> gravel; 80% gravel, cobbles and boulders up to > 50 cm, 3-12 % sand, 1-7% silt, 16-1% mottled clay; gravel is angular to subrounded, predominantly lightly welded to nonwelded tuff (bedrock) with occasional rounded dacite cobbles; large boulders separated by matrix which varies from clay to sandy loam with roots; matrix has moderate to strong, fine angular blocky and prismatic structure; hard reddish dry consistence; sticky, nonplastic to very slightly plastic wet consistence; no carbonate in soil matrix but brown & few thin rinds on boulders (Stage I+); many moderately thick films on ped faces, pores and bridges and brown occasional thick clay films on boulders; few very fine to fine irregular pores and few very fine tubular pores; lower boundary is abrupt wavy. Unit 2b differs from Unit 2a because of the high percentage of gravel and increased clay content of the matrix.

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Woodward-Clyde Federal Services	

TRENCH 5
LITHOLOGIC DESCRIPTIONS

Table
8a

Stratigraphic Unit (Color - dry)	Description
2c (7.5 YR 5/3)	<u>Residuum</u> ; gravel; 80% gravel, cobbles and boulders, 11% sand, 9% silt, trace clay; gravel is angular to subangular and predominantly lightly welded to non-welded tuff (bedrock); gravel and brown boulders separated by sandy loam matrix; matrix is massive; matrix has hard dry consistence and sticky, nonplastic wet consistence; no carbonate; few discontinuous clay films on grains; few, very fine irregular pores and few coarse tubular pores; lower boundary is abrupt and wavy. Unit 2c differs from Unit 2a because of the high percentage of gravel, cobbles and boulders. Unit 2c differs from Unit 2a and Unit 2b because it contains very little clay and does not have an angular blocky or prismatic structure.
3 (7.5 YR 7/2)	<u>Bedrock</u> ; lightly welded to nonwelded tuff; up to 10 % pumice, occasional dacite cobbles; pumice are predominantly sub-horizontally aligned and show 3:1 flattening ratio; dacite cobbles are subangular to pinkish to subrounded and up to 10 cm diameter; matrix is massive, coarsely crystalline and contains gray predominantly volcanic glass with quartz and sanidine crystals; Unit 3 of the Bandelier Tuff defined by Vaniman and Wohletz (1990).
4 (2.5 YR 5/6)	<u>Fracture/Void filling</u> ; gravelly sand; 30% gravel and cobbles, 51% sand, 11% silt, 8% clay; clay content increases towards edges of fractures/voids; gravel contains subrounded to rounded dacite, welded 4/6 tuff and lightly welded to nonwelded tuff; single grain structure; dry hard consistence; slightly red sticky, nonplastic wet consistence; locally disseminated carbonate and 1-2 mm carbonate rinds on fracture/void sides; many moderately thick to thick clay films on grains and bridges between grains and on cobbles; many medium irregular pores; lower boundary is abrupt and irregular.

Project No. 92C0774A	LANL TA - 63	TRENCH 5 LITHOLOGIC DESCRIPTIONS	Table 8b
Woodward-Clyde Federal Services			

TA-63 TRENCH 5 (data east to west)												
FRACTURE No.	METERS	AZIMUTH	DIP	SLICKS	FRACTURE FILL	WIDTH	CORR. FREQ.	15M WIDTH	WIDTH	FRACTURE FREQ.	CORR. FRAC. FREQ.	V&W
	(log)					(mm)		(INTERVAL)	(AVE/15M)	(/15M INTER)	(/15M INTER)	
T5-1	7	30	75 W		CL,S	12	1.09	15	31.0	4	4.95	9
T5-2	7	26	90		CL,S	12	1.06	30	8.6	7	8.07	9
T5-3	7	310	90		CL,S	30	1.79	45	12.5	4	11.14	11
T5-4	14	8	90		CL,S,CA	70	1.00	60	6.3	6	6.76	15
T5-5	18	10	90		CL,CA	2	1.00	75	4.8	3	7.05	5
T5-6	18	50	73 E		CL,CA	2	1.39	90	9.0	5	6.29	14
T5-7	21	12	85 W		S	10	1.01	105	13.7	3	3.91	12
T5-8	22	345	90		CA	5	1.07	120	5.1	4	8.24	10
T5-9	25	330	90		S,CA,CL	12.5	1.24	145	9.6	5	5.23	7
T5-10	27	325	85 E		CL,S,CA	3.5	1.33		11.2	4.6	6.8	
T5-11	30	21	90		CL,CA	25	1.04		7.6	1.3	2.0	
T5-12	33	85	76 S		S,CL,CA	7.5	5.24					
T5-13	37	338	90		S,CL,CA	7.5	1.13		LEGEND			
T5-14	40	80	88 S		S,CL,CA	10	3.63					
T5-14A	43	35	80 W		S,CL,CA	20	1.14		CL = CLAY			
T5-15	46	334	90		S,CL,CA	10	1.18		CA = CALCIUM CARBONATE			
T5-16	49	0	90		S,CL,CA	10	1.01		S = SAND/GRAVEL			
T5-17	49	0	80 E		CL,CA	2	1.01		R = ROOTS			
T5-18	53	30	90		S,CL,CA,D	4	1.09		DA = DACITE CLAST			
T5-19	56	0	90		S,CL	10	1.01		WT = WELDED TUFF CLAST			
T5-20	57	319	76 SW		S,CL,CA	1.5	1.47					
T5-21	63	84	90		S,CL,CA	5	4.81					
T5-22	66	345	78 E		CL,CA	7.5	1.07					
T5-23	70	37	90		CL,CA	2	1.17					
T5-24	77	42	90		S,CL	7	1.24					
T5-24a	81	280	90		S,CL	5	1.24					
T5-25	85	45	85 SE		R,CL,CA,S	6.5	1.29					
T5-26	87	55	90		S,CL,CA	20	1.52					
T5-27	90	0	83 W		CL,S,CA	4	1.01					
T5-28	97	47	90		S,CA,CL	10	1.33					
T5-29	98	57	78 NW		S,CA,CL	6	1.59					
T5-30	102	5	90		S,CL,CA	25	1.00					
T5-31	108	80	86 SE		CL,CA	5	3.63					
T5-32	111	355	90		S,CL,CA	2	1.02					
T5-33	115	73	90		S,CL,CA	3.5	2.56					
T5-34	120	21	88 NW		S,CL,CA	10	1.04					
T5-35	122	354	85 E		S,CL,CA	3	1.02					
T5-36	130	8	86 E		S,CL,CA	20	1.00					

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TRENCH 5 FRACTURE DATA

Table
9a

TA-63 TRENCH 5 CONTINUED (data east to west)												
FRACTURE No.	METERS	AZIMUTH	DIP	SLICKS	FRACTURE FILL	WIDTH	CORR. FREQ.					
	(log)					(mm)						
T5-37	136	4	90		S,CL,CA	10	1.00		LEGEND			
T5-38	140	28	90		S,CL,CA	10	1.08					
T5-39	145	338	90		CL,CA	5	1.13		CL = CLAY			
									CA = CALCIUM CARBONATE			
									S = SAND/GRAVEL			

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TRENCH 5 FRACTURE DATA

Table
9b

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TRENCH 1
INDEX OF DETAILED TRENCH LOGS

Figure
3

LEGEND

Unit 6 Nonwelded to lightly-welded, coarsely-crystalline and fractured Bandelier Tuff

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TRENCH 1, 1A AND 1B

Figure
3a

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LEGEND

Unit 6 Nonwelded to lightly-welded, coarsely-crystalline and fractured Bandelier Tuff

Project No. 92C0774	LANL TA-63	TRENCH 1, 2A & 2B	Figure 3b
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LEGEND

Unit 6 Nonwelded to lightly-welded, coarsely-crystalline and fractured Bandelier Tuff

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TRENCH 1, 3A AND 3B

Figure
3c

LEGEND

Unit 2 Sandy silt, which contains a buried B soil horizon, numerous, narrow (<5 mm) CaCO_3 -filled fractures and basal gravel with a light-gray, silty-sand matrix

Unit 6 Nonwelded to lightly-welded, coarsely-crystalline and fractured Bandelier Tuff

①

Gas pipe or void fill; coarse sand made up mostly of crystals and some clay; dacite and welded-tuff clasts are frequent constituents

Project No. 92C0774	LANL TA-63	TRENCH 1, 4A AND 4B	Figure 3d
Woodward-Clyde Federal Services			

LEGEND

Unit 1 Thin Ap (plowed) soil horizon developed within loess/ re-worked loess; contains blocky structure at depth

Unit 2 Sandy silt, which contains a buried B soil horizon, numerous, narrow (<5 mm) CaCO₃-filled fractures and basal gravel with a light-gray, silty-sand matrix

Unit 6 Nonwelded to lightly-welded, coarsely-crystalline and fractured Bandelier Tuff

Project No. 92C0774	LANL TA-63	TRENCH 1, 5A AND 5B	Figure 3e
Woodward-Clyde Federal Services			

LEGEND

- Unit 1 Thin Ap (plowed) soil horizon developed within loess/re-worked loess; contains blocky structure at depth
- Unit 2 Sandy silt, which contains a buried B soil horizon, numerous, narrow (<5 mm) CaCO_3 -filled fractures and basal gravel with a light-gray, silty-sand matrix
- Unit 6 Nonwelded to lightly-welded, coarsely-crystalline and fractured Bandelier Tuff
- ① Gas pipe or void fill; coarse sand made up mostly of crystals and some clay; dacite and welded-tuff clasts are frequent constituents
- ● Radiocarbon sample location TA-63 T1 RCS 2. C-14 age years B.P. 650 +/- 80 using standard sample technique on charcoal

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Woodward-Clyde Federal Services

TRENCH 1, 6A AND 6B

Figure
3f

LEGEND

Unit 1 Thin Ap (plowed) soil horizon developed within loess re-worked loess; contains blocky structure at depth

Unit 2 Sandy silt, which contains a buried B soil horizon, numerous, narrow (<5 mm) CaCO_3 -filled fractures and basal gravel with a light-gray, silty-sand matrix

Unit 6 Nonwelded to lightly-welded, coarsely-crystalline and fractured Bandelier Tuff

Gas pipe or void fill; coarse sand made up mostly of crystals and some clay; dacite and welded-tuff clasts are frequent constituents

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TRENCH 1, 7A AND 7B

Figure
3g

LEGEND

Unit 1 Thin Ap (plowed) soil horizon developed within loess/ re-worked loess; contains blocky structure at depth

Unit 2 Sandy silt, which contains a buried B soil horizon, numerous, narrow (<5 mm) CaCO₃-filled fractures and basal gravel with a light-gray, silty-sand matrix

Unit 6 Nonwelded to lightly-welded, coarsely-crystalline and fractured Bandelier Tuff

①

Gas pipe or void fill; coarse sand made up mostly of crystals and some clay; dacite and welded-tuff clasts are frequent constituents

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TRENCH 1, 8A AND 8B

Figure
3h

LEGEND

Unit 1 Thin Ap (plowed) soil horizon developed within loess/ re-worked loess; contains blocky structure at depth

Unit 2 Sandy silt, which contains a buried B soil horizon, numerous, narrow (<5 mm) CaCO₃-filled fractures and basal gravel with a light-gray, silty-sand matrix

Unit 6 Nonwelded to lightly-welded, coarsely-crystalline and fractured Bandelier Tuff

①

Gas pipe or void fill; coarse sand made up mostly of crystals and some clay; dacite and welded-tuff clasts are frequent constituents

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TRENCH 1, 9A AND 9B

Figure
3i

LEGEND

- Unit 1 Thin Ap (plowed) soil horizon developed within loess/ re-worked loess; contains blocky structure at depth
- Unit 2 Sandy silt which contains a buried B soil horizon, numerous, narrow (<5 mm) CaCO_3 -filled fractures and a thin (10 cm), light-gray basal silt deposit
- Unit 4 Reddish-brown, buried soil B horizon with strong prismatic structure
- Unit 6 Nonwelded to lightly-welded, coarsely-crystalline and fractured Bandelier Tuff

①

Gas pipe or void fill; coarse sand made up mostly of crystals and some clay; dacite and welded-tuff clasts are frequent constituents

T1 TS1

Location of thin section sample

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TRENCH 1, 10A AND 10B

Figure
3j

LEGEND

- Unit 1 Thin Ap (plowed) soil horizon developed within loess/re-worked loess; contains blocky structure at depth
- Unit 2 Sandy silt which contains a buried B soil horizon, numerous, narrow (<5 mm) CaCO_3 -filled fractures and a thin (10 cm), light-gray basal silt deposit
- Unit 3 Silty-sand/sandy silt fill deposit within a depression in Unit 4; sand is in discontinuous lenses
- Unit 4 Reddish-brown, buried soil B horizon with strong prismatic structure
- Unit 5 Silty-sand/sandy silt fill deposit within a depression in bedrock; sand is contained in discontinuous lenses while gravel is located mostly near the base of the unit
- Unit 6 Nonwelded to lightly-welded, coarsely-crystalline and fractured Bandelier Tuff

①

Narrow (<5mm) fractures connected to underlying fractures in bedrock are probably not contemporaneous because of differences in morphology and fill

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TRENCH 1, 11A AND B

Figure
3k

LEGEND

Unit 1 Thin Ap (plowed) soil horizon developed within loess/re-worked loess; contains blocky structure at depth

Unit 2 Sandy silt which contains a buried B soil horizon, numerous, narrow (<5 mm) CaCO_3 -filled fractures and a thin (10 cm), light-gray basal silt deposit

Unit 3 Silty-sand/sandy silt fill deposit within a depression in Unit 4; sand is in discontinuous lenses

Unit 4 Reddish-brown, buried soil B horizon with strong prismatic structure

Unit 5 Silty-sand/sandy silt fill deposit within a depression in bedrock; sand is contained in discontinuous lenses while gravel is located mostly near the base of the unit

Unit 6 Nonwelded to Lightly-welded, coarsely crystalline and fractured Bandelier Tuff

Radiocarbon sample location TA-63 T1 RCS 1.
C-14 age years B.P. 3050 +/- 70 using AMS technique on a very small fleck of charcoal

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TRENCH 1, 12A

Figure
3L

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**TRENCH 2
INDEX OF DETAILED TRENCH LOGS**

**Figure
4**

LEGEND

- Unit 1 Loess/ re-worked loess with thin A soil horizon; silty sand
- Unit 2 Reddish-brown sandy clay often with roots; probable stripped Btb soil horizon developed in tuff residuum
- Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff

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TRENCH 2, 1A AND 1B

Figure
4a

LEGEND

- Unit 1 Loess/ re-worked loess with thin A soil horizon; silty sand
- Unit 2 Reddish-brown sandy clay often with roots; probable stripped Btb soil horizon developed in tuff residuum
- Unit 3 Lightly-welded to nonwelded, coarsely crystalline Bandelier Tuff
- 1-2 mm CaCO₃ stringer, probably not contemporaneous with fracture T2-8

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TRENCH 2, 2A AND 2B

Figure
4b

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TRENCH 3
INDEX OF DETAILED TRENCH LOGS

Figure
5

LEGEND

- Unit 1 Loess/ re-worked loess with thin A soil horizon; silty sand
- Unit 2 Reddish-brown sandy clay often with roots; probable stripped Btb soil horizon developed in tuff residuum
- Unit 3 Lightly-welded to nonwelded, coarsely crystalline Bandelier Tuff

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TRENCH 3, 1A AND 1B

Figure
5a

LEGEND

- Unit 1 Loess/ re-worked loess with thin A soil horizon; silty sand
- Unit 2 Reddish-brown sandy clay often with roots; probable stripped Btb soil horizon developed in tuff residuum
- Unit 3 Lightly-welded to nonwelded, coarsely crystalline Bandelier Tuff

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TRENCH 3, 2A AND 2B

Figure
5b

LEGEND

- Unit 1 Loess/ re-worked loess with thin A soil horizon; silty sand
- Unit 2 Reddish-brown sandy clay often with roots; probable stripped Btb soil horizon developed in tuff residuum
- Unit 3 Lightly-welded to nonwelded, coarsely crystalline Bandelier Tuff

STRING LINE

T3-22
N 12° E
62° E

3-4A

60 59 58 57

STRING LINE

Unit 3

3-4B

0 69 68 67 66.5

LEGEND

Unit 1 Loess/ re-worked loess with thin A soil horizon; silty sand

Unit 2 Reddish-brown sandy clay often with roots; probable stripped Btb soil horizon developed in tuff residuum

Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff

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TRENCH 3, 4A AND 4B

Figure
5d

3-5A

79 78 77 76

3-5B

88 87 86 85.5

LEGEND

- Unit 1 Loess/ re-worked loess with thin A soil horizon; silty sand
- Unit 2 Reddish-brown sandy clay often with roots; probable stripped Btb soil horizon developed in tuff residuum
- Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff

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TRENCH 3, 5A AND 5B

Figure
5e

- ### LEGEND
- Unit 1 Loess/ re-worked loess with thin A soil horizon; silty sand
  - Unit 2 Reddish-brown sandy clay often with roots; probable stripped Btb soil horizon developed in tuff residuum
  - Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff

Project No. 92C0774	LANL TA-63	TRENCH 3, 6A AND 6B	Figure 5f
Woodward-Clyde Federal Services			

LEGEND

Unit 1 Loess/ re-worked loess with thin A soil horizon; silty sand

Unit 2 Reddish-brown sandy clay often with roots; probable stripped Btb soil horizon developed in tuff residuum

Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff

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TRENCH 3, 7A AND 7B

Figure
5g

LEGEND

- Unit 1 Loess/ re-worked loess with thin A soil horizon; silty sand
- Unit 2 Reddish-brown sandy clay often with roots; probable stripped Btb soil horizon developed in tuff residuum
- Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff

Project No. 92C0774	LANL TA-63	TRENCH 3, 8A AND 8B	Figure 5h
Woodward-Clyde Federal Services			

LEGEND

Unit 1 Loess/ re-worked loess with thin A soil horizon; silty sand

Unit 2 Reddish-brown sandy clay often with roots; probable stripped Btb soil horizon developed in tuff residuum

Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff

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Woodward-Clyde Federal Services			

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TRENCH 4
INDEX OF DETAILED TRENCH LOGS

Figure
6

LEGEND

- Unit 1 Silty sand; loess/re-worked loess containing a platy soil Ap horizon (plowed zone)
- Unit 2 Sandy silt containing a poorly developed buried soil B horizon
- Unit 3 Strongly-developed, stripped, buried soil B horizon
- Unit 4 Lithified, cross-bedded, fine to medium grain sand; probable surge deposit
- Unit 5 Coarsely crystalline, fractured, nonwelded to lightly-welded Bandelier Tuff
- ① Void filled with coarse crystals and clay with dacite gravel

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TRENCH 4, 1A AND 1B

Figure
6a

LEGEND

- Unit 1 Silty sand; loess/re-worked loess containing a platy soil Ap horizon (plowed zone)
- Unit 2 Sandy silt containing a poorly developed buried soil B horizon
- Unit 3 Strongly-developed, stripped, buried soil B horizon
- Unit 4 Lithified, cross-bedded, fine to medium grain sand; probable surge deposit
- Unit 5 Coarsely crystalline, fractured, nonwelded to lightly-welded Bandelier Tuff
- ① Void filled with coarse crystals and clay with dacite gravel

Project No. 92C0774	LANL TA-63	TRENCH 4, 2A AND 2B	Figure 6b
Woodward-Clyde Federal Services			

T4-16
N 5° E
90°

4-3A

43 44 45

LEGEND

- Unit 1 Silty sand; loess/re-worked loess containing a platy soil Ap horizon (plowed zone)
- Unit 2 Sandy silt containing a poorly developed buried soil B horizon
- Unit 3 Strongly-developed, stripped, buried soil B horizon
- Unit 4 Lithified, cross-bedded, fine to medium grain sand; probable surge deposit
- Unit 5 Coarsely crystalline, fractured, nonwelded to lightly-welded Bandelier Tuff
- ① Void filled with coarse crystals and clay with dacite gravel

4-3B

52 53 54

Project No. 92C0774	LANL TA-63	TRENCH 4, 3A AND 3B	Figure 6c
Woodward-Clyde Federal Services			

LEGEND

- Unit 1 Silty sand; loess/re-worked loess containing a platy soil Ap horizon (plowed zone)
- Unit 2 Sandy silt containing a poorly developed buried soil B horizon
- Unit 3 Strongly-developed, stripped, buried soil B horizon
- Unit 4 Lithified, cross-bedded, fine to medium grain sand; probable surge deposit
- Unit 5 Coarsely crystalline, fractured, nonwelded to lightly-welded Bandelier Tuff
- ① Void filled with coarse crystals and clay with dacite gravel

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TRENCH 4, 4A AND 4B

Figure
6d

LEGEND

- Unit 1 Silty sand; loess/re-worked loess containing a platy soil Ap horizon (plowed zone)
- Unit 2 Sandy silt containing a poorly developed buried soil B horizon
- Unit 3 Strongly-developed, stripped, buried soil B horizon
- Unit 4 Lithified, cross-bedded, fine to medium grain sand; probable surge deposit
- Unit 5 Coarsely crystalline, fractured, nonwelded to lightly-welded Bandelier Tuff
- Location of sample for paleomagnetic analysis
- Void filled with coarse sand size crystals and clay

Project No. 92C0774	LANL TA-63	TRENCH 4, 5A AND 5B	Figure 6e
Woodward-Clyde Federal Services			

LEGEND

	Unit 1 Silty sand; loess/re-worked loess containing a platy soil Ap horizon (plowed zone)
	Unit 2 Sandy silt containing a poorly to moderately developed buried soil B horizon
	Unit 3 Strongly-developed, stripped, buried soil B horizon
	Unit 4 Lithified, cross-bedded, fine to medium grain sand; probable surge deposit
	Unit 5 Coarsely crystalline, fractured, nonwelded to lightly-welded Bandelier Tuff
	Location of sample for paleomagnetic analysis
	Location of thin section sample

Project No. 92C0774	LANL TA-63	TRENCH 4, 6A AND 6B	Figure 6f
Woodward-Clyde Federal Services			

LEGEND

- Unit 1 Silty sand; loess/re-worked loess containing a platy soil Ap horizon (plowed zone)
- Unit 2 Sandy silt containing a poorly to moderately developed buried soil B horizon
- Unit 4 Lithified, cross-bedded, fine to medium grain sand; probable surge deposit
- Unit 5 Coarsely crystalline, fractured, nonwelded to lightly-welded Bandelier Tuff

T4 PM 1 Location of sample for paleomagnetic analysis

TA-63 T4 TS 1 Location of thin section sample

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TRENCH 4, 7A

Figure
6g

Project No. 92C0774A	LANL TA - 63	TRENCH 5 INDEX OF DETAILED TRENCH LOGS	Figure 7
Woodward-Clyde Federal Services			

LEGEND

Unit 1a Silty sand; loess/re-worked loess containing a granular to platy soil Ap horizon (plowed)

Unit 1b Silty sand as above, but with a massive to very large blocky structure

Unit 2a Sandy silt with clay; buried soil B horizon with moderate, medium, angular blocky structure

Unit 2b Blocks of tuff with a clay to sandy clay matrix; clay accumulation is, in part, related to Unit 2a, but may reflect translocation from other soil B horizons prior to Unit 2a

Unit 2c Residuum containing a matrix of silty sand with little or no clay. May be a subunit of Unit 1

Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff

Unit 4 Void or gas-pipe filled with coarse crystals, clay and, commonly, dacite clasts

Unit 5 Coarsely crystalline, fractured, nonwelded to lightly-welded Bandelier Tuff

Radiocarbon sample locations. T5-RCS-1 and T5-RCS-2 C-14 age years B.P. 980 +/- 60 using standard sample technique on charcoal

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Woodward-Clyde Federal Services

TRENCH 5, 1A AND 1B

Figure
7a

West

LEGEND

Unit 1a Silty sand; loess/re-worked loess containing a granular to platy soil Ap horizon (plowed)

Unit 1b Silty sand as above, but with a massive to very large blocky structure

Unit 2a Sandy silt with clay; buried soil B horizon with moderate, medium, angular blocky structure

Unit 2b Blocks of tuff with a clay to sandy clay matrix; clay accumulation is, in part, related to Unit 2a, but may reflect translocation from other soil B horizons prior to Unit 2a

Unit 2c Residuum containing a matrix of silty sand with little or no clay. May be a subunit of Unit 1

Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff

Unit 4 Void or gas-pipe filled with coarse crystals, clay and, commonly, dacite clasts

Unit 5 Coarsely crystalline, fractured, nonwelded to lightly-welded Bandelier Tuff

West

Project No.
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Woodward-Clyde Federal Services

TRENCH 5, 2A AND 2B

Figure
7b

LEGEND

- Unit 1a Silty sand; loess/re-worked loess containing a granular to platy soil Ap horizon (plowed)
- Unit 1b Silty sand as above, but with a massive to very large blocky structure
- Unit 2a Sandy silt with clay; buried soil B horizon with moderate, medium, angular blocky structure
- Unit 2b Blocks of tuff with a clay to sandy clay matrix; clay accumulation is, in part, related to Unit 2a, but may reflect translocation from other soil B horizons prior to Unit 2a
- Unit 2c Residuum containing a matrix of silty sand with little or no clay. May be a subunit of Unit 1
- Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff
- Unit 4 Void or gas-pipe filled with coarse crystals, clay and, commonly, dacite clasts
- Unit 5 Coarsely crystalline, fractured, nonwelded to lightly-welded Bandelier Tuff

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TRENCH 5, 3A AND 3B

Figure
7c

LEGEND

Unit 1a Silty sand; loess/re-worked loess containing a granular to platy soil Ap horizon (plowed)

Unit 1b Silty sand as above, but with a massive to very large blocky structure

Unit 2a Sandy silt with clay; buried soil B horizon with moderate, medium, angular blocky structure

Unit 2b Blocks of tuff with a clay to sandy clay matrix; clay accumulation is, in part, related to Unit 2a, but may reflect translocation from other soil B horizons prior to Unit 2a

Unit 2c Residuum containing a matrix of silty sand with little or no clay. May be a subunit of Unit 1

Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff

Unit 4 Void or gas-pipe filled with coarse crystals, clay and, commonly, dacite clasts

Unit 5 Coarsely crystalline, fractured, nonwelded to lightly-welded Bandelier Tuff

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TRENCH 5, 4A AND 4B

Figure
7d

LEGEND

Unit 1a Silty sand; loess/re-worked loess containing a granular to platy soil Ap horizon (plowed)

Unit 1b Silty sand as above, but with a massive to very large blocky structure

Unit 2a Sandy silt with clay; buried soil B horizon with moderate, medium, angular blocky structure

Unit 2b Blocks of tuff with a clay to sandy clay matrix; clay accumulation is, in part, related to Unit 2a, but may reflect translocation from other soil B horizons prior to Unit 2a

Unit 2c Residuum containing a matrix of silty sand with little or no clay. May be a subunit of Unit 1

Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff

Unit 4 Void or gas-pipe filled with coarse crystals, clay and, commonly, dacite clasts

Unit 5 Coarsely crystalline, fractured, nonwelded to lightly-welded Bandelier Tuff

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TRENCH 5, 5A AND 5B

Figure
7e

West

LEGEND

Unit 1a Silty sand; loess/re-worked loess containing a granular to platy soil Ap horizon (plowed)

Unit 1b Silty sand as above, but with a massive to very large blocky structure

Unit 2a Sandy silt with clay; buried soil B horizon with moderate, medium, angular blocky structure

Unit 2b Blocks of tuff with a clay to sandy clay matrix; clay accumulation is, in part, related to Unit 2a, but may reflect translocation from other soil B horizons prior to Unit 2a

Unit 2c Residuum containing a matrix of silty sand with little or no clay: May be a subunit of Unit 1

Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff

Unit 4 Void or gas-pipe filled with coarse crystals, clay and, commonly, dacite clasts

Unit 5 Coarsely crystalline, fractured, nonwelded to lightly-welded Bandelier Tuff

West

Project No.
92C0774

LANL TA-63

Woodward-Clyde Federal Services

TRENCH 5, 7A AND 7B

Figure
7g

West

LEGEND

- Unit 1a Silty sand; loess/re-worked loess containing a granular to platy soil Ap horizon (plowed)
- Unit 1b Silty sand as above, but with a massive to very large blocky structure
- Unit 2a Sandy silt with clay; buried soil B horizon with moderate, medium, angular blocky structure
- Unit 2b Blocks of tuff with a clay to sandy clay matrix; clay accumulation is, in part, related to Unit 2a, but may reflect translocation from other soil B horizons prior to Unit 2a
- Unit 2c Residuum containing a matrix of silty sand with little or no clay. May be a subunit of Unit 1
- Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff
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⊙ Radiocarbon sample locations. T5-RCS-3, C-14 age years B.P. 60 +/- 50. T5-RCS-2 C-14 age years B.P. 1130 +/- 60, both using standard sample technique on charcoal

West

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TRENCH 5, 6A AND 6B

Figure
7f

LEGEND

Unit 1a Silty sand; loess/re-worked loess containing a granular to platy soil Ap horizon (plowed)

Unit 1b Silty sand as above, but with a massive to very large blocky structure

Unit 2a Sandy silt with clay; buried soil B horizon with moderate, medium, angular blocky structure

Unit 2b Blocks of tuff with a clay to sandy clay matrix; clay accumulation is, in part, related to Unit 2a, but may reflect translocation from other soil B horizons prior to Unit 2a

Unit 2c Residuum containing a matrix of silty sand with little or no clay. May be a subunit of Unit 1

Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff

Unit 4 Void or gas-pipe filled with coarse crystals, clay and, commonly, dacite clasts

Unit 5 Coarsely crystalline, fractured, nonwelded to lightly-welded Bandelier Tuff

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TRENCH 5, 8A AND 8B

Figure
7h

LEGEND

Unit 1a Silty sand; loess/re-worked loess containing a granular to platy soil Ap horizon (plowed)

Unit 1b Silty sand as above, but with a massive to very large blocky structure

Unit 2a Sandy silt with clay; buried soil B horizon with moderate, medium, angular blocky structure

Unit 2b Blocks of tuff with a clay to sandy clay matrix; clay accumulation is, in part, related to Unit 2a, but may reflect translocation from other soil B horizons prior to Unit 2a

Unit 2c Residuum containing a matrix of silty sand with little or no clay. May be a subunit of Unit 1

Unit 3 Lightly welded to nonwelded, coarsely crystalline Bandelier Tuff

Unit 4 Void or gas-pipe filled with coarse crystals, clay and, commonly, dacite clasts

Unit 5 Coarsely crystalline, fractured, nonwelded to lightly-welded Bandelier Tuff

5.0 CONCLUSIONS

There is no geomorphic evidence for Holocene active faulting at TA-63. Approximately 6 km to the north, however, Holocene activity has been demonstrated along the Guaje Mountain fault (Gardner et al., 1990), where up to 12 m of post-Bandelier (<1.1 Ma) apparent vertical displacement has been documented. At TA-63, no vertical displacement of the Bandelier Tuff is evident. Additional evidence against Holocene activity at TA-63 can be drawn from comparison of the projected Guaje Mountain fault near TA-63 to the Guaje Mountain and Rendija Canyon faults to the north. Based on geomorphic and paleoseismic evidence gathered from our current seismic hazard studies and from previous studies (Gardner et al., 1990), these two faults have similar styles and amounts of deformation. At the Guaje Pines Cemetery to the north, the Rendija Canyon fault is associated with a prominent scarp, approximately 3 m high. At this location, at least one Holocene event has been documented in the trenches along the fault. The associated apparent vertical displacement is a minimum of 1 to 1.5 m and possibly up to 2 to 3 m. By comparison, no scarps were identified within TA-63 or adjacent to the site along the fault projection proposed by Vaniman and Wohletz (1990). This suggests that either the fault dies out to the north of the site or that late Pleistocene displacements have been too small to be preserved on the mesa surface in the Bandelier Tuff. Thus, if coseismic rupture does occur along structures adjacent to or within the TA-63 boundary during 1 to 3 m displacement events to the north, the amount of vertical displacement is either negligible along an individual fault plane or the displacement is distributed across a broad zone. Thus, individual fractures or faults would move less than a few mm per event which might not be detectable in the trench exposures.

Based on our field observations, we conclude:

- The trenches exposed Unit 3, of the Tshirege member of the 1.1 Ma Bandelier Tuff surge, sheetwash colluvial or possibly fluvial deposits and a thin veneer of loess or reworked loess. The northwest half of the site, consisting of a gentle easterly slope, also has two soils developed on the fine grained deposits. The southeast half of the site and the vicinity of Trench 5 have steeper slopes and are adjacent

to the mesa edges. Few deposits occur above the tuff and the record of soil development is mostly confined to depressions that have escaped erosion.

- Based on previous investigations by Vaniman and Wohletz (1990), the Guaje Mountain fault has been projected to cross near the northwestern corner of TA-63. No geomorphic evidence of Holocene faulting is present within or adjacent to TA-63. Fracturing within the Bandelier Tuff is present throughout all of the trenches.
- Fractures are narrow (less than 1 cm) toward the west of the site nearest the projection of the Guaje Mountain fault. Fractures to the east tend to be wider (1 to 3 cm) and filled with a reddish-yellow clayey sand. Fracture frequency did not significantly increase toward or within the fault projection and there appears to be little correlation between frequency and width. The increase in average fracture width toward the mesa edge to the east is probably due to settling and mass wasting of Tuff blocks along existing fractures.
- In the northwest half of the site where most of the post-Bandelier (1.1 Ma) deposits occur, most fractures within the tuff do not continue upward into the younger units. Where fractures do continue upward into younger deposits, their character significantly changes and they appear to be related to roots, weather, and other pedogenic processes.
- Fractures dominantly strike north-northeast and are subvertical.
- Evidence against recent fracture activity is provided by a dense reddish-brown clay overlying and commonly partially filling fractures where preserved. This clay probably represents residual accumulation from one or, possibly, more pedogenic B horizon(s). Additionally, the character of most fracture fills is distinctly different from overlying deposits in color, texture, and composition.
- One constraint on a minimum age of fracture fill and a maximum age for the overlying soil B horizon is provided by fracture T2-2 in Trench 2. The upper 10 cm of fracture fill containing El Cajete pumice (approximately 150 ka) is overlain by reddish brown clay of the buried soil B horizon.

- The majority of the fractures are very small tensional openings and are not faults. No evidence of repeated movement along the fractures is evident.
- Slickensides, which indicate that past movement has taken place, are present within the clay filling of only a few fractures. In general, the slickensides are nearly horizontal.
- Our assessment is that the slickensides probably reflect gravitational slip of individual blocks of Bandelier tuff toward the drainages along the eastern boundary of the site. The motion appears to be relatively small (less than a few cm between blocks) based on the apparent separation within the fractures.
- In several locations, apparent vertical steps in the surface of the Bandelier tuff occur above vertical fractures. In most instances, these steps cannot be located on the opposing wall of the trench. We interpret these features to be the result of root heaving of the tuff during tree fall.
- Based on preserved soils and deposits, a reasonable reconstruction of the geologic and pedologic history of the TA-63 site would include: 1) deposition of Unit 3 of the Tshirege Member of the Bandelier Tuff; 2) deposition of a surge bed (Trench 4, Unit 4); 3) cooling and fracturing of the tuff including formation of irregular shaped voids and pipes; 4) filling of fractures, pipes, and voids, 5) erosion of the tuff surface including channels (Trench 1 188 to 208 m); 6) eruption and transport of El Cajete pumice into exposed fractures (e.g., Trench 2, T2-2); 7) depositions of channel fill (Trench 1, Unit 5); 8) formation of a soil (e.g., Trench 1, Unit 4 and Trench 4, Unit 3); 9) surface erosion (Trench 1 200 to 206 m); 10) deposition (Trench 1 Unit 3); 11) erosion, deposition and soil formation (e.g., Trench 1 and 4, Unit 2); 12) erosion followed by deposition of loess (e.g., Trench 1, 130 to 137 m and Trench 4, 48 to 51 m); and 13) reworking of the loess and development of a thin soil A horizon.
- Holocene movement along each individual fracture cannot be precluded due to a lack of continuous late Quaternary deposits over the entire site; however, the lack of geomorphic expression, lack of offset along the top of the Bandelier tuff at

fracture locations, and lack of displacement within probable pre-Holocene deposits and soils supports the contention that Holocene faulting at the site is probably absent or possibly too small to detect and hence not significant.

REFERENCES

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- Aldrich, M. J., 1986, Tectonics of the Jemez Lineament in the Jemez Mountains and Rio Grande rift: *Journal of Geophysical Research*, v. 91, p. 1753-1762.
- Aldrich, M. J., and Dethier, D. P., 1990, Stratigraphic and tectonic evolution of the northern Española basin, Rio Grande rift, New Mexico: *Geological Society of America Bulletin*, v. 102, p. 1695-1705.
- Anderson, E. M., 1905, Dynamics of faulting, *Edinburgh Geological Society Transactions*, v. 8, pt. 3, p. 387-402.
- Angelier, J., 1984, Tectonic analysis of fault slip data sets: *Journal of Geophysical Research*, v. 89, p. 5835-5848.
- Angelier, J., Colletta, B., and Anderson, R. E., 1985, Neogene paleostress changes in the Basin and Range: A case study at Hoover Dam, Nevada- Arizona: *Geological Society of America Bulletin*, v. 96, p. 347-361.
- Baltz, E. H., 1976, Seismotectonic analysis of the central Rio Grande rift, New Mexico; A progress report on geological investigations: *U.S. Geological Survey Administrative Report*.
- Birkeland, P.W., 1984, *Soils and Geomorphology*: Oxford University Press, 372 p.
- Budding, A. J., 1978, Subsurface geology of the Pajarito Plateau: interpretation of gravity data: *New Mexico Bureau of Mines and Mineral Resources, Circular 163*, p. 196-198.
- Chapin, C. E., 1979, Evolution of the Rio Grande rift: A summary: *in* Rio Grande rift: Tectonics and Magmatism, R. E. Rieker, ed., *American Geophysical Union Special Publication*, p. 1-16.
- Chapin, C. E., and Seager, W.R., 1975, Evolution of the Rio Grande rift in Socorro and Los Cruces areas: *New Mexico Geological Society, 26th field conference, guidebook*, p. 297-321.
- Crowe, B. M., Linn, G. W., Heiken, G., and Bevier, M. L., 1978, Stratigraphy of the Bandelier Tuff in the Pajarito Plateau: *Los Alamos National Laboratory Report, LA-7225-MS*.

- Dames and Moore, 1972, Report of geologic, foundation, hydrologic, and seismic investigation: Plutonium Processing Facility, Los Alamos Scientific Laboratory, Los Alamos, NM, unpublished report prepared for LASL.
- DeGraff, J. M., and Aydin, A., 1987, Surface morphology of columnar joints and its significance to mechanics and direction of joint growth: Geological Society of America Bulletin, v. 99, p. 605-617.
- Doell, R. R., Dalrymple, G. B., Smith, R. L., and Bailey, R. A., 1968, Paleomagnetism, potassium-argon ages, and geology of rhyolites and associated rocks of the Valles caldera: Geological Society of America Memoir 116, p. 211-248.
- Dransfield, B.J., and Gardner, 1985, Subsurface geology of the Pajarito Plateau, Española Basin, New Mexico: Los Alamos National Laboratory Report LA-10455-MS.
- Gardner, J. N., 1985, Tectonic controls of petrologic evolution of the Keres Group: Implications for the development of the Jemez volcanic field, New Mexico: Ph.D. dissertation, University of California, Davis.
- Gardner, J. N., 1990, Results of geological setting of TA-SS Project: Los Alamos National Laboratory Memorandum EES1-SH90-18.
- Gardner, J. N., and Goff, F., 1984, Potassium-argon dates from the Jemez volcanic field: Implications for tectonic activity in the north-central Rio Grande rift: New Mexico Geological Society Guidebook 35, p. 75-81.
- Gardner, J. N., and House, L., 1987, Seismic hazard investigations at Los Alamos National Laboratory, 1984 to 1985: Los Alamos National Laboratory Report LA- 11072-MS, 76 p.
- Gardner, J. N., Goff, F., Garcia, S., and Hagan, R. C., 1986, Stratigraphic relations and lithologic variations in the Jemez Volcanic field, New Mexico: Journal of Geophysical Research, v. 91, p. 1763-1778.
- Gardner, J. N., Baldrige, W. S., Gribble, R., Manley, K., Tanaka, K., Geissman, J. W., Gozalez, M., and Baron, G., 1990, Results from seismic hazards trench #1 (SHT-1): Los Alamos Seismic Hazards Investigations Report EES1-SH90-19, 57 p.
- Golombek, M. P., 1983, Geology, structure, and tectonics of the Pajarito fault zone in the Espanola basin of the Rio Grande rift, New Mexico: Geological Society of America Bulletin, v. 94, p. 192-205.

- Gonzalez, M. A., and Dethier, D. P., 1991, Geomorphic and neotectonic evolution along the margin of the Colorado Plateau and Rio Grande rift, northern New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 137, p. 29-45.
- Griggs, R.L., 1964, Geology and groundwater resources of the Los Alamos area, New Mexico: U.S. Geological Survey Water Supply Report 1753.
- House, L., and Cash, D. J., 1988, A review of historic and instrumental earthquake activity and studies of seismic hazards near Los Alamos, New Mexico: Los Alamos National Laboratory Report LA-11323-MS, 41 p.
- Ingersoll, R.V., Cavazza, W., Baldrige, W.S., and Shafiqullah, M., 1990, Cenozoic sedimentation and paleotectonics of north-central New Mexico: Implications for initiation and evolution of the Rio Grande rift: Geological Society of America Bulletin, v. 102, p. 1280-1296.
- Kamb, W. B., 1959, Ice petrofabrication observations from Blue Glacier, Washington, in relation to theory and experiment: Journal of Geophysical Research, v. 64, p. 1891-1909.
- Long, P. E., and Wood, B. J., 1986, Structures, textures and cooling histories of Columbia River basalt flows: Geological Society of America Bulletin, v. 97, p. 1144-1155.
- Machette, M.N. and Personius, S. F., 1984, Map of Quaternary and Pleistocene faults in the eastern part of the Aztec 1° x 2° quadrangle and the western part of the Raton 1° x 2° quadrangle, northern New Mexico, U.S. Geological Survey Map MF-1465-B, Scale 1:250,000.
- Manley, K., 1979, Stratigraphy and structure of the Espanola Basin, Rio Grande Rift, New Mexico, in Rio Grande Rift: Tectonics and Magmatism, Riecker, R. E., ed., American Geophysical Union Special Publication, pp. 71-86.
- Muehlberger, W. R., 1979, Embudo fault between Pilar and Arroyo Hondo, New Mexico: an active intracontinental transform fault: New Mexico Geological Society, 30th Field Conference, Guidebook, p. 77-82.
- Olsen, K. H., 1979, The seismicity of north-central New Mexico with particular reference to the Cerillos earthquake of May 28, 1918: New Mexico Geological Society Guidebook 30, p. 65-75.
- Pollard, D. D., and Aydin, A., 1988, Progress in understanding jointing over the past century: Geological Society of America Bulletin, v. 100, p. 1181-1204.

- Sanford, S. R., Olsen, K. H., and Jaksha, L. H., 1979, Seismicity of the Rio Grande rift: Rio Grande rift: Tectonics and Magmatism, R. E. Reicker, ed., American Geophysical Union, Special Publication, p. 145-168.
- Self, S., Kircher, D.E., and Wolff, J.A., 1988, The El Cajete Series, Valles Caldera, New Mexico: Journal of Geophysical Research, v. 93, p. 6113-6127.
- Smith, R. L., Bailey, R. A., and Ross, C. S., 1970, Geologic map of the Jemez Mountains, New Mexico: U. S. Geological Survey Miscellaneous Investigations Map, I-571.
- Spell, T.L., and Harrison, T.M., 1993, $^{40}\text{Ar}/^{39}\text{Ar}$ Geochronology of Post-Valles Caldera Rhyolites, Jemez Volcanic Field, New Mexico: Journal of Geophysical Research, v. 98, p. 8031-8051.
- Sylvester, A. G., 1988, Strike-slip faults: Geological Society of America Bulletin, v. 100, p. 1666-1703.
- Terzaghi, R., 1965, Sources of error in joint surveys: Geotechnique, v. 5, p. 287.
- Vaniman, D., and Wohletz, K., 1990, Results of geologic mapping/fracture studies: TA-55 area: Los Alamos National Laboratory Memorandum No. EES1-SH90-17.
- Wachs, D., Harrington, C.D., Gardner, J. N., and Maassen, L. W., 1988, Evidence of young fault movements on the Pajarito fault system in the area of Los Alamos, New Mexico: Los Alamos National Laboratory Report LA-11156-MS, 23 p.
- Wong, I., Hemphill-Haley, M., Kelson, K., Kolbe, T., Green, R., Kanakari, H., Bott, J., Silva, W., Haraden, C., Gardner, J., House, L., and Reneau, S., 1993, Seismic hazards evaluation of the Los Alamos National Laboratory, 3 Volumes, unpublished report prepared for the Los Alamos National Laboratory.
- Wilcox, R. E., Harding, T. P., and Seely, D. R., 1973, Basic wrench tectonics: American Association of Petroleum Geologists Bulletin, v. 57, p. 74- 96.
- Zoback, M. L., Zoback, M. D., Adams, J., Bell, S., Suter, M., Suarez, G., Jacob, K., Estabrook, C., and Magee, M., 1991, Stress map of north America: The Geological Society of America Continent-scale Map-005, Scale 1:5,000,000.

APPENDIX A

STRUCTURAL ANALYSIS

INTRODUCTION

We conducted a structural analysis of fractures and shears observed in the TA-63 exploratory trenches to provide information about their probable origin. Because of concern about coseismic surface faulting due to the close proximity of TA-63 to the projected Guaje Mountain fault (Vaniman and Wohletz, 1990), we attempted to assess whether the fault or a significant trace of the fault might cross the facility boundary. Trenches excavated across the Rendija Canyon fault at the Guaje Pines Cemetery (approximately 5.5 km north of TA-63) exposed a relatively narrow (< 4 m) zone of dominantly vertical (down-to-the-west) displacement along a fault dipping greater than 60° W. At that location late Pleistocene and Holocene surface faulting events have formed at minimum a 2.5 m high scarp in displaced fluvial and debris flow deposits. An exposure of the Rendija Canyon fault at the Los Alamos County landfill (approximately 2.3 km northwest of TA-63) revealed a zone of shear greater than 22 m wide. Characteristics of the fault at this location included horst and graben structures with apparent vertical separations of up to 3 m. Smaller scale normal and reverse faults are located within the zone of shearing. No prominent, large displacement faults or fault zone were identified in this investigation with characteristics similar to those observed along exposures of the Rendija Canyon fault to the north. Because no structures directly attributable to primary movement along the Guaje Mountain fault were exposed at the TA-63 site, six models of origin were for fractures found in the trenches:

- (1) the fractures result from secondary faulting associated with movement along the Guaje Mountain fault and are tectonically derived (this includes fractures formed as a result of stress concentrations at the tip of the Guaje Mountain fault);
- (2) the fractures are part of a broad network of small conjugate faults within the Bandelier Tuff possibly related to the Guaje Mountain, Rendija Canyon, and Pajarito faults, and tectonically derived;

- (3) the fractures are due to shallow mass-wasting of the Bandelier Tuff toward Cañada del Buey to the east and south of TA-63 and are not tectonically derived;
- (4) the fractures are cooling features of the Tshirege member of the Bandelier Tuff and are not tectonically derived.
- (5) fractures were formed by tree roots.

We have examined these hypotheses by evaluating the fractures exposed in the exploratory trenches. The fracture analysis was conducted with the intent of providing a basis for selecting the appropriate model. Based on the character of the fractures, their orientations, the lack of evidence for demonstrable offset along the fractures, and patterns of fracture density throughout the trenches, we believe that most of the steeply-dipping fractures probably formed during cooling of the tuff, whereas shallow dipping and irregular fractures probably were formed by tree roots and/or mass wasting. However, it should be noted that the possibility that some fractures were tectonically derived cannot be precluded by our results.

For the purposes of this study, fractures were divided into two groups; faults and joints, based on the presence or absence of slickensides. Faults are defined here as those fractures in which displacements are dominantly shear and joints are those in which the displacement consists of their opening (Pollard and Aydin, 1988). Some joints may have other origins including shearing, where shear fabric is not preserved, opening by tree roots, or by clay infilling and frost wedging.

POSSIBLE MODELS FOR OBSERVED JOINT AND FAULT FORMATION

Secondary Faulting

Secondary faulting as a result of movement along the nearby Guaje Mountain fault, might be responsible for fractures observed within the tuff. This subsidiary faulting might be characterized by small faults or joints, depending on the amount of slip along the main fault (e.g., Wilcox et al., 1973). Two fracture surveys conducted along the mesa reported an increase in fracture frequency and fracture opening toward the projected locations of the

Guaje Mountain and Rendija Canyon faults (Vaniman and Wohletz, 1990). The surveys indicated that the average strike of fractures near the fault projections were approximately north-northeast.

The style of deformation along secondary faults is comparable to that of the primary fault, thus normal displacement along the main fault would be accompanied by normal motion on parallel secondary faults. Ideally, in the case of strike-slip faulting, two sets of secondary faults would form, synthetic and antithetic faults (Riedel and conjugate Riedel shears, respectively) (Wilcox et al., 1973; Sylvester, 1988). The angles between these faults vary with the amount of rotation about the main fault; however, the Riedel and conjugate Riedel shears should occur at 10° to 30° and 70° to 90° , respectively, to the main fault (Wilcox et al., 1973). Vertical offsets along the Guaje Mountain fault die out south of Los Alamos Canyon (Wong et al., 1993). If the Guaje Mountain fault is growing southward, however, stress concentrations at the southern fault tip can cause secondary fractures south of the fault tip.

Conjugate Fractures

Conjugate fractures are pairs of fractures or fracture sets that intersect at angles of ϕ and $-\phi$ to the direction of shortening, where ϕ is the angle of internal friction of the rock mass (e.g. Anderson, 1905; Sylvester, 1988). These fracture sets would reflect pure shear resulting from tectonic stresses that prevailed at the time they last moved. Evidence for conjugate fracturing would be nearly equal but opposite senses of displacement between sets of faults that are oriented roughly symmetrical to the principal shortening direction and that appear to have been activated nearly simultaneously.

Shallow Mass Wasting

Shear displacements may be the result of mass wasting due to erosion of Bandelier Tuff into nearby canyons. Steep-walled canyons bound the local mesas and mass wasting on a large-scale has been reported at some locations (Gardner, 1990). Gravitational forces might cause dislocated blocks of fractured tuff to slide or rotate toward the mesa edges. Fracture shear fabric could be the result of differential movement between individual blocks. Evidence supporting this model might be increased fracture frequency and fracture width toward the mesa edge relative to the interior of the mesa and an increase in the vertical component of

slip along fractures nearer to the mesa edge. Phenomena that might also be identified to be associated with gravitational displacements would be open fractures and block instability (e.g., toppling) near the mesa edge.

Cooling Fractures

Cooling of the Bandelier Tuff may have been responsible for formation of cooling fractures. Much of the investigation of cooling-related structures has been directed toward basaltic lavas (DeGraff and Aydin, 1987). DeGraff and Aydin (1987) describe the majority of cooling fractures, formed in lavas ranging from rhyolitic (similar to Bandelier Tuff) to basaltic, to form polygonal or column forms. Long and Wood (1986) describe cooling features in flood basalts of the Columbia River Basalt Group as having columnar or colonnade structure near the lower 10% to 30% of flows and possibly the upper 10% to 20%. The central 60% to 70% of the flows were commonly occupied by entablature structures, having smaller, irregular columns and sub-vertical, irregular fractures.

Tree Roots

Trees are abundant in the TA-63 area and there is no reason to suspect that climate change in the Quaternary was sufficient to alter the pattern of vegetation significantly. Root growth along vertical and horizontal zones of weakness may, over time and many generations, be sufficient to create a significant number of surface fractures.

DATA ANALYSIS

The frequency, width, and orientation of fractures and characteristics of infilling material were recorded for this analysis. Fractures that extend across the width of the trench and have a dip greater than 45° were selected. These fractures were judged to be the most likely to yield information related to origin. Fractures were defined as faults based on evidence of movement such as shear fabric or slickensides regardless of tectonic or non-tectonic origin. Fractures without evidence for movements were referred to as joints although fault displacement on some of them cannot be ruled out. Strikes and dips of faults and fractures are tabulated along with orientations of slickensides in Tables 2a, 2b, 4, 5a, 5b, 7, 9a and 9b. Contoured stereonet plots of poles to fracture planes are shown in Figure 8.

Six faults were identified in the trench exposures based on presence of slickensides or shear fabric. The rakes were determined for five of the faults based on slickenside data. Three nearby vertical faults strike N36°W, N42°W, and N57°W and intersect Trenches 1, 2, and 3, respectively. Two of these faults have horizontal slickensides suggesting horizontal motion; however, slickensides were preserved on clay fracture fill and not on tuff surfaces. Therefore, the slickensides could have formed during repeated cycles of wetting and drying of the clay and not be tectonically derived (Birkeland, 1984). Additionally, there was no evidence of offset.

Three nearly vertical faults with northeast strikes were also noted: the first intersects Trench 1, strikes N18°E and has horizontal slickensides; the second intersects Trench 2, strikes N58°E has slickensides that plunge 8° to the northeast; and the third fault intersects Trench 3, and has slickensides that plunge 45° to the northeast. This fault is located near the mesa edge at the southeast part of the site; the strike of the fault is roughly parallel to the strike of the cliff face.

Fracture Frequency and Width

The frequency of observed fractures and their associated widths were plotted on plan view to assess whether frequency and width are affected by proximity to the Guaje Mountain fault or the mesa edge (Figure 2). Fractures were counted and their frequencies plotted within 15 m intervals. In order to test whether fracture counting was biased because of trench orientation, frequencies were corrected using the method of Terzaghi (1965). In general, the corrected frequencies were proportional to the raw count suggesting that there was no bias and also that the trenches were oriented nearly perpendicular to the majority of the fractures. Fracture distribution is relatively uniform with minor zones of clustering occurring across the site (Figure 2). Small clusters of fractures were observed in some locations and were noted. One zone of more densely spaced fractures was observed near the east end of Trench 4. Two clusters of northeast- and northwest-striking fractures are located about 60 m from the west and east ends of Trench 1. A zone of relatively densely spaced fractures is located near the east end of Trench 2 (Figure 2). Fracture frequencies in Trench 3 are relatively high about 55 m from the west end of the trench and near the east end of Trench 5.

Average fracture widths, along 15 m increments, are plotted next to corrected fracture frequencies in plan view (Figure 2). There does not appear to be a correlation between the frequency and the width of fractures along the lengths of the trenches. However, there does appear to be an increase in fracture width at the ends of Trenches 1, 2, and 3 nearest the mesa edge to the east. We interpret this widening of fractures to be related to dilation of the fractures due to settling of tuff blocks toward the canyon.

Based on our observations of fracture frequency and width in the trenches spanning the TA-63 site, we do not see a trend of increased incidence of fractures or increased fracture widths toward or across the projection of the Guaje Mountain fault. Based on the report of Vaniman and Wohletz, (1990), a noticeable increase should occur near or at the fault. In addition, no significant increase in fracture frequency was observed toward the mesa edge; however, the width of fractures does increase in the eastern ends of the three trenches nearest Canyon del Buey. This may be most easily explained by small, canyonward movements of tuff blocks as a form of mass wasting. The motion of the blocks is along existing fractures.

Orientation Analysis

Poles to planes of strikes and dips for each trench and cumulatively for all trenches show a principal mode of fracture strikes between N and N30°E (Figure 8). While the Vaniman and Wohletz data show more dispersed strikes, strikes along East Jemez Road to the north of TA-63 have a mode that is north-northeast, similar to that at TA-63. The Pajarito Road data is more easterly oriented, between N30°E and N60°E. If the fracture orientation data from the Pajarito Road survey is related to structure of the Rendija Canyon fault then the TA-63 fractures may not be directly attributable of tectonism.

Contoured lower hemisphere stereonet of poles to fracture planes are plotted to demonstrate the three-dimensional distribution of fracture orientations (Figure 8). Contours are based on a statistical method developed by Kamb (1959) and depict the probability that the observed concentration was not derived from a random, non-oriented population. The contour interval is 2σ , where σ is the standard deviation of the total number of points in a given area under random sampling. The counting area is selected so that the expected frequency for no preferred orientation is 3σ . When the observed density is two or three times this value, the preferred orientation is likely to be significant. The advantage of this method is that it helps

discriminate between significant clustering and that produced by random fluctuations of small populations.

The contoured stereonet plots indicate that near-vertical, north-northeast striking fractures constitute the most densely clustered orientations. This clustering of data is weak in Trench 2 where the number of observations is so small (N=13) that the statistical significance of the clusters is questionable.

DISCUSSION AND CONCLUSIONS

Based on structural analysis, we conclude:

- Fracture frequencies and widths do not increase closer to the projection of the Guaje Mountain fault. According to the model of Vaniman and Wohletz (1990), this suggests the Guaje Mountain fault does not project through the site of the proposed facilities.
- Data supporting the model for gravity-driven displacements include a fault oriented parallel to the cliff face near to the east end of Trench 3. Based on slickensides, this fault apparently has a 1:1 ratio of horizontal to vertical slip. This is the largest vertical component of all the faults, further suggesting gravity-driven movement. However, no increases in joint frequency were observed toward the cliff edge.
- Secondary strike-slip faulting related to a nearby principal fault is not likely because of the lack of evidence for offset and the orientations do not show conjugated distributions. Other evidence against secondary faulting as a mechanism is the lack of a systematic increase in fractures or faults towards and within the projected Guaje Mountain fault. However, at a location to the north, an increase in fracture density was observed by Vaniman and Wohletz (1990).
- Irregular and shallow fractures are probably related to tree roots or mass wasting.
- No offsets were observed within the Bandelier Tuff or offsets were too negligible to be recognized. However, because the Bandelier Tuff exhibits a relatively

uniform composition and texture, and lacks marker horizons, it is difficult to demonstrate no offset across all fractures. One fracture (Trench 2, T2-3) fortuitously split a large pumice clast thereby allowing the lack of offset to be demonstrated. While steps were noted in the tuff surface, none projected across the trench and all could be the product of mass wasting or root heaving.

- Slickensides were not well developed and occurred on clay fracture fill and not on fracture of tuff surfaces. They could easily be formed by wetting and drying of fracture fill.
- Fractures are near vertical and orientations are compatible with cooling fractures formed in a stress field characterized by west-northwest extension. However, the possibility that some fractures are tectonically derived cannot be precluded based on these results alone.

TA-63, Trench 1. Lower hemisphere schmidt projection. Kamb contours of poles to fractures.

TA-63, Trench 2. Lower hemisphere schmidt projection. Kamb contours of poles to fractures.

TA-63, Trench 3. Lower hemisphere schmidt projection. Kamb contours of poles to fractures.

TA-63, Trench 4. Lower hemisphere schmidt projection. Kamb contours of poles to fractures.

TA-63, Trenches 1 through 4. Lower hemisphere schmidt projection. Kamb contours of poles to fractures.

TA-63, Trenches 1 through 5. Lower hemisphere schmidt projection. Kamb contours of poles to fractures.

Project No.
92C0774A

LANL TA - 63

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CONTOURED LOWER HEMISPHERES STERONE
PLOTS OF FRACTURE POLES TO PLANES

Figure
8

APPENDIX B
RADIOCARBON DATING ANALYSES

BETA ANALYTIC INC.

DR. J.J. STIPP and DR. M.A. TAMERS

UNIVERSITY BRANCH

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MIAMI, FLORIDA, USA 33155

PH: 305/667-5167 FAX: 305/663-0964

REPORT OF RADIOCARBON DATING ANALYSES

IR: Tom Kolbe
Woodward-Clyde Federal Services
_____
_____

DATE RECEIVED: August 9, 1993
DATE REPORTED: September 7, 1993
SUBMITTER'S
PURCHASE ORDER # _____

IR LAB NUMBER YOUR SAMPLE NUMBER C-14 AGE YEARS B.P. $\pm 1\sigma$

ta-65111 TA-63 T1 RCS 2 650 +/- 80 BP (charcoal-0.4gm C)

te: the small sample was given extended counting time.

These dates are reported as RCYBP (radiocarbon years before 1950 A.D.). By international convention, the half-life of radiocarbon is taken as 5568 years and 95% of the activity of the National Bureau of Standards Oxalic Acid (original patch) used as the modern standard. The quoted errors are from the counting of the modern standard, background, and sample being analyzed. They represent one standard deviation statistics (68% probability), based on the random nature of the radioactive disintegration process. Also by international convention, no corrections are made for DeVries effect, reservoir effect, or isotope fractionation in nature, unless specifically noted above. Stable carbon ratios are measured on request and are calculated relative to the PDB-1 international standard; the adjusted ages are normalized to -25 per mil carbon 13.

BETA ANALYTIC INC.

DR. J.J. STIPP and DR. M.A. TAMERS

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PH: 305/667-5167 FAX: 305/663-0964

REPORT OF RADIOCARBON DATING ANALYSES

DR: Tom Kolbe
Woodward-Clyde Consultants
_____
_____

DATE RECEIVED: March 22, 1993
DATE REPORTED: June 11, 1993
SUBMITTER'S
PURCHASE ORDER # _____

UR LAB NUMBER YOUR SAMPLE NUMBER C-14 AGE YEARS B.P. $\pm 1\sigma$

a-61734 TA-63 T1 RC1 3050 +/- 70 BP (organics)
S-6887

ie: this sample was done using the AMS technique. The reported date has
an adjusted by carbon 13.

These dates are reported as RCYBP (radiocarbon years before 1950 A.D.). By international convention, the half-life of radiocarbon is taken as 5568 years and 95% of the activity of the National Bureau of Standards Oxalic Acid (original batch) used as the modern standard. The quoted errors are from the counting of the modern standard, background, and sample being analyzed. They represent one standard deviation statistics (68% probability), based on the random nature of the radioactive disintegration process. Also by international convention, no corrections are made for DeVries effect, reservoir effect, or isotope fractionation in nature, unless specifically noted above. Stable carbon ratios are measured on request and are calculated relative to the PDB-1 international standard; the adjusted ages are normalized to -25 per mil carbon 13.

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REPORT OF RADIOCARBON DATING ANALYSES

DR: Tom Kolbe
Woodward-Clyde Federal Services
_____
_____

DATE RECEIVED: July 13, 1993
DATE REPORTED: August 5, 1993
SUBMITTER'S
PURCHASE ORDER # _____

UR LAB NUMBER	YOUR SAMPLE NUMBER	C-14 AGE YEARS B.P. $\pm 1\sigma$

Beta-64167	TA-63 T2 RCS 1	940 +/- 70 BP	(charcoal)
Beta-64168	TA-63 T5 RCS 1 & 2	980 +/- 60 BP	(char/wood)
Beta-64169	TA-63 T5 RCS 3	60 +/- 50 BP	(charcoal)
Beta-64170	TA-63 T5 RCS 4	1130 +/- 60 BP	(charcoal)

These dates are reported as RCYBP (radiocarbon years before 1950 A.D.). By international convention, the half-life of radiocarbon is taken as 5568 years and 95% of the activity of the National Bureau of Standards Oxalic Acid (original batch) used as the modern standard. The quoted errors are from the counting of the modern standard, background, and sample being analyzed. They represent one standard deviation statistics (68% probability), based on the random nature of the radioactive disintegration process. Also by international convention, no corrections are made for DeVries effect, reservoir effect, or isotope fractionation in nature, unless specifically noted above. Stable carbon ratios are measured on request and are calculated relative to the PDB-1 international standard; the adjusted ages are normalized to -25 per mil carbon 13.