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EVALUATION OF FAULTING AT THE CHEMISTRY AND METALLURGY RESEARCH FACILITY REPLACEMENT (CMRR) SITE BASED ON EXAMINATION OF CORE FROM GEOTECHNICAL DRILLING STUDIES, TA-55, LOS ALAMOS NATIONAL LABORATORY

by

Alexis Lavine, Jamie Gardner, and Emily Schultz

ABSTRACT

Borehole logs and cores from geotechnical drilling studies performed at the site of the Chemistry and Metallurgy Research Facility Replacement at Technical Area (TA)-55 in the central portion of Los Alamos National Laboratory were examined to determine whether the elevation of contacts in the Tshirege Member of the Bandelier Tuff (Qbt) reveal any faulting at the site. The site is located approximately 1 km to the east of the Rendija Canyon fault zone. Previous detailed geologic mapping found no faulting in this area. Preliminary examination of the depth of the Qbt3-Qbt4 contact on the original borehole logs from Kleinfelder, Inc., combined with surveyed surface elevations of the boreholes, revealed many anomalies in the elevation of the contact at the site. To determine the source of these anomalies, we examined core from 45 boreholes and determined the upper and lower bounds for the elevation of the Qbt3-Qbt4 contact. We could not accurately and confidently assess the elevation of the contact in the cores primarily because of extremely poor recovery at the contact zone [typically <1 ft (0.3 m) of core recovered over a 5 ft (1.5 m) zone] in most of the boreholes. Additionally, a number of human-induced factors such as mislabeling or lack of labeling of run blocks and core boxes and core boxed upside down make accurate depth determinations of the contact uncertain. Anomalies found in the initial analysis of the Qbt3-Qbt4 contact data were caused by incorrect placement of the contact [in some cases the contact was shown where no Qbt4 was even present, and in other cases with good recovery of the contact it was misplaced by up to 7 ft (2.1 m) on the logs]; inconsistent placement of the contact in intervals with little or no recovery; and possibly by questionable marking of depth indicators in the core boxes. After careful examination of the cores, the elevation of the Qbt3-Qbt4 contact was found to lie within an interval of uncertainty from 0 ft to as much as 23 feet (0–7 m). We evaluated the data within the interval of uncertainty for each borehole, using elevations for the contact that were within the upper and lower bounds and in most reasonable relation to the elevation of the contact in adjacent boreholes. Several anomalies in the elevation of the contact still exist but are caused by paleotopographic undulations on the top surface of unit Qbt3. When the revised elevations of both the Qbt3-Qbt4 and Qbt2-Qbt3 contacts are evaluated with respect to surveyed geologic contacts from adjacent canyons, there is no indication of faulting. The abundance of data on surveyed geologic contacts in the western half of the site and the lack of anomalies in the elevation of the contact from boreholes in the western half of the site do not indicate the presence of faults. Although it is possible that small-displacement [<3 ft (1 m) of vertical displacement] faults exist in the eastern half of the site, where only the gradational Qbt2-Qbt3 contact has been previously mapped and some anomalies from the borehole data still exist, there is no evidence of large-scale [several feet (>1 m) of vertical displacement] faulting.

Introduction

Because Los Alamos National Laboratory (LANL) lies on the active western margin of the Rio Grande rift (Figure 1), seismic hazards, including the potential for seismic surface rupture, must be assessed before construction of any new facilities housing nuclear or other hazardous materials. The Rio Grande rift is a north-south trending series of asymmetrical extensional basins that runs from central Colorado to Mexico (Figure 1). The rift has been the site of volcanic and seismic activity for the last ~30 million years (e.g., Riecker, 1979; Baldridge et al., 1984; Keller, 1986) and continues to be an active tectonic and volcanic province (e.g., Kelley, 1979; Harrington and Aldrich, 1984; Menges, 1990; Sanford et al., 1991; Kelson and Olig, 1995; Wolff and Gardner, 1995; Machette et al., 1998; Steck et al., 1998). In the area of Los Alamos, the rift boundary is locally defined by the Pajarito fault system, which includes the Pajarito, Rendija Canyon, and Guaje Mountain faults (Figure 2).

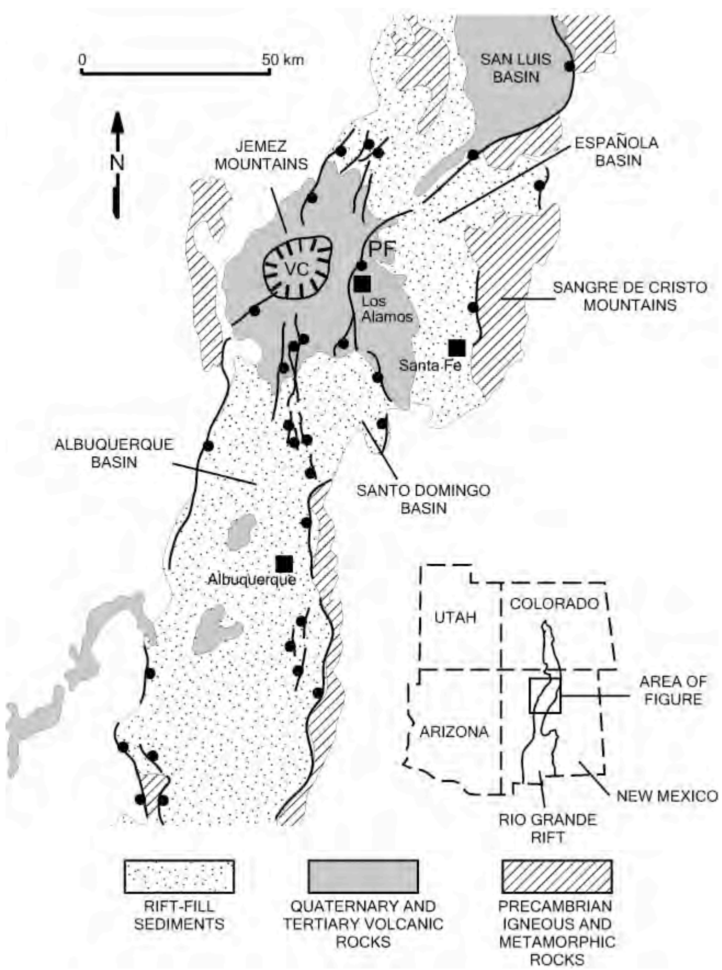

Figure 1. Map of the Rio Grande rift in northern New Mexico. Major fault systems are shown schematically (ball on downthrown side). Abbreviations: PF, Pajarito fault; VC, Valles-Toledo caldera complex, the source of the Bandelier Tuff. Modified from Gardner and Goff (1984).

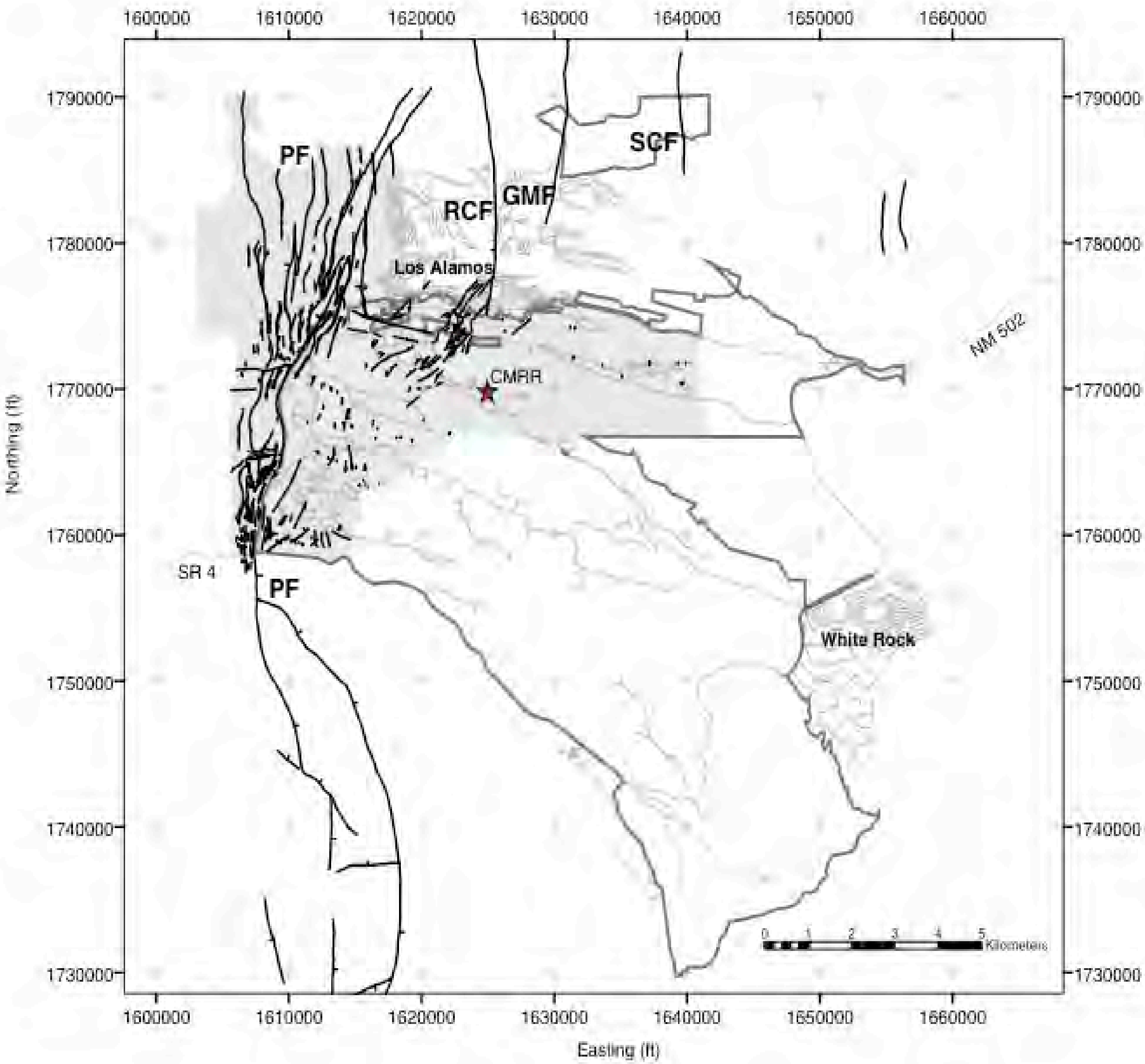

Figure 2. Map showing the Pajarito fault system in the vicinity of Los Alamos National Laboratory. Gray shaded area shows the area that has been mapped in detail to assess faulting. Gray outlined area shows the extent of LANL. The study area for this project is located at TA-55 and is shown by a red star labeled CMRR. Faults and related folds shown in black are from Gardner and House (1987), Reneau et al. (1995), Gardner et al. (1999, 2001), Lewis et al. (2002), Lavine et al. (2003), Lewis et al. (unpublished mapping), and Gardner and Reneau (unpublished mapping). Abbreviations: PF, Pajarito fault; RCF, Rendija Canyon fault; GMF, Guaje Mountain fault; SCF, Sawyer Canyon fault.

Paleoseismic investigations indicate that there have been three Holocene seismic events of magnitude 6–7 on the Pajarito fault system (Gardner et al., 1990; Wong et al., 1995; Kelson et al., 1996; McCalpin, 1998, 1999; Reneau et al., 2002; Gardner et al., 2003; LANL Seismic Hazards Geology Team, in prep.). Numerous smaller earthquakes have occurred over the last few decades, some of which have been felt by residents (Gardner and House, 1987, 1994, 1999). The fault system in the western and northern parts of LANL and west of LANL has been mapped in detail to better understand the kinematics of the fault system and to assess the potential for seismic surface rupture at specific sites at the Laboratory (e.g., Gardner et al., 1998, 1999, 2001; Lewis et al., 2002; Lavine et al., 2003; Schultz et al., 2003). Additionally, probabilistic surface rupture studies have been performed for both existing and proposed facilities (Olig et al., 1998, 2001). Geologic mapping to determine the location and magnitude of faulting at LANL has primarily focused on the Tshirege Member of the Bandelier Tuff (Qbt), which is made up of a complex sequence of ignimbrites that were erupted from the Valles caldera 1.2 million years ago (Bailey et al., 1969; Izett and Obradovich, 1994). Individual subunits within the Tshirege Member are defined by variations in welding, mineralization, and lithology (Figure 3; e.g., Broxton and Reneau, 1995). Contacts between the subunits of the Tshirege Member serve as useful markers for determining the presence or absence of faulting (e.g., Gardner et al., 1998, 1999, 2001; Lewis et al., 2002; Lavine et al., 2003; Schultz et al., 2003).

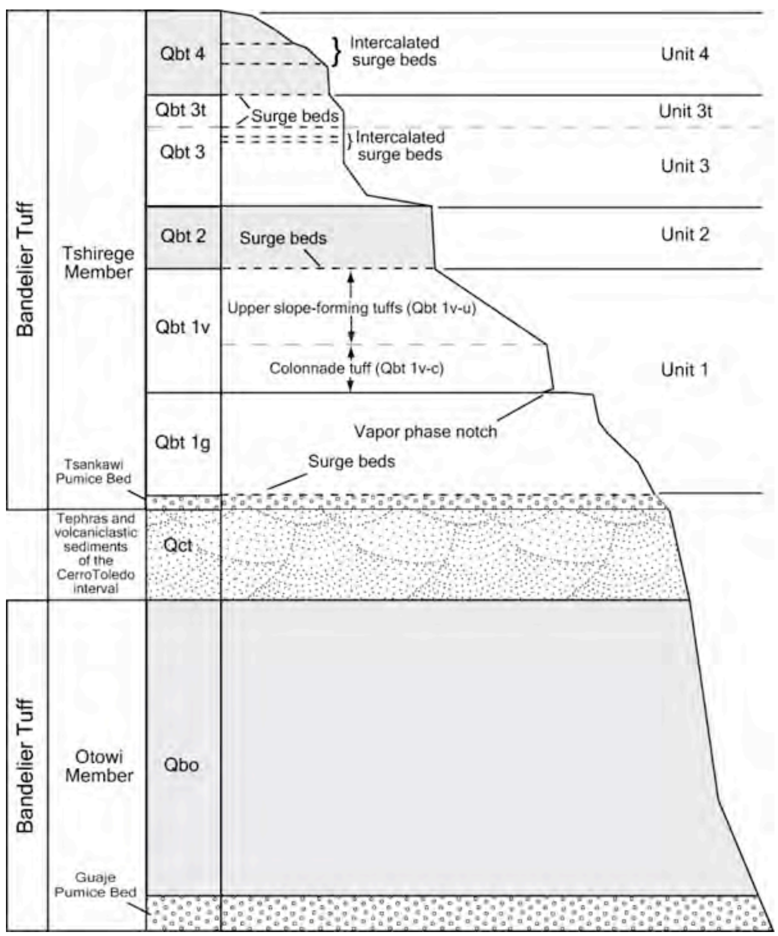

Figure 3. Generalized stratigraphy of the Bandelier Tuff (from Gardner et al., 1999). Thickness of units is shown schematically and varies over the Pajarito Plateau.

The Chemistry and Metallurgy Research Facility Replacement (CMRR) site is located at Technical Area 55 (TA-55) in the central portion of LANL (Figure 2) on Bandelier Tuff and younger sedimentary deposits. Although previous detailed mapping (Gardner et al., 1998, 1999) revealed no faulting at the site, recent drilling at the footprint of the site provides subsurface data from a heavily urbanized area and may therefore provide data to reveal small faults that could not be recognized through geologic mapping. Recent geotechnical studies at the CMRR site by Kleinfelder, Inc. have included drilling 50 boreholes (with more planned). Most of the boreholes are less than 100 ft deep, but five of them extend to ~400 feet, penetrating the base of the Tshirege Member. Samples from the boreholes provide information on rock mechanical properties, and the elevation of the Qbt3-Qbt4 contact in the boreholes can be used to further assess faulting at the site. Examination of the contact elevations as reported by Kleinfelder, Inc. (Kleinfelder, unpublished borehole logs) from the CMRR boreholes revealed some substantial anomalies on the elevation of the Qbt3-Qbt4 contact, which was based on the depth of the contact from the logs and the surveyed elevations of the boreholes (KSL, unpublished survey data). Numerous factors may contribute to the elevation anomalies based on data from the original logs, including incorrect placement of the contact, incorrect survey of the borehole locations, undulations on the contact because of paleotopography, or faulting. To determine the source of these anomalies, we examined cores from these boreholes. This report discusses the results of our examination of the core, analysis of the data, and remaining uncertainties.

Previous Work

Geologic studies performed in the TA-55 area at LANL include geologic mapping, trenching, and fracture studies. Trenching at the footprint of the Plutonium Facility at TA-55 by Dames and Moore (1972) was inconclusive with respect to faulting at the site because no stratigraphic markers extended through the trench. Fracture studies by Purtymun et al. (1995) in an excavation for a basement at TA-55 revealed numerous fractures associated with cooling of the tuff, but no evidence for faulting was found. Vaniman and Wohletz (1990) performed reconnaissance geologic mapping and detailed fracture studies in the TA-55 area. Their mapping revealed several fracture zones, but no significant faulting in the area. More recently, Gardner et al. (1998, 1999) performed detailed total station geologic mapping in this area to determine the location of the Rendija Canyon fault and the potential for surface rupture at TA-55. The study found that the Rendija Canyon fault does not underlie TA-55, but rather the fault splays to the southwest beneath TA-48 and TA-3 into a wide zone of distributed faulting made up of small-vertical-displacement faults. The CMRR site lies approximately 3000 ft (1 km) to the east of the Rendija Canyon fault zone (Figure 2; Gardner et al., 1999). The site of the CMRR facility is in an area that has been extensively urbanized, minimizing exposure of geologic contacts. Detailed geologic mapping of Gardner et al. (1998, 1999) included total station surveying of the Qbt3-Qbt4 contact in the western half of the CMRR site along Pajarito Road and the Qbt2-Qbt3 contact in Twomile Canyon to the south and Mortandad Canyon to the north. The most useful marker horizon for finding very-small-displacement faults [<1 ft (0.3 m) vertical displacement] in this area is the Qbt3-Qbt4 contact, which is generally quite sharp and commonly marked by a pyroclastic surge. The Qbt2-Qbt3 contact is more gradational and not quite as useful for finding very small faults; however, the presence of both contacts enhances determination of the presence or absence of faulting. In the area of the potential site for the CMRR, no faults were found on the Qbt2-Qbt3 contact in the canyons to the north and south of the site, and no faults were found on the Qbt3-Qbt4 contact, which was only exposed in the western part of the site (Gardner et al., 1998, 1999). Much of the Qbt3-Qbt4 contact mapped by Gardner et al. (1998, 1999) in this area has since been covered by artificial fill.

The LANL seismic hazards geology team has used shallow drilling to assess the potential for seismic surface rupture in several urbanized areas of the Laboratory (Krier et al., 1998a, 1998b; Gardner et al., 2001; Krier, 2001). This method of assessing faulting with drilling has been quite effective because of nearly total (99–100%) recovery of core.

Methods

After completion of drilling and logging of 50 boreholes at the CMRR site by Kleinfelder, Inc., we examined the borehole logs and analyzed the reported elevations of the Qbt3-Qbt4 contact to identify anomalies to evaluate the presence or absence of faulting at the site. The elevation of the contact in this first analysis was based on the surveyed locations of the boreholes and depth to the contact depicted on the logs. Three-dimensional surface models of the surface defined by the Qbt3-Qbt4 contact were calculated using kriging (a linear regression technique for minimizing the variance of unsampled values between points; Deutsch and Journel, 1992) in the computer software Surfer© and were then contoured to examine anomalies and trends in the surface defined by the contact. This analysis showed many anomalies on the elevation of the contact (Figure 4). These anomalies make no geological sense, and no reasonable fault scenarios can explain them.

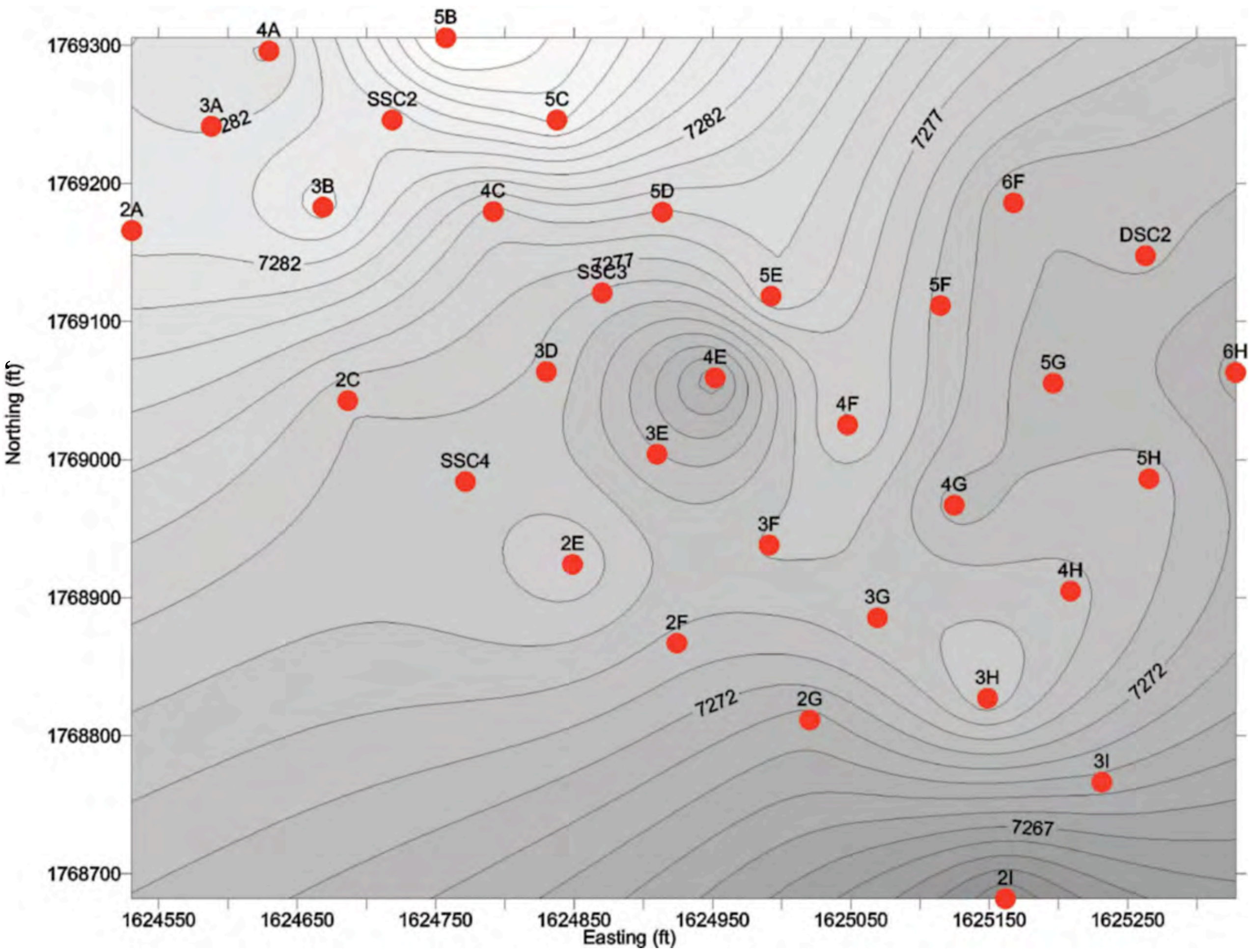

Figure 4. Surface model of the Qbt3-Qbt4 contact based on reported contact depths from original borehole logs and survey data. Red dots represent CMRR boreholes. The surface was calculated using kriging; contour interval is 1 ft (0.3 m). Grid is in the State Plane Coordinate System, New Mexico Central Zone, 1983 North American Datum (in feet).

Core recovered from the boreholes was boxed in core boxes or in plastic tubes and stored both at LANL and at the Kleinfelder, Inc., offices in Albuquerque. We examined the recovered core from 45 boreholes in detail to determine our own placement of the contact. Examination of the core was necessary to determine if the anomalies initially identified were the result of previous inconsistent logging, incorrect survey elevations, or actual anomalies in the elevation of the contact.

Boxes of core that contained the Qbt3-Qbt4 contact were examined in detail to determine the depth to the contact or presence of the contact. We also examined the depth to the Qbt2-Qbt3 contact in the boreholes that penetrated to sufficient depth. Criteria for defining contacts in the Tshirege Member were the same as those used in previous geologic mapping and drilling studies at LANL (e.g., Gardner et al., 1998, 1999; Krier et al., 1998a, 1998b; Krier, 2001; see "Geology" section below). In a few cases, core was stored in plastic tubing, and we could not examine the Qbt3-Qbt4 contact. Our measurement of depths was, by necessity, based on the run blocks, placed by the on-site geologist during drilling, within the core boxes that recorded depths as well as locations of samples taken. In many cases, the recovery in the area of the contact was extremely poor, and the contact could only be determined to lie within a certain depth interval. We recorded our determinations of the contact depth, or upper and lower bounds of the contact depth, and any inconsistencies or errors on the original Kleinfelder logs in a notebook while examining the core.

Because in most cases the contact could only be determined to lie within a certain depth interval, we analyzed the data to determine if the magnitude of the anomalies could lie completely within the limits of uncertainty. Additionally, we resurveyed the locations of several of the boreholes that exhibited the larger anomalies to determine if the anomalies may have been the result of a poor-quality survey. Our survey was done using a Trimble 5700 GPS.

Geology

The Tshirege Member of the Bandelier Tuff is divided into subunits that can be distinguished from each other based on distinctive characteristics such as welding, mineralization, and lithology (Figure 3; e.g., Smith and Bailey, 1966; Broxton and Reneau, 1995; Gardner et al., 1999). This section discusses only units Qbt2 through Qbt4 because these are the only geologic units that are important to this specific study. Although lower subunits of the Tshirege Member are found in this area, they were only encountered in the deeper boreholes and are not pertinent to this analysis. Artificial fill and older alluvial deposits are also found near or at the surface at the CMRR site.

Qbt2: In the area of TA-55, unit Qbt2 is approximately 80–100 ft (24.4–30.5 m) thick. Unit Qbt2 is moderately to densely welded and is commonly a cliff-forming unit. Welding generally increases toward the top of the unit and to the west. The lower part of the unit includes flow units that are mapped as unit Qbt1v to the east; what is referred to as Qbt2 in this area is equivalent to unit Qbt2 (+1vw) of Lavine et al. (2003) in the northeastern part of LANL. Unit Qbt2 contains approximately 10–15% vapor-phase altered pumice lapilli, which range in size from <0.2 to 3 in (5 mm to 8 cm) in diameter. Phenocrysts make up 15–25% of the unit, with subequal amounts of quartz and sanidine up to 0.2 in (5 mm) in diameter near the top of the unit. Some sanidine is chatoyant. The unit contains <1–2% accidental lithic fragments that are up to 1 in (2.5 cm) in diameter but mostly <0.2 in (5 mm) in diameter. The top of Qbt2 is marked by a decrease in welding over a 1.5–3 ft (0.5–1 m) interval from densely to moderately welded unit Qbt2 to nonwelded unit Qbt3.

Qbt3: In the area of TA-55, Qbt3 is approximately 110–120 ft (33.5–36.6 m) thick. The contact between underlying moderately to densely welded Qbt2 and the nonwelded base of Qbt3 is a fairly sharp change in welding, from densely welded to nonwelded, that occurs over less than 1 m (3 ft). Welding and induration increase slightly toward the top of the unit, making the upper part of Qbt3 a cliff-forming unit. Unit Qbt3 is distinct from underlying and overlying units in that it contains more pumice lapilli, more crystals, generally larger crystals, and up to 5% accidental lithic fragments. The unit contains ~5–20% vapor-phase-altered, gray pumice lapilli that are mostly ~2.5 in (1 cm), but as large as 6 in. (15 cm), in diameter. Pumice lapilli are vapor-phase altered throughout Qbt3, but are not as friable near the top of the section. Phenocrysts constitute 25–35% of the unit, consist of quartz and sanidine in subequal amounts, and are <0.3 in (1–6 mm) in diameter. Accidental lithic fragments constitute 3–5% of the unit and are up to 6 in (15 cm) in diameter, but are mostly <2 in (<5 cm) in diameter.

Qbt3T: Qbt3t does not occur in the TA-55 vicinity. It pinches out west of TA-55 (Gardner et al., 1999).

Qbt4: Unit Qbt4 ranges from 0 to ~25 ft (0–7.6 m) thick in the study area and pinches out to the east. Unit Qbt4 is relatively pumice-poor (less than 5% pumice) and crystal-poor [10–15% phenocrysts of mostly quartz and feldspar ~0.1 in. (2–3 mm) across] with rare accidental lithic fragments. A pyroclastic surge deposit commonly marks the base of the unit. The basal surge is a crystal-rich deposit, which ranges in thickness from 0.3 to 2 ft (0.1–0.6 m) thick. The surge is greater than 90% sand-sized crystal and lithic fragments and exhibits low-angle cross beds and plane beds.

Results

We examined the contact in 33 of the 45 boreholes and confirmed the absence of the contact in several of the other cores. The Qbt2-Qbt3 contact was also examined in the five cores that penetrated it. Surveying the surface elevation of several of the boreholes with the largest anomalies showed that the surveyed coordinates for the boreholes were accurate.

After careful examination of the core, we found that placement of the Qbt3-Qbt4 contact as depicted on the original Kleinfelder logs was in many cases inconsistent in areas of poor recovery, and in some cases placement of the contact was incorrect [in one case with good recovery of the sharp and obvious Qbt3-Qbt4 contact, the logs show the contact nearly 7 ft (2.1 m) away]. There were also reports on the logs of the Qbt3-Qbt4 contact in holes that contained no Qbt4, including one log that reports tuff at 10.3 ft (3.1 m), but the core at that depth in the box is concrete (likely associated with a nearby fire hydrant system). It is likely that there was Qbt4 in the area of this borehole (5G) before construction activities at the site. Additionally, many run blocks in the core boxes were mislabeled or absent, and in one case the core was boxed upside down, making it difficult to know what should be believed in the way of depth indicators. The placement of the Qbt2-Qbt3 contact as shown on the logs is also inconsistent with where we would place the contact based on criteria used by Gardner et al. (1998, 1999, 2001). Lingering uncertainties in the elevation of the Qbt3-Qbt4 contact are primarily due to extremely poor core recovery at the contact horizon. Commonly, a five-foot (1.5-m) core run spanned the contact with no recovery. In such areas with no recovery across the contact, the Kleinfelder logs in some cases depict the contact at the top of the no-recovery zone, in others at the bottom of the no-recovery zone, and in one case in the middle of the no-recovery zone. Previous shallow drilling investigations at LANL (e.g., Krier et al., 1998a, 1998b; Krier, 2001) have been successful in recovering nearly 100% core in this stratigraphic interval. Poor recovery at CMRR is likely due to drilling methods.

Because of the above-mentioned uncertainties, in most cases we were only able to determine upper and lower bounds for the elevation of the contacts in each core (Tables 1 and 2). Figure 5 shows the size of the uncertainty interval (in feet) in the elevation of the Qbt3-Qbt4 contact for each of the CMRR boreholes. Given this uncertainty, which ranges from 0 to 23 ft (0–7 m), it is not possible to evaluate the potential for small scale [less than a few feet (<1 m)] faulting based on these data. However, we have analyzed the data within the limits of uncertainty to determine if at least some of the larger elevation anomalies from the preliminary analysis of the contact elevation based on borehole logs could have been caused by the above-mentioned problems. We determined the most reasonable elevation for the contact between the possible upper and lower bounds of the contact based on the elevation of the contact in adjacent boreholes, then re-analyzed the elevation of the contact using kriging to interpolate the surface with Surfer software (Figure 6). We found that several anomalies remain; primarily, the elevation of the contact in holes 4E, 4F, and, to a lesser degree, 4G creates a depression in the surface defined by the contact (Figure 6). However, comparing the apparent thickness of unit Qbt4 (Figure 7) with Figure 6 shows that holes 4E, 4F, and 4G have some of the greatest thicknesses of Qbt4 relative to surrounding holes and are near the center of a broad [~550 ft (~170 m) wide] low spot on the surface of Qbt3. Thus, the anomalies associated with holes 4E, 4F, and 4G appear to be caused by undulations on the surface of Qbt3. Such undulations on the upper surfaces of pyroclastic flows are common, and can occur as levees and channels, edges of flow lobes, or erosional features (e.g., Rowley et al., 1981; Wilson and Head, 1981). Surveyed elevations of the ground surface at the borehole locations were correct. When our "best pick" for the Qbt3-Qbt4 contact elevations from the boreholes (excluding holes 4E and 4F for clarity) are plotted together with survey data from Gardner et al. (1998, 1999), no significant anomalies occur in the western half of the CMRR site (Figure 8). Survey data of Gardner et al. (1998, 1999) only extend through the western half of the site because of lack of exposures farther east. However, the dip of the Qbt3-Qbt4 contact in the eastern part of the area is shallower than to the west (Figure 8), possibly reflecting the effects of the paleotopography on the surface of Qbt3, discussed above.

The original placement of the Qbt2-Qbt3 contact as shown on the Kleinfelder logs is inconsistent with where we would place the contact [by 5 to 15.5 ft (1.5–4.7 m)] based on criteria of Gardner et al. (1998, 1999, 2001). When the Qbt2-Qbt3 contact from the boreholes is plotted with surveyed data on the Qbt2-Qbt3 contact from Gardner et al. (1998, 1999), no anomalies in the elevation of the contact are apparent (Figure 9), and there is no suggestion of faulting. Table 2 shows the locations of the CMRR boreholes and elevations of the Qbt2-Qbt3 contact.

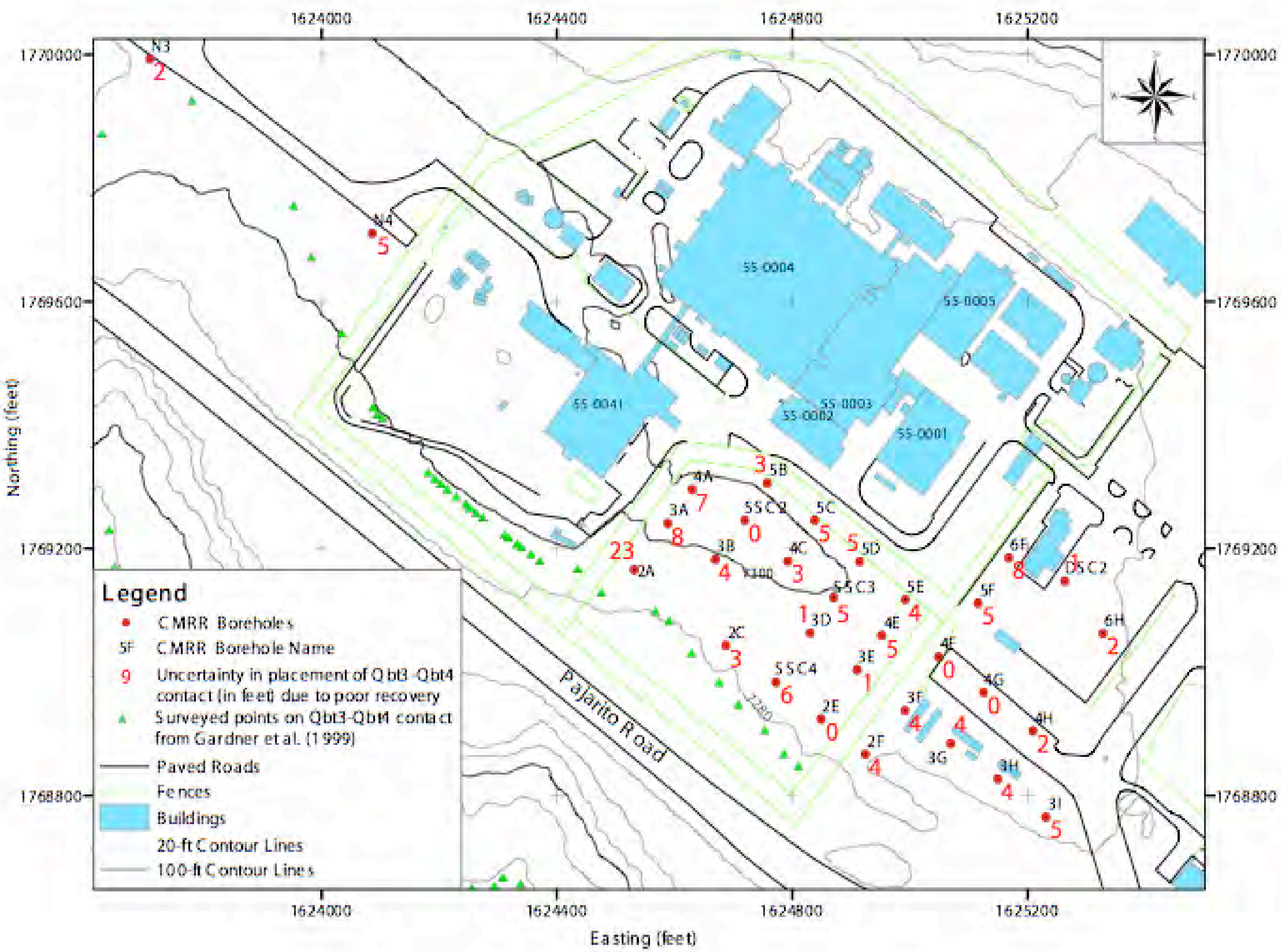

Figure 5. Map of CMRR boreholes showing the uncertainty (in feet) of the placement of the Qbt3-Qbt4 contact (large red numbers) based on examination of CMRR cores. These uncertainties are based only on poor recovery around the contact; additional uncertainties may exist (see text) Green triangles are survey data of Gardner et al. (1998, 1999) from the Qbt3-Qbt4 contact. Grid is in the State Plane Coordinate System, New Mexico Central Zone, 1983 North American Datum (in feet).

Table 1. Table of locations of the CMRR boreholes, elevations of the Qbt3-Qbt4 contact based on the original Kleinfelder logs, and the upper and lower bounding elevations of the Qbt3-Qbt4 contact based on LANL examination of the CMRR cores. (All coordinates are in feet.)

Borehole	Northing	Easting	Surface	Kleinfelder 3/4 Contact Elevation	LANL 3/4 Contact Elevation (upper bound)	LANL 3/4 Contact Elevation (lower bound)
1A	1769077.246	1624465.908	7275.095	N/A	N/A	N/A
1B	1769021.949	1624546.104	7271.911	N/A	N/A	N/A
1C	1768974.830	1624636.119	7272.723	N/A	N/A	N/A
1D	1768900.427	1624701.451	7271.460	N/A	N/A	N/A
1E	1768842.071	1624800.724	7272.281	N/A	N/A	N/A
1F	1768783.482	1624869.237	7271.441	N/A	N/A	N/A
1G	1768724.302	1624950.405	7260.142	No Core	No Core	No Core
1H	1768664.393	1625030.352	7260.800	N/A	N/A	N/A
1I	1768577.195	1625163.889	7264.232	N/A	N/A	N/A
2A	1769165.948	1624530.552	7292.899	7282.399	7282.399	7259.899
2C	1769042.710	1624686.590	7290.625	7276.125	7279.625	7276.325
2E	1768924.110	1624848.924	7291.914	7276.914	7277.014	7277.014
2F	1768866.929	1624924.324	7282.669	7273.669	7272.669	7268.669
2G	1768811.425	1625020.230	7277.551	7270.551	CNE	CNE
2I	1768681.917	1625161.683	7266.996	7261.996	CNE	CNE
3A	1769241.434	1624587.971	7302.022	7281.922	7285.322	7277.022
3B	1769182.913	1624668.644	7295.549	7284.549	7283.549	7279.549
3D	1769063.651	1624830.011	7293.720	7275.82	7277.72	7276.72
3E	1769003.904	1624909.934	7293.195	7273.095	273.595	7273.095
3F	1768938.114	1624990.870	7288.666	7275.166	7276.466	7272.866
3G	1768885.404	1625069.176	7290.769	7274.869	7274.669	7270.369
3H	1768827.074	1625148.630	7287.836	7275.836	7276.636	7272.636
3I	1768766.333	1625231.247	7285.627	7269.627	7274.527	7269.727
4A	1769296.026	1624629.611	7305.790	7280.79	7287.79	7280.59
4C	1769179.658	1624791.656	7297.648	7278.548	7281.848	7278.548
4E	1769059.242	1624951.930	7293.917	7269.117	7269.117	7264.117
4F	1769025.202	1625047.606	7291.787	7277.287	7270.537	7270.537
4G	1768967.021	1625124.684	7289.462	7272.462	7273.462	7273.462
4H	1768904.745	1625208.715	7286.511	7274.311	7274.111	7272.011
5B	1769305.557	1624757.346	7296.839	7289.839	7290.139	7287.439
5C	1769246.006	1624837.694	7296.188	7286.288	7281.988	7281.988
5D	1769179.286	1624913.858	7294.795	7278.895	7280.395	7275.695
5E	1769118.473	1624992.360	7294.066	7278.966	7278.866	7275.066
5F	1769111.623	1625114.690	7288.690	7274.69	7277.69	7272.69
5G	1769055.287	1625196.180	7287.254	7272.254	N/A	N/A
5H	1768986.060	1625265.324	7286.001	7273.501	CNE	CNE
6F	1769186.001	1625167.504	7287.592	7273.092	7280.892	7273.092
6H	1769063.155	1625327.866	7282.646	7270.646	7272.646	7270.646
DSC2	1769147.752	1625262.747	7283.412	7273.312	7275.812	7274.712
SSC1	1769099.385	1624613.269	7291.047	N/A	N/A	N/A
SSC2	1769245.984	1624718.639	7299.253	7283.353	7283.353	7283.353
SSC3	1769120.801	1624870.330	7296.137	7275.837	7280.737	7275.737
SSC4	1768984.022	1624771.551	7291.570	7275.57	7276.57	7271.07
N1	1769766.803	1623551.333	7302.880	7287.58	N/A	N/A
N2	1769494.473	1623922.828	7286.082	7259.982	N/A	N/A
N3	1769992.937	1623707.834	7316.701	7312.9	7313.201	7311.601
N4	1769710.879	1624085.835	7314.739	7299.9	7304.439	7299.639
N5	1770257.280	1624139.388	7274.595	N/A	N/A	N/A
N6	1770124.012	1624404.741	7268.179	N/A	N/A	N/A

Footnotes:

CNE = Could Not Evaluate--core stored in plastic tubing; N/A= holes were drilled in a location where no Qbt4 is present

Table 2. Table of locations of the CMRR boreholes and elevations of the Qbt2-Qbt3 contact based on the original Kleinfelder logs and LANL examination of the CMRR cores. (All coordinates are in feet.)

Borehole	Northing	Easting	Surface Elevation	Kleinfelder 2/3 Contact Elevation	LANL 2/3 Contact Elevation
SSC1	1769099.385	1624613.269	7291.047	7165.047	7160.047
SSC2	1769245.984	1624718.639	7299.253	7173.453	7163.253
SSC3	1769120.801	1624870.330	7296.137	7170.737	7160.137
SSC4	1768984.022	1624771.551	7291.570	7165.570	7156.570
DSC2	1769147.752	1625262.747	7283.412	7163.412	7151.912

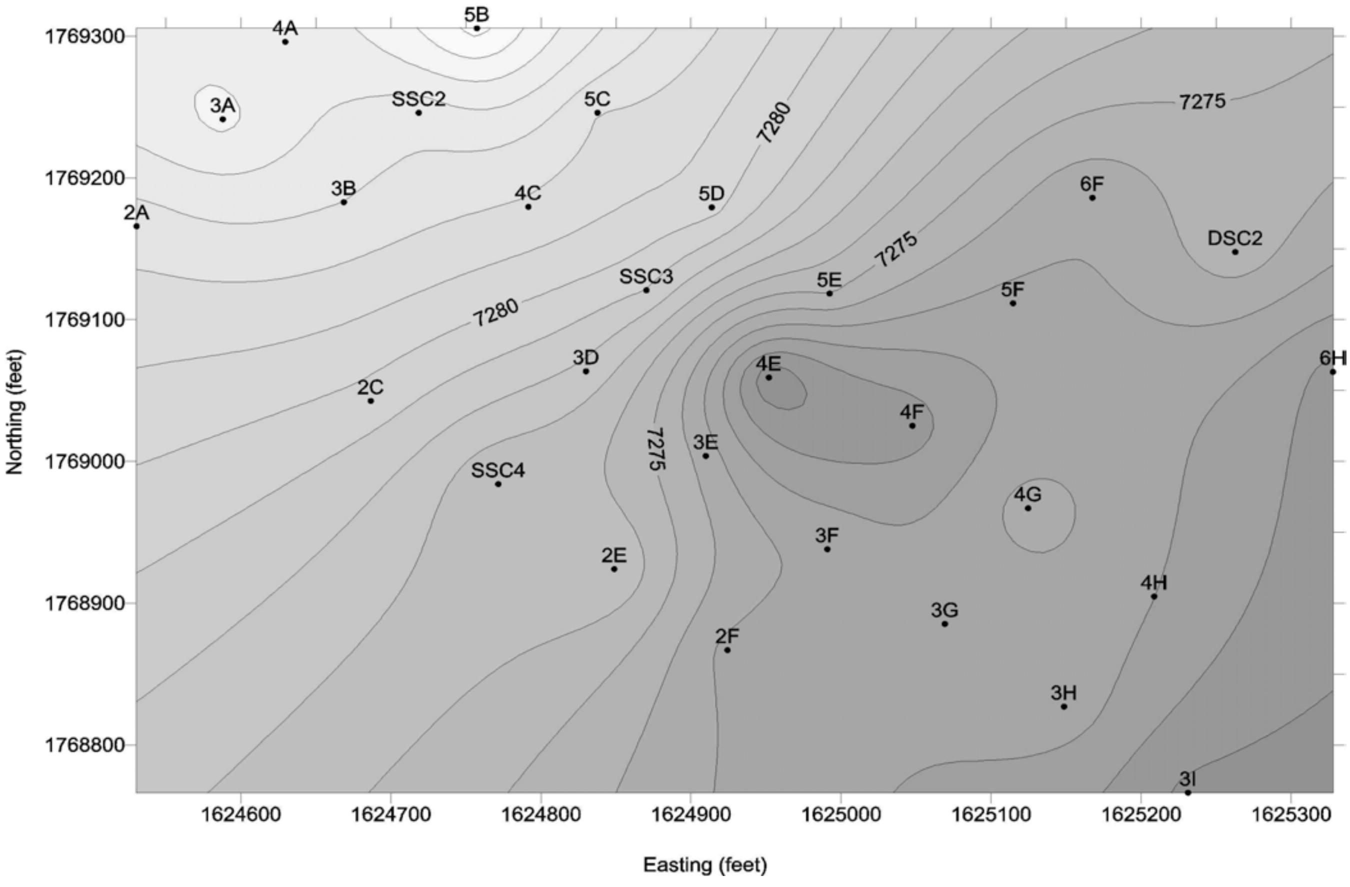

Figure 6. Surface model of the Qbt3-Qbt4 contact based on best calls on the elevation of the contact (within the interval of uncertainty) in relation to adjacent boreholes. Black dots represent CMRR boreholes. The surface was interpolated using kriging; contour interval is 1 ft (0.3 m). Grid is in the State Plane Coordinate System, New Mexico Central Zone, 1983 North American Datum (in feet).

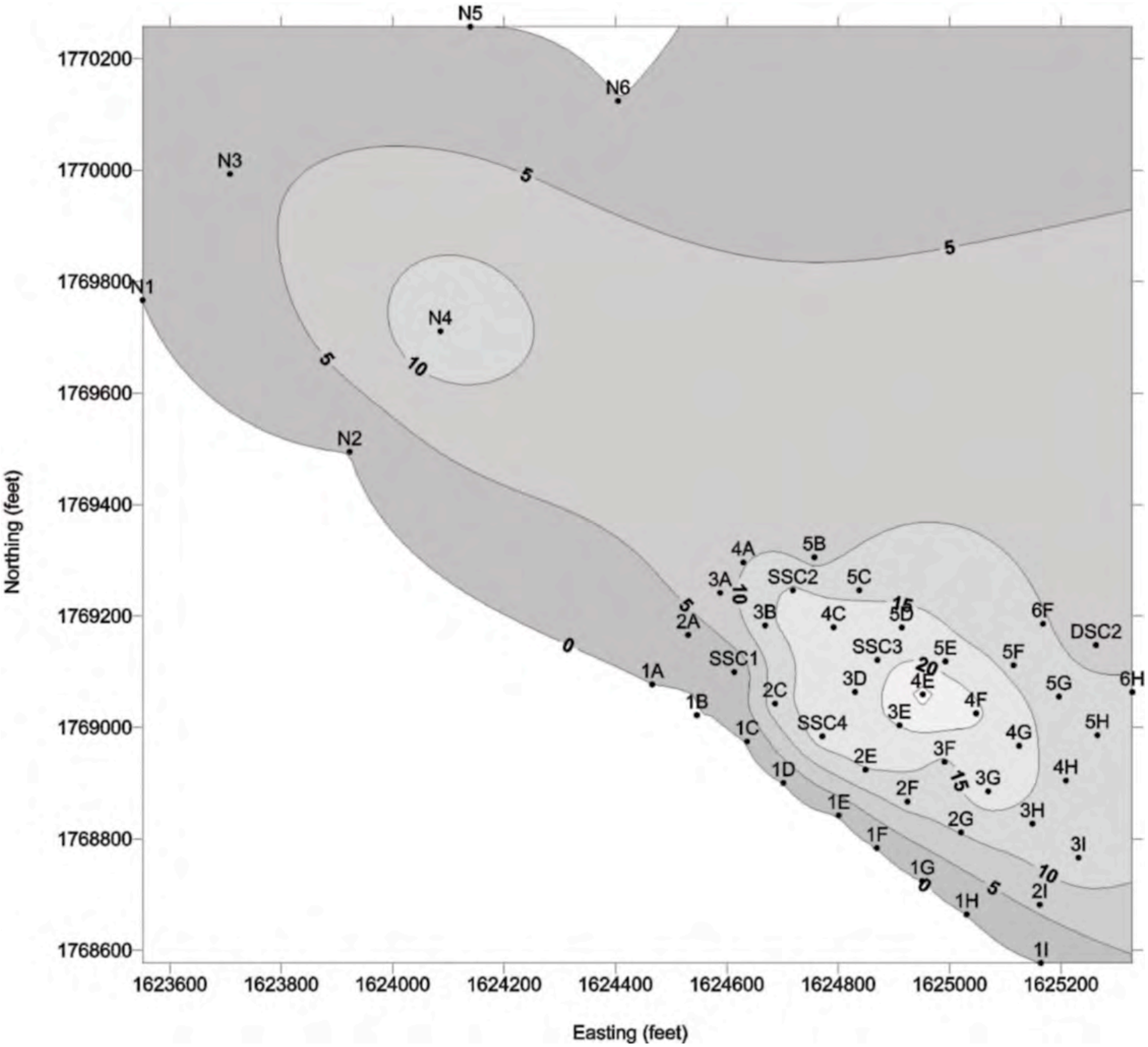

Figure 7. Isopach (thickness) map of Qbt4 from the CMRR boreholes. Black dots represent CMRR boreholes. Thicknesses are accurate to within ~3.5 ft (1.1 m) because of poor recovery. Additionally, although some boreholes penetrated thin surface fill or alluvium, we assumed the surface to represent the top of Qbt4. Greater thickness of Qbt4 in the area of boreholes 4E and 4F likely represents undulations on the top of unit Qbt3. The surface was interpolated using kriging; contour interval is 5 ft (1.5 m). Grid is in the State Plane Coordinate System, New Mexico Central Zone, 1983 North American Datum (in feet).

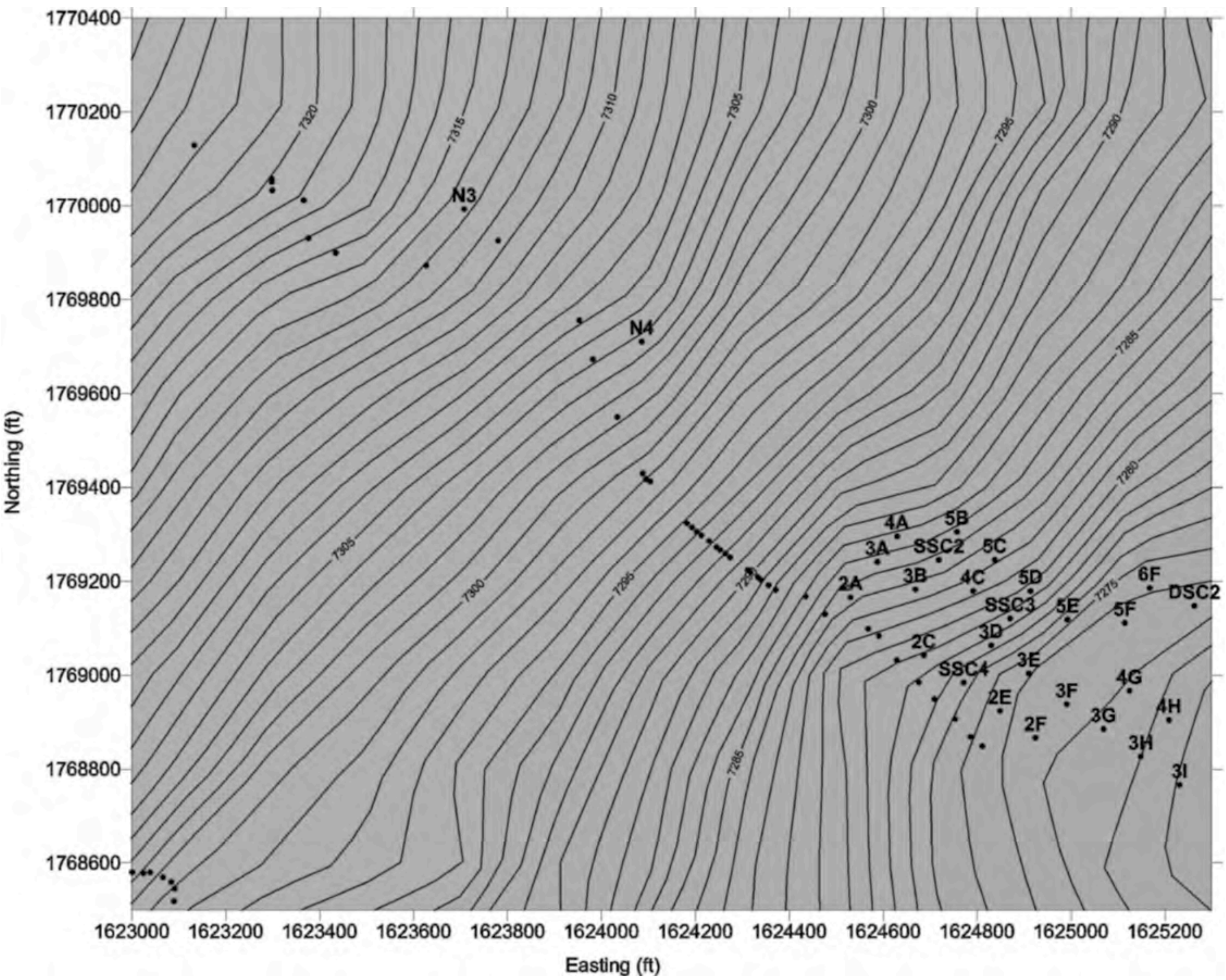

Figure 8. Surface model of the Qbt3-Qbt4 contact based on best calls of the elevation of the Qbt3-Qbt4 contact from the CMRR boreholes (without data from boreholes 4E and 4F) and survey data from Gardner et al. (1998, 1999). Black dots represent CMRR boreholes and survey data. The surface was interpolated using kriging; contour interval is 1 ft (0.3 m). Grid is in the State Plane Coordinate System, New Mexico Central Zone, 1983 North American Datum (in feet).

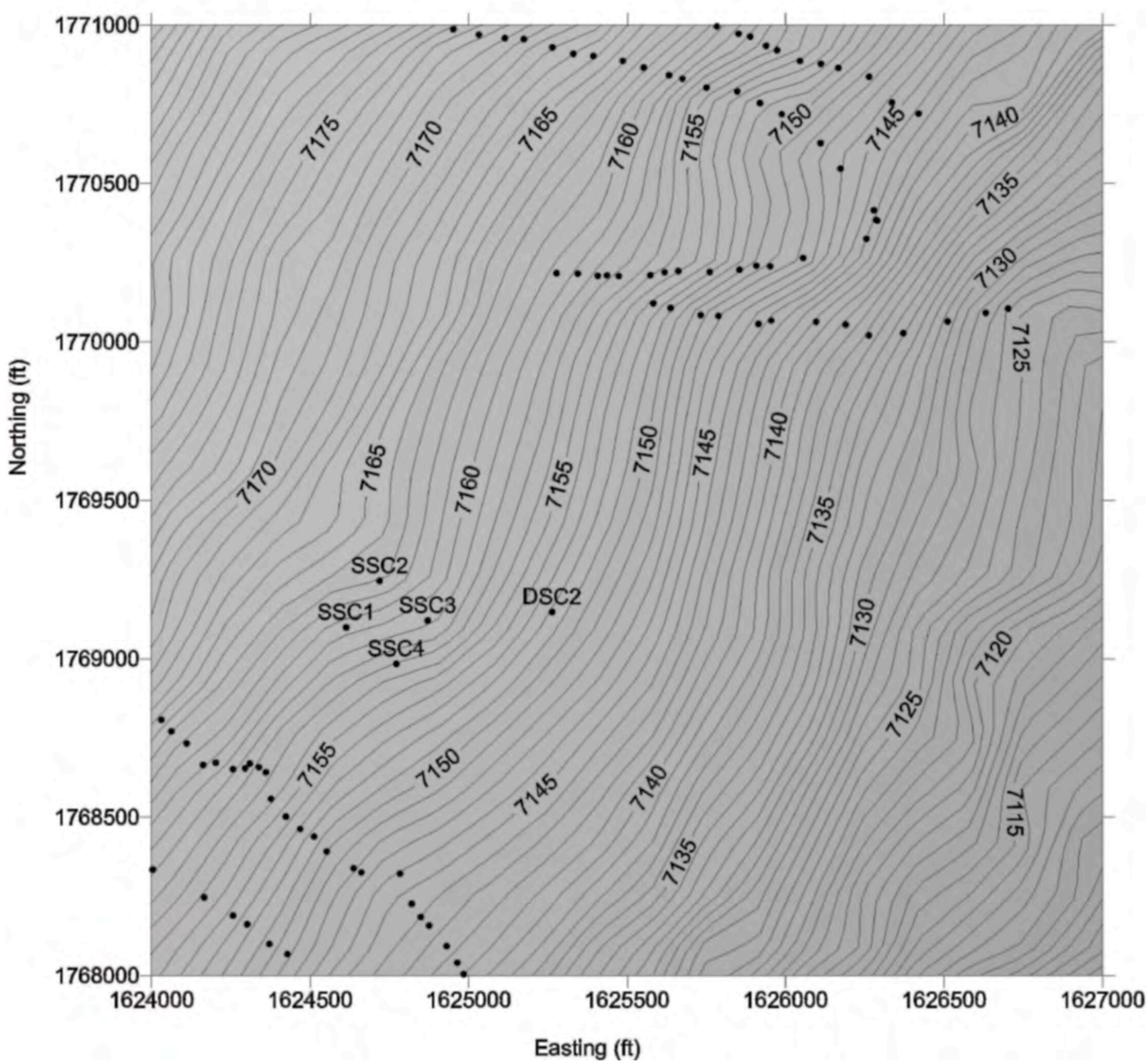

Figure 9. Surface model of the Qbt2-Qbt3 contact from CMRR boreholes and survey data from Gardner et al. (1998, 1999). Black dots represent CMRR boreholes and survey data. The surface was interpolated using kriging; contour interval is 1 ft. Grid is in the State Plane Coordinate System, New Mexico Central Zone, 1983 North American Datum (in feet).

Conclusions

Careful examination of core recovered from geotechnical drilling investigations at the CMRR site revealed a number of factors that preclude sufficiently accurate determination of the elevation of Tshirege Member contacts for assessing the potential for small magnitude [<1 ft (0.3 m) vertical displacement] fault offsets at the site. Our examination of the core revealed inconsistencies in placement of Tshirege Member contacts and incorrect placement of the contact on the original logs, which created a number of anomalies in the initial evaluation of the elevation of the Qbt3-Qbt4 contact in this area (Figure 4). Poor recovery of core in the contact zone limited us, in most cases, to determining an upper and lower bounding elevation for the contact (Figure 5). A number of other factors, including missing run blocks, mislabeled run blocks, and core boxed upside down, make assessments of depth of the contact in the core uncertain. To analyze the elevation of the contact within the uncertainties, we determined the most reasonable elevation within the upper and lower bounds relative to the elevation of the contact in adjacent boreholes. These data yield the surface model of unit Qbt3 in Figure 6. Combining information from Figure 6 with apparent thickness data on unit Qbt4 (Figure 7) shows that holes 4E, 4F, and 4G lie near the center of a broad low spot on the surface of unit Qbt3. Using the most reasonable elevations for the contact from the CMRR cores based on our observations together with survey data of Gardner et al. (1998, 1999), the remaining anomalies are readily explained by undulations on the surface of unit Qbt3 (Figures 7 and 8).

The western half of the CMRR site lies within the area mapped in detail by Gardner et al (1998, 1999), where no faults were found on the Qbt3-Qbt4 or Qbt2-Qbt3 contact. Additionally, best calls of the elevation of the contact from the boreholes are consistent with data from Gardner et al. (1999) in that they do not create anomalies in the surface defined by the top of Qbt3 with respect to these data, and further indicate the absence of faulting in this area. However, in the eastern half of the CMRR site, Gardner et al. (1998, 1999) were only able to map the Qbt2-Qbt3 contact because the Qbt3-Qbt4 contact was not exposed. Given the gradational nature of the Qbt2-Qbt3 contact, it is possible that small-vertical-displacement faults [<1 ft (30 cm) vertical displacement] may not have been recognized. Although we are unable to assess the potential for small-scale [<3 ft (1 m)] faulting at the CMRR site based on the elevation of the Qbt3-Qbt4 contact from core from geotechnical drilling investigations, analysis of the data does not suggest the presence of large-scale [>3 ft (1 m)] faulting at the site.

Based on available data from the boreholes, some anomalies still exist in the eastern part of the site, and uncertainties in the elevation of the contact exist for most of the boreholes drilled. A more detailed evaluation of potential small-displacement faults at the site could be achieved through trenching to a depth that would encounter the Qbt3-Qbt4 contact for the length of the trench or possibly through drilling with methods that could recover nearly 100% core.

Probabilistic surface rupture analyses by Olig et al. (1998, 2001) at TA-3 for the Rendija Canyon fault zone suggest that even in the case of 1-in-10,000-year events, seismic surface rupture is only a measurable hazard on the main trace of the Rendija Canyon fault. In probabilistic surface rupture studies for both the Pajarito and Rendija Canyon faults, the main splays of the faults have cumulative vertical displacements of >50 ft (>15 m) in Tshirege Member units (Olig et al., 1998, 2001). Based on detailed geologic mapping by Gardner et al. (1999), this study, and other previous studies, the CMRR site lies approximately ~3000 ft (1 km) to the east of the Rendija Canyon fault zone, and no large faults exist at the site. Therefore, if any unrecognized small displacement faults exist at the CMRR site, they have extremely low probability for surface rupture.

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