Permit 3/17/10 ENTERED

STATE OF NEW MEXICO
BEFORE THE SECRETARY OF ENVIRONMENT

IN THE MATTER OF:

APPLICATION OF THE UNITED STATES	)	
DEPARTMENT OF ENERGY AND	)	
LOS ALAMOS NATIONAL SECURITY, LLC	)	**No. HWB 09-37(P)**
FOR A HAZARDOUS WASTE FACILITY	)	**HWB 10-04(P)**
PERMIT FOR LOS ALAMOS NATIONAL	)	
LABORATORY	)	

TESTIMONY OF EMILY SCHULTZ-FELLENZ

My name is Emily Schultz-Fellenz and my testimony will address the RCRA seismic location standards as they apply to Building 185 at Technical Area (TA)-55, Building 39 at TA-54, and Dome 375 at TA-54.

Qualifications

I have a Bachelors Degree in geology from Lawrence University and a Masters Degree in geology from Oregon State University. I have worked on the LANL Seismic Hazards Geology Team since 2003. I work upon request from projects and facility planners to evaluate site suitability with respect to surface geologic faulting. A copy of my qualifications is attached to my testimony.

Direct Testimony

For new or enlarged hazardous waste management units, the Applicants are required to demonstrate compliance with the seismic location standards found at 40 CFR 264.18(a) and 270.14.b(11). Pursuant to 40 CFR 264.18(a), a new facility "where treatment, storage or disposal of hazardous waste will be conducted must not be located within 61 meters (200 feet) of a fault which has had displacement in Holocene time." The regulations do not apply to currently permitted or interim status units. At LANL, for purposes of the RCRA permit renewal, the only units subject to the seismic location standard requirements are Building 185 at TA-55, Building 39 at TA-54, and Dome 375 at TA-54.

The seismic analyses are based on published data, aerial reconnaissance, analysis of photographs, geological reconnaissance or trenching. 40 CFR §§270.14(b)(11)(ii). The first step of the analysis is to determine if Holocene faults or lineaments are present within 3000 feet of a proposed new unit. *Id.* If faults or lineaments are present within 3000 feet, a comprehensive geologic analysis is required to establish that no faults pass within 200 feet of the unit. *Id.*

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I conducted a RCRA seismic compliance evaluation for each of the three units and submitted a report for each unit to the New Mexico Environment Department (NMED) on June 29, 2009. As discussed in the reports, I relied primarily on published data and also conducted field reconnaissance at each site. For each site, the analysis began with a regional examination of the geology and structure of the Pajarito Plateau and ended with a specific focus on the area surrounding the facility to be permitted. Each report presents a Pajarito Plateau-scale map of faults and lineaments located within a five-mile radius of the facility to provide an overview of the structural setting and state of knowledge of the area. The reports discuss published mapping of the Pajarito fault system to determine the presence or absence of Holocene-aged surface rupturing faults. For clarification, Holocene represents the most recent epoch of geologic time, from 11,700 years ago until the present. The reports include an analysis of aerial photography covering a 3,000-feet radius of the particular unit being evaluated, and a summary of published geologic studies completed in and around either TA-54 or TA-55 for purposes of evaluating Holocene faulting hazards for each of the three units. The studies provide important control on the known extent of possible faults in the area. Field reconnaissance was conducted for sites at TA-54 and TA-55 where mapped lineaments project into the 3,000 ft radius surrounding the site.

The compliance evaluation for Building 185 at TA-55 demonstrates that, while there are some small faults identified within 3,000 feet of Building 185, the faults show only small amounts of displacement (less than two feet) and cannot be traced laterally across mesas or to other canyon exposures, the faults do not break the ground surface, there is no evidence for movement along the faults in Holocene time, the faults do not displace units younger than the Tshirege Member of the Bandelier Tuff (which has been dated at 1.256 million years old), and the faults do not have clear connections to other major regional faults. None of these faults project within 200 feet of Building 185. Therefore, these small faults do not constitute a seismic hazard to Building 185. Based on the data presented in the report, it was demonstrated that no faults with Holocene displacement are present within 200 feet of Building 185. NMED personnel were present at a geologic site visit to the Building 185 area in May, 2009.

For this testimony, we submit an exhibit pertaining to Building 185. This exhibit is a revised version of Plate 2, a figure originally submitted in the compliance evaluation for this facility. The figure has been modified to enhance clarity and understanding of the seismic setting near Building 185. As attached here, Plate 2 has been modified as follows: the TA-55 technical area boundary has been removed; the 200-ft radius line around Building 185 is shown; and the legend has been modified to reflect these changes. The modifications listed here make this exhibit different than the Plate 2 currently found within the Administrative Record.

The compliance evaluation for Building 39 at TA-54 demonstrated that, while faults have been documented within 3,000 ft of Building 39, these faults have small displacements (less than two feet), they lack lateral continuity, there is not evidence for movement along these faults in Holocene time, they do not have clear connections to other major regional

faults, the small faults do not break the ground surface, and do not displace units younger than the Tshirege Member of the Bandelier Tuff. Therefore, these small faults do not constitute a seismic hazard to Building 39 or neighboring facilities. Based on the data presented in the report and the field reconnaissance of lineaments and contact elevations, it was demonstrated that no faults with Holocene displacements are present within 200 feet of Building 39. Additionally, no lineaments which suggest the presence of a fault (that has had displacement during Holocene time) are found within 200 feet of Building 39. NMED personnel were present at a geologic site visit to the Building 39 area in May, 2009.

For this testimony, we submit an exhibit pertaining to Building 39. This exhibit is a revised version of the report text, originally submitted in the compliance evaluation for this facility. The report has been modified to correct improper figure references. The modifications make this report different than that currently found within the Administrative Record.

The compliance evaluation for Dome 375 at TA-54 demonstrated that, while faults have been documented within 200 feet of Dome 375 based on geologic investigations of nearby pits, these faults have small displacements (less than one foot), they lack lateral continuity, there is not evidence for movement along the faults in Holocene time, the faults do not displace units younger than the Tshirege Member of the Bandelier Tuff, and they do not have clear connections to other major regional faults. Therefore, these small faults do not constitute a seismic hazard to Dome 375 or neighboring facilities. Based on the data presented in the report and the field reconnaissance of lineaments and contact elevations, it was demonstrated that no faults with Holocene displacements are present within 200 feet of Dome 375. Additionally, no lineaments which suggest the presence of a fault (that has had displacement in Holocene time) are found within 200 feet of Dome 375. NMED personnel were present at a geologic site visit to the Dome 375 area in May, 2009.

As discussed in this testimony, the three reports submitted to NMED on June 29, 2009 demonstrated that there are no Holocene faults within 200 feet of Building 185 at TA-55, Building 39 at TA-54 and Dome 375 at TA-54 and the RCRA seismic standard is satisfied for each of the units. The July 6, 2009 NMED Fact Sheet, states that the Department determined the seismic location standard had been satisfied for TA-55 Building 185, TA-54 Dome 375, and TA-54 Building 39 based on the reports submitted by me.

FURTHER AFFIANT SAYETH NAUGHT

Emily Schultz-Fellenz

STATE OF NEW MEXICO)
) ss.
COUNTY OF LOS ALAMOS)

SUBSCRIBED, SWORN TO AND ACKNOWLEDGED before me this 17th day of March, 2010

NOTARY PUBLIC

My Commission Expires:
02/22/2012

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EDUCATION

BA, Geology, Lawrence University, Appleton, Wisconsin (2002)
MS, Geology (Tectonic Geomorphology/Structural Geology/Paleoseismology), Oregon State University, Corvallis, Oregon (2006)

EMPLOYMENT

January 2003-present
Los Alamos National Laboratory (now Los Alamos National Security, LLC)
Research Technologist, EES-16
Geoscience field and laboratory researcher and collaborator with other staff throughout LANL. High-precision survey lead and Laboratory-wide resource (total station and global positioning systems). Designated person-in-charge for field investigations to determine presence of faulting at the site of the Chemistry and Metallurgy Research Facility Replacement at LANL, with heavy federal project oversight. Principal contact and researcher for issues of surficial seismic hazards at LANL; currently, SME for ENV-RCRA interactions with NMED and TA-54 closure plans, field researcher/PI for geologic investigations at TA-50, TA-52, and TA-54. Member of LANL Water Stewardship Program—Canyon Sediment Transport Team; assist with Environmental Restoration project surveys and geomorphic studies. Initially employed as a post-baccalaureate fellow, I converted from student status to full-time permanent staff in January 2007.

August 2004-April 2006
Oregon State University
Research and Teaching Assistant
Assisted major advisor Dr. Andrew Meigs with field studies in Argentina while completing my master's thesis research; Instructor for GEOL 101 (Introductory Geology), GEOL 210 (Topics in Environmental Geoscience) and GEOL 340 (Structural Geology).

PROFESSIONAL RESEARCH INTERESTS

Seismic hazards (including earthquake rupture processes, seismic surface rupture, ground motion, fault system interaction and evolution, and probabilistic evaluation), volcanic hazards, structural geology, paleoseismology, innovative uses for geodetic survey tools, geomorphology and soil morphology, contaminant transport, paleomagnetism, hyperspectral imaging applications to geologic fieldwork and homeland security initiatives

ACTIVE MEMBERSHIPS AND AFFILIATIONS

Professional Societies

- Member, Geological Society of America
- Member, American Geophysical Union
- Member, Association of Women Geoscientists
- Associate Member, Sigma Xi
- Member, New Mexico Network of Women in Science and Engineering
- Member, Sigma Gamma Epsilon

Committee Service

- Chair, Academic and Applied Geoscience Relations Committee, Geological Society of America

- Member-at-Large, Minorities and Women in the Geosciences Committee, Geological Society of America
- Member, EES Worker Safety and Security Team
- Member-at-Large, EES Division Diversity Committee
- Member-at-Large, LANL Student Programs Advisory Committee
- Executive Committee Member, Los Alamos Women in Science
- Member, Expanding Your Horizons Conference Planning Committee
- Vice-President, Los Alamos Geological Society

AWARDS AND HONORS

- LAAP Award for Extraordinary Efforts in Completing the CMRR Report (2008)
- LAAP Award for Exceptional Performance in Science, Safety, Quality Assurance, and Logistics for the CMRR Project (2006)
- LANL SPOT Award for Excellence in Scientific Work and Professional Interactions with the NMED (2007)
- LANL SPOT Award for Superlative Safety Efforts for the CMRR Seismic Geology Team (2006)
- Outstanding Graduate Student Presentation in Earth and Space Sciences, LANL (2006)
- Taubeneck Fellow, Department of Geoscience, Oregon State University (2005-2006)
- The National Dean's List Exceptional College Student (2002)
- Ronald Tank Award in Geology, Lawrence University (2001)
- Eloise Frick Cherven Memorial Scholarship for Research in Geology, Lawrence University (2001)
- Kimberly-Clark Honor Scholar, Lawrence University (1998-2002)

SELECTED ABSTRACTS, PUBLICATIONS, PRESENTATIONS, AND REPORTS

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ES SCHULTZ-FELLENZ and RE Kelley, 2009, Evaluation of potential seismic hazards from surface-rupturing faults at Dome 375, Technical Area 54, Los Alamos National Laboratory: memorandum submitted to the New Mexico Environment Department, EES16-SHG-2009-001.

ES SCHULTZ-FELLENZ and RE Kelley, 2009, Evaluation of potential seismic hazards from surface-rupturing faults at Building 185, Technical Area 55, Los Alamos National Laboratory: memorandum submitted to the New Mexico Environment Department, EES16-SHG-2009-002.

Sussman, AJ, CJ Lewis, S Mason, ES SCHULTZ-FELLENZ, B Oliva-Urcia, J Geissman, and J Gardner, in review, Paleomagnetism and stratigraphic relations in the Quaternary Bandelier Tuff, Jemez Mountains: Implications for the Tectonic Evolution of the Rio Grande rift: submitted to a USGS Special Volume on the Española Basin.

ES SCHULTZ-FELLENZ, JN Gardner, FA Caporuscio, CJ Lewis, RE Kelley, and MK Greene, 2008, Insights on Post-Emplacement Deformation of the Bandelier Tuff, Rio Grande Rift, New Mexico: EOS, Trans. Am. Geophys. Union.

Caporuscio, FA, JN Gardner, ES SCHULTZ-FELLENZ, CJ Lewis, RE Kelley, and MK Greene, 2008, Fossil fumarolic pipes in the Tshirege Member of the Bandelier Tuff: EOS, Trans. Am. Geophys. Union.

Mason, S., A Sussman, JW Geissman, C Lewis, B Oliva-Urcia, E SCHULTZ-FELLENZ, and J Gardner, 2008, New Paleomagnetic Data from the Quaternary Bandelier Tuff: Implications for the Tectonic Evolution of the Rio Grande Rift: EOS, Trans. Am. Geophys. Union.

Gardner, JN., ES SCHULTZ-FELLENZ, FA Caporuscio, CJ Lewis, RE Kelley, and MK Greene, 2008, Geology and structure of the Chemistry and Metallurgy Research Facility Replacement site, Los Alamos National Laboratory, New Mexico: Los Alamos National Laboratory report LA-14378, 297 pp.

SCHULTZ-FELLENZ, ES, JN Gardner, FA Caporuscio, RE Kelley, and MK Greene, 2007, A high-precision, 3-dimensional fracture characterization study in the Bandelier Tuff, Pajarito Plateau, northern New Mexico: EOS, Trans. Am. Geophys. Union.

SCHULTZ-FELLENZ, ES, and JN Gardner, 2007, Review of the geologic and structural setting near the site of the proposed transuranic waste facility (TRUWF), Technical Area 52 (TA-52), Los Alamos National Laboratory: Los Alamos National Laboratory report LA-14343, 16 pp.

SCHULTZ, ES, 2006. Can growth strata identify individual paleoearthquakes and characterize fold kinematics? A case study from the La Laja Fault System, Sierra de Villicum, Argentina: Oregon State University master's thesis, 94 pp.

SCHULTZ, ES, AJ Meigs, D Ragona, TK Rockwell, C Costa, E Ahumada, T Middleton, and D Verdugo, 2005, Using paleoseismic investigations to test hypothesized fold growth mechanisms: a case study from the La Laja fault system, San Juan province, Argentina: EOS, Trans. Am.Geophys. Union.

Lavine, A., JN Gardner, and ES SCHULTZ, 2005, Evaluation of faulting at the Chemistry and Metallurgy Facility Replacement (CMRR) Site based on examination of core from geotechnical drilling studies, TA-55, Los Alamos National Laboratory: Los Alamos National Laboratory report LA-14170, 21 pp.

SCHULTZ, ES, CJ Lewis, A Lavine, JN Gardner, and SL Reneau, 2003, Along-strike variation in a faulted monocline, Pajarito fault, Los Alamos, New Mexico: *Geol. Soc. Am. Abstracts with Programs* **34**, no. 7.

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Symbol: EES16-SHG-2009-002-R1
Date: June 29, 2009

memorandum

Earth and Environmental Sciences Division

REVISED: Evaluation of potential seismic hazards from Holocene-age surface-rupturing faults at Building 185, Technical Area 55, Los Alamos National Laboratory

This revised memorandum summarizes geologic investigations at and around Building 185 at Technical Area 55 (TA-55) of the Los Alamos National Laboratory (LANL) in Los Alamos County, New Mexico.

When selecting a site for a hazardous waste treatment, storage, and/or disposal facility, such as Building 185 at TA-55, the owner/operator (in this case, LANS, LLC and NNSA) must adhere to certain location standards, as identified in the Code of Federal Regulations, Title 40 (40 CFR), Part 264.18. The guidelines used to demonstrate compliance with the aforementioned location standard are presented in 40 CFR, Part 270.14(b)(11).

In this document, we address compliance with the seismic location standard through published geologic data, beginning with a regional view of the Pajarito Plateau and ending with specific focus on the facility to be permitted, Building 185. We present a Pajarito Plateau-scale map of faults and lineaments located within a five-mile radius of the facility to provide an overview of the structural setting and state of knowledge of the area. We discuss recent published mapping of the Pajarito fault system to determine the presence or absence of Holocene-aged surface-rupturing faults. We include analysis of aerial photography covering a 3,000-ft radius of the facility, and a summarization of published geologic studies completed in and around TA-55 for purposes of evaluating Holocene seismic hazards to Building 185. These studies provide important control on the known extent of possible faults in the area. We will end by discussing field reconnaissance of sites at TA-55 where mapped lineaments project through the site (examinations of Bandelier Tuff contact elevations).

Definitions

The following technical terms are used frequently throughout this document. Definitions are taken from The Dictionary of Geological Terms (Bates and Jackson, eds., 1984).

Displacement: a general term for the relative movement of the two sides of a fault, measured in any chosen direction; also, the specific amount of such movement. [Within this report, "displacement" and "offset" are interchangeable terms.]

Holocene: an epoch of the Quaternary period, from the end of the Pleistocene, approximately 8 thousand years ago [*sic*; Ogg et al. (2008) have updated the beginning of the Holocene to 11,700 years ago] to the present time.

Fault: a fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.

Fracture: a crack, joint, fault, or other break in rocks.

Lineament: a linear topographic feature of regional extent that is believed to reflect crustal structure. Examples are fault lines, aligned volcanoes, and straight stream courses.

Note that the definition of "lineament" does not imply that such an identified feature is actually a surficial manifestation of crustal structure with recent tectonic activity until the local geology is carefully considered. Additionally, unless otherwise clarified through detailed field examination or other means, the definition of "fault" does not imply a tectonic mechanism for genesis and/or growth. The definition also does not imply that each "fault" is independently seismogenic. Features defined as faults through geologic mapping must be considered in the context of the surrounding geology before their mechanism of formation is determined.

General Geologic Setting

TA-55 and Building 185 sit atop an unnamed mesa between Twomile and Mortandad Canyons in the north-central part of LANL (Figure 1). The local bedrock is the Bandelier Tuff, formed in two eruptive pulses from nearby Valles caldera, located approximately 10 miles west of Building 185. The older member, or Otowi Member, of the Bandelier Tuff has been dated at 1.61 Ma (Izett and Obradovich 1994). The younger member, or Tshirege Member, of the Bandelier Tuff has been dated at 1.256 Ma (age from Phillips et al. 2007) and is widely exposed as the mesa-forming unit around Los Alamos. Several discrete subunits comprise the Tshirege Member of the Bandelier Tuff, and commonly accepted stratigraphic nomenclature is described in detail by Broxton and Reneau (1995) and Lewis et al. (2009). The subunits exposed at TA-55 include Qbt2, Qbt3, and limited exposure of Qbt4. Understanding the subtle differences between Tshirege Member subunits and the nature of the contacts between subunits is critical to identifying fault-generated displacements around the Pajarito Plateau.

The Pajarito Plateau is bounded on its western edge by the Pajarito fault system, a 50-km-long system locally comprised of the down-to-the-east Pajarito fault (the master fault) and subsidiary down-to-the-west Rendija Canyon, Guaje Mountain, and Sawyer Canyon faults (Figure 1). This fault system forms the local active western margin of the Rio Grande rift near Los Alamos.

Regional Structural and Seismic Studies

Geologic quadrangle mapping

Goff et al. (2001) completed geologic and structural mapping of the Frijoles (Los Alamos area) quadrangle at 1:24,000 scale. This study did not identify surficial geologic faults that disrupt the Bandelier Tuff or younger units in the immediate vicinity (e.g., within 200 ft) of Building 185 at TA-55.

Lineament mapping

Before the completion of detailed geologic mapping at LANL, previous studies had inferred the surface traces of the Rendija Canyon and Guaje Mountain faults to continue southward through TA-55 and TA-63, (including Rogers et al. 1996; Dransfield and Gardner 1985; Vaniman and Wohletz 1990; Wong et al. 1995; Olig et al. 1996; and Wohletz 2004). Studies by Gardner et al. (1998, 1999), Lewis et al. (2002), Lavine et al. (2003), Lavine et al. (2005), Gardner et al. (2008), and Lewis et al. (2009) have utilized the most widely-accepted and detailed published stratigraphy of the Bandelier Tuff (that of Broxton and Reneau 1995; published in peer-reviewed literature by Lewis et al. 2009) to map small displacements across subunit contacts in the Tshirege Member across much of the western and central LANL campus.

Additionally, these more recent studies have acquired information on fault locations and amount of displacement using high-precision geodetic mapping of Tshirege Member subunit contacts along canyon edges. These recent, detailed studies have shown that previously-mapped lineaments in this area are not expressed as young surface-rupturing projections of the Rendija Canyon and Guaje Mountain faults transecting TA-55 and TA-63. In fact, the surface trace of the Rendija Canyon fault bends southwesterly and splays into TA-3 instead of continuing directly through TA-55, and the surface expression of the Guaje Mountain fault is not visible south of Pueblo Canyon. Gardner et al. (1999) evaluated pre-1947 stereo aerial photographs and correlated a few lineaments from the aerial photographs to minor surficial faulting of the Bandelier Tuff in the vicinity of TA-48.

While lineament mapping has been completed at a regional scale across much of the Pajarito Plateau, we emphasize that for determining the presence of Holocene faults, conventional field geologic mapping must be employed or consulted to confirm that (1) a lineament is truly a fault, and (2) that it displaces young units. Olig et al. (1998) supports this:

> The lineaments [shown on Plate 1 from Wong et al. 1995] were identified on aerial photographs or observed during an aerial reconnaissance and field-checked at a reconnaissance level. However, this generalized map ... should be considered preliminary in nature until a more comprehensive and detailed surficial mapping of LANL is completed.

Plate 1 shows TA-55, Building 185, a five-mile buffer around the facility (as mandated by 40 CFR 270.14(b)(11)(A)(2)), mapped surficial faults (Lewis et al. 2009), and mapped lineaments (Vaniman and Wohletz 1990; Wong et al. 1995). The surficial faults shown on Plate 1 and mapped by Lewis et al. (2009) represent the most recent and detailed state of knowledge of the surficial expression of the Pajarito fault system near LANL. Mapping of the Pajarito fault system was done at 1:1,200 scale by personnel with a detailed knowledge of structural geology and Tshirege Member subunits, and represents a culmination of many years of work by the LANL Seismic Hazards Geology Team. In many locations around TA-55, high-precision geodetic surveying was used to identify minor (< 3 ft) displacements on the contacts of Tshirege Member subunits along canyon exposures, thus determining the presence or absence of faults in anthropogenically-disturbed areas. Some faults associated with the Pajarito fault system fall within the buffer shown on Plate 1, but none are within 200 ft of Building 185.

Microseismic monitoring and analyses

The Los Alamos Seismic Network maintains a small number of seismic stations around north-central New Mexico. Their data is accessible publicly at the following URL: http://www.lanl.gov/orgs/ees/ees11/geophysics/lasn/lasn.html. All earthquakes identified in the LANL area have magnitudes of 2 or less and appear to cluster at the northern part of the Pajarito fault system. No earthquake epicenters are noted within 3,000 ft of Building 185, nor do they appear to occur systematically or non-systematically along mapped lineaments projecting within 200 ft of Building 185.

Published geologic studies of relevance to seismic hazards issues at TA-55

Several geologic investigations have taken place specifically at TA-55, given the sensitive nature of some facilities at that site and early geologic studies' projections of the Rendija Canyon fault through the site. These studies provide important constraint on the location, size, distribution, and implications of known faults with relation to Building 185. This memorandum summarizes some key geologic studies in the TA-55 area in chronological order by publication date.

- **Dames and Moore 1972**, Report of geologic, foundation, hydrologic and seismic investigation, Plutonium Processing Facility, Los Alamos Scientific Laboratory, Los Alamos, New Mexico [unpublished consulting report for the US Atomic Energy Commission]

  The engineering firm Dames and Moore completed a detailed geologic study for the site of the then-planned Plutonium Facility at TA-55. The study included an evaluation of geologic features within a 200-mile radius of the site and a detailed investigation of the immediate site area. In geologic reconnaissance of the site, the report notes that the main Pajarito fault trace is located approximately 2.7 miles west of the site, no tectonic fracture system associated with faulting or volcanism passes through the immediate facility footprint, and a fracture zone trending 340° to 345° (N20W to N15W) was identified 1,000 ft to the east of the facility footprint. A trench 1,000 ft long, 3 ft wide, and 8 ft deep was excavated diagonally (WNW–ESE) across the site and found no evidence of tectonic faulting. The log for this trench, however, was inconclusive because no coherent stratigraphic markers could be carried across the trench.

- **Dransfield and Gardner 1985**, Subsurface Geology of the Pajarito Plateau, Española Basin, New Mexico [report number LA-10455-MS]

  This report provides a description of geologic structure in units predating the Bandelier Tuff, based upon drill cores and geophysical surveys across the Pajarito Plateau. The authors note prominent aerial photographic lineaments projecting southward from Pueblo Canyon, and correlate these lineaments to subsurface projections of the Rendija Canyon and Guaje Mountain faults as far south as Water Canyon. The study attributes the lineaments to surficial manifestations of eroded fracture zones propagating upward from the subsurface trace of the faults. Both the Rendija Canyon and Guaje Mountain faults appear in seismic reflection transects south of their mapped surficial traces. A detailed surficial mapping campaign for the antithetic structures of the Pajarito fault system (Rendija Canyon and Guaje Mountain) had not yet been undertaken by the Laboratory at the time of publication of Dransfield and Gardner's work.

- **Reneau et al. 1995**, Surficial Materials and Structure at Pajarito Mesa [from Reneau and Raymond, eds., report number LA-13089-MS]

  A proposed mixed waste disposal facility at Pajarito Mesa prompted geologic surface mapping, high-precision total station mapping, and exploratory trenching around TA-67, south of TA-55. At the time of this study, it was postulated that young surface faulting associated with the Rendija Canyon fault might trend southward from the Los Alamos townsite, directly through TA-60, TA-48, TA-55, TA-40, and TA-67. Previous studies (including Dransfield and Gardner, 1985) had shown southern projections of the Rendija Canyon and Guaje Mountain faults through Pajarito Mesa. The geological mapping and trenching of Reneau et al. (1995) showed that faulting had affected Pajarito Mesa in the past, but the faulting is more complicated than previously inferred by Dransfield and Gardner (1985). Both down-to-the-east and down-to-the-west faulting is seen at Pajarito Mesa. These small faults were identified through conventional geologic mapping and mesa-edge investigations. Their lateral continuity could not be constrained, so these small faults are identified on maps as point-locations of offset on Tshirege Member subunits (cf. Plate 2). A full paleoseismic history was not determined through the trenching investigations of this study, but it was determined that faults did not affect geologic units younger than 50-60 ka. No increase in fracture density across the projections of the Rendija Canyon or Guaje Mountain faults was seen, and a detailed geodetic survey of pyroclastic surge beds showed no displacement of the Bandelier Tuff along the Rendija Canyon fault projection.

- **Gardner et al. 1998**, High-Precision Geologic Mapping to Evaluate the Potential for Seismic Surface Rupture at TA-55, Los Alamos National Laboratory [report number LA-13456-MS]

  Because early studies showed subsurface traces of the Rendija Canyon fault trending beneath TA-55, and because sensitive facilities exist at TA-55, there was concern that a fault might pass through TA-55 and possibly affect facility integrity. This study used high-precision total station mapping of Tshirege Member subunit contacts to recognize vertical fault displacement so small that they would be overlooked and unmapped by conventional geologic mapping techniques. Similar to the high-precision surveying by Reneau et al. (1995), locations of offset on the Tshirege subunit contacts were identified on geologic maps, often because the fracture along which the displacement occurred could not be traced vertically (across Tshirege subunit contacts lower in the stratigraphic section) or laterally (across mesas).

  The study found that 1,500 ft west of the Plutonium Facility at TA-55, one location had 2 ft down-to-the-southeast offset of the Qbt3 – Qbt4 contact. Similar offset could not be found on the Qbt2 – Qbt3 contact lower in Twomile Canyon in the same location, and the fault could not be traced laterally across Twomile or Mortandad Canyons. Additionally, another single location of offset was located along the Qbt3 – Qbt4 contact in Twomile Canyon ~2,000 ft west of Building 185 (Plate 2). This offset correlates to a mapped lineament from Vaniman and Wohletz (1990). At this location, displacement was not noted at the Qbt2-Qbt3 contact, nor was displacement seen within younger units. Because displacement was not found at other stratigraphic contacts or in younger units along those same lineaments, and because offset was not found in other exposures along-trend, these lineaments does not represent geologic structures, and therefore do not present a seismic hazard to TA-55.

  The high-precision geologic mapping also identified an increase in down-to-the-west faulting to the west of TA-48, and a zone of intense faulting at the Los Alamos County Landfill that merited further investigation to determine its relationship to the Rendija Canyon fault.

- **Gardner et al. 1999**, Structural Geology of the Northwestern Portion of Los Alamos National Laboratory, Rio Grande Rift, New Mexico: Implications for Seismic Surface Rupture Potential from TA-3 to TA-55 [report number LA-13589-MS]

  Sparked by the findings of Gardner et al. (1998), Gardner et al. (1999) gathered structural geologic data for a region of LANL stretching from TA-3 to TA-55 using high-precision geologic mapping, conventional geologic mapping, stratigraphic studies, drilling, petrologic studies, and stereographic aerial photograph analysis. This mapping is seen in Figure 2. This study found that the Rendija Canyon fault, which is a single, simple down-to-the-west structure north of the Los Alamos townsite, splays to the southwest in a broad zone of deformation south of Los Alamos Canyon, through the Los Alamos County Landfill and TA-3, and likely dies out just south of Twomile Canyon. The potential for seismic surface rupture at TA-55 was estimated as extremely low because virtually no identifiable or mappable deformation younger than 1.2 million years (the age of the Tshirege Member) could be documented at TA-55.

  Additionally, this study evaluated and synthesized the findings of prior fracture investigations in areas to the north (Los Alamos Canyon) and to the south (Pajarito Mesa) of TA-55. Along the north edge of Los Alamos Canyon, Wohletz (1995) identified zones of abundant fractures by walking the mesa edge and measuring fracture orientation, aperture, and density. Wohletz (1995) could not determine whether tectonic movement produced the increased number of fractures seen east of Omega Site in Los Alamos Canyon, or further opened fractures which originated as cooling joints.

Detailed studies involving trenching, however, at sites on Pajarito Mesa have shown no correlation between higher-density zones of fractures and surficial faults (Kolbe et al. 1994; Reneau et al. 1995).

- **Lavine et al. 2005**, 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 [report number LA-14170]

  A team of LANL geologists was tasked with reviewing the findings of a geotechnical borehole study by an outside contractor at the site of the proposed Chemistry and Metallurgy Research Facility Replacement (CMRR) site at TA-55 to determine possible faulting at CMRR through evaluating contact elevations in boreholes. The northwestern corner of the CMRR site is located approximately 360 ft SSE of Building 185.

  The outside contractor completed a thorough drilling campaign of the proposed footprint of the facility. Preliminary examination of the contact elevations recorded from the boreholes (as identified by the outside contractor's site geologists) revealed many anomalies in the Qbt3 – Qbt4 contact elevation across the site. After careful re-examination of the core, the authors determined that a combination of poor core recovery across the critical contact area, human error (e.g., inconsistent contact calls, mislabeled core boxes, unlabeled run blocks, cores boxed upside-down) and unfamiliarity with the Tshirege Member subunits by the outside contractor's site geologists made for uncertain depth determinations of the Qbt3 – Qbt4 contact. The re-evaluation of the cores found no evidence of large-scale faulting (> 3 ft of vertical displacement) at the site, but some anomalies from the contact elevations of the boreholes could not be resolved with the core data alone and warranted further study.

- **Gardner et al. 2008**, Geology and Structure of the Chemistry and Metallurgy Research Facility Replacement Site, Los Alamos National Laboratory, New Mexico [report number LA-14378]

  As a follow-up from the work of Lavine et al. (2005), discussions began among the CMRR project staff and LANL's Seismic Hazards Geology Team to develop an appropriate approach to excavations for seismic surface rupture studies at the proposed CMRR site. A solution was reached to excavate a "seismic pit", allowing the LANL Seismic Hazards Geology Team unobstructed access to the pit walls to evaluate the geology exposed there for evidence of possible faulting, while also providing a lay-down yard and staging area for construction of the neighboring Radiological Laboratory / Utility / Office Building (RLUOB). Detailed geologic investigations at the site of the proposed CMRR at TA-55 mapped in detail the Qbt3 –Qbt4 contact (cf. Broxton and Reneau 1995) and the variably-interbedded pyroclastic surge deposit, and identified and measured over 1,200 accessible and well-exposed fractures for the purpose of determining the potential seismic surface rupture hazard at the site.

  Many fractures exposed in the excavation had near-vertical dips, narrow apertures, and curvilinear trends. One fault at the CMRR site had a curving failure surface; updip, it showed reverse movement, while showing normal movement downdip. These fracture characteristics are similar to those seen at Mesita del Buey (TA-54) and identified by Purtymun and Kennedy (1971) as indicative features of cooling joints. One suite of fractures found in the CMRR seismic pit displaces only the Qbt4 – surge contact or the surge – Qbt3 contact. These fractures either do not displace both contacts or do not exhibit vertical continuity through both contacts. This suite of structures is a clear example of cooling features. Similar offset variability was identified by Gardner et al. (1998) at a location 1,500 ft west of the Plutonium Facility. Overall, the fractures identified at the CMRR site also had a

wide range of orientations, with a slightly dominant pattern of west-northwest and north-northwest fracture strikes. The orientation data show no convincing relationship between the structures at the proposed CMRR site and the Pajarito fault system or the Rio Grande rift.

Analyses of the fractures at the proposed CMRR facility showed that only a very small percentage (2%) could be classified as faults. These identified faults commonly formed the bounding edge of areas identified as fossil fumaroles, which are volcanogenic features. The fossil fumaroles are interpreted to be regions of active degassing of the hot tuff very shortly after emplacement (on the order of one to ten years after deposition; cf. Dunne et al., 2003). Only one fault could be correlated between two of the excavation walls, but could not be found along-strike on another excavation wall. Additionally, Gardner et al. (1999) did not map this fault where its along-strike continuation would intersect natural exposures of the Qbt3 – Qbt4 contact about 250 ft west of the CMRR pit's western edge. This study concluded that fractures and faults at the proposed CMRR site formed very shortly after emplacement of the tuff at 1.256 Ma as a result of cooling and compaction, and the structures identified at the proposed CMRR site pose no independent seismic surface rupture hazard.

Local Lineament Mapping and Field Reconnaissance at TA-55 and Surrounding Canyons

We present a local lineament map (Plate 2) of the 3,000-ft buffer area surrounding Building 185. Present on both Plates 1 and 2 are lineaments from Wong et al. (1995) and Vaniman and Wohletz (1990) that trend roughly north-south. According to previously published geologic studies that have examined the canyon exposures at areas where the lineaments are projected to cross TA-55 (*cf.* Gardner et al., 1998, 1999), some lineaments do correspond to small displacements of the Bandelier Tuff. However, displacement often cannot be traced down or up through the stratigraphic section, faults are not visible as surficial offset, they cannot be traced across mesa-tops through conventional geologic mapping, and are not found to displace units younger than the tuff.

At TA-55, high-precision geodetic surveying was used to identify displacements on the Tshirege subunit contacts along canyon exposures, thus determining the presence or absence of small-displacement faults. Gardner et al. (1998; 1999) performed high-precision geodetic surveying of Twomile and Mortandad Canyons to locate small-displacement faults, and while they located numerous small faults further west and south within TA-55, they found no faults within 200 ft of the projection of Building 185 to the north wall of Twomile Canyon.

For verification purposes, we performed a field reconnaissance for this report. The reconnaissance included examining the exposed Twomile Canyon subunit contacts at the location where the footprint of Building 185 would project to the wall, plus 200 ft west and east, to identify contact elevation anomalies that may reflect faulting. We used handheld GPS to locate positions along the cliff edges where the facility margins would project, and walked along the Qbt2 – Qbt3 contact to evaluate possible contact elevation anomalies indicative of faulting. This field reconnaissance found no evidence of contact anomalies or displacements that fall within 200 ft of Building 185. NMED personnel were present at a geologic site visit of the Building 185 area in May 2009, and no issues regarding geologic interpretations were raised at that time.

Figure 3 is a map of the Building 185 area, with 200-ft (red) and 3,000-ft (blue) buffers for RCRA seismic considerations. This map shows no mapped faults within the 200-ft buffer. Four identified points of offset on the Bandelier Tuff Tshirege Member subunits fall on or within the 3,000 ft buffer. The three point-locations wholly within the 3,000 ft buffer were mapped by Reneau et al. (1995) and Gardner et al. (1999), and the point-location along the buffer in the northeastern quadrant was mapped by Lavine et al.

(2003). These points of offset were found to have no greater than 3 ft of displacement and nearly zero lateral continuity.

We identify a few lineaments on Plate 2 (red dotted lines) that broadly correlate to previously mapped lineaments. The lineament trending towards the southwestern corner of TA-55 is roughly aligned with the inferred subsurface projection of the Rendija Canyon fault mapped by Dransfield and Gardner (1985). Beyond a possible correlation between the north-northwesterly trending lineament that projects into the southwest corner of the 3,000 ft RCRA buffer and two point-locations of identified offset from Reneau et al. (1995; Plate 1), other lineaments identified in this mapping do not correlate to known surficial geologic faults or have not been found to displace the Bandelier Tuff or younger units (where present) in the previous studies summarized above.

Discussion

Site-specific geologic investigations at TA-55, described above, show that the lineaments mapped through TA-55 on Plates 1 and 2 do not correlate with any identified, mapped, throughgoing Holocene faults. Two locations of offset in Twomile Canyon mapped by Reneau et al. (1995) and Gardner et al. (1998) fall along previously mapped lineaments. However, displacement is not continuous through the stratigraphic section and was not identified in other nearby canyons along the same lineaments. Neither geologic investigations at the TA-55 area, nor geologic quadrangle mapping in the Los Alamos area show Holocene faults in areas where lineaments have been identified on Plate 1.

Detailed geodetic surveying of the Qbt2 – Qbt3 contact and Qbt3 – Qbt4 contact by Gardner et al. (1998, 1999, 2008) did find small-displacement faulting around TA-55 and at CMRR, but did not locate faults within 200 ft of Building 185. In the work of Gardner et al. (2008), displacements on Tshirege subunit contacts were frequently correlated to fossil fumaroles, which are non-tectonic features. A walking reconnaissance of exposures along the north side of Twomile Canyon confirmed that no faults project into the 200 ft buffer surrounding Building 185 along that canyon exposure. It is believed that the lineaments identified in aerial photographs near TA-55 reflect eroded fracture zones propagating upward from the subsurface trace of the Rendija Canyon fault. These lineaments do not correlate with Holocene displacement of the Bandelier Tuff or younger units in the region around Building 185.

Anthropogenic disturbance affects the entire area within the 200-ft buffer of Building 185. Nearly all post-Bandelier Tuff sediments have been stripped from the mesa-top within the technical area for construction purposes. Without undisturbed post-Bandelier Tuff sediments, conducting future geologic field studies with the purpose of identifying potential Holocene movement(s) across geologic structures (including paleoseismic trenching or borehole investigations) would be extremely challenging, if not impossible, in the vicinity of Building 185. A recent, large-scale geologic investigation within the 3,000-ft buffer around Building 185 confirmed the paucity of post-Bandelier sediments in the area and also attributed faulting to cooling and compaction of the tuff shortly after emplacement (Gardner et al. 2008). Detailed geologic studies of the greater TA-55 area over the last 20 years have identified faults that are small, both in displacement and in lateral continuity. In comparison, other locations around Los Alamos where Holocene faulting has occurred and paleoearthquakes have been documented often show tens to hundreds of feet of displacement along a linear feature that is several miles long. These faults at TA-55 are likely too small to be individually seismogenic and thus the seismic hazard to Building 185 is extremely low.

Conclusions

Small faults have been identified near TA-55 by previous geologic studies. Two locations of offset on Tshirege subunits within the 3,000 ft buffer correlate to two different mapped lineaments. Some of these small faults fall within the 3,000 ft RCRA buffer around Building 185. These faults show small displacements (no greater than 3 ft) on Tshirege subunit contacts along the mesa edges. The faults cannot be traced across mesas or to other canyon exposures, they do not show movement in Holocene time, and they do not have clear connections to other major regional faults. Also, none of these faults project within the 200 ft buffer around the facility. Therefore, these small faults should not be considered a seismic hazard to Building 185. Based on the data presented in this memo using information from published geologic studies at and around TA-55, aerial reconnaissance of the area within a five-mile radius from Building 185, an analysis of aerial photographs, and field reconnaissance of lineaments and contact elevations, we demonstrate that no faults with Holocene displacement are present within 200 ft of Building 185. No displacement affects the Qbt2 - Qbt3 contact in Twomile Canyon across the region where the facility boundaries would project to the canyon edge. NMED personnel were present at a geologic site visit of the Building 185 area in May 2009, and no issues regarding geologic interpretations were raised at that time. Aerial reconnaissance, detailed geologic mapping of the LANL campus, and paleoseismic trenching investigations show that the focus of potential Holocene faulting is concentrated along the main structures of the Pajarito fault system, over two miles west of Building 185.

Figure Captions

Figure 1. Map of the Pajarito fault system in the vicinity of Los Alamos National Laboratory (green outline). TA-55 (gray polygon with red border) and Building 185 (red dot) are highlighted. PF = Pajarito fault; RCF = Rendija Canyon fault; GMF = Guaje Mountain fault; SCF = Sawyer Canyon fault. Structural mapping (bold black lines) from Lewis et al. (2009).

Figure 2. Portion of the high-precision geologic map of Gardner et al. (1999). Red dots are surveyed points along the Qbt2 - Qbt3 contact; green dots are surveyed points along the Qbt3 - Qbt4 contact. Note that the point of offset marked 2SE (2 ft down-to-the-southeast) on the Qbt3 - Qbt4 contact (located below the TA-48 label) does not correspond to offset on the Qbt2 - Qbt3 contact in either Twomile or Mortandad Canyons.

Figure 3. Map of Building 185 (small red polygon) in relation to the 200 ft (red) and 3,000 ft (blue) buffers. Three locations of offset identified on Tshirege subunit contacts fall within the 3,000 ft buffer. None fall within the 200 ft buffer. See text for further discussion.

Plate 1. Color orthophotography, mapped faults, and mapped lineaments within five miles (black ghosted line) of TA-55, Building 185. Structural mapping (bold black lines) from Lewis et al. (2009). Mapped lineaments from Vaniman and Wohletz (1990; orange lines), Wong et al. (1995; yellow lines), and this study (red dotted lines). TA-55 is east of the main trace of the Pajarito fault system. See text for further discussion.

Plate 2. Orthophotography, mapped faults, and mapped lineaments in the area surrounding Building 185. Lineaments from Vaniman and Wohletz (1990; orange lines), Wong et al. (1995; yellow lines), and this study (red dotted lines). Four separate lineaments project into the 3,000 ft buffer around Building 185. None project within 200 ft of the facility. Three locations of offset fall within the 3,000 ft buffer and were mapped by high-precision geodetic studies (Reneau et al. 1995; Gardner et al. 1998). Two offset locations fall along mapped lineaments; however, displacement could only be identified on one subunit contact and was not found along the same lineaments in Mortandad Canyon. See text for further discussion.

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Attachments (3 figures; 2 plates)

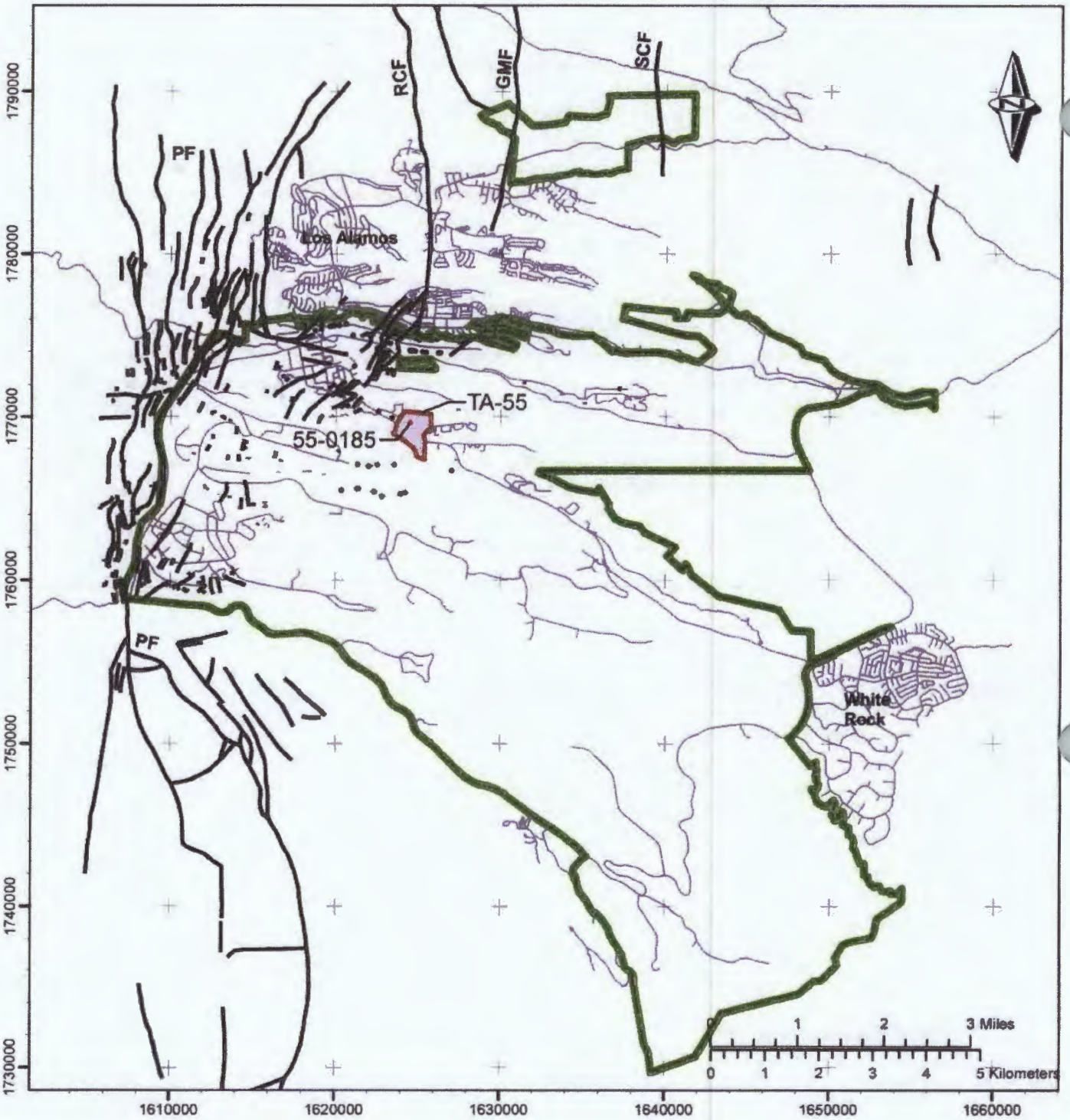

Figure 1:
Map of the Pajarito Fault System in the Vicinity of Los Alamos National Laboratory

Legend
- 55-0185
- Faults
- LANL boundary
- TA-55 boundary
- Identified Offsets
- Roads

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum
Grid Provides Units in Feet

GISLab Map No. m202033, rev. 1
GISLab Req. No. 14340
Cartography by Richard E. Kelley
June 12, 2009

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GISLab Los Alamos National Laboratory

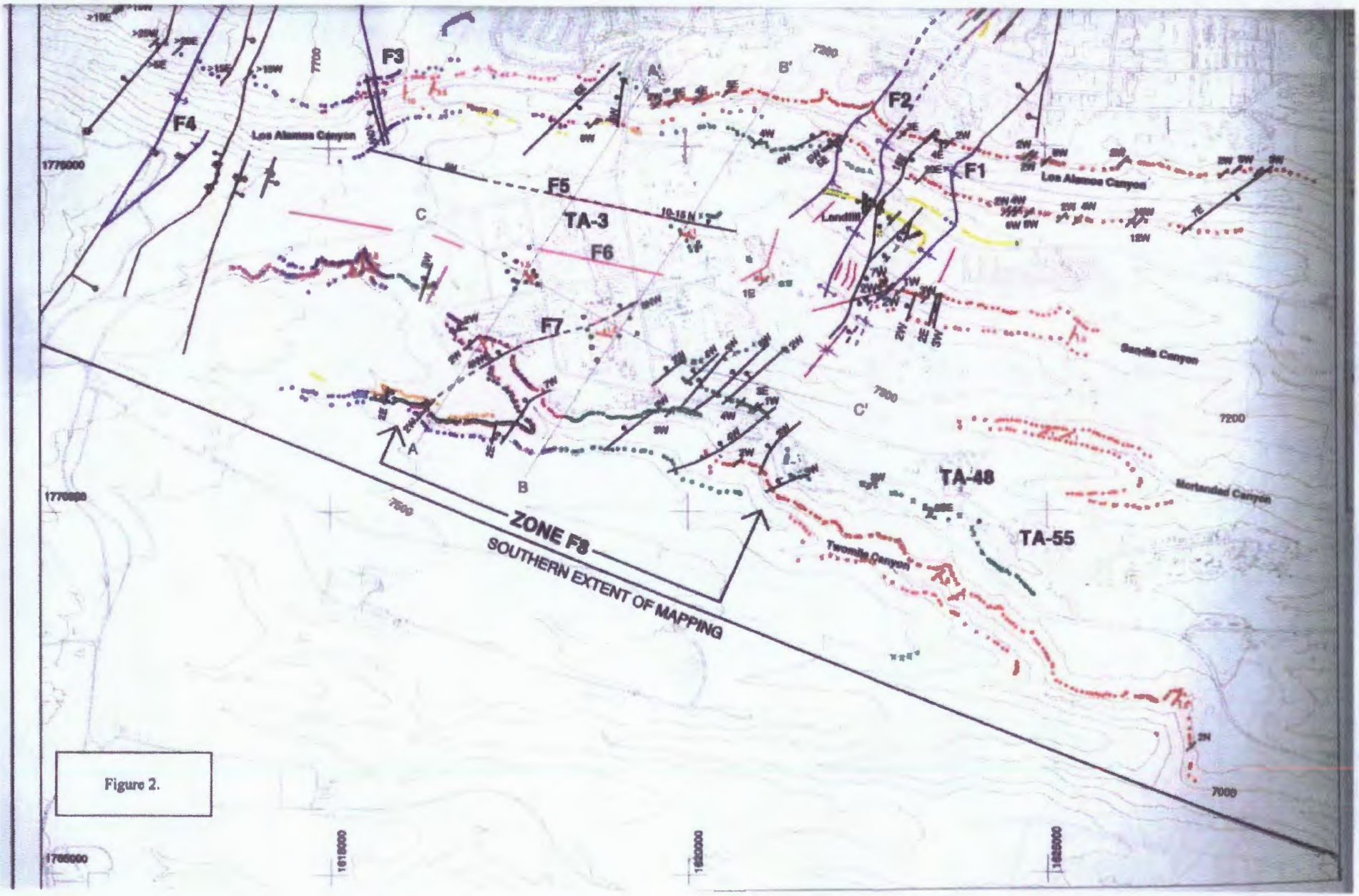
F1
F2
F3
F4
F5
F6
F7
TA-3
TA-48
TA-55
Los Alamos Canyon
Los Alamos Canyon
Landfill
Sandia Canyon
Mortandad Canyon
Twomile Canyon
ZONE F8
SOUTHERN EXTENT OF MAPPING
A
A'
B
B'
C
C'
7200
7000
1775000
1770000
1765000
1615000
1620000
1625000

Figure 2.

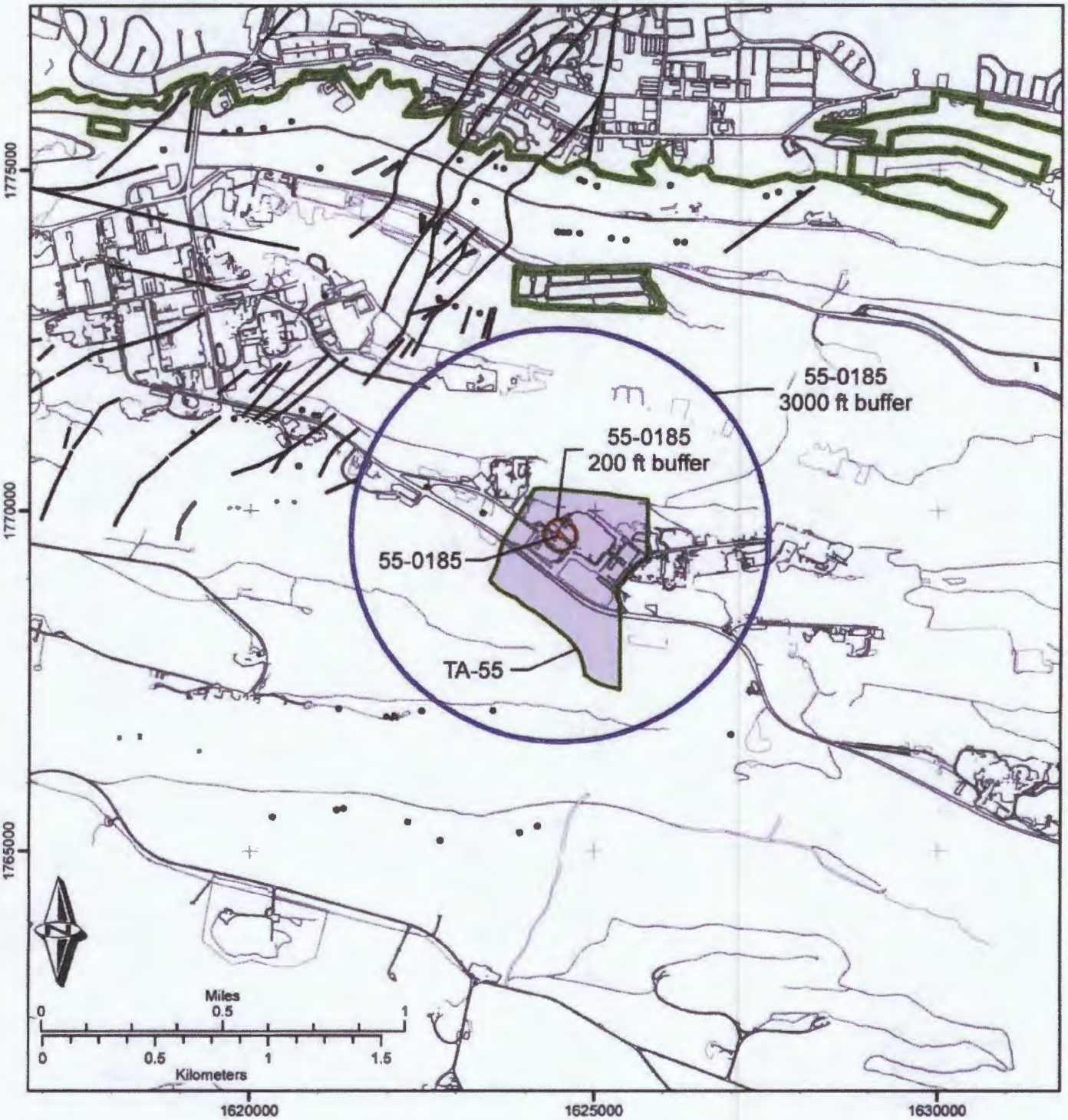

Figure 3:
200 ft and 3000 ft. Buffers of TA-55-0185

Legend

- Faults
- Identified Offsets
- LANL boundary
- 200ft. buffer
- 3000ft buffer
- 55-0185
- Paved roads
- Dirt roads
- TA-55 boundary

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum
Grid Provides Units in Feet

GISLab Map No. m202032, rev. 1
GISLab Req. No. 14240
Cartography by Richard E. Kelley
June 12, 2009

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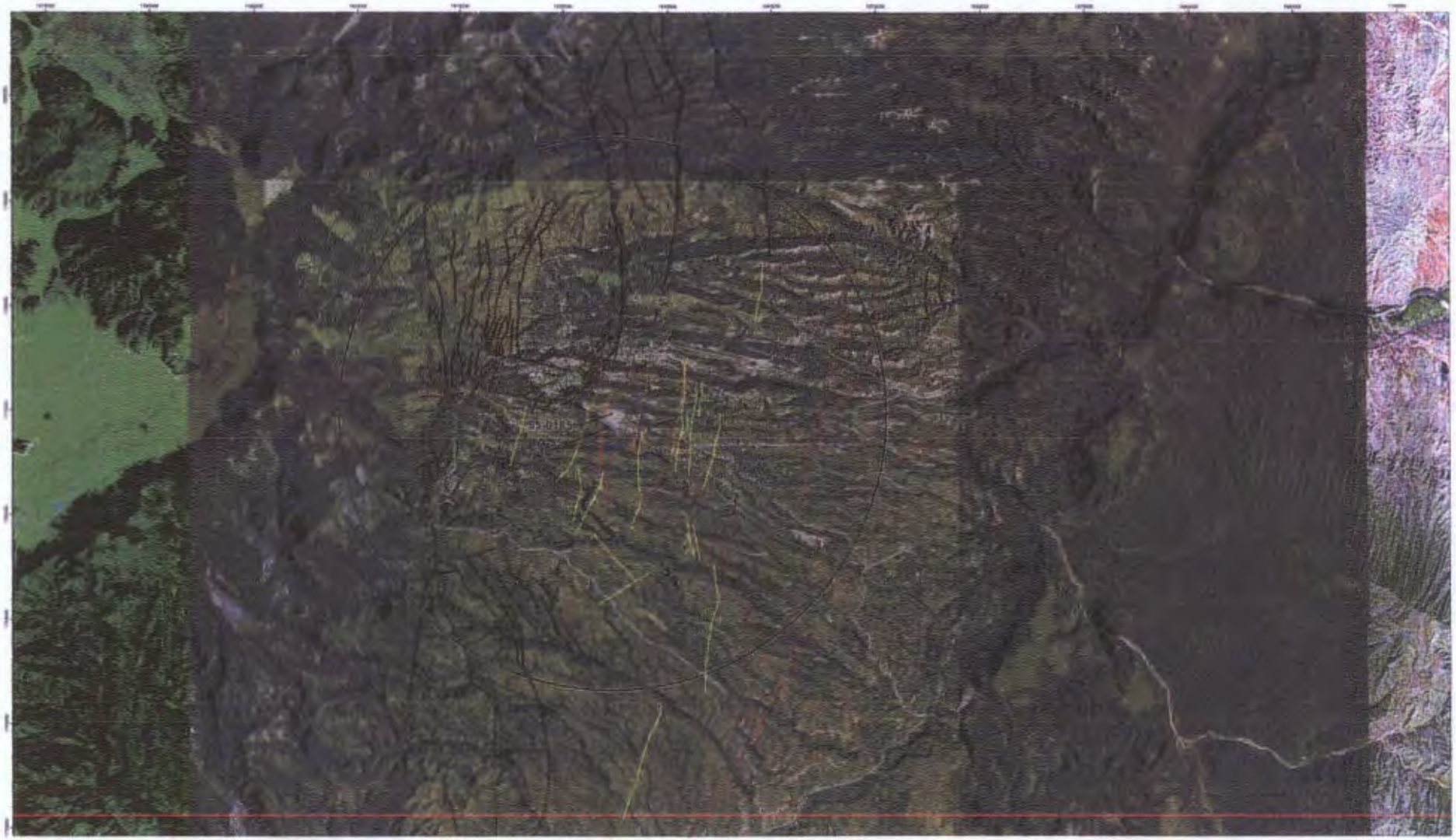

0 5,000 10,000 15,000 Feet

0 1,000 2,000 3,000 4,000 Meters

Plate 1:
Color Orthophoto Map of the Area
Surrounding Technical Area 55

RCR00042.001

0 1,000 2,000 Feet

0 300 600 Meters

Legend

Plate 2:
Ortho-photographic Map of the Area
Surrounding Technical Area 55

Aerial photography by Bohannan-Huston, Inc.
Data collected 5/7/2006 - 9/14/2006.

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memorandum

Earth and Environmental Sciences Division

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From/MS: Emily S. Schultz-Fellenz, EES-16, D452
Richard E. Kelley, EES-16, D452
Phone/Fax: 7-3605/Fax 7-1628
Symbol: EES16-SHG-2009-001-R1
Date: June 29, 2009

REVISED: Evaluation of potential seismic hazards from Holocene-age surface-rupturing faults at Dome 375, Technical Area 54, Los Alamos National Laboratory

This revised memorandum summarizes geologic investigations at and around Dome 375 at Technical Area 54 (TA-54) of the Los Alamos National Laboratory (LANL) in Los Alamos County, New Mexico.

When selecting a site for a hazardous waste treatment, storage, and/or disposal facility, such as Dome 375 at TA-54, the owner/operator (in this case, LANS, LLC and NNSA) must adhere to certain location standards, as identified in the Code of Federal Regulations, Title 40 (40 CFR), Part 264.18. The guidelines used to demonstrate compliance with the aforementioned location standard are presented in 40 CFR, Part 270.14(b)(11).

In this document, we outline compliance with the seismic location standard through published geologic data, beginning with a regional view of the Pajarito Plateau and ending with specific focus on the facility to be permitted, Dome 375. We present a Pajarito Plateau-scale map of faults and lineaments located within a five-mile radius of the facility to provide an overview of the structural setting and state of knowledge of the area. We discuss recent published mapping of the Pajarito fault system to determine the presence or absence of Holocene-aged surface-rupturing faults. We include analysis of aerial photography covering a 3,000-ft radius of the facility, and a summarization of published geologic studies completed in and around TA-54 for purposes of evaluating Holocene seismic hazards to Dome 375. These studies provide important control on the known extent of possible faults in the area. We will end by discussing field reconnaissance of sites at TA-54 where mapped lineaments project through the site (examinations of Bandelier Tuff contact elevations).

Definitions

The following technical terms are used frequently throughout this document. Definitions are taken from The Dictionary of Geological Terms (Bates and Jackson, eds., 1984).

Displacement: a general term for the relative movement of the two sides of a fault, measured in any chosen direction; also, the specific amount of such movement. [Within this report, "displacement" and "offset" are interchangeable terms.]

Holocene: an epoch of the Quaternary period, from the end of the Pleistocene, approximately 8 thousand years ago [*sic*; Ogg et al. (2008) have updated the beginning of the Holocene to 11,700 years ago] to the present time.

Fault: a fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.

Fracture: a crack, joint, fault, or other break in rocks.

Lineament: a linear topographic feature of regional extent that is believed to reflect crustal structure. Examples are fault lines, aligned volcanoes, and straight stream courses.

Note that the definition of "lineament" does not imply that such an identified feature is actually a surficial manifestation of crustal structure with recent activity until the local geology is carefully considered. Additionally, unless otherwise clarified through detailed field examination or other means, the definition of "fault" does not imply a tectonic mechanism for genesis and/or growth. The definition also does not imply that each "fault" is independently seismogenic. Features defined as faults through geologic mapping must be considered in the context of the surrounding geology before their mechanism of formation is determined.

General Geologic Setting

TA-54, MDA G, and Dome 375 sit atop Mesita del Buey in the eastern part of LANL (Figure 1). The local bedrock is the Bandelier Tuff, formed in two eruptive pulses from nearby Valles caldera, located approximately 14 miles west of MDA G. The older member, or Otowi Member, of the Bandelier Tuff has been dated at 1.61 Ma (Izett and Obradovich 1994). The younger member, or Tshirege Member, of the Bandelier Tuff has been dated at 1.256 Ma (age from Phillips et al. 2007) and is widely exposed as the mesa-forming unit around Los Alamos. Several discrete subunits comprise the Tshirege Member of the Bandelier Tuff, and commonly accepted stratigraphic nomenclature is described in detail by Broxton and Reneau (1995) and Lewis et al. (2009). The subunits exposed at Mesita del Buey include Qbt1 and Qbt2. Understanding the subtle differences between Tshirege Member subunits and the nature of the contacts between subunits is critical to identifying fault-generated displacements around the Pajarito Plateau.

The Pajarito Plateau is bounded on its western edge by the Pajarito fault system, a 50-km-long fault system locally comprised of the down-to-the-east Pajarito fault (the master fault) and subsidiary down-to-the-west Rendija Canyon, Guaje Mountain, and Sawyer Canyon faults (Figure 1). This fault system forms the local active western margin of the Rio Grande rift near Los Alamos.

Regional Structural and Seismic Studies

Geologic quadrangle mapping

Dethier (1996) and Goff et al. (2001) completed geologic and structural mapping of the White Rock and Frijoles (Los Alamos area) quadrangles at 1:24,000 scale, respectively. Neither of these studies identified surficial geologic faults that disrupt the Bandelier Tuff or younger units in the vicinity of TA-54.

Lineament mapping

Before the completion of detailed geologic mapping at LANL, previous studies had inferred the southern tips of the Rendija Canyon and Guaje Mountain faults to continue southward through TA-55 and TA-63 (including Rogers et al. 1996; Dransfield and Gardner 1985; Vaniman and Wohletz 1990; Wong et al. 1995; and Olig et al. 1996). Studies by Reneau et al. (1998), Gardner et al. (1998, 1999), Reneau et al. (2002), Lewis et al. (2002), Lavine et al. (2003), Schultz-Fellenz and Gardner (2007), Gardner et al. (2008), and Lewis et al. (2009) have utilized the most widely-accepted and detailed published stratigraphy of the Bandelier Tuff (that of Broxton and Reneau, 1995; published in peer-reviewed literature by Lewis et al., 2009) to map small displacements across Tshirege Member subunit contacts across much of the western and central LANL campus. Additionally, these more recent studies have acquired information on fault locations using high-precision geodetic mapping of Tshirege Member subunit contacts along canyon

edges. These recent, detailed studies have shown that previously-mapped lineaments in this area are not expressed as young surface-rupturing projections of the Rendija Canyon and Guaje Mountain faults transecting TA-55 and TA-63. In fact, the surface expression of the Rendija Canyon fault bends southwesterly at Los Alamos Canyon and splays into TA-3, and the surface expression of the Guaje Mountain fault is not visible south of Pueblo Canyon. Gardner et al. (1999) also evaluated pre-1947 stereo aerial photographs and correlated only a few lineaments from the aerial photographs to minor surficial faulting of the Bandelier Tuff. Those correlated structures are found in the vicinity of TA-48.

While lineament mapping has been completed at a regional scale across much of the Pajarito Plateau, we emphasize that for determining the presence of Holocene faults, conventional field geologic mapping must be employed or consulted to confirm that (1) a lineament is truly a fault, and (2) that it displaces young units. Olig et al. (1998) supports this:

> The lineaments [shown on Plate 1 from Wong et al., 1995] were identified on aerial photographs or observed during an aerial reconnaissance and field-checked at a reconnaissance level. However, this generalized map ... should be considered preliminary in nature until a more comprehensive and detailed surficial mapping of LANL is completed.

Plate 1 shows TA-54, Dome 375, a five-mile buffer around Dome 375 (as mandated by 40 CFR 270.14(b)(11)(A)(2)), mapped surficial faults (Lewis et al. 2009) and mapped lineaments (Vaniman and Wohletz 1990; Wong et al. 1995). The surficial faults shown on Plate 1 as mapped by Lewis et al. (2009) represent the most recent and detailed state of knowledge of the surficial expression of the Pajarito fault system near LANL. Mapping of the Pajarito fault system was done at a detailed scale by personnel with knowledge of structural geology and Tshirege Member subunits, and represents a culmination of many years of work by the LANL Seismic Hazards Geology Team. No fault strands with clear association to the structures of the Pajarito fault system are seen near Dome 375 in Plate 1.

Microseismic monitoring and analyses

The Los Alamos Seismic Network maintains a small number of seismic stations around north-central New Mexico. Their data is accessible publicly at the following URL: http://www.lanl.gov/orgs/ees/ees11/geophysics/lasn/lasn.html. All earthquakes identified in the LANL area have magnitudes less than or equaled to 2, and appear to cluster at the northern part of the Pajarito fault system. No earthquake epicenters are noted within 3,000 ft of Dome 375, nor do they appear to occur systematically or non-systematically along mapped lineaments projecting within 200 ft of Dome 375.

Published Geologic Studies of Relevance to the Seismic Location Standard at TA-54

Several geologic investigations have taken place at LANL with specific focus on TA-54. Data from these area-specific studies provide constraint on the location, size, distribution, and implications of known faults with relation to Dome 375. This memorandum summarizes some key studies in chronological order.

- **Purtymun and Kennedy 1971**, Geology and Hydrology of Mesita del Buey [report number LA-4660]

  This report describes the geology, structure, and hydrology of the TA-54 area for basic background and geologic site characterization. Purtymun and Kennedy (1971) identified three joint sets: 310° to 330° (N50W to N30W); 280° to 300° (N80W to N60W); and 40° to 60° (N40E to N60E). The authors described these joints as tensional, formed by the contraction of the tuff as it cooled, based upon the

joints' near-vertical attitudes and curvilinear trends. Purtymun and Kennedy (1971) identified a sequence of basalts underlying the Bandelier Tuff that, according to borehole studies, thin considerably towards the west across Mesita del Buey. They describe the basalts as a paleo-topographic high over which the Bandelier Tuff was deposited.

- **Rogers 1977**, History and Environmental Setting of LASL Near-Surface Land Disposal Facilities for Radioactive Wastes (Areas A, B, C, D, E, F, G, and T): A Source Document [report number LA-6848-MS, 2 vols.]

This report consolidated a vast amount of historic and geologic information on the beginnings and growth of material disposal areas around LANL. Here, we discuss geologic characterizations of pits located within 200 ft of Dome 375 that were available at the time of Rogers' (1977) report publication. Figure 2 shows the position of Dome 375 with respect to disposal pits at MDA G.

Pit 6 – geologic inspection in September and October, 1969. This pit, located in the moderately-welded Qbt2, was identified as having a soil cover thickness of 0-1 ft around the edges of the pit. Fractures range in dip from 60° to vertical. The fracture density average was documented as one fracture per six linear feet of pit wall. Three principal joint sets were identified: 24% of joints were oriented from 310° to 340° (N50W to N20W); 17% were oriented from 50° to 70° (N50E to N70E); and 15% were oriented from 350° to 10° (N10W to N10E). The remaining 44% of joints were of random orientation. Fracture apertures ranged from 0-1 in. No faults were identified.

Pit 7 – geologic inspection in August, 1973. This pit was also located in Qbt2. No soil cover characterization was documented for this pit. Fractures ranged in dip from 60° to vertical. Fracture density average was one fracture per six linear feet of pit wall, similar to other pits in the area. No joint had an aperture greater than 1 in. No faults were identified.

Pits 8 and 17 – geologic inspection in July, 1971. These pits were also located in Qbt2 and a thin layer of "reworked sediments", later identified as a pyroclastic surge deposit, was identified within Qbt2 here. It is the presence of this pyroclastic surge that allowed investigators to identify offsets along vertical fractures. Offsets of "several inches" were documented. Investigators attributed these offsets to cooling and compaction of the lower tuff units. Fracture density average was about one fracture per six linear feet of pit wall, similar to other pits in the area. Most fractures ranged in dip from 70° to vertical.

Pit 9 – geologic inspection in November, 1974. Only a Rose diagram of fracture orientations was recorded from geologic inspections at this pit. A greater percentage of fractures appear to have a roughly east-west orientation (between 60° and 90° azimuth), with another minor data peak showing north-northwest striking fractures (between 320° and 350° azimuth). No detailed information on fracture aperture or dip was available.

Pits 10, 18, 19 – no specific geologic information available.

Pit 24 – geologic inspections in November and December, 1973; and June, 1975. Geologic inspections at this pit were recorded only in a Rose diagram of fracture orientations. Many fractures identified in this pit appear to have orientations between 340° (N20W) and 50° (N50E) azimuth. No detailed information on fracture aperture or dip was available. No faults were noted.

Some faults were identified in pits beyond the 200-ft radius of Dome 375; however, the displacements on these faults are quite small (less than or equal to 3.5 in), they did not have lateral continuity (could not be correlated to larger structures), and the age of displacement could only be determined as younger than 1.2 Ma (the age of the Bandelier Tuff). Therefore, these small faults do not constitute a seismic hazard to Dome 375.

In summary, of the pits within 200 ft of Dome 375 that have available geologic information, the geologic data suggests a wide range of fracture orientations, near-vertical fracture dips, narrow apertures, and some minor faulting with offsets of less than a foot since the deposition of the Bandelier Tuff. These small-displacement faults with no documented lateral continuity do not pose a seismic hazard to Dome 375, and have been attributed to cooling and compaction of the tuff shortly after emplacement.

- **Dransfield and Gardner 1985,** Subsurface Geology of the Pajarito Plateau, Española Basin, New Mexico [report number LA-10455-MS]

  This report provides a description of geologic structure in units predating the Bandelier Tuff, based upon drill cores and geophysical surveys across the Pajarito Plateau. They note the presence of numerous down-to-the-west faults averaging 100 ft of displacement within basalts below TA-54. Cumulatively, 600 ft of displacement was identified along the sequence of pre-Bandelier Tuff faults. One of the easterly subsurface faults, near to the TA-54 area, correlates to a gravity inflection. This gravity anomaly may indicate of the western margin of the thick basalt sequence underlying the Bandelier Tuff, as identified in the cross-section from Purtymun and Kennedy (1971). None of these identified pre-Bandelier Tuff faults propagate upwards into the Bandelier Tuff or younger units.

- **Reneau et al. 1998,** Structure of the Tshirege Member of the Bandelier Tuff at Mesita del Buey, Technical Area 54, Los Alamos National Laboratory [report number LA-13538-MS]

  This study was performed to determine the presence or absence of faults at TA-54 through use of high-precision geodetic surveying of the Qbt1v – Qbt2 contact along the flanks of Mesita del Buey. Reneau et al. (1998) identified widely-distributed, small-scale faults at Mesita del Buey along a 2.2 mile traverse of the north wall of Pajarito Canyon and an 0.4 mile traverse of the north wall of a tributary to Cañada del Buey. A total of 37 faults with offsets ranging from 5 to 65 cm (2 to 25 in) were recorded. Typical fault offset was 20 to 30 cm (8 to 12 in) and all observed fault planes were steeply dipping. Since the exposure of the Qbt1 – Qbt2 contact was incomplete along the canyon wall traverses, Reneau et al. (1998) postulate that several additional faults of similar magnitude to those identified may exist in obscured areas. 65% of observed offset on identified faults was down-to-the-west, while the remaining 35% of observed offset was down-to-the-east. Opposing fault displacements partially compensate for each other, reducing cumulative offset along the surveyed transects. These identified faults were not concentrated in discrete areas or zones. Figure 3 shows that four locations of displacement are found within 3,000 ft of Dome 375, and none of these small-displacement faults are located within 200 ft of Dome 375. Figure 4 is a topographic profile of the Qbt1 – Qbt2 contact near Dome 375 along which Reneau et al. (1998) collected displacement information. Elevation data was not readily available from the Reneau et al. (1998) database, so this profile is based upon 2000 LIDAR elevation data. The LIDAR data creates some elevation anomalies seen in the western portion of the profile. Between 4,000 and 5,000 ft distance, displacement on the contact is seen; however, net displacement across this zone is nearly zero.

The general absence of large displacements along the Qbt1v – Qbt2 contact suggests that these small-displacement structures are not associated with major fault zones. Reneau et al. (1998) suggest that these small-displacement faults may record secondary deformation across the Pajarito Plateau associated with large earthquakes on the main Pajarito fault, several miles to the west, or even perhaps earthquakes on other regional faults. The small single offsets, reduced cumulative offset due to opposing fault displacements, lack of lateral continuity of these small faults across the mesa, and no displacements of units younger than the Bandelier Tuff along similar fractures support the statement that these small faults do not pose a seismic hazard to Dome 375.

- **Reneau and Vaniman 1998,** Fracture Characteristics in a Disposal Pit on Mesita del Buey, Los Alamos National Laboratory [report number LA-13539-MS]

  A study by Reneau and Vaniman (1998) documented fracture characteristics within Pit 39 at MDA G. Pit 39 is located ~ 600 ft west of Dome 375. This study identified moderate average fracture spacing, ranging from 3.2 to 4.2 ft in horizontal transects. The mean fracture dip is 76° and 77° for the lower and upper walls, respectively, and the median fracture dips are 84° and 87°. Fracture apertures were typically small, with average apertures of 0.1 to 0.2 in. The measurements of fracture dip and aperture at Pit 39 appear to be consistent with previous measurements from other pits at MDA G. While acknowledging directional bias in their fracture orientation data, Reneau and Vaniman (1998) observed fracture sets centered at about 95° (N85W) and 20° (N20E), with possible additional fracture sets centered at about 50° (N50E) and 165° (N15W).

Local Lineament Mapping and Field Reconnaissance at Mesita del Buey and Surrounding Canyons
We present a local lineament map (Plate 2) of the 3,000-ft buffer area surrounding Dome 375. Present on both Plates 1 and 2 is a roughly north-south trending lineament that enters the 3,000 ft buffer around Dome 375 and crosses Mesita del Buey approximately 2,000 ft west of the facility. North of Mesita del Buey, a bulldozed fire break visually exploits this lineament. Another lineament does not enter the 3,000 ft buffer but was projected through the site along-strike as a conservative measure. According to previously published geologic studies of Mesita del Buey that have examined the canyon exposures at areas where the lineament is projected to cross the mesa (cf. Reneau and Vaniman, 1998; Reneau et al., 1998), this lineament does not correspond to displacement of the Bandelier Tuff or younger units.

The lineaments identified in Plate 2 do not line up with mapped Holocene faults, nor do they correlate to locations at canyon edges where displacement of the Qbt1 – Qbt2 contact has been documented. These short-length lineaments typically do not imply the presence of tectonic faults. In comparison, locations around Los Alamos where Holocene faulting has occurred and paleoearthquakes have been documented often show tens to hundreds of feet of displacement along a linear feature that is several miles long.

In many locations within LANL, high-precision geodetic surveying was used to identify displacements on the Tshirege subunit contacts along canyon exposures, thus determining the presence or absence of small-displacement faults in anthropogenically-disturbed areas. TA-54 is one such location. Reneau et al. (1998) performed high-precision geodetic surveying of the north wall of Pajarito Canyon to locate small-displacement faults, and while they located numerous small faults further west within TA-54, their study found no faults along the north wall of Pajarito Canyon within 200 ft of the projection of Dome 375.

For verification purposes, we performed a field reconnaissance for this report. The reconnaissance included examining the exposed Tshirege Member subunit contacts at the location where the footprint of

Dome 375 would project to the canyon wall, plus 200 ft west and east, to identify contact elevation anomalies that may reflect faulting. We used handheld GPS to locate positions along the cliff edges where the facility margins would project, and walked along the Qbt1 – Qbt2 contact to evaluate the contact and possible contact elevation anomalies indicative of faulting. This field reconnaissance found no evidence of contact anomalies or displacements across projected lineaments that fall within the 3,000 ft buffer surrounding Dome 375, nor did we (or, as described herein, previous studies) identify contact elevation anomalies that suggest faulting within 200 ft of Dome 375. NMED personnel were present at this geologic site visit of the Dome 375 area in May 2009, and no issues regarding geologic interpretations were raised at that time.

Figure 5 is a map of the Dome 375 area, and includes 200-ft (red) and 3,000-ft (blue) buffers for RCRA seismic location standard considerations. The map shows no identified and mapped surficial faults within the RCRA-mandated distance buffers from Dome 375.

Discussion

Site-specific geologic investigations at TA-54, described above, show that the lineaments mapped as projecting through TA-54 on Plates 1 and 2 do not correlate with any identified, mapped Holocene faults. Neither geologic investigations at the TA-54 area, nor geologic quadrangle mapping in the Los Alamos and White Rock areas show Holocene faults in areas where lineaments have been identified on Plate 1. Detailed geodetic surveying of the Qbt1 – Qbt2 contact by Reneau et al. (1998) did find small-displacement faulting further west within TA-54, but did not locate faults within 200 ft of Dome 375 (Figure 3). A walking reconnaissance of exposures along the north side of Pajarito Canyon confirmed there are no faults beneath or within 200 ft of Dome 375. It is possible that the lineaments identified in aerial photographs near MDA G reflect old geologic structures beneath the Bandelier Tuff (e.g., faults whose most recent activity is greater than 1.61 Ma in age) or some other sort of depositional paleotopography on the top of the basalts that underlie the tuff. These lineaments do not correlate with displacement of the Bandelier Tuff or younger units. Additionally, Dransfield and Gardner (1985) interpreted subsurface data as indicating predominantly down-to-the-west displacement on generally north-trending faults in units older than the Bandelier Tuff in the eastern Pajarito Plateau area.

According to evidence described by Rogers (1977), very little soil cover is present atop the Bandelier Tuff at MDA G. Decades of continued activities at TA-54 have stripped virtually all post-Bandelier Tuff sediments off Mesita del Buey. Without undisturbed young sediments, conducting future geologic field studies with the purpose of identifying possible Holocene movement across faults (e.g., paleoseismic trenching, borehole investigations) would be extremely challenging, if not impossible near Dome 375. Identification of faults in the vicinity of TA-54 through more detailed geologic mapping, without the presence of post-Bandelier Tuff sediments, would not be able to determine the age of the most recent activity on such faults beyond the constraint of the age of the tuff.

Conclusions

Faults have been documented within 200 ft of Dome 375 in the disposal pits at MDA G (Rogers 1977). However, these faults have small displacements (less than a foot of offset on Tshirege subunits), they lack lateral continuity (they cannot be traced across mesas or to other canyon exposures), they do not show movement in Holocene time, and they do not have clear connections to other major regional faults. Therefore, these small faults should not be considered a seismic hazard to Dome 375 or neighboring facilities. Based on the data presented in this memo using information from published geologic studies at and around TA-54, aerial reconnaissance of the area within a five-mile radius from Dome 375, an

analysis of aerial photographs, and field reconnaissance of lineaments and contact elevations, we demonstrate that no faults with Holocene displacement are present within 200 ft of Dome 375. Additionally, no lineaments which suggest the presence of a fault (that has had displacement in Holocene time) are found within 200 ft of Dome 375. The lineaments seen on aerial photographs do not reflect Holocene faulting, based upon previous studies and the data summarized here.

Figure Captions

Figure 1. Map of the Pajarito fault system in the vicinity of Los Alamos National Laboratory (green outline). TA-54 (gray polygon with red border), MDA G (brown polygon) and Dome 375 (red dot) are highlighted. PF = Pajarito fault; RCF = Rendija Canyon fault; GMF = Guaje Mountain fault; SC = Sawyer Canyon fault. Structural mapping (bold black lines) from Lewis et al. (2009). This figure shows that Dome 375 is distal to faulting associated with the Pajarito fault system.

Figure 2. Location of Dome 375 (labeled; 200 ft buffer shown in red) relative to waste disposal pits at MDA G (olive polygon). See discussion of the work of Rogers (1977) for detailed information on the geology of pits near Dome 375.

Figure 3. Measured offsets on the Qbt1 – Qbt2 contact near Dome 375 as mapped by Reneau et al. (1998). Displacement (in cm) on the Qbt1 – Qbt2 contact is color-coded by magnitude; please refer to map legend for more information. Some areas of displacement do fall within the 3,000 ft buffer; none fall within 200 ft of the facility (or the projection thereof at Twomile Canyon). See text for further discussion.

Figure 4. Topographic profile of the Qbt1 – Qbt2 contact near Dome 375 along which Reneau et al. (1998) collected displacement information; approximately 20x vertical exaggeration. Elevation data was not readily available in the Reneau et al. (1998) database, so this profile is based upon 2000 LIDAR elevation data. The LIDAR data creates some of the elevation anomalies seen in the western portion of the profile. Between 4,000 and 5,000 ft distance, displacement on the contact is visible; however, net displacement is nearly zero.

Figure 5. Map of Dome 375 (small pink polygon) in relation to the 200 ft (red) and 3,000 ft (blue) buffers. No mapped faults are shown within the 3,000 ft or 200 ft buffers. See text for further discussion.

Plate 1. Color orthophotography, mapped faults, and mapped lineaments within five miles (black ghosted line) of TA-54, Dome 375. Structural mapping (bold black lines) from Lewis et al. (2009). Mapped lineaments from Vaniman and Wohletz (1990; orange lines), Wong et al. (1995; yellow lines), and this study (red dotted lines). TA-54 is well east of the main trace of the Pajarito fault system. See text for further discussion.

Plate 2. Orthophotography, mapped faults, and mapped lineaments in the area surrounding Dome 375. Mapped lineaments (red dotted lines) from this study. One lineament crosses into the 3,000 ft buffer around Dome 375. No faults or lineaments project within 200 ft of the facility. See text for further discussion.

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Attachments (5 figures; 2 plates)

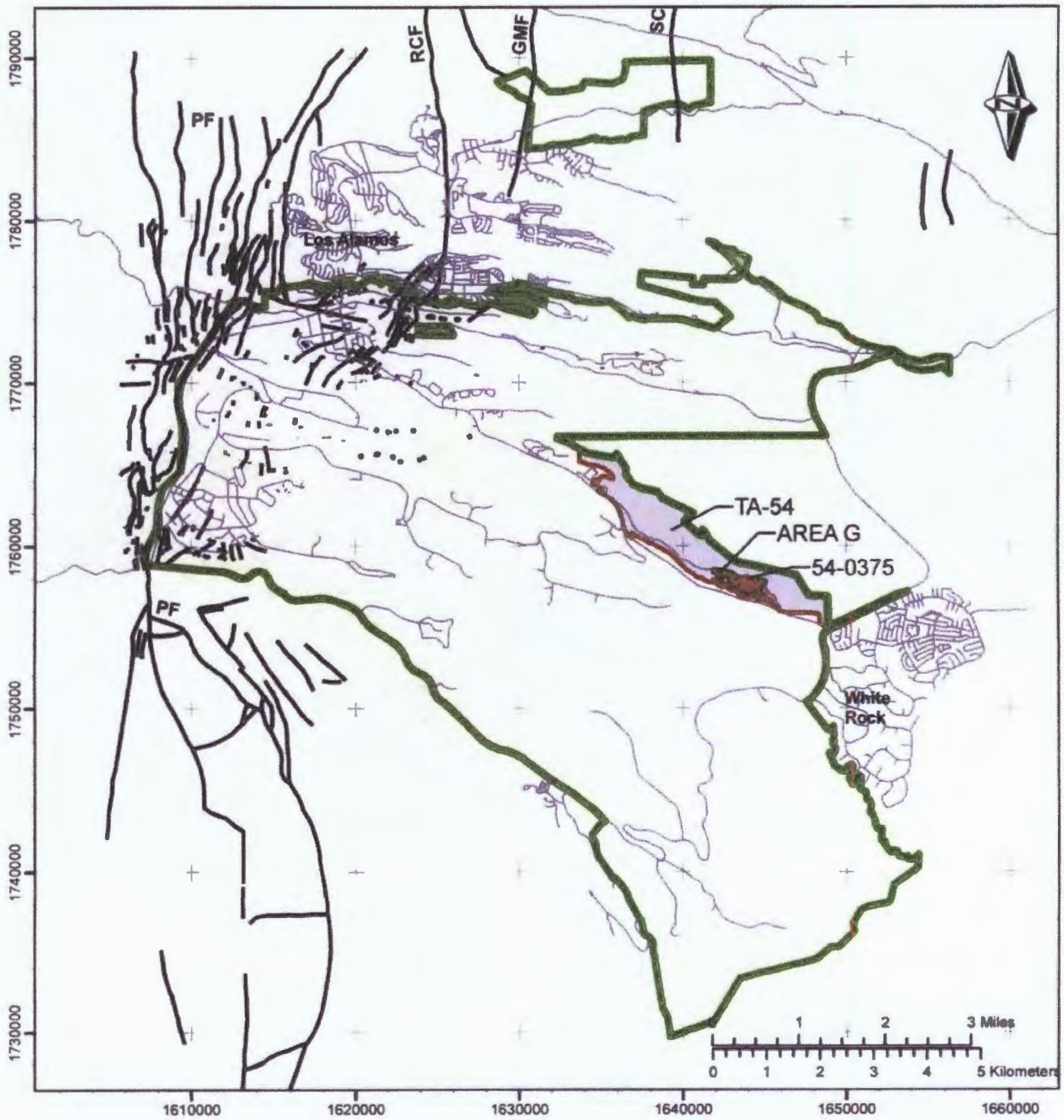

Figure 1:
Map of the Pajarito Fault System in the Vicinity of Los Alamos National Laboratory

Legend

- KSL_structures_ply20081015
- lac_centerlin_arc20071203
- Faults
- LANL boundary
- KSL_fodland_ply20081015
- TA-54 boundary
- Identified Offsets

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum
Grid Provides Units in Feet

GISLab Map No. m202017, rev. 1
GISLab Req. No. 14228
Cartography by Richard E. Kelley
June16, 2009

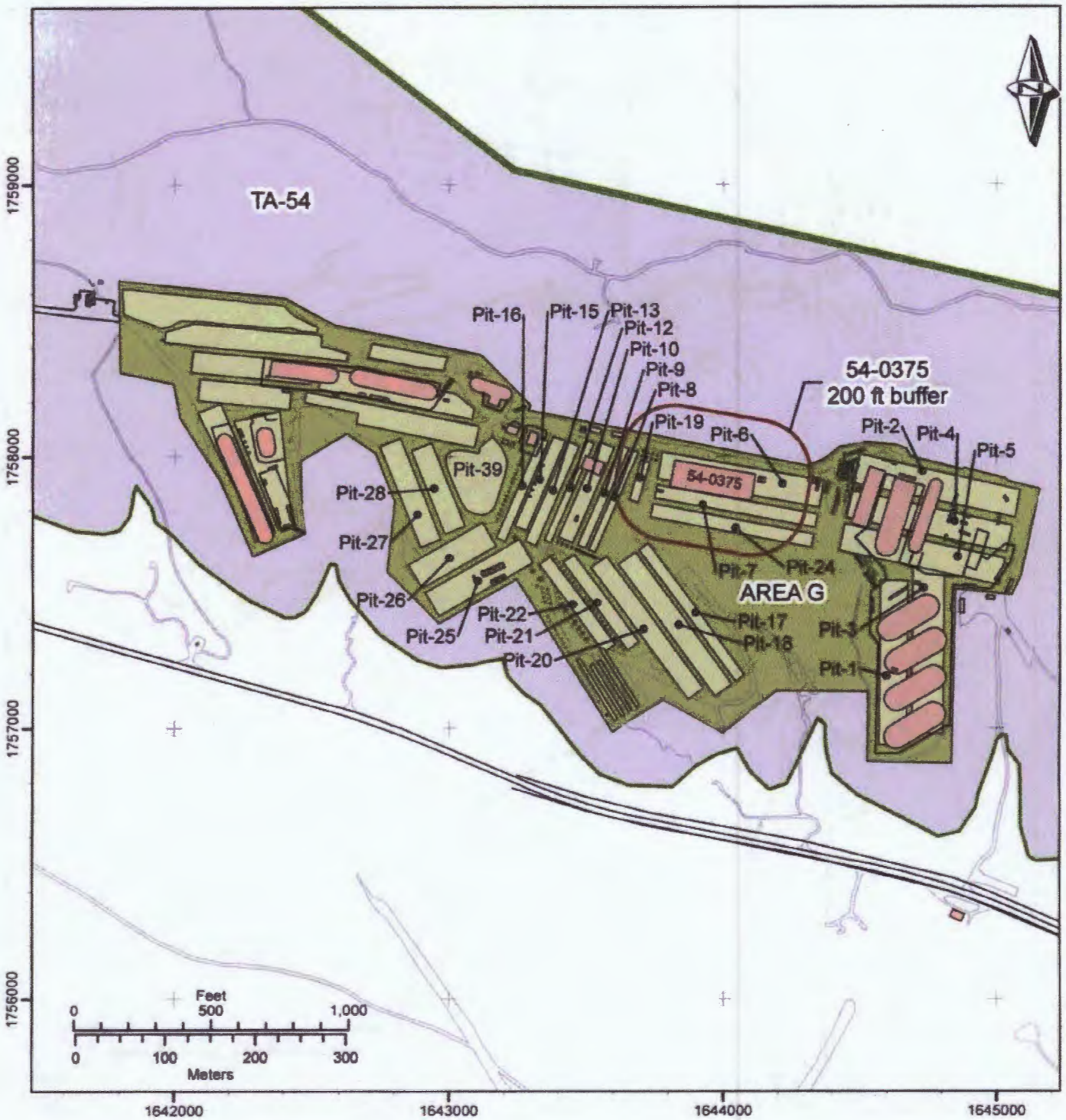

Figure 2:
WSF Pits near Bldg. 54-0375

Legend

- Paved roads
- LANL boundary
- 54-0375 200ft buffer
- Structures
- wsf_ply
- Dirt roads
- Area G
- TA-54 boundary

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum
Grid Provides Units in Feet

GISLab Map No. m202024, rev. 1
GISLab Req. No. 14228
Cartography by Richard E. Kelley
June 16, 2009

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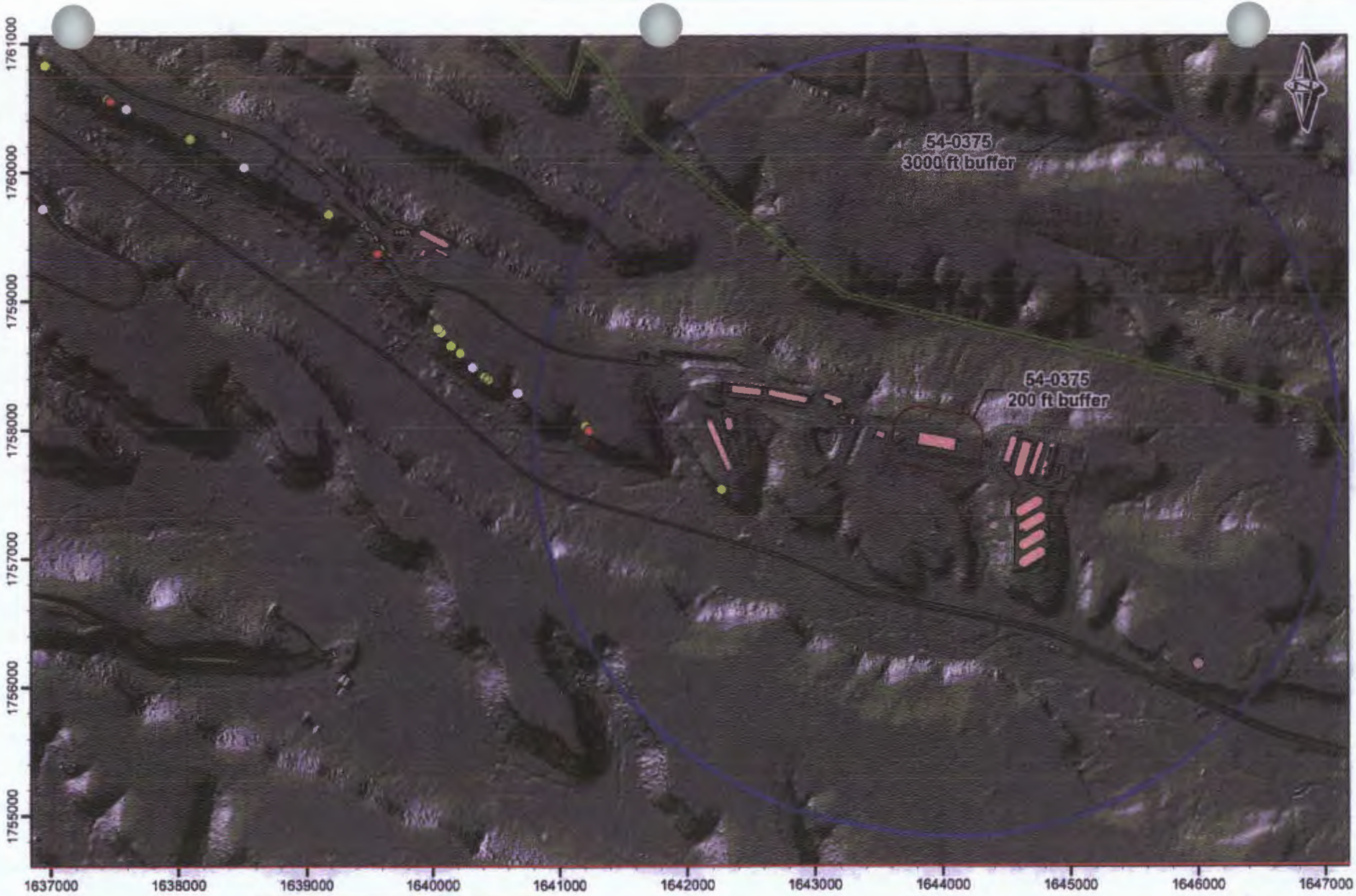

Feet
0 500 1,000
0 100 200 300
Meters

Legend

Unit 2-Unit 3 Offset (cm)
- 0 - 5
- 6 - 15
- 16 - 30
- 31 - 44
- 45 - 60

- Paved roads
- Dirt roads
- LANL boundary
- 54-0375 200ft buffer
- TA-54 3000ft buffer
- Structures

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum
Grid Provides Units in Feet

GISLab Map No. m202062, rev. 0
GISLab Req. No. 14240
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June 15, 2009

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Figure 3:
Measured Offsets on the Unit-2 Unit-3 Contact Near 54-0375 (elevations derived from 2000 LIDAR survey)

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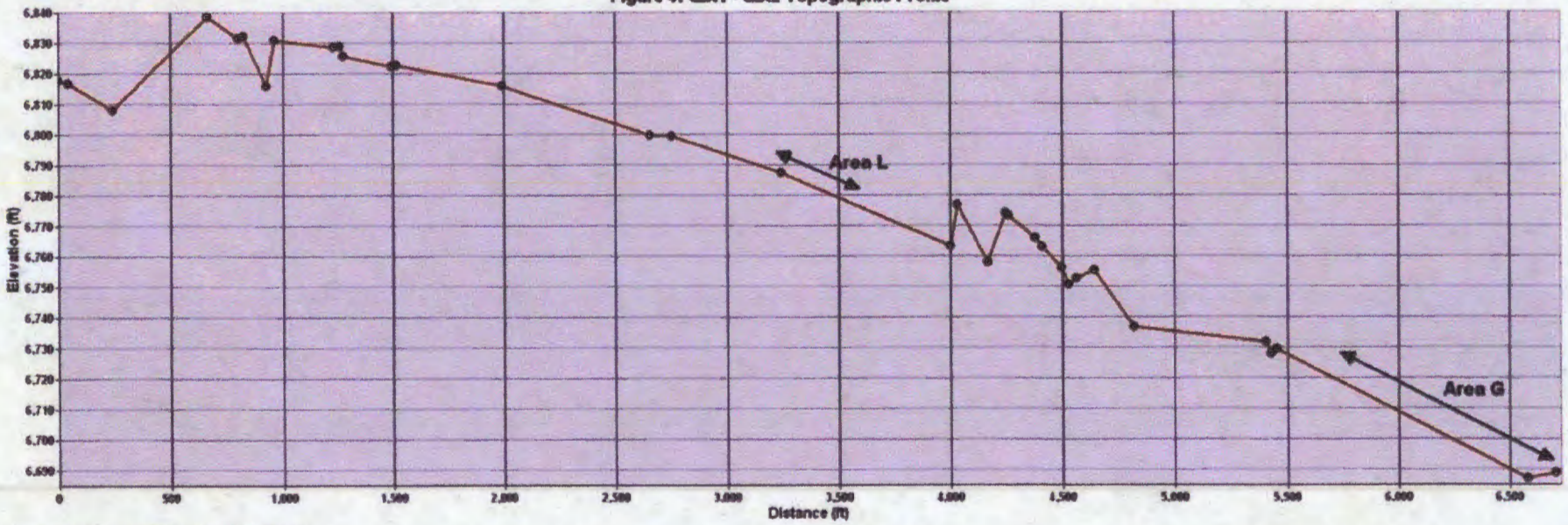
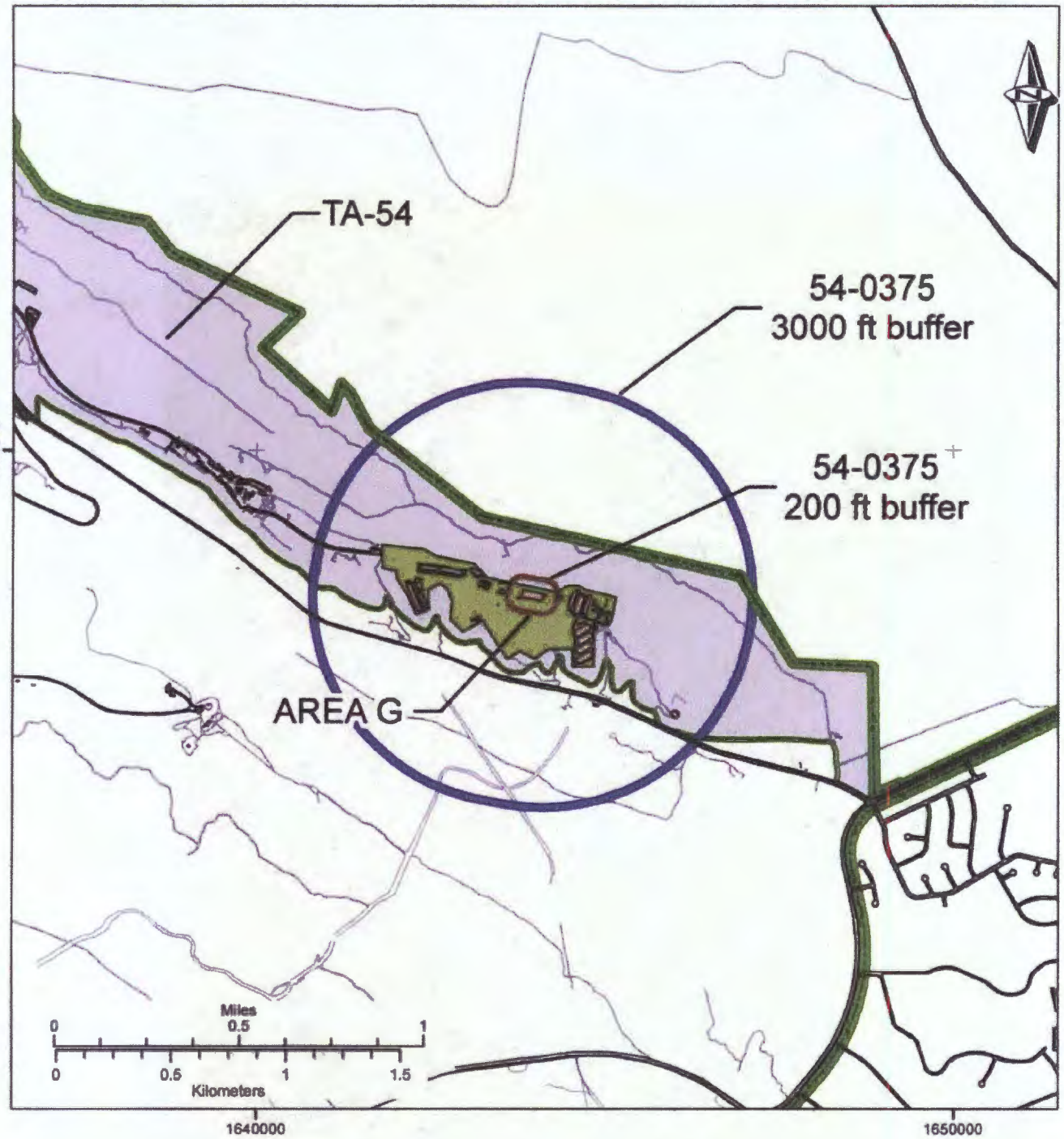
Figure 4: Qbt1 - Qbt2 Topographic Profile



Viewed west to east, elevation based on 2000 LIDAR data



Legend

- lac_street_row_arc
- KSL_structures_ply20081015
- Faults
- LANL boundary
- 54_0375_200_buff
- TA-54 3000ft buffer
- KSL_fodland_ply20081015
- KSL_dirt_rds_arc20081015
- TA-54 boundary
- Identified Offsets

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum
Grid Provides Units in Feet

GISLab Map No. m202020, rev. 0
GISLab Req. No. 14228
Cartography by Richard E. Kelley
March 10, 2009

200ft and 3000 ft. Buffers of Bldg. 54-0375

Work Performed on Behalf of ENV-RCRA
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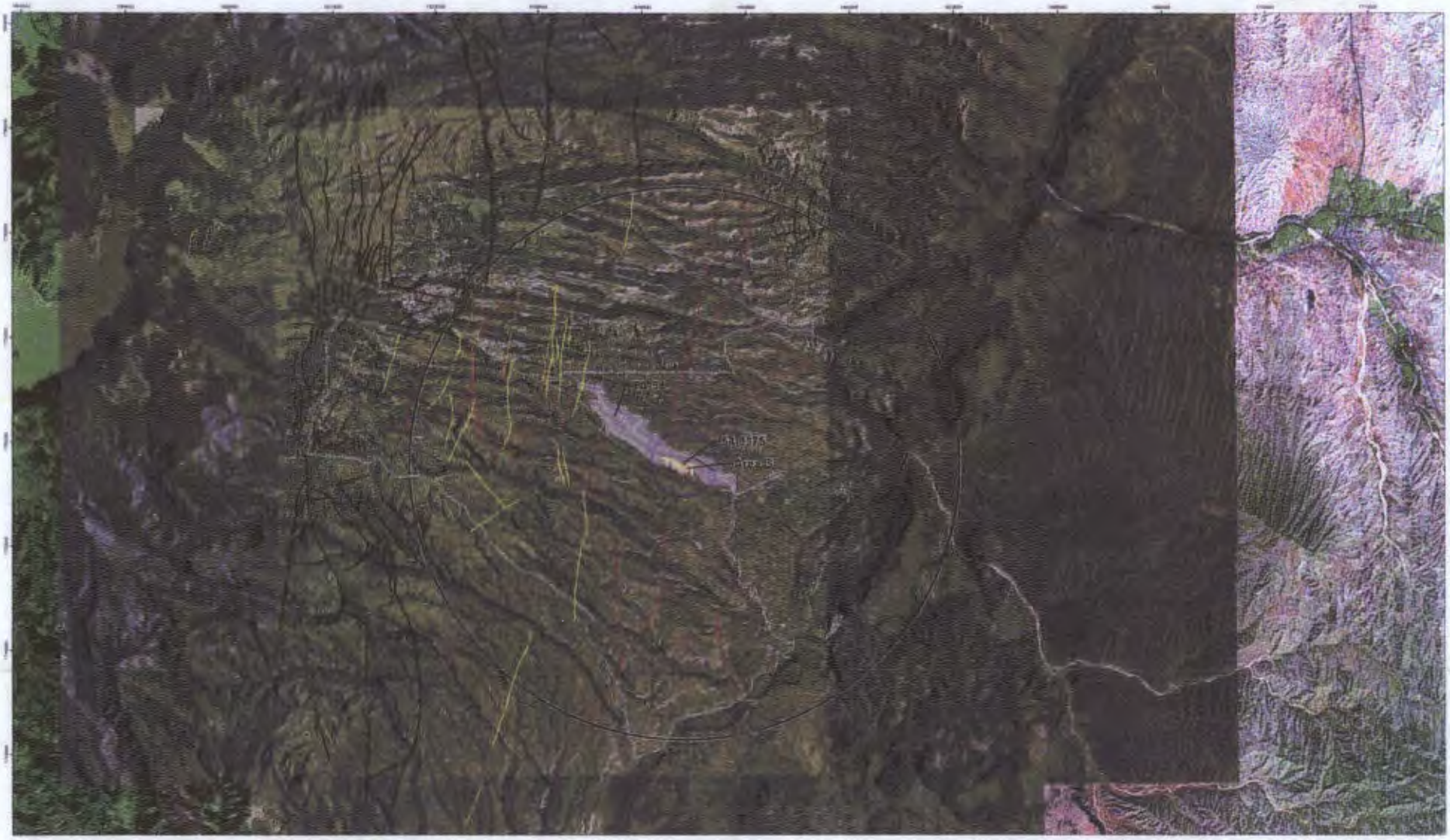
FIGURE 5.



0 5,000 10,000 15,000 Feet

0 1,000 2,000 3,000 4,000 Meters

Plate 1:
Color Orthophoto Map of the Area
Surrounding Technical Area 54

RCR00050.001

0 1,000 2,000 Feet

0 300 600 Meters

Legend

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum
Grid Paradise Units in Feet

GIS Lab Rec. No. [illegible]
GIS Lab Proj. No. [illegible]
Cartography by Richard S. Bailey
June 13, 2000

Plate 2:
Ortho-photographic Map of the Area
Surrounding Technical Area 54, Area-G

Aerial photography by Bohannan-Huston, Inc.
Date collected 8/7/2000 - 9/16/2000.

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RCR00051.001

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memorandum

Earth and Environmental Sciences Division

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From/MS: Emily S. Schultz-Fellenz, EES-16, D452
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Phone/Fax: 7-3605/Fax 7-1628

Symbol: EES16-SHG-2009-003
Date: June 29, 2009

Evaluation of potential seismic hazards from Holocene-age surface-rupturing faults at Building 39, Technical Area 54, Los Alamos National Laboratory

This memorandum summarizes geologic investigations at and around Building 39 at Technical Area 54 (TA-54) of the Los Alamos National Laboratory (LANL) in Los Alamos County, New Mexico.

When selecting a site for a hazardous waste treatment, storage, and/or disposal facility, such as Building 39 at TA-54, the owner/operator (in this case, LANS, LLC and NNSA) must adhere to certain location standards, as identified in the Code of Federal Regulations, Title 40 (40 CFR), Part 264.18. The guidelines used to demonstrate compliance with the aforementioned location standard are presented in 40 CFR, Part 270.14(b)(11).

In this document, we outline compliance with the seismic location standard through published geologic data, beginning with a regional view of the Pajarito Plateau and ending with specific focus on the facility to be permitted, Building 39. We present a Pajarito Plateau-scale map of faults and lineaments located within a five-mile radius of the facility to provide an overview of the structural setting and state of knowledge of the area. We discuss recent published mapping of the Pajarito fault system to determine the presence or absence of Holocene-aged surface-rupturing faults. We include analysis of aerial photography covering a 3,000-ft radius of the facility, and a summarization of published geologic studies completed in and around TA-54 for purposes of evaluating Holocene seismic hazards to Building 39. These studies provide important control on the known extent of possible faults in the area. We will end by discussing field reconnaissance of sites at TA-54 where mapped lineaments project through the site (examinations of Bandelier Tuff contact elevations).

Definitions

The following technical terms are used frequently throughout this document. Definitions are taken from The Dictionary of Geological Terms (Bates and Jackson, eds., 1984).

Displacement: a general term for the relative movement of the two sides of a fault, measured in any chosen direction; also, the specific amount of such movement. [Within this report, "displacement" and "offset" are interchangeable terms.]

Holocene: an epoch of the Quaternary period, from the end of the Pleistocene, approximately 8 thousand years ago [*sic*; Ogg et al. (2008) have updated the beginning of the Holocene to 11,700 years ago] to the present time.

Fault: a fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.

Fracture: a crack, joint, fault, or other break in rocks.

Lineament: a linear topographic feature of regional extent that is believed to reflect crustal structure. Examples are fault lines, aligned volcanoes, and straight stream courses.

Note that the definition of "lineament" does not imply that such an identified feature is actually a surficial manifestation of crustal structure with recent activity until the local geology is carefully considered. Additionally, unless otherwise clarified through detailed field examination or other means, the definition of "fault" does not imply a tectonic mechanism for genesis and/or growth. The definition also does not imply that each "fault" is independently seismogenic. Features defined as faults through geologic mapping must be considered in the context of the surrounding geology before their mechanism of formation is determined.

General Geologic Setting

TA-54, MDA L, and Building 39 sit atop Mesita del Buey in the eastern part of LANL (Figure 1). The local bedrock is the Bandelier Tuff, formed in two eruptive pulses from nearby Valles caldera, located approximately 13 miles west of MDA L. The older member, or Otowi Member, of the Bandelier Tuff has been dated at 1.61 Ma (Izett and Obradovich 1994). The younger member, or Tshirege Member, of the Bandelier Tuff has been dated at 1.256 Ma (age from Phillips et al. 2007) and is widely exposed as the mesa-forming unit around Los Alamos. Several discrete subunits comprise the Tshirege Member of the Bandelier Tuff, and commonly accepted stratigraphic nomenclature is described in detail by Broxton and Reneau (1995) and Lewis et al. (2009). The subunits exposed at Mesita del Buey include Qbt1 and Qbt2. Understanding the subtle differences between Tshirege Member subunits and the nature of the contacts between subunits is critical to identifying fault-generated displacements around the Pajarito Plateau.

The Pajarito Plateau is bounded on its western edge by the Pajarito fault system, a 50-km-long fault system locally comprised of the down-to-the-east Pajarito fault (the master fault) and subsidiary down-to-the-west Rendija Canyon, Guaje Mountain, and Sawyer Canyon faults (Figure 1). This fault system forms the local active western margin of the Rio Grande rift near Los Alamos.

Regional Structural and Seismic Studies

Geologic quadrangle mapping

Dethier (1996) and Goff et al. (2001) completed geologic and structural mapping of the White Rock and Frijoles (Los Alamos area) quadrangles at 1:24,000 scale, respectively. Neither of these studies identified surficial geologic faults that disrupt the Bandelier Tuff or younger units in the vicinity of TA-54.

Lineament mapping

Before the completion of detailed geologic mapping at LANL, previous studies had inferred the southern tips of the Rendija Canyon and Guaje Mountain faults to continue southward through TA-55 and TA-63 (including Rogers et al. 1996; Dransfield and Gardner 1985; Vaniman and Wohletz 1990; Wong et al. 1995; and Olig et al. 1996). Studies by Reneau et al. (1998), Gardner et al. (1998, 1999), Reneau et al. (2002), Lewis et al. (2002), Lavine et al. (2003), Schultz-Fellenz and Gardner (2007), Gardner et al. (2008), and Lewis et al. (2009) have utilized the most widely-accepted and detailed published stratigraphy of the Bandelier Tuff (that of Broxton and Reneau, 1995; published in peer-reviewed literature by Lewis et al., 2009) to map small displacements across Tshirege Member subunit contacts across much of the western and central LANL campus. Additionally, these more recent studies have acquired information on fault locations using high-precision geodetic mapping of Tshirege Member subunit contacts along canyon

edges. These recent, detailed studies have shown that previously-mapped lineaments in this area are not expressed as young surface-rupturing projections of the Rendija Canyon and Guaje Mountain faults transecting TA-55 and TA-63. In fact, the surface expression of the Rendija Canyon fault bends southwesterly at Los Alamos Canyon and splays into TA-3, and the surface expression of the Guaje Mountain fault is not visible south of Pueblo Canyon. Gardner et al. (1999) also evaluated pre-1947 stereo aerial photographs and correlated only a few lineaments from the aerial photographs to minor surficial faulting of the Bandelier Tuff. Those correlated structures are found in the vicinity of TA-48.

While lineament mapping has been completed at a regional scale across much of the Pajarito Plateau, we emphasize that for determining the presence of Holocene faults, conventional field geologic mapping must be employed or consulted to confirm that (1) a lineament is truly a fault, and (2) that it displaces young units. Olig et al. (1998) supports this:

> The lineaments [shown on Plate 1 from Wong et al. 1995] were identified on aerial photographs or observed during an aerial reconnaissance and field-checked at a reconnaissance level. However, this generalized map ... should be considered preliminary in nature until a more comprehensive and detailed surficial mapping of LANL is completed.

Plate 1 shows TA-54, Building 39, a five-mile buffer around Building 39 (as mandated by 40 CFR 270.14(b)(11)(A)(2)), mapped surficial faults (Lewis et al. 2009) and mapped lineaments (Vaniman and Wohletz 1990; Wong et al. 1995). The surficial faults shown on Plate 1 as mapped by Lewis et al. (2009) represent the most recent and detailed state of knowledge of the surficial expression of the Pajarito fault system near LANL. Mapping of the Pajarito fault system was done at a detailed scale by personnel with knowledge of structural geology and Tshirege Member subunits, and represents a culmination of many years of work by the LANL Seismic Hazards Geology Team. No fault strands with clear association to the faults of the Pajarito fault system are seen near Building 39 in Plate 1.

Microseismic monitoring and analyses

The Los Alamos Seismic Network maintains a small number of seismic stations around north-central New Mexico. Their data is accessible publicly at the following URL: http://www.lanl.gov/orgs/ees/ees11/geophysics/lasn/lasn.html. All earthquakes identified in the LANL area have magnitudes less than or equaled to 2, and appear to cluster at the northern part of the Pajarito fault system. No earthquake epicenters are noted within 3,000 ft of Building 39, nor do they appear to occur systematically or non-systematically along mapped lineaments projecting within 200 ft of Building 39.

Published Geologic Studies of Relevance to the Seismic Location Standard at TA-54

Several geologic investigations have taken place at LANL with specific focus on TA-54. Data from these area-specific studies provide constraint on the location, size, distribution, and implications of known faults with relation to Building 39. This memorandum summarizes some key studies in chronological order.

- **Purtymun and Kennedy 1971**, Geology and Hydrology of Mesita del Buey [report number LA-4660]

  This report describes the geology, structure, and hydrology of the TA-54 area for basic background and geologic site characterization. Purtymun and Kennedy (1971) identified three joint sets: 310° to 330° (N50W to N30W); 280° to 300° (N80W to N60W); and 40° to 60° (N40E to N60E). The authors described these joints as tensional, formed by the contraction of the tuff as it cooled, based upon the

joints' near-vertical attitudes and curvilinear trends. Purtymun and Kennedy (1971) identified a sequence of basalts underlying the Bandelier Tuff that, according to borehole studies, thin considerably towards the west across Mesita del Buey. They describe the basalts as a paleo-topographic high over which the Bandelier Tuff was deposited.

- **Dransfield and Gardner 1985,** Subsurface Geology of the Pajarito Plateau, Española Basin, New Mexico [report number LA-10455-MS]

  This report provides a description of geologic structure in units predating the Bandelier Tuff, based upon drill cores and geophysical surveys across the Pajarito Plateau. They note the presence of numerous down-to-the-west faults averaging 100 ft of displacement within basalts below TA-54. Cumulatively, 600 ft of displacement was identified along the sequence of pre-Bandelier Tuff faults. One of the easterly subsurface faults, near to the TA-54 area, correlates to a gravity inflection. This gravity anomaly may indicate of the western margin of the thick basalt sequence underlying the Bandelier Tuff, as identified in the cross-section from Purtymun and Kennedy (1971). None of these identified pre-Bandelier Tuff faults propagate upwards into the Bandelier Tuff or younger units.

- **Reneau et al. 1998,** Structure of the Tshirege Member of the Bandelier Tuff at Mesita del Buey, Technical Area 54, Los Alamos National Laboratory [report number LA-13538-MS]

  This study was performed to determine the presence or absence of faults at TA-54 through use of high-precision geodetic surveying of the Qbt1v – Qbt2 contact along the flanks of Mesita del Buey. Reneau et al. (1998) identified widely-distributed, small-scale faults at Mesita del Buey along a 2.2 mile traverse of the north wall of Pajarito Canyon and an 0.4 mile traverse of the north wall of a tributary to Cañada del Buey. A total of 37 faults with offsets ranging from 5 to 65 cm (2 to 25 in) were recorded. Typical fault offset was 20 to 30 cm (8 to 12 in) and all observed fault planes were steeply dipping. Since the exposure of the Qbt1 – Qbt2 contact was incomplete along the canyon wall traverses, Reneau et al. (1998) postulate that several additional faults of similar magnitude to those identified may exist in obscured areas. 65% of observed offset on identified faults was down-to-the-west, while the remaining 35% of observed offset was down-to-the-east. Opposing fault displacements partially compensate for each other, reducing cumulative offset along the surveyed transects. These identified faults were not concentrated in discrete areas or zones. Figure 2 shows that several locations of displacement are found within 3,000 ft of Building 39, but none of these small-displacement faults are located within 200 ft of Building 39. Figure 3 is a topographic profile of the Qbt1 – Qbt2 contact near Building 39 along which Reneau et al. (1998) collected displacement information. Elevation data was not readily available from the Reneau et al. (1998) database, so this profile is based upon 2000 LIDAR elevation data. The LIDAR data creates some elevation anomalies seen in the western portion of the profile. Between 4,000 and 5,000 ft distance, displacement on the contact is seen; however, net displacement across this zone is nearly zero.

  The general absence of large displacements along the Qbt1 – Qbt2 contact suggests that these small-displacement structures are not associated with major fault zones. Reneau et al. (1998) suggest that these small-displacement faults may record secondary deformation across the Pajarito Plateau associated with large earthquakes on the main Pajarito fault, several miles to the west, or even perhaps earthquakes on other regional faults. The small single offsets, reduced cumulative offset due to opposing fault displacements, lack of lateral continuity of these small faults across the mesa, and no displacements of units younger than the Bandelier Tuff along similar fractures support the statement that these small faults do not pose a seismic hazard to Building 39.

Local Lineament Mapping and Field Reconnaissance at Mesita del Buey and Surrounding Canyons
We present a local lineament map (Plate 2) of the 3,000-ft buffer area surrounding Building 39. Present on both Plates 1 and 2 is a roughly north-south trending lineament that enters the 3,000 ft buffer around Building 39 in the northeast quadrant. North of Mesita del Buey, a bulldozed fire break visually exploits this lineament. The lineament is not clearly distinguishable south of Mesita del Buey. As a conservative measure, lineaments have been projected along-strike through the 3,000 ft buffer area even if they do not appear to continue through the entire are. According to previously published geologic studies of Mesita del Buey that have examined the canyon exposures at areas where the lineament is projected to cross the mesa (cf. Reneau and Vaniman, 1998; Reneau et al., 1998), this lineament does not correspond to displacement of the Bandelier Tuff or younger units.

The lineament identified in Plate 2 do not line up with mapped Holocene faults, nor does it correlate to a location at the canyon edge where displacement of the Qbt1 - Qbt2 contact has been documented. This short-length lineament typically does not imply the presence of a tectonic fault. To compare, locations around Los Alamos where Holocene faulting has occurred and paleoearthquakes have been documented often show tens to hundreds of feet of displacement along a linear feature that is several miles long.

In many locations within LANL, high-precision geodetic surveying was used to identify displacements on the Tshirege subunit contacts along canyon exposures, thus determining the presence or absence of small-displacement faults in anthropogenically-disturbed areas. TA-54 is one such location. Reneau et al. (1998) performed high-precision geodetic surveying of the north wall of Pajarito Canyon to locate small-displacement faults, and while they located numerous small faults near MDA L, their study found no faults within 200 ft of the projection of Building 39 to the north wall of Pajarito Canyon.

For verification purposes, we performed a field reconnaissance for this report. The reconnaissance included examining the exposed Tshirege Member subunit contacts at the location where the footprint of Building 39 would project to the canyon wall, plus 200 ft west and east, to identify contact elevation anomalies that may reflect faulting. We used handheld GPS to locate positions along the cliff edges where the facility margins would project, and walked along the Qbt1 - Qbt2 contact to evaluate the contact and possible contact elevation anomalies indicative of faulting. This field reconnaissance found evidence of contact displacements across projected lineaments that fall within the 3,000 ft buffer surrounding Building 39, but no previous studies (nor our field reconnaissance) identified contact elevation anomalies within 200 ft of Building 39. NMED personnel were present at this geologic site visit of the Building 39 area in May 2009, and no issues regarding geologic interpretations were raised at that time.

Figure 4 is a map of the Building 39 area, and includes 200-ft (red) and 3,000-ft (blue) buffers for RCRA seismic location standard considerations. The map shows no identified and mapped surficial faults (from Lewis et al., 2009) within the RCRA-mandated distance buffers from Building 39.

Discussion
Site-specific geologic investigations at TA-54, described above, show that the lineaments mapped as projecting through TA-54 on Plates 1 and 2 do not correlate with any identified, mapped Holocene faults. Neither geologic investigations at the TA-54 area, nor geologic quadrangle mapping in the Los Alamos and White Rock areas show Holocene faults in areas where lineaments have been identified on Plate 1. Detailed geodetic surveying of the Qbt1 - Qbt2 contact by Reneau et al. (1998) did find small-displacement faulting at MDA L, but did not locate faults within 200 ft of Building 39 (Figure 2). A

walking reconnaissance of exposures along the north side of Pajarito Canyon confirmed there are no faults that project beneath or within 200 ft of Building 39. NMED personnel were present at a geologic site visit of the Building 39 area in May 2009, and no issues regarding geologic interpretations were raised at that time.

Conclusions

Many small displacements have been documented along the Qbt1 – Qbt2 contact at MDA L by high-precision total station geologic mapping. These faults all exhibit less than two feet of offset, cannot be traced across mesa tops or to other canyon exposures, do not break the ground surface, and do not displace units younger than the Bandelier Tuff. Based on the data presented in this memo using information from published geologic studies at and around TA-54, aerial reconnaissance of the area within a five-mile radius from Building 39, an analysis of aerial photographs, and field reconnaissance of lineaments and contact elevations, we demonstrate that no faults with Holocene displacement are present within 200 ft of Building 39. Additionally, no lineaments which suggest the presence of a fault (that has had displacement in Holocene time) are found within 200 ft of Building 39. The lineaments seen on aerial photographs do not reflect Holocene faulting, based upon previous studies and the data summarized here.

Figure Captions

Figure 1. Map of the Pajarito fault system in the vicinity of Los Alamos National Laboratory (green outline). TA-54 (gray polygon with red border), MDA G (brown polygon) and Dome 375 (red dot) are highlighted. PF = Pajarito fault; RCF = Rendija Canyon fault; GMF = Guaje Mountain fault; SC = Sawyer Canyon fault. Structural mapping (bold black lines) from Lewis et al. (2009). This figure shows that Dome 375 is distal to faulting associated with the Pajarito fault system.

Figure 2. Measured offsets on the Qbt1 – Qbt2 contact near Building 39 as mapped by Reneau et al. (1998). Displacement (in cm) on the Qbt1 – Qbt2 contact is color-coded by magnitude; please refer to map legend for more information. Numerous locations where displacement was identified do fall within the 3,000 ft buffer; none fall within 200 ft of the facility (or the projection thereof at Pajarito Canyon). See text for further discussion.

Figure 3. Topographic profile of the Qbt1 – Qbt2 contact at TA-54 along which Reneau et al. (1998) collected displacement information; approximately 20x vertical exaggeration. Elevation data was not readily available in the Reneau et al. (1998) database, so this profile is based upon 2000 LIDAR elevation data. The LIDAR data extrapolation creates the elevation anomalies seen in the western portion of the profile. Between 4,000 and 5,000 ft distance, displacement on the contact is visible; however, net displacement is nearly zero.

Figure 4. Map of Building 39 (small pink polygon) in relation to the 200 ft (red) and 3,000 ft (blue) buffers. No mapped faults are found within the 3,000 ft or 200 ft buffers. See text for further discussion.

Plate 1. Color orthophotography, mapped faults, and mapped lineaments within five miles (black ghosted line) of TA-54, Building 39. Structural mapping (bold black lines) from Lewis et al. (2009). Mapped lineaments from Vaniman and Wohletz (1990; orange lines), Wong et al. (1995; yellow lines), and this study (red dotted lines). TA-54 is well east of the main trace of the Pajarito fault system. See text for further discussion.

Plate 2. Orthophotography, mapped faults, and mapped lineaments in the area surrounding Building 39. Mapped lineaments (red dotted lines) from this study. No faults or lineaments project within 200 ft of the facility. See text for further discussion.

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Attachments (4 figures; 2 plates)

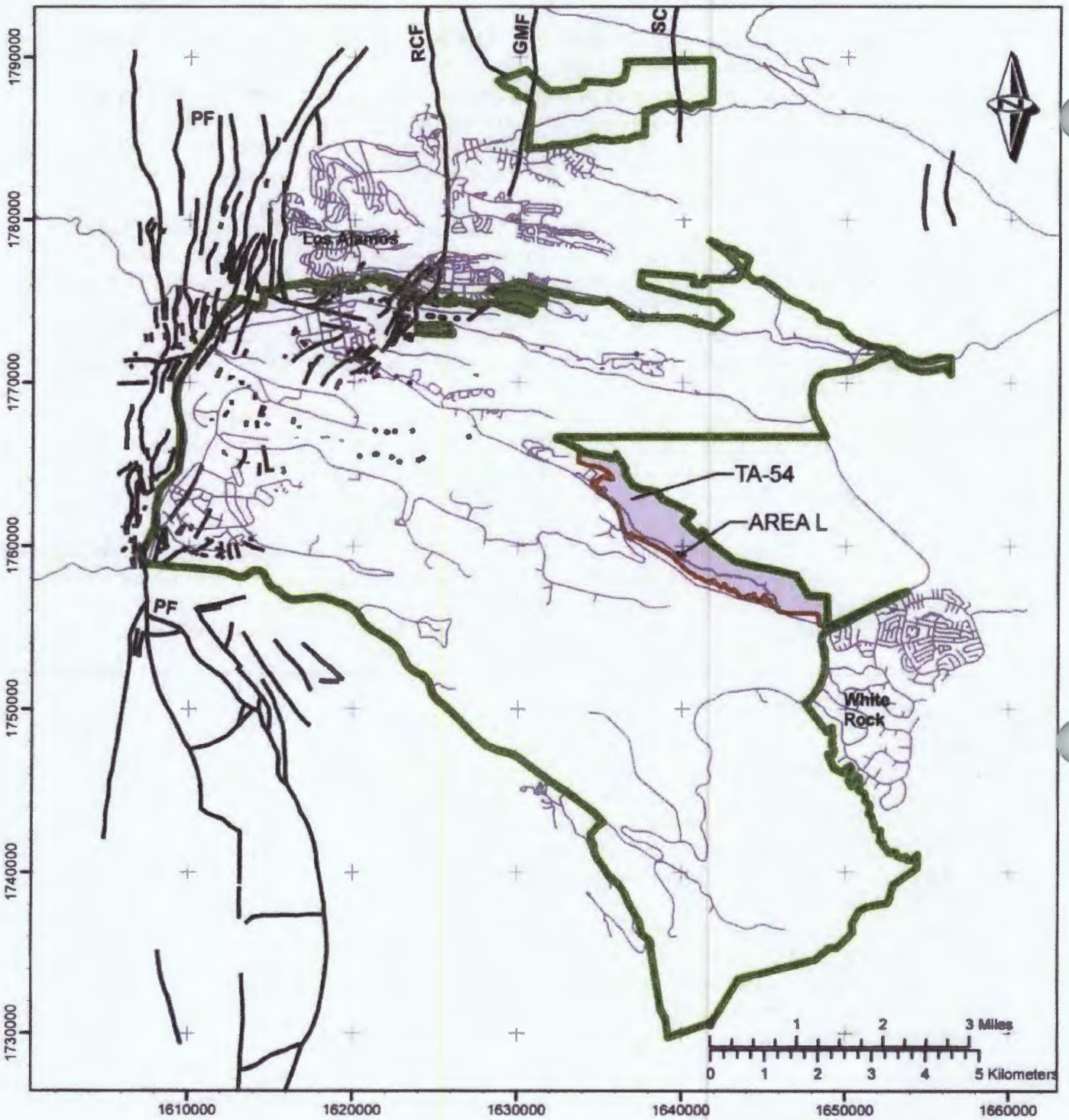


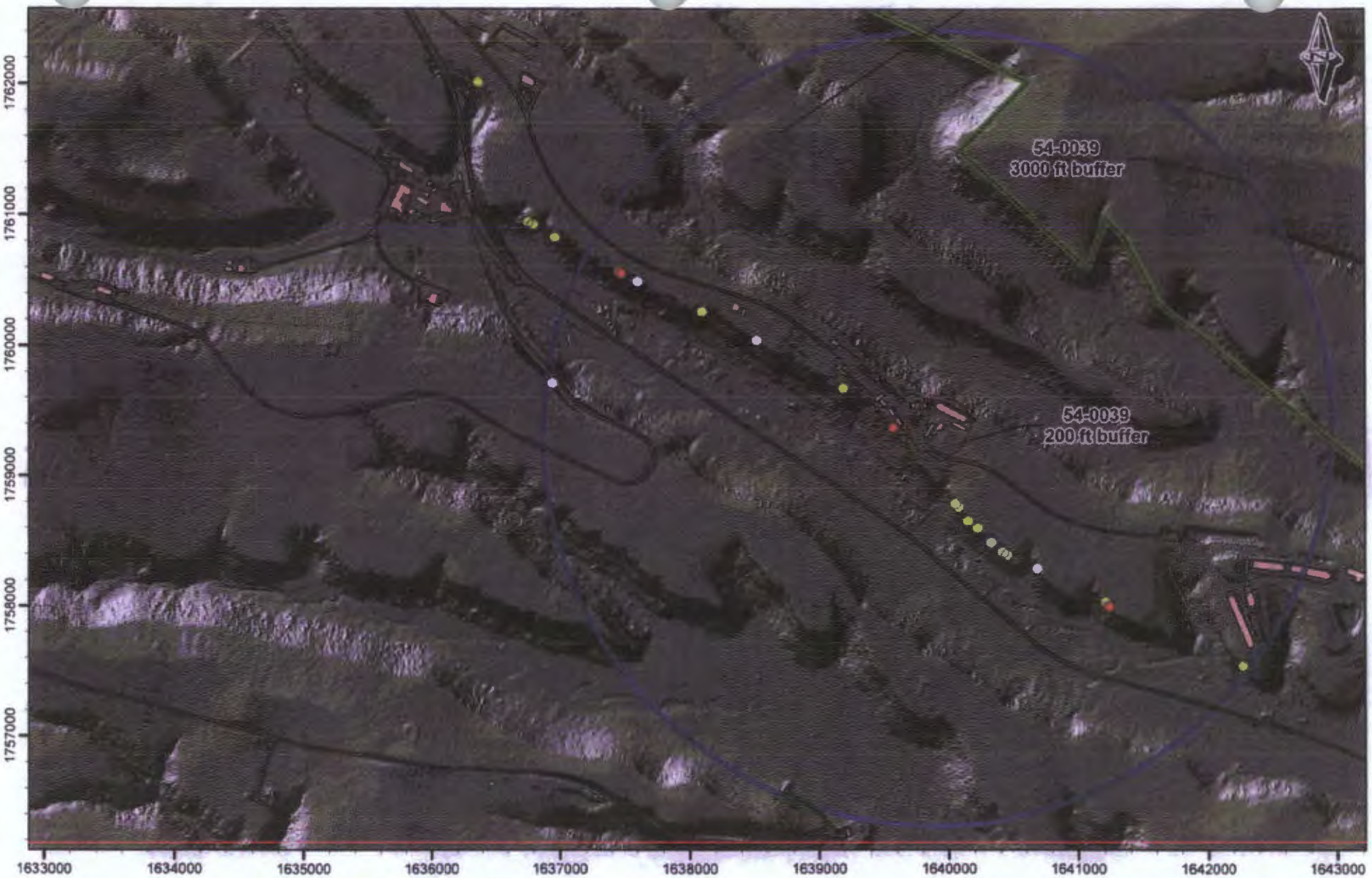
Figure 1:
Map of the Pajarito Fault System in the Vicinity of Los Alamos National Laboratory

Legend

- lac_centerlin_arc20071203
- KSL_structures_ply20081015
- Faults
- LANL boundary
- mda_ply
- TA-54 boundary
- Identified Offsets

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum
Grid Provides Units in Feet

GISLab Map No. m202046, rev. 0
GISLab Req. No. 14268
Cartography by Richard E. Kelley
June 10, 2009



Feet
0 500 1,000
0 100 200 300
Meters

Legend

Qbt1-Qbt2 offset (cm)
- 0 - 5
- 6 - 15
- 16 - 30
- 31 - 44
- 45 - 60

- Paved roads
- Dirt roads
- LANL boundary
- 54-0039 200ft buffer
- 54-0039 3000ft buffer
- Structures

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum
Grid Provides Units in Feet

GISLab Map No. m292062, rev. 0
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Figure 2:
Measured Offsets on the Qbt1-Qbt2 Contact Near 54-0039 (elevations derived from 2000 LIDAR survey)

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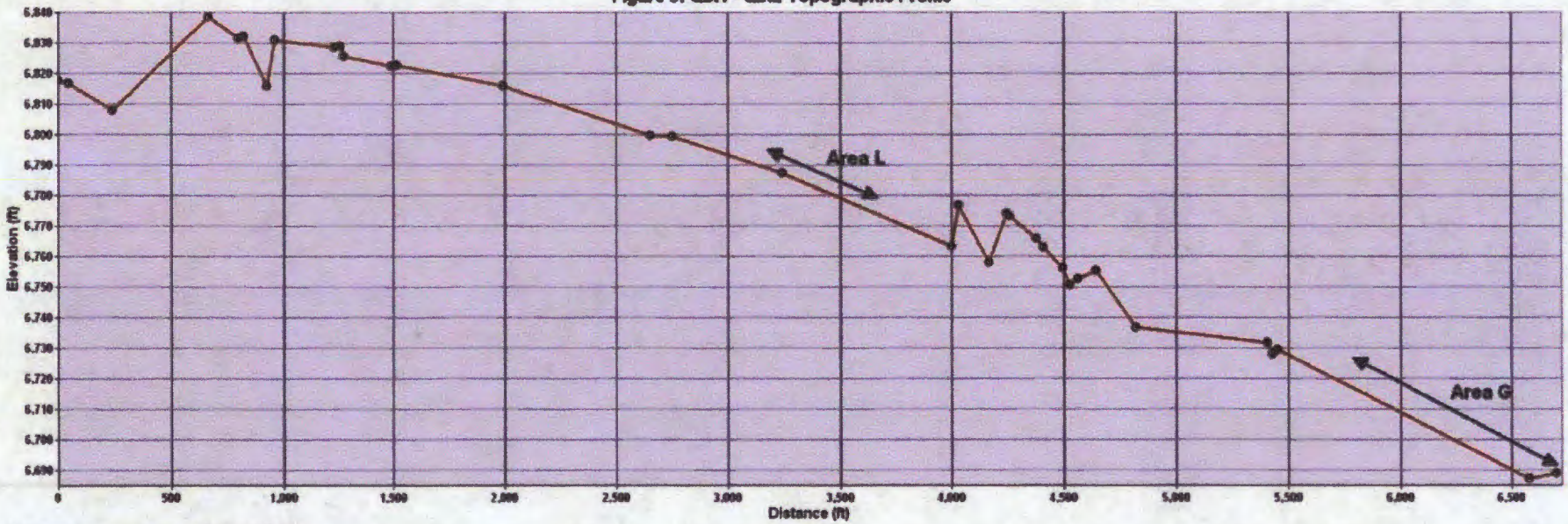
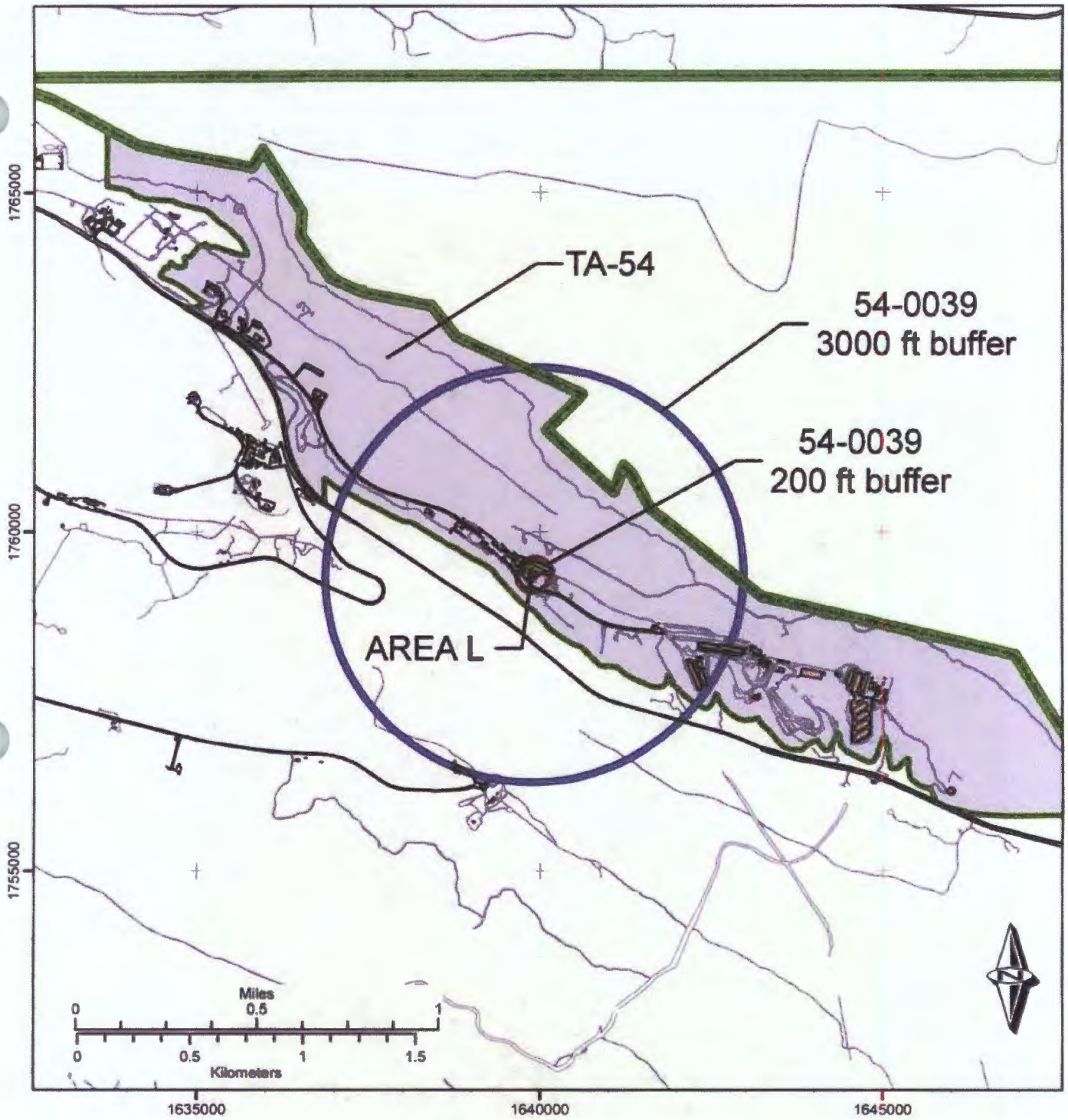
Figure 3: Qbt1 - Qbt2 Topographic Profile



Viewed west to east, elevation based on 2000 LIDAR data



Legend

- Paved road
- Structures
- Faults
- LANL boundary
- MDA-L
- 54_0039_200_buff
- TA-54 3000ft buffer
- Dirt road
- TA-54 boundary
- Identified Offsets

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum
Grid Provides Units in Feet

GISLab Map No. m202020, rev. 1
GISLab Req. No. 14228
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Figure 4:
200ft and 3000 ft. Buffers of Bldg. 54-0039

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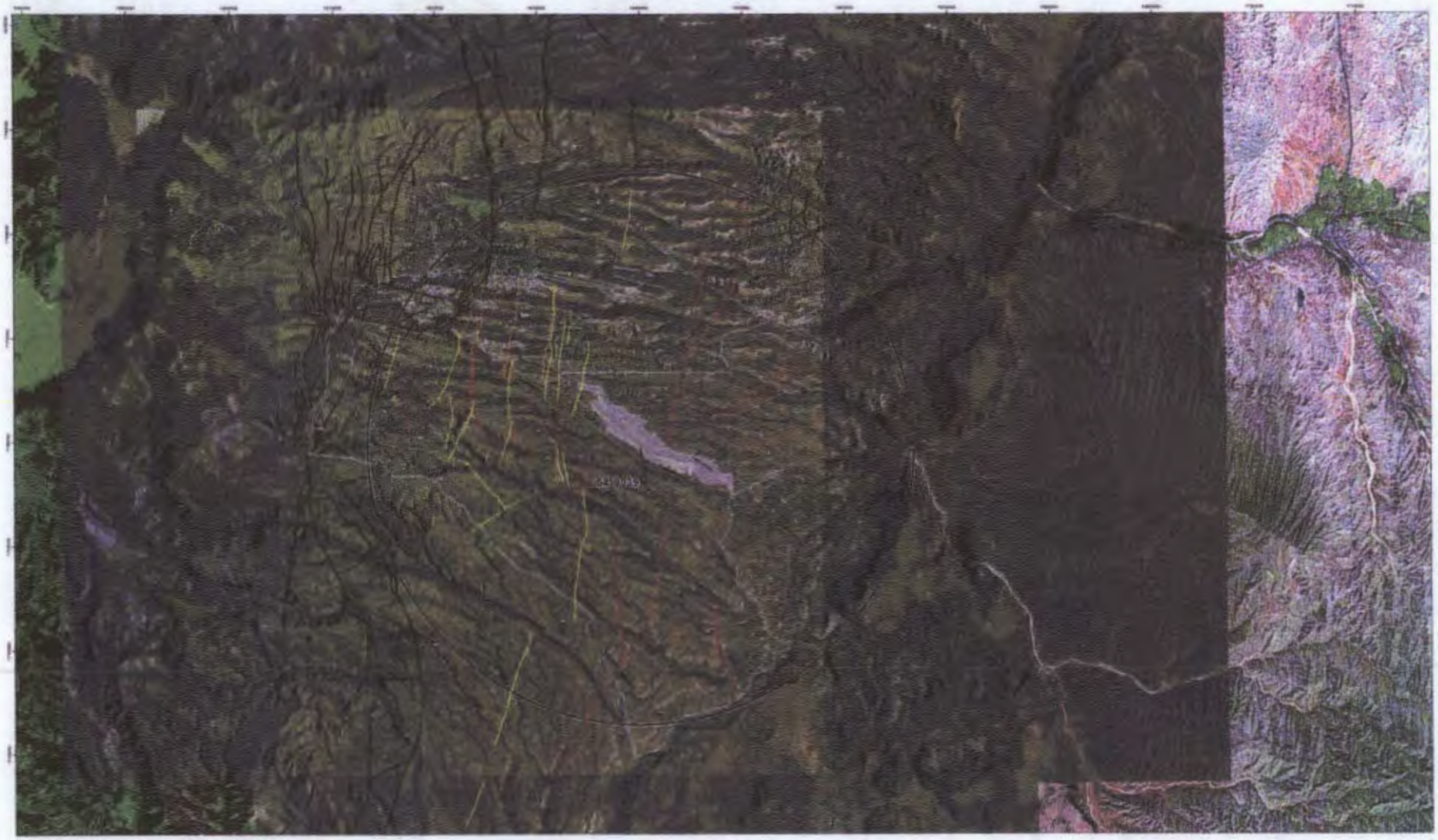

0 5,000 10,000 15,000 Feet

0 1,000 2,000 3,000 4,000 Meters

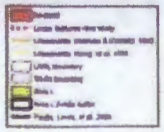

Plate 1:
Color Orthophoto Map of the Area
Surrounding Technical Area 54

RCR00057.001

0 1,000 2,000 Feet

0 300 600 Meters

Legend

Plate 2:
Ortho-photographic Map of the Area
Surrounding Technical Area 54, Area-L

Aerial photography by Bohannan-Huston, Inc.
Date collected 9/7/2000 - 9/16/2000

RCR00058.001