REASSESSMENT OF SEISMIC HAZARDS AT THE LOS ALAMOS NATIONAL LABORATORY

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ABSTRACT

A comprehensive seismic hazards evaluation program has been initiated at the Los Alamos National Laboratory (LANL) to update the current seismic design criteria. In part, this program has been motivated by recent studies which suggest that faults of the nearby Pajarito fault system may be capable of generating a large magnitude earthquake (M > 7). The specific objectives of this program are to: (1) characterize the tectonic setting of the LANL area; (2) characterize the nature, amount, and timing of late Quaternary fault displacements; (3) reevaluate the recorded seismicity in the LANL region to allow for the evaluation of seismogenic faults and the tectonic state of stress; (4) characterize the subsurface geologic conditions beneath the LANL required for the estimation of strong ground motions and site response; (5) estimate potential strong ground shaking both deterministically and probabilistically; and (6) develop the appropriate seismic design criteria. The approach and initial results of this seismic hazards program are described in this paper.

INTRODUCTION

The Los Alamos National Laboratory (LANL) is located along the western margin of the Rio Grande rift in north-central New Mexico, a major tectonic feature in the western U.S. (Figure 1). Although the historical seismicity record includes no damaging earthquake larger than approximately Richter magnitude (M_L) 6 within the rift and no events larger than M_L 5 within 50 km of LANL, geologic evidence exists for large surface-faulting events (M > 7 or greater) occurring with the Rio Grande rift during the Holocene. Recent studies have identified repeated episodes of displacement possibly as young as 4,000 to 6,000 years ago on the Guaje Mountain fault, which is a possible segment of the 100-km-long Pajarito fault system. This fault system forms the western boundary of the LANL (Figure 2). In an effort to update the seismic design criteria

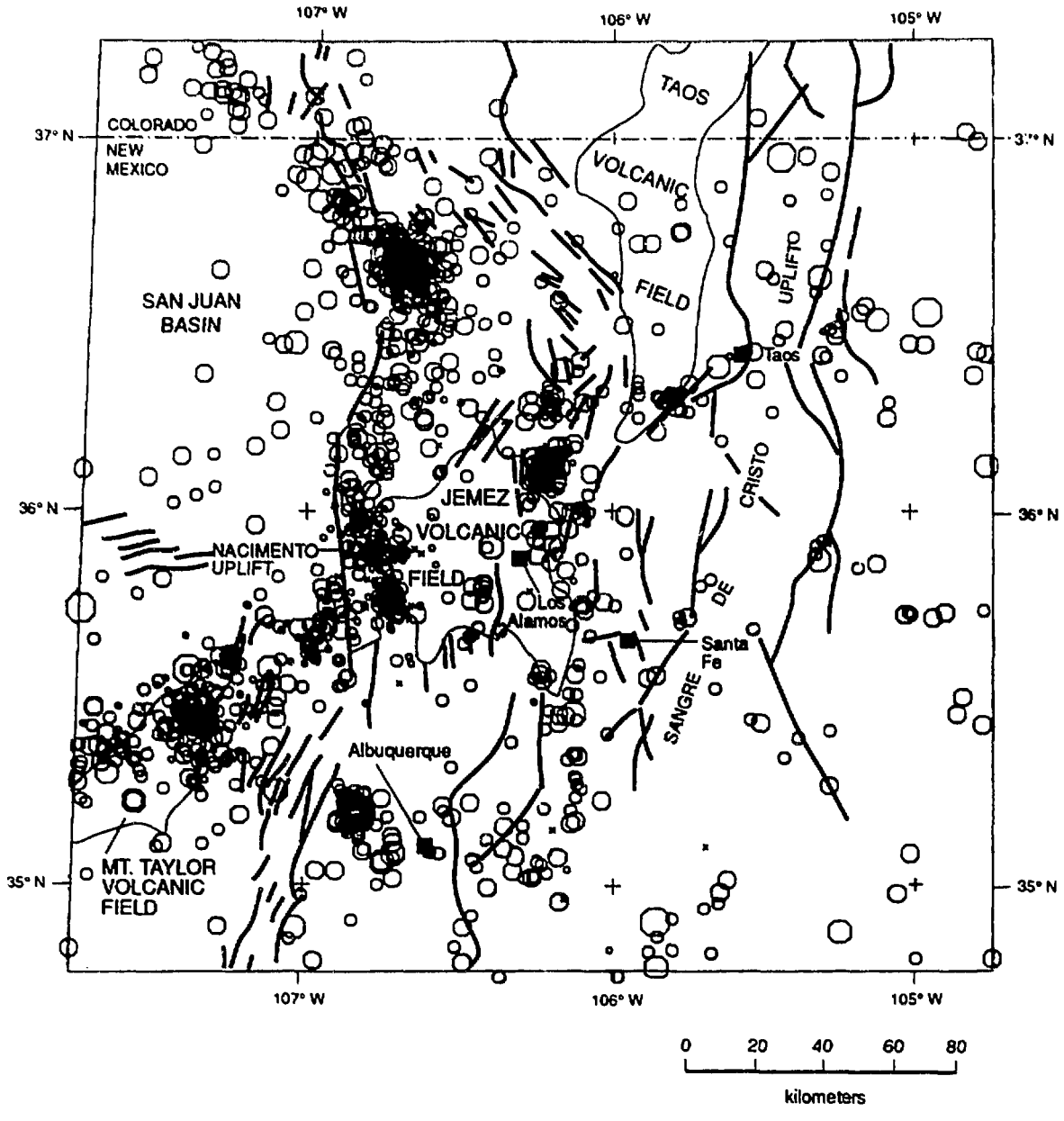

Figure 1. SEISMICITY, 1973 TO 1984 AND GENERALIZED GEOLOGIC AND TECTONIC FEATURES IN NORTHERN NEW MEXICO. FROM HOUSE AND CASH [4].

presently being used at LANL, which were developed in 1972, a comprehensive seismic hazards program of seismologic, geologic and geotechnical studies has been initiated (Figure 3). These studies include analysis of aerial photography, Quaternary mapping, paleoseismic trenching investigations, evaluation of fault characteristics and segmentation, reevaluation of contemporary seismicity recorded by the LANL microearthquake network, sub-surface site investigations (drilling and downhole geophysics), dynamic laboratory testing of drillhole core samples, and both probabilistic and deterministic ground motion evaluations. The following paper describes in detail the seismic hazards program and the initial results obtained to date.

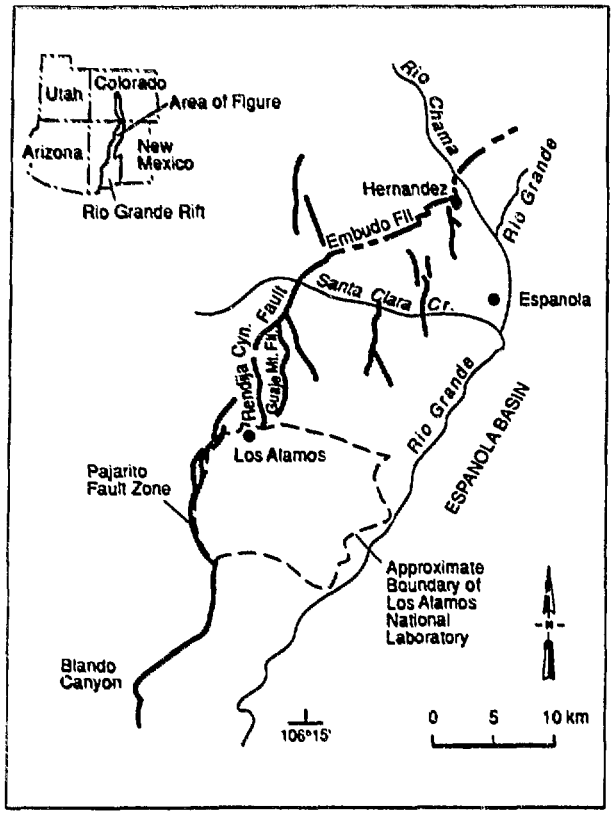

Figure 2. GEOLOGIC SETTING OF LANL AND THE PAJARITO FAULT SYSTEM.

SCOPE OF WORK

The objective of this program is to identify and characterize seismic sources capable of generating strong ground shaking at the LANL and to quantify those ground motions for the purposes of evaluating the seismic safety of existing and future facilities. To accomplish this objective, the following activities have been and will be performed:

- Assess the nature, amount, and timing of surface displacements along faults in the LANL region. Of highest priority are the Frijoles Canyon, Rendija Canyon, and Guaje Mountain fault segments of the Pajarito fault system (Figure 2).

- Assess potential rupture dimensions of fault segments of the Pajarito fault system. Necessary data include potential rupture lengths, down-dip fault width and geometry, and persistence of segment boundaries.

- Assess the regional tectonic setting of the LANL, including structural relations along the northern and southern extensions of the Pajarito fault system, fault segmentation, possible associations between contemporary seismicity and geologic structures, and the regional stress regime.

- Improve the hypocentral locations and determine focal mechanisms of earthquakes recorded since 1973 by the LANL seismographic network to assess possible associations between seismicity and known geologic structures.

- Assess subsurface geologic conditions at specific LANL facilities for the estimation of potential strong ground shaking. Site-specific data required for this assessment include shear wave velocities, damping, and dynamic properties of subsurface strata.

- Perform both deterministic and probabilistic analyses of seismic hazards. Data required include physical and behavioral characteristics of known potential seismic sources, and uncertainties associated with these characteristics.

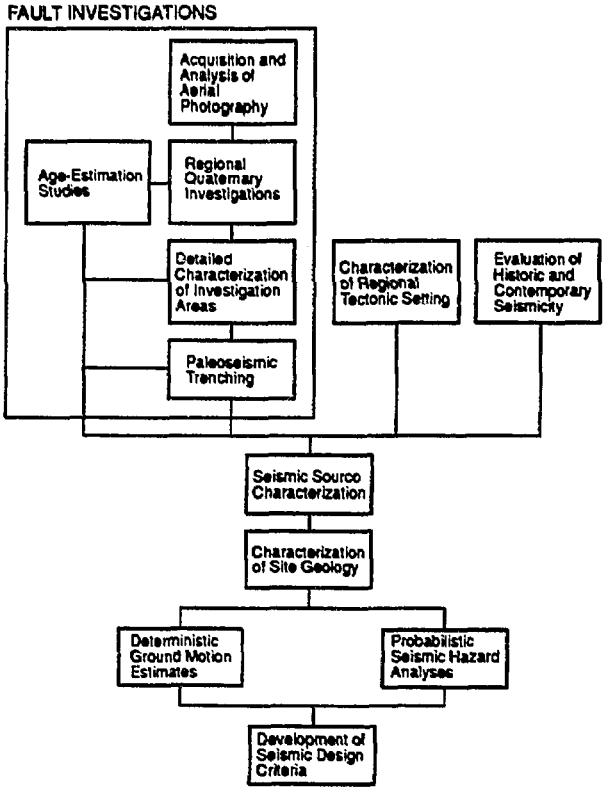

Figure 3. FLOW DIAGRAM OF LANL SEISMIC HAZARD STUDIES.

- Ground motion estimates resulting from the above analyses will provide the basis for developing new site-specific seismic design criteria.

- Develop criteria for microzonation of the LANL for both strong ground shaking and potential surface rupture hazards.

Previous Studies

The assessment of earthquake strong shaking and the development of seismic design criteria at LANL have been based, to a large extent, on a study performed for the Plutonium Processing facility in 1972 [1]. At that time, the possibility of a large earthquake occurring on the nearby Pajarito fault system was not recognized. Dames and Moore [1] recommended a design peak horizontal acceleration of 0.33 g, based on an estimated maximum expected level of potential ground shaking corresponding to a Rossi-Forel intensity (RF) VIII (roughly equivalent to a Modified Mercalli [MM] intensity VII). This design value was based on an evaluation of the historical earthquake record, which unfortunately is incomplete, temporally short, and probably not indicative of future earthquake activity. In addition, Dames and Moore [1] did not assess the seismogenic capability of faults within the LANL region.

Reviews by Gardner and House [2] and Woodward-Clyde Consultants (WCC) [3] of the available geological information both concluded that additional data are required to fully assess seismic hazards at the LANL and to update the 1972 seismic design criteria. In particular, additional data concerning the nature, amount, and timing of displacements on the Pajarito fault system, and on potential ground motions and site response are required.

SEISMOTECTONIC SETTING AND HISTORICAL SEISMICITY

Numerous small to moderate magnitude earthquakes have occurred in the Los Alamos area within the past 100 years, the approximate length of the historical earthquake record [4]. The largest event was the 1918 Cerrillos earthquake, which based on felt reports may have been M_L 5 to 6. This earthquake was located approximately 55 km south-southeast of Los Alamos and has been reported to have had a maximum intensity of RF VIII [4]. This probably produced the highest ground shaking in Los Alamos (RF VI) in historical times. The largest earthquakes known to have occurred within the Rio Grande rift in historical times were part of the 1906-1907 Socorro swarm. Three events in the swarm are thought to have had maximum intensities of MM VIII, equivalent to approximately M_L 6. Several earthquakes of M_L 3 to 4, some felt by local residents, have also occurred in the Los Alamos area.

In contrast to the historical earthquake record, there is some evidence for large prehistoric surface-faulting events in the Rio Grande rift. In the central portion of the rift, paleoseismic investigations have revealed at least five surface rupture events, M_L 7 occurring during the late-Quaternary along the 35-km long La Jencia fault near Socorro [5]. Like the Pajarito fault system, the La Jencia fault is a major basin-margin normal fault that borders the west edge of the Rio Grande rift.

The Pajarito fault system is a major structural element within the northern Rio Grande rift that separates the Jemez Mountains volcanic pile on the west from the central Española Basin on the east [6, 7]. Although prominent topographic scarps in the 1.1 Ma Tshirege Member of the Bandelier Tuff clearly suggest multiple late-Quaternary displacements along the Pajarito fault system, the only direct evidence of fault capability in the Los Alamos area is described along the Guaje Mountain fault segment by Gardner et al. [8]. They report post-6 ka displacement of strata exposed in a trench across the fault in Cabra Canyon. Gonzalez and Gardner [9] also suggest that a 180- to 250-ka-old geomorphic surface is displaced approximately 12 m in a down-to-the-west sense along the fault.

Several other lines of geologic or geomorphic evidence suggest, but do not unequivocally indicate, that other faults within the Pajarito fault system in the Los Alamos area have been recently active. For example, along the Frijoles Canyon segment, topographic scarps up to 125 m high in Bandelier Tuff indicate substantial post-1.1 Ma displacement [2]. In addition, Gardner and House [2] identified displaced Quaternary alluvium in one exposure along the Bland-Sanchez Canyon segment of the Pajarito fault system, about 11 km south of the LANL. The age of this alluvium is poorly constrained. The number and sense of displacements represented in the Bland Canyon exposure are unknown, but it is possible that the 6 m of apparent vertical separation was produced by more than one event. These relations suggest that there have been multiple displacements during the Quaternary and therefore this fault segment may be capable. In summary, geologic data suggest that fault segments in the LANL area have been active in the late Quaternary. Studies proposed in the seismic hazards program have been designed to test this hypothesis and to determine whether the faults of the Pajarito fault system are capable of generating large-magnitude earthquakes.

CURRENT STUDIES AND INITIAL RESULTS

The seismic hazards evaluation program developed to update seismic design criteria at the LANL consists of twelve primary tasks (Table 1 and Figure 3). Each of these tasks

TABLE 1
TASKS IN LANL SEISMIC HAZARDS STUDY

Task 1: Acquisition and Analysis of Aerial Photography
- Conventional black-and-white and color photography
- Low-sun-angle or oblique photography

Task 2 : Regional Quaternary Investigations
- Field reconnaissance
- Helicopter and fixed-wing aircraft overflights
- Verify and, as appropriate, adopt previous Quaternary map units
- Prepare regional Quaternary maps (scale 1:12,000) along the Pajarito, Embudo, and La Bajada fault zones.
- Assess deformation of base of Bandelier Tuff via refinement of structure contour map

Task 3: Detailed Characterization of Investigation Areas
- Delineate linear and planar datums (fluvial terrace surfaces, alluvial fan surfaces, active and buried channels, planated bedrock surfaces, valley margins, and stratigraphic markers)
- Field mapping and topographic surveying
- Assess surficial expression of deformation (lineaments, drainage, patterns, linear ridges, fault scarps)

Task 4: Paleoseismic Trenching
- Excavation, shoring, logging, interpretation
- Assessment of Quaternary deformation and near-surface fault geometry

Task 5: Age-Estimation Studies
- Estimate ages of Quaternary deposits and geomorphic surfaces
- Numerical techniques (radiocarbon, thermoluminescence, potassium-argon)
- Correlative techniques (tephrochronology, amino acid racemization)
- Relative techniques (topographic position, soil-profile development, surface morphology, deposit characteristics)

Task 6: Characterization of Regional Tectonic Setting
- Review of published and unpublished data
- Interaction with active researchers
- Compilation of regional tectonic map (1:100,000)
- Refine existing or develop new tectonic models

Task 7: Evaluation of Contemporary Seismicity
- Seismic data review and reanalysis
- Development of crustal velocity model
- Earthquake relocations and determination of focal mechanisms

Task 8: Seismic Source Characterization
- Significant sources and locations
- Fault geometry, type, slip rates, segmentation, maximum earthquakes
- Assessment of earthquake recurrence

Task 9: Characterization of Site Geology
- Drilling and lithologic logging
- In situ shear-wave velocity and shear-wave damping measurements
- Dynamic laboratory testing

Task 10: Deterministic Ground Motion Estimates
- Empirical estimates
- Stochastic site-specific estimates

Task 11: Probabilistic Seismic Hazard Analyses
- Treatment of uncertainties through logic trees
- Site-specific probabilistic hazard curves
- Probabilistic response spectra

Task 12: Development of Seismic Design Criteria
- Acceleration response spectra for design
- Time histories for design

involves several subtasks, and many of the tasks and subtasks are co-dependent. The first phases of the program are designed to characterize potential seismic sources through fault investigations, characterization of the regional tectonic setting, and evaluation of contemporary seismicity. Initial results from these phases (Figure 3) which provides input to the seismic source characterization are briefly described below.

Available conventional aerial photography and low-sun-angle photography was analyzed at a reconnaissance level. New low-sun-angle photography was obtained to assess the geomorphic expression of the Pajarito fault system and to identify investigation areas for detailed paleoseismic studies. Aerial reconnaissance was also conducted along the Pajarito, Embudo and La Bajada fault zones. During this flight, fault-related features possibly associated with the Rendija Canyon fault were identified in the Los Alamos County landfill.

Regional field mapping has been conducted along the Frijoles Canyon segment of the Pajarito fault system and along the Rendija Canyon and Guaje Mountain faults. The objectives of this mapping are to map late-Quaternary surficial deposits and fault-related features with the intent of selecting potential trench locations. In addition, a preliminary working model of stratigraphic relations for surficial deposits younger than the Bandelier Tuff has been developed. This model should aid in providing approximate relative age-estimates for undisplaced and displaced deposits along the fault zones. As part of this mapping of surficial deposits, existing borehole and building-foundation data in the vicinity of the LANL has been compiled. This compilation provides information on the thickness and distribution of late-Quaternary alluvium overlying the Bandelier Tuff and on the presence or absence of late Quaternary faulting. Based on field studies, we have selected a total of nine investigation areas for possible trenching along the Pajarito fault system. Four of these areas are along the Frijoles Canyon fault segment, two areas are along the Rendija Canyon fault, and three areas are along the Guaje Mountain fault.

Based on aerial and field reconnaissance studies, a major strand of the Rendija Canyon fault was identified in the 12- to 15-m high northern wall of the Los County landfill. Stratigraphic and structural contacts (faults and fractures) exposed in the excavation wall were flagged, surveyed, and then plotted on a map of the pit wall at a scale of approximately 1:20. Contacts were mapped from an aerial lift and from the ground. Detailed structural data were collected for several major faults and fractures. Sediment samples were collected and will be submitted for paleomagnetic analysis. Analysis of the fault at this site provides information on the style and amount of middle to late Quaternary displacement along this major fault strand of the Pajarito fault system. In brief, the presence of both extensional and compressional features within the fault zone exposed at the landfill suggests this fault strand is characterized by a large component of lateral displacement. Additional investigations will be designed to address the sense of slip, as well as the timing and amount of displacement, along this fault.

A program of drilling was initiated and is currently in progress with the intent of providing sufficient data to characterize the subsurface geology beneath the LANL and, in particular, beneath all moderate to high-hazard facilities. A specific objective is to characterize the Bandelier Tuff and any other unwelded volcanic unit or unconsolidated sedimentary unit in the subsurface above basement rock. Such units can have a significant impact on strong ground shaking due to their damping properties and tendency to behave nonlinearly under high strain levels. A total of two 213-m-deep and two 61-m-deep boreholes are planned to be drilled. The first hole located at one of the high hazard facilities was completed at a depth of 213 m. Samples were collected for dynamic laboratory testing. Downhole shear-wave velocity measurements will be performed in each borehole. Based on geologic and shear-wave velocity profiles extending to depths of basement or high velocity rock, site-specific ground motion estimates will be made.

A program of relocating a subset of the earthquakes recorded by the LANL regional seismographic network since 1973 is also partially completed. Approximately 900 events in a region out to a distance of 150 km have been relocated through systematically evaluating the original arrival time data, deleting obvious reading errors and, in some cases, rereading arrival times.

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