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REPORT OF
GEOLOGIC, FOUNDATION, HYDROLOGIC AND SEISMIC INVESTIGATION
PLUTONIUM PROCESSING FACILITY
LOS ALAMOS SCIENTIFIC LABORATORY
LOS ALAMOS, NEW MEXICO

FOR

U.S. ATOMIC ENERGY COMMISSION

BY

DAMES & MOORE

LOS ANGELES, CALIFORNIA

JOB NUMBER: 0651-120-02

NOVEMBER 29, 1972

November 29, 1972

Fluor Corporation
2500 South Atlantic Boulevard
Los Angeles, California 90047

Attention: Mr. D. C. Van Dine

Gentlemen:

Attached are 30 copies of our, "Report of Geologic, Foundation, Hydrologic and Seismic Investigation, Plutonium Processing Facility, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, for U.S. Atomic Energy Commission," dated November 29, 1972.

The proposed site for the plutonium processing facility has been designated Technical Area (TA) 55, and is located rather centrally within the present laboratory boundaries. The proposed facility will consist of a large reinforced concrete structure some 265 by 285 feet in plan dimensions. There will be several smaller support structures also located on the site, such as a control room, generator building, pump houses, administration building, and sewage treatment plant. These structures are described in more detail in the section titled "Foundation Investigation."

The investigation was planned in discussions with Mr. Richard Bierman of Fluor Corporation. The scope was first outlined in a proposal to you dated July 9, 1971. Additional information became available, leading to a proposal dated April 10, 1972, which was the basis on which this investigation was performed. As the work progressed, changes in scope occurred, with resultant changes in the agreement with Fluor. These changes were discussed in our letters of May 6, 1972 and June 27, 1972. The work was authorized by your Purchase Order No. 4401-0-001.

During the work, several meetings and reviews were held with representatives of Fluor, Los Alamos Scientific Laboratory (LASL) and with the USAEC. Meetings also were held with various individuals, including Dr. Budding and Dr. Sanford of the New Mexico Institute of Mining and Technology, and Dr. Smith and Mr. Bailey of the USGS.

It is our opinion that the site proposed for the plutonium facility, designated as TA-55, is suitable for this proposed use, from the standpoint of its geologic, foundation, hydrologic, and seismologic setting.

If you have any questions concerning this report, please contact us.

Very truly yours,

DAMES & MOORE

Vernon A. Smoots

Vernon A. Smoots
Registered Professional Engineer
State of New Mexico
Certificate No. 3778

VAS rc

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ABSTRACT

This report describes a geological and engineering investigation of the proposed site for a new plutonium processing facility. The facility will be located at Los Alamos, New Mexico, and will be operated by the Los Alamos Scientific Laboratory (LASL). The site is located on the Pajarito plateau, situated on the eastern flanks of the Jemez Mountains.

The site lies within the Rio Grande trough, which is a tectonic rift zone with bordering faults.

The proposed site has been designated as Technical Area 55, located at about the center of the existing laboratory property. The site is located approximately 2.7 miles east of the main trace of the Pajarito fault system. It has been inferred that movement has occurred along this fault system two or more times during the last 500,000 years, and it is therefore considered "active" according to AEC criteria. The site is also near the presently dormant Jemez volcanic locus. The plateau itself was formed by periodic volcanic activity at the Jemez volcanic locus.

We have evaluated the geologic features within a radius of 200 miles of the site. In addition, we made a detailed study of the immediate area of the site. As a result of this investigation, it is our conclusion that the TA-55 site is suitable, from a geologic standpoint, for the proposed plutonium processing facility. We conclude that the risks of

possible future surface faulting or volcanism are minimal. There is a risk of moderate future seismic ground motion at the site.

In our investigation, extensive studies were made of the regional geology. Black and white aerial photographs were available from past studies, and, at our suggestion, new color infrared aerial photographs were flown of the area. These photos are considered to be of excellent quality. Extensive field mapping and inspection were done to correlate field conditions with the aerial photographs. In addition, to make double sure there was no indication of extension of faults into the area of the proposed site, a geologic trench was dug on the site. The trench was about 1000 feet long, 3 feet wide, and 8 feet deep. It was excavated diagonally across the site. This trench was studied in detail, to search for any possible sign of tectonic faulting at the TA-55 site. No such evidence could be found.

Based on the available data, it appears unlikely that earthquake motion greater than an estimated Intensity VI has been experienced at the proposed site in historic time. The largest nearby earthquake of record was the 1918 Cerrillos earthquake, located approximately 35 miles southeast of the site. It resulted in ground shaking at Los Alamos of estimated Intensity VI. Larger intensity earthquakes have been located farther south. The geologic and tectonic features of the Rio Grande rift indicate that larger earthquakes are possible.

The Jemez volcanic locus has been extensively studied by the personnel of the US Geological Survey, predominantly Dr. Robert L. Smith and Mr. Roy A. Bailey. The Jemez volcanic locus is included in the Rio Grande rift zone. Our geologists interviewed Smith and Bailey in Washington, D.C. and Bishop, California. We learned that Smith and Bailey consider the Jemez volcanic locus to be active but presently dormant. Smith indicated that the site is in the late stages of volcanic activity and that a major eruption is not probable. Should there be any future volcanic activity, it would very likely be similar to or smaller than the last eruption which occurred approximately 40,000 years ago.

The hydrology of the Los Alamos area has been studied over the years by USGS personnel and by LASL geologists. Study was necessary because a reliable domestic water supply has been of prime concern. In addition, LASL has studied the implications of long-term discharging of low-level radioactive liquid waste to the ground surface within the LASL project.

Investigation of the hydrology of the site indicates that the amount of surface water infiltration is small. It results mostly from snowmelt; some infiltration of runoff occurs after summer thunderstorms. There is practically no drainage basin for collection of water on the site, and the water which leaves the site flows into Mortandad Canyon. In Mortandad Canyon, the surface runoff infiltrates into the shallow alluvium.

During the years that the Los Alamos facility has been in operation, waste materials have been treated and then disposed of into Mortandad Canyon. These materials also infiltrate into the shallow alluvium. This alluvium is composed of fine-grained materials, is of limited extent and storage capacity, and therefore is not being used for water wells, or for any other human use.

The water in the shallow alluvium (or shallow aquifer) flows through the shallow aquifer toward the Rio Grande. This flow, however, is intercepted by trees and vegetation in the canyon, and is transferred into the atmosphere by transpiration before reaching the county line, which is about five miles west of the river. We feel that it is not possible for contaminated liquid released at the TA-55 site to find its way into the Rio Grande, the nearest body of water.

There is a deeper aquifer underlying the area of the site, which is approximately 1000 feet below the bottom of Mortandad Canyon. Infiltration of surface water from the site into this deeper aquifer is negligible.

We propose that the plutonium processing facilities be designed on the basis of two earthquake events: an "Operating Basis Earthquake," which would assume ground motion at the site of Intensity VII, but less than VIII, and a "Safe Shutdown Earthquake," assuming ground motion at the site of Intensity VIII.

This report contains response spectra based on horizontal ground motion accelerations of 0.33g for the Safe Shutdown Earthquake, and of 0.17g for the Operating Basis Earthquake. The spectra are based on an envelope of actual and synthetic spectra appropriate to the site, including modifying the record of the 1935 Helena, Montana earthquake to fit the dynamic properties of the TA-55 site.

The subsurface conditions at the site were explored for the purpose of developing recommendations for the design of foundations for the proposed structure. Since the plutonium building will be founded in an excavation 10 to 25 feet deep, all foundations will bear on the Tshirege member of the Bandelier tuff. The tuff underlying the site is a moderately welded volcanic rock formation which will provide good lateral and vertical support for foundations. It is recommended that spread foundations be used for support of the structures.

It is believed that foundation settlements will be well within tolerable limits, even though structural loads will be substantial.

INTRODUCTION

GENERAL

In this report we present the results of our geology and fault study, seismology studies, hydrology studies and foundation investigation for the plutonium processing facility to be constructed at Los Alamos, New Mexico.

The site, designated TA-55, was selected prior to the start of our work. It is located at the northwest corner of Pajarito Road and Pecos Drive on U. S. Atomic Energy Commission property in Los Alamos. Descriptions of the proposed structures and a plot plan of the facility are contained in the Foundation Investigation section of this report.

The purpose of the investigation was to obtain geologic, foundation, fault, hydrologic and seismologic information necessary for the design and safety analysis of the facility, and to present the information in a comprehensive report with such detail and specific opinions as to provide a design basis for the facility and to meet PSAR requirements.

SCOPE OF WORK

STUDY SEQUENCE

It was intended that studies proceed in such sequence that the effect of local considerations which could adversely affect site suitability, such as earthquake intensity and surface faulting, be investigated prior to a detailed investigation at Site TA-55. However, sufficient preliminary investigation was to be performed initially at TA-55 to provide data for preliminary facility design and to locate any major considerations which could affect site suitability. The studies were performed in steps.

The first step was preliminary in nature and involved a review of literature and a site inspection. We reviewed the results of this step verbally with Fluor, and prepared a specific work outline for the following steps.

The second step was a detailed investigation. In this step, a detailed review of pertinent literature, regional geology studies and some on-site geologic mapping were performed. The geology and fault studies performed are described in the following paragraphs.

GEOLOGY

The purposes of the geological interpretation and analyses were:

1. To describe the geology of the region and the site with emphasis on important geological characteristics or natural geological hazards which could influence the design or safety of the proposed facility.
2. To prepare a detailed geologic profile of the site.

A detailed review of pertinent geologic literature and a detailed reconnaissance of the site and surrounding region were performed in order to identify important geologic features.

Interpretation of available aerial photographs of the site and general area were utilized as a means to aid in recognition of important geological and geomorphic characteristics of the area.

Adequate aerial photography of the site and general area was not available at the time we commenced the detailed geology and fault studies. Tentative arrangements had been made for black and white aerial photos to be provided to us, but they had not yet been flown. Therefore, we recommended that stereoscopic color infrared aerial photography be performed,and this recommendation was followed. The use of the color infrared aerial photography made possible an improvement of about 20 percent in the quality of our interpretation of the aerial photography, and thus enhanced the credibility of conclusions derived therefrom. The color infrareds will also be useful in long-range geology, seismology and fault studies being conducted by others.

A geologic profile was developed to evaluate any conditions which might be hazardous or have an influence on plant safety and design. Work included mapping of the Pajarito fault known to be located a few miles from Site TA-55, and studies of other faults that might affect the facility. The fault investigation is described below.

FAULT STUDY

The fault study was conducted using procedures outlined in the proposed 10 CFR 100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," presently under consideration by AEC.

This work was performed in two phases. The first phase was to define the local faults so that their possible influence with respect to Site TA-55 could be determined in accordance with 10 CFR 100, Appendix A. The second phase was to be necessary only if Site TA-55 were deemed to be within the "zone requiring detailed faulting investigation;" Phase 2 would be a detailed investigation with regard to the possibility of surface faulting at Site TA-55.

The Phase 1 work indicated that the site was within the "zone requiring detailed faulting investigation", and the Phase 2 fault study was required. The purposes were to verify the extent of two fault branches north of the site, their precise relationship to the site, and their potential influence on the facility, and to evaluate the possibility of future volcanic activity in the region.

The general requirements for the Phase 2 fault study are indicated in 10 CFR 100, Appendix A, for sites within the zone requiring detailed fault investigation. The scope of Phase 2 included:

1. Field checking of the alignment and extent of the two fault branches that might pass close to the site. Checking for evidence that the faults may die out, may extend westerly but miss the site, or may extend toward the site. Extend the investigation to the south of the site.

Check the canyon walls on both sides of the site for any signs of either fault. Make a more detailed examination of the area.

2. Excavation of a geologic trench across the length of the site, in an east-west direction. The trench would be approximately 1,000 feet long. It would be excavated to a sufficient depth to extend approximately five feet into the tuff bedrock. The trench would be cut with a backhoe or trenching machine, or other appropriate equipment. It would be cut to a width of approximately three feet to permit entry and careful examination and mapping by a geologist. The mapping would include a record of fracture patterns and any indication of displacements on any fractures. A stereo net plot of the structural attitudes of the fractures would be made to analyze the structural significance of the rock fracture patterns.

A primary advantage of trenching was that much more detail could be seen in a fresh-cut trench. Examination of canyon walls is less revealing because of the lack of a continuous exposure of bedrock. This results from slope debris and weathering which tends to obscure features in the rock.

3. A meeting with the U. S. Geological Survey in Washington, D.C. They have geologists such as Smith and Bailey whose experience in this area dates back to the 1930's, and who have mapped the Valles caldera area. The USGS has made a detailed study of the geologic history of volcanic activity in the caldera area. The purpose of meeting with the USGS was to review their findings and opinions regarding the status of volcanic activity, possible future volcanic activity, and the geologic structure of the area.

SEISMOLOGY

The purposes of the seismological investigation and analyses were to evaluate the following:

1. The "Safe Shutdown Earthquake" and the "Operating Basis Earthquake" to be used in the plutonium processing facility design.
2. The effects (such as changes in strength or compressibility characteristics) of earthquake motion on the foundation materials.

3. Dynamic elastic moduli of representative foundation materials to be used in the design of principal structures.
4. Recommended response spectra of the "Safe Shutdown Earthquake" and the "Operating Basis Earthquake."
5. Comments on the influence of the subsurface conditions and earthquake motion on the design of structures.

Similar procedures to those outlined in the proposed 10 CFR 100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," presently under consideration by AEC, were used for determining the quantitative design basis for vibrating ground motion at the site due to earthquakes.

The study included a review of the seismic history of the region using all available sources of information. The seismic history of the region and site were evaluated in the light of the tectonic history of the area developed in the geologic studies. If faults in the region surrounding the site are active faults, (as determined per 10 CFR 100), the most severe expected earthquakes associated with these faults were to be evaluated.

FOUNDATION STUDY

The foundation study was conducted in two steps. The first step was preliminary, carried to the degree that the following could be accomplished:

1. Provide sufficient data for preliminary facility design.
2. Provide a base for a more detailed site investigation.
3. Identify any major conditions which could affect plant safety.

The second step provided data to develop detailed foundation recommendations. This step was taken after sufficient work had been performed in geology, earthquake intensity and surface faulting, to anticipate the suitability of the site.

HYDROLOGY

The purpose of the hydrological investigation and analysis was as follows:

1. An evaluation of the hydraulic characteristics of the subsurface strata and an estimate of the depths, direction and rate of flow of the ground water.
2. An evaluation of the characteristics of existing wells within the area, including depths, yields and the extent of the aquifers which the wells penetrate.

3. An evaluation of the movements of surface waters on the site and the effects which changes of surface features will have on site drainage and the direction of surface water flow.

4. An evaluation of the safety of the proposed plutonium processing facility with respect to hydrologic environment and specifically with respect to accidental releases above or below ground.

A detailed review of pertinent hydrologic literature and a hydrologic reconnaissance of the site and surrounding areas were performed in order to identify important hydrologic features. Available aerial photographs of the site and the general area were interpreted as an aid in recognition of important hydrologic characteristics of the site.

Results of this work were supplemented by the detailed hydrologic information obtained from the geology and test borings.

The investigation of surface water and ground water conditions within the site area included an inventory of local wells which might conceivably be affected or influenced by the construction and operation of the proposed plutonium processing facility.

GEOLOGY

SUMMARY

GENERAL

The TA-55 site, located on Mesita del Lucy, Los Alamos, New Mexico, in our opinion is suitable from a geological standpoint for the intended facility. Following study and evaluation of the geologic features within a radius of 200 miles of the site, we have concluded that the risks from possible future surface faulting and volcanism are minimal. We have also concluded that there is a risk of moderate seismic ground motions at the site.

Investigation of the regional stratigraphy and tectonic structure of the area surrounding the proposed TA-55 site has shown that it lies within the Rio Grande structural trough, a tectonic rift zone. The site is situated adjacent to the Pajarito fault system ("active" according to AEC criteria) and adjoins the presently dormant Jemez volcanic locus.

EVALUATION OF GEOLOGICAL FEATURES

Surface Faulting

No fault members of the Pajarito fault system or associated tectonic fracture system pass through the site. It is therefore inferred that there has been no faulting at the site within the last one million years.

The two nearest active faults of the Pajarito fault system, the "West" and the "East" members, terminate their southward extensions one and one-half and two miles north of the site, respectively. The orientation of the West fault member at its southernmost extension is to the southwest, trending away from the proposed site. A structurally related tectonic fracture system comprising several en echelon members does lie 1000 feet east of the site but shows no significant displacement.

The surface expression of the members of the Pajarito fault system show a general north-south orientation. From the nature of the fault zones, the en echelon fault pattern, and the long history of recurrent fault movement, it is possible that the East and West faults, as well as older, but structurally related fault branches and fractures, may extend southward beneath the undisturbed surface rocks (the 1,000,000-year old Bandelier tuff) on Mesita del Buey in the vicinity of the site. However, there is considerable local variation in the strike direction and in the length of individual branches. It is, therefore, quite difficult to infer even the approximate location or length of concealed fault and fracture lineations. In any case, it has been inferred that faulting has not occurred on Mesita del Buey since one million years ago, if it has occurred there at all.

Surface faulting has occurred in several places along the Pajarito Plateau associated with the main trace of the

Pajarito fault system. The nature of the individual fault zones indicates that displacement has recurred along pre-existing fault branches. Therefore, from a structural point of view, the site is a better location than areas on the plateau nearer to active fault branches with post-Bandelier tuff movement.

Considering the widely spaced distribution and structural position of the most recently active faults within the Rio Grande depression, the probability of similar surface faulting occurring in the immediate vicinity of the site during the lifetime of the facilities appears remote.

Volcanic Activity

The Rio Grande trough possesses the potential for future volcanic eruptions as does the presently dormant Jemez volcanic locus. The probability of another major rhyolite eruption of the Bandelier tuff type is remote, however. There is a possibility of another smaller rhyolite eruption of the El Cajete type. The structural development and periodicity of past eruptions indicate that the probability of such an event occurring within the next one thousand years is very low.

Tectonically and structurally related eruptions of basalt flows similar to recent flows near Grants and Carrizozo, over 95 miles to the southwest and 165 miles to the southeast, respectively, have the highest probability of occurrence. The inferred periodicity of these eruptions, however, is measured in hundreds of years. Furthermore, the relatively non-violent nature of these basaltic eruptions and their structural position along the outer flanks or medial axis of the rift zone minimizes the possible effects of such an eruption on the safety of inhabitants and buildings within the Los Alamos area. Even in the event of a renewal of volcanic activity in the Rio Grande rift zone during the facility lifetime, the probability that the site would be adversely affected is not significant.

Tectonism and Seismicity

Instrumental and historical data indicate a moderate seismic activity over the entire extent of the Rio Grande rift zone.

It is possible that earthquakes may occur in response to either volcanic activity or faulting. However, faulting is a more likely cause.

Seismic activity may occur with or without accompanying surface rupture. The regional and structural framework of the Rio Grande rift zone suggests, however, a causal relationship between surface faulting associated with the development of the rift zone and seismic events occurring within the rift zone.

Calculations of the seismic periodicity of the Pajarito fault system based on measured fault parameters indicate that more than two displacements have occurred within the last 500,000 years. Thus, the Pajarito fault system may be considered active, acording to AEC criteria.

FAVORABLE GEOLOGIC CONDITIONS

The proposed site is underlain by the Bandelier tuff, which is physically and chemically stable. Furthermore, the site is located on Mesita del Buey, an area of relatively gentle topography. Landslides, rock falls, severe erosion, and ground compaction due to withdrawal of water are not likely to occur and are judged to be insignificant as hazards in the vicinity of the site.

PURPOSE AND SCOPE

The investigation was undertaken to provide the initial geological data required by the AEC seismic and geologic siting criteria (10 CFR Part 100, Appendix A of the Federal Register, Vol. 36, No. 228, pp. 22601-22605, November, 1971). As prescribed by these regulations, the scope of the study included:

1. Identification of the regional tectonic structures located within 200 miles of the proposed site at Los Alamos, New Mexico.
2. Determination of the regional lithology, stratigraphy, structure, and geological history of the area surrounding the site.

METHOD OF INVESTIGATION

A comprehensive review was made of all available published and unpublished literature concerning the geologic and tectonic setting of an area radially extending 200 miles from the proposed site. This review was chiefly involved in the examination of the Rio Grande rift zone.

The areas of late Quaternary faulting and volcanism were examined by air and ground reconnaissance.

A detailed photogeologic analysis of a 12 X 19 mile area surrounding the proposed site was made using color infrared photographs. This examination was followed by geologic field mapping of the 16 X 20 mile area requiring detailed fault investigation.

Detailed geologic mapping of several square miles of area surrounding the site and of a trench excavated across the foundation rock of the proposed facility and the construction of a detailed geologic cross section from a core drilling program completed the geologic investigations.

DISCUSSION

PHYSIOGRAPHIC SETTING

The site of the proposed facility at Los Alamos, New Mexico, lies on the Pajarito Plateau along the eastern flank of the Jemez Mountains. It is within the southern part of the southern Rocky Mountain Province.

MAJOR TECTONIC PROVINCES

The conspicuous tectonic feature within the area of this investigation is the Rio Grande trough or rift structure which extends from southern Colorado to northern Mexico and includes the Pajarito Plateau and the proposed site. This tectonic trough is a series of linked, intermontane, en echelon structural depresions flanked by a series of uplifted, northward-trending structural blocks (Plates 1, 2, and 3).

The Rio Grande rift zone is bounded to the west and to the east by the tectonically and seismically less active Colorado Plateau and Great Plains Provinces, respectively, (Plate 2).

DEVELOPMENT OF THE RIO GRANDE RIFT ZONE

The Laramide orogeny, which began in late Mesozoic time, developed the complexly folded and faulted belts of pre- and early-Tertiary rocks presently flanking the Rio Grande graben. Initial graben development began 18 to 21 million years ago with deposition of Miocene alluvial sediments derived from bordering highlands of deformed rocks; these now form the early members of the Santa Fe Group. The main development of the graben culminated in what may be termed the Cascadian orogeny toward the end of the Pliocene time.

Gravity data indicate a history of continued faulting and subsidence penecontemporaneous with late Tertiary and early Quaternary sedimentation. Deposition of Santa Fe-type sediments and renewed faulting within the graben continued throughout the Pleistocene and Holocene epochs (page GA-6).

Volcanism has played a role in the structural development of the rift zone since its inception; one investigator suggests that the rate of volcanism increased through geologic time as the Rio Grande trough continued to develop.

The concepts of plate tectonics can be applied to account for the tangential and tensional forces which have resulted in the present system of high-angle thrusts and gravity faults. The concepts of crustal extension and rifting also help explain the temporal and spatial distribution of volcanic and seismic events within the structural depression (pages GA-8 and GA-9 and Plate G-6).

DESCRIPTION OF THE RIO GRANDE TECTONIC TROUGH AND SURROUNDING AREA IN THE VICINITY OF THE JEMEZ UPLIFT

The proposed site of the facility lies on the eastern flank of the Jemez Mountains. The Jemez Mountains are bounded on the north by the late Paleozoic and Mesozoic sedimentary rocks of the Chama basin and on the west by the Nacimiento uplift (Plate G-4).

The pre-Pliocene to Pleistocene Nacimiento fault system, a steep, northward-trending vertical to reverse fault zone, appears to have served as an avenue for Quaternary fumaroles; its southern extention may have served a similar role for the Albuquerque volcanoes (page GA-12 and Plate G-20). The Jemez fault system of mid-Tertiary origin approximately defines the eastern margin of the Nacimiento uplift and the western structural margin of the Rio Grande tectonic trough. It is a series of northeast-trending, en echelon normal faults dominantly down-thrown to the east. The Jemez volcanic rocks erupted along this zone, which evidences several thousand feet of pre-Pliocene-Pleistocene (pre-Tschicoma Formation) displacement and several hundred feet of post-Pleistocene (post-Bandelier tuff) displacement. All surface fault displacements along the Jemez system appear to be more than 100,000 years old (pre-Valles rhyolite) and/or pre-Holocene (pre-landslide and terrace deposits). (See pages GA-12, GA-13, and GA-14, and Plate G-19.)

The Jemez Mountains are bounded on the south by the Santo Domingo basin and the San Ysidro embayment of the Albuquerque-Belen basin, both of which exhibit Cenozoic sediments. The north-trending San Felipe fault system is the structural divide between these two basins. The San Felipe system of en echelon normal faults, generally displaced downward to the east, was probably initiated prior to Pliocene-Pleistocene time and exhibits post-Pliocene-Pleistocene movement (post-Santa Ana mesa basalts). Some fault members of the San Felipe, however, have not moved within the last 1,300,000 years (since deposition of the Otowi member of the Bandelier tuff), and others have not moved within the last 100,000 years (since deposition of the El Cajete member of the Valles rhyolite) (page GA-16).

The Espanola basin, comprised chiefly of Cenozoic Santa Fe Group sediments, bounds the Jemez Mountains to the east. The La Bajada fault system is the structural divide between the Santo Domingo and Espanola basins. The en echelon faults of the La Bajada have displacements which are predominantly downward on their western side. The fault system was probably initiated in Pliocene or earlier time and has offset the early Pleistocene Ancha Formation and the Pleistocene andesites. These andesites are stratigraphically equivalent to the Bandelier tuff. Although this fault system has had post-Bandelier tuff movement, it is concealed beneath undisturbed Holocene fan and landslide deposits (pages GA-18, GA-19 and GA-20 and Plate G-3).

The Pajarito fault system lies near the western margin of the Espanola basin and along the eastern margin of the Jemez uplift. This system comprises a complex series of en echelon normal faults with displacement downward on both the east and west blocks. The faults have offset rocks older than the Bandelier tuff by several thousand feet and have displaced both members of the Bandelier tuff and also displaced the stratigraphically equivalent Cerro Toledo rhyolite by several hundred feet. Possible maximum fault displacement within the last 1,000,000 years (post-Bandelier tuff) is approximately 400 feet. No movement has occurred subsequent to the development of Holocene alluvial and landslide deposits, but erosional surfaces developed on the Bandelier tuff have an apparent displacement of up to 430 feet (pages GA-21, GA-34, GA-35, GA-51, and Plate G-7).

It should be noted in relation to the seismicity of the proposed site that the regional tectonic framework indicates the Pajarito fault system to be, in our opinion, structurally related to the La Bajada fault system and the faults of Lobato mesa (page GA-22 and Plate G-7).

The eastern margin of the Espanola basin is defined by the Sangre de Cristo uplift. The fault escarpment along the western margin of the uplift evidences en echelon normal displacement before, during, and after deposition of all but the youngest strata of the Santa Fe Group; the fault traces do not disturb Holocene alluvial deposits (pages GA-21, GA-22 and Plates G-3 and G-19).

The eastern margin of the Sangre de Cristo uplift lies near the longitude of Las Vegas, New Mexico. This structural boundary is characterized by reverse faulting. Movements along a steep reverse fault have also taken place along the north-trending Picuris-Pecos fault (down to the east) which separate the Precambrian rocks of the western Sangre de Cristo Mountains from the late Paleozoic rocks exposed predominately in the eastern Sangre de Cristo range (Plate G-19).

REGIONAL AND HISTORICAL GEOLOGY OF THE JEMEZ UPLIFT

The beginning of volcanic activity within the Jemez uplift corresponded to the period of structural development which formed the present Rio Grande tectonic trough, dated to earliest Miocene. Volcanic rocks of the Jemez uplift unconformably overlie Precambrian igneous and metamorphic rocks to late Tertiary igneous and sedimentary rocks (Plates G-4, G-7, and G-8).

The Jemez uplift constitutes a complex accumulation of early to late Pleistocene volcanic rocks which were extruded from three distinct eruptive centers. Between 1.4 and 1.1 million years ago after a period of quiescence and subaerial erosion, volcanic activity in the youngest of these eruptive centers resulted in major eruptions of great rhyolitic ash flows and ash falls. Resurgent magmatic pressures subsequent to the rhyolitic pyroclastic eruptions produced the Valles caldera, the Redondo structural dome, and a nearly complete series of rhyolitic intrusive domes along a ring-fracture zone; these latter have been dated at 0.7, 0.5, 0.4, and 0.1 million years before the present (pages GA-31 and GA-32).

EVIDENCE OF RECENT FAULTING AND VOLCANISM WITHIN THE JEMEZ UPLIFT

The Pajarito and Jemez fault systems have experienced displacement before, during, and after deposition of the Bandelier tuff. Disruption of the geomorphic surfaces both east and west of the Valles caldera and preservation of the resultant fault scarps, together with evidence of a long history of recurrent fault movement and post-Bandelier tuff fault displacement with periodicities based on the resultant estimated seismicity indicate that both the Pajarito and Jemez fault systems are geologically active; both zones have undergone more than one period of faulting in the last 500,000 years. Numerous fault scarps estimated to be 400,000 to 10,000 years old have cut Pleistocene geomorphic surfaces and alluvial deposits near both ends of the Rio Grande tectonic trough, indicating that differential movement is still continuing, in a geological sense, within the trough (pages GA-34, GA-35, GA-36 and GA-42 and Plates G-2, G-21, G-22, G-23).

Quaternary volcanism in the general vicinity of Los Alamos may have a causal relationship to the Quaternary tectonism. The historical nature of resurgent magmas, the systematic periodicity of eruptive activity, and the tectonic and structural setting of the volcanism indicate that the volcanic center responsible for the Valles caldera is geologically active, but presently dormant (pages GA-43, GA-44 and GA-45, and Plates G-2 and G-20).

RELATIONSHIP BETWEEN EARTHQUAKE EPICENTERS AND THE RIO GRANDE GRABEN STRUCTURES

Although there is a general lack of gecgraphical correlation between zones of microearthquake activity within the Rio Grande trough and the graben faults, the regional tectonic and structural framework of the Rio Grande rift zone indicates that local seismic activity is causally related to faulting forming the trough (page GA-47) and see Seismic Section in this report).

SYNOPSIS OF REGIONAL GEOLOGY

The Rio Grande rift was formed by two distinct periods of tectonic activity, one prior to the initial deposition of the Santa Fe Group (pre-Oligo-Miocene) and the other after much of the Santa Fe Group had been deposited (post-Pliocene-Pleistocene).

Initial development of the fracture systems, the isolated en echelon, trough-like structural basins and the prominent tilted blocks characteristic of the present Rio Grande depression and adjoining uplifts probably began about 18 to 21 million years ago in early Miocene time. With the development of the graben basins, between 4,000 to 10,000 feet of Santa Fe Group alluvial fan sediments began to accumulate.

In early Pliocene time, extensive volcanism began along the western slope, a basin of sedimentation now occupied by the Jemez uplift and was accompanied and followed by faulting along the Jemez and San Felipe fault systems. Volcanism continued through the Pliocene and culminated after a period of quiescence and erosion with Pleistocene rhyolite eruptions and the development of calderas about one million years ago. Subsequent intrusion and extrusion formed a ring of rhyolitic domes and ash falls within the existing Jemez caldera between 900,000 and 100,000 years ago. Volcanism within the Jemez uplift is currently restricted to solfataric and hot spring activity.

Pliocene-Pleistocene deformation was evidenced in the Jemez uplift by renewed movement along the Jemez and San Felipe fault systems and by initiation of the Pajarito fault system. The structurally related Jemez and Pajarito fault systems have post-Bandelier tuff movement (displacement during the last 1,000,000 years) and post-plateau surface development movement (displacement between 500,000 to 100,000 years ago). Numerous fault scarps offsetting Pleistocene and pediment surfaces (estimated to be 300,000 to 10,000 years old), Holocene alluvial fans, and recent seismicity within 200 miles of the Jemez uplift indicate that differential movement within the Rio Grande tectonic trough is continuing.

Thus, the geologic history of this region indicates repeated deformation from earliest Tertiary to Recent time. Late Quaternary fault and volcanic activity associated with the Rio Grande tectonic trough suggests that the deformational forces are currently active.

The Rio Grande trough is a great rift zone which has been subjected to both tensional and compressional forces. These deep-seated forces may be explained by the principles of plate tectonics. The Rio Grande tectonic trough may have been formed consequent to the rifting away of the Colorado Plateau block from the continental interior, the latter resulting from tensional crustal fragmentation subsidiary to movement between crustal plates or from convection current across a magmatic rise (pages GA-48 through GA-53).

SITE GEOLOGICAL INVESTIGATIONS

The zone that the AEC requires for detailed fault investigation was mapped. All active faults within this zone were identified by interpretation of infrared aerial photographs and by field examination, and those over 1000 feet long and ranging within five miles of the site were examined and mapped in detail (pages GA-57 through GA-67).

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The petrology, stratigraphy, and structure of the rocks underlying proposed site TA-55 on Mesita del Buey were described on the basis of detailed field mapping and core drilling (pages GA-68 through 90, and Plates G-12, G-14, G-15, and G-16).

The foundation of the proposed facilities will lie entirely within pumiceous rhyolite tuff. The total thickness of the Bandelier tuff underlying Mesita del Buey in the vicinity of the proposed site ranges from 785 feet in the northwest part of the mesa to 210 feet in the southeast part (Plates G-14 and G-16).

The surface of the mesa at the proposed site is underlain by sandy-silty B and C soil horizons, ranging from one and one half to three feet and two to four feet thick, respectively, (pages GA-80, GA-81, GA-88, GA-89 and Plate G-23.) Mesita del Buey is part of the Jemez volcanic locus which forms a gently-dipping homoclinal structure.

Photogeological interpretation of infrared aerial photographs, field mapping surface geology, and examination and detailed mapping of trench excavations on the proposed site has shown that no fault members of the Pajarito fault system exhibiting post-Bandelier tuff movement pass through the site. Therefore, there has been no faulting at the site during the last 1,000,000 years.

No tectonic fracture system associated with faulting or volcanism passes through the proposed site, but a fracture zone trending N 15-20 W and which may be roughly en echelon with the East member of the Pajarito fault system lies about 1000 feet east of the site (pages GA-82 and GA-83).

The dominant structure within the Bandelier tuff is jointing, caused by tensional forces during cooling and solidification. Local criteria were established to distinguish such joints from tectonic fractures.

Joint densities and orientations appear to vary slightly among the three stratigraphic units of the Bandelier tuff. An average joint density of one master joint for every ten feet of horizontal exposure was recorded for Subunit 3b. The average of the three joint sets intersecting at angles of 60 degress for Subunit 3b are N 70 W to N 90 W, N 10 W to N 30 W, and N 30 E to N 50 E, comprising 40 percent of all the joints measured.

The geological hazards of greatest significance to the proposed TA-55 site are: seismic activity related to tectonic and/or volcanic forces, especially reactivation of surface faulting along the adjacent Pajarito fault system, and renewed volcanism within the presently dormant Jemez volcanic locus (page GA-90).

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A geological hazard of considerably lesser significance is the probability of future rock falls and small isolated gravity block slides of jointed tuff along the mesa rim cliffs of Mesita del Buey. The risk to the proposed building from such hazards is considered extremely low.

Landslides, severe erosion, and ground compaction due to withdrawal of subsurface water are not expected to pose significant problems to the site (pages GA-90 and GA-21).

ATTACHMENTS

Plate G-1	Location Maps of the Rio Grande Structural Depression
Plate G-2	Generalized Map of the Entire Rio Grande Rift
Plate G-3	Tectonic Map of the Middle Rio Grande Depression
Plate G-4	Tectonic Map of the Rio Grande Depression Near Los Alamos
Plate G-5	Geologic Column and Time Scale
Plate G-6	Diagrams of Crustal Extension and Drift in Western North America
Plate G-7	Regional Geologic Map Showing Area of Detailed Fault Investigation
Plate G-7A	Geologic Legend for Plate G-7
Plate G-8	Generalized Geologic Map of the Jemez Mountains
Plate G-9	Index Map of the Proposed TA-55 Site
Plate G-10-11A	Geologic Legend for Plates G-10 and G-11
Plate G-10	Geologic Map of Guaje Mountain 7-1/2 Min. Quadrangle
Plate G-11	Geologic Map of Frijoles Canyon 7-1/2 Min. Quadrangle
Plate G-12	Detailed Geologic Map of Site Area

Plate G-13 Diagrammatic Cross Section of the Los Alamos Area

Plate G-14 Stratigraphic Column of Rocks Underlying the Site

Plate G-15 Detailed Geologic Cross Section of Site

Plate G-16 Geologic Cross Section of Part of Mesita del Buey

Plate G-17 Joint Orientation Diagrams

Plate G-18 Rose Diagrams of Joint Orientations

Plates G-19-
G-23 Photographs

Bibliography for Geology Section

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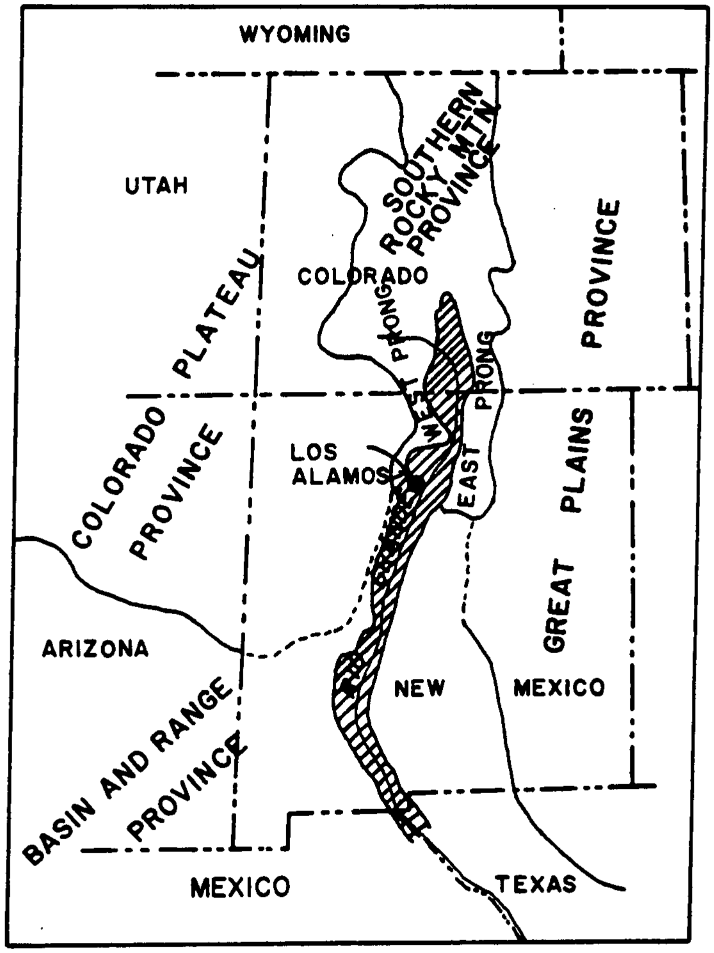
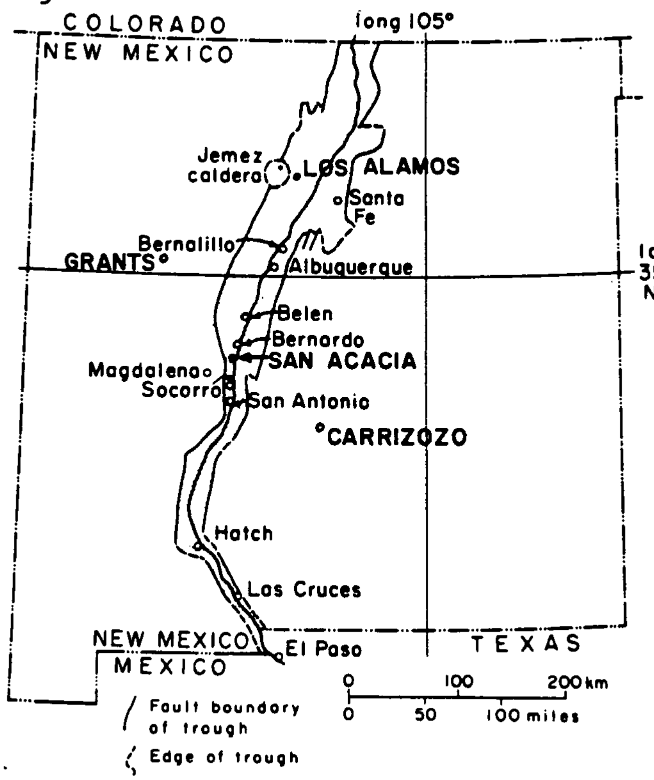
November 29, 1972

Los Angeles, California



The Rio Grande Structural Depression (shown by hatching) in relation to the physiographic provinces of the region.



Location map for the Rio Grande Structural Depression within New Mexico.

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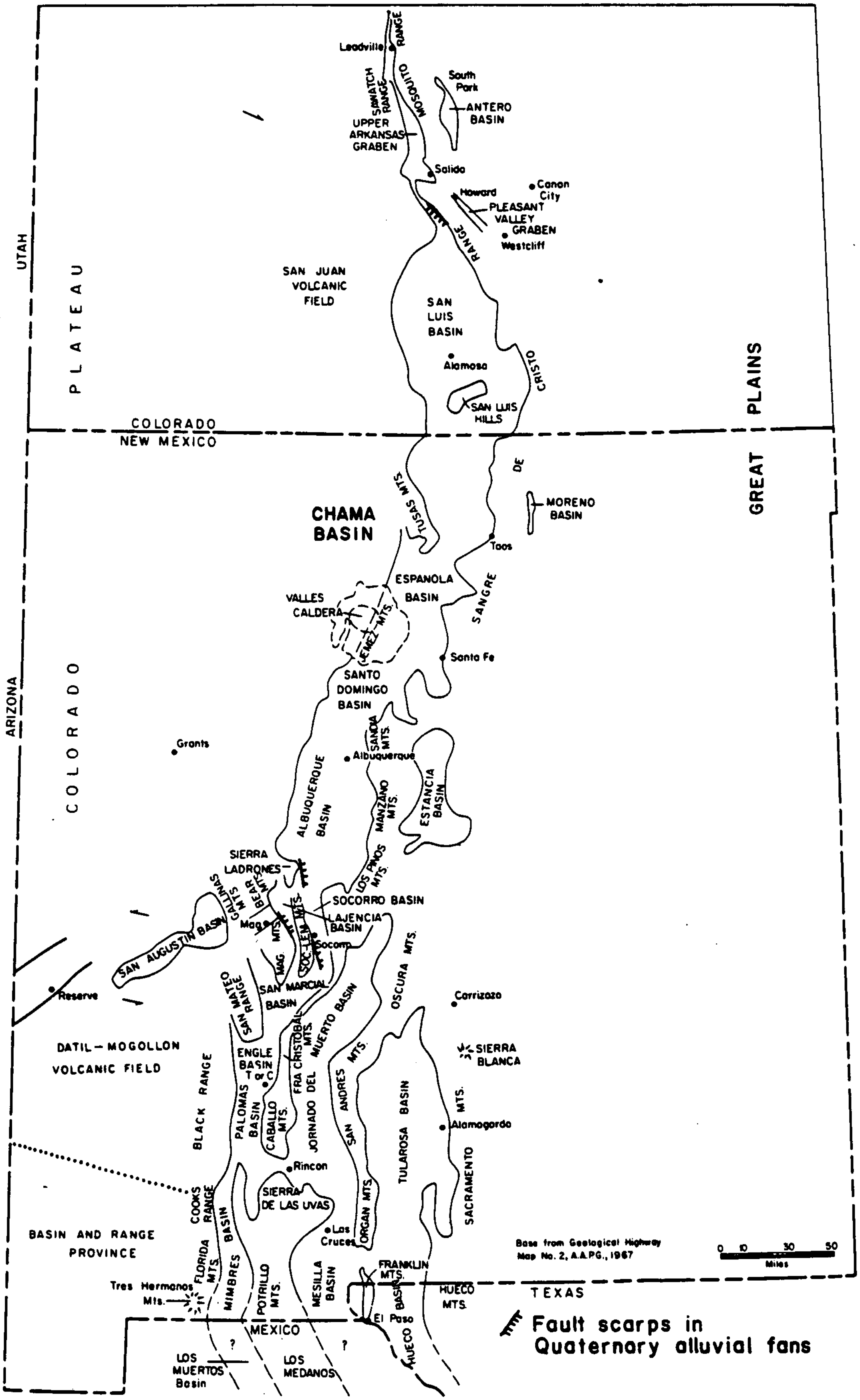
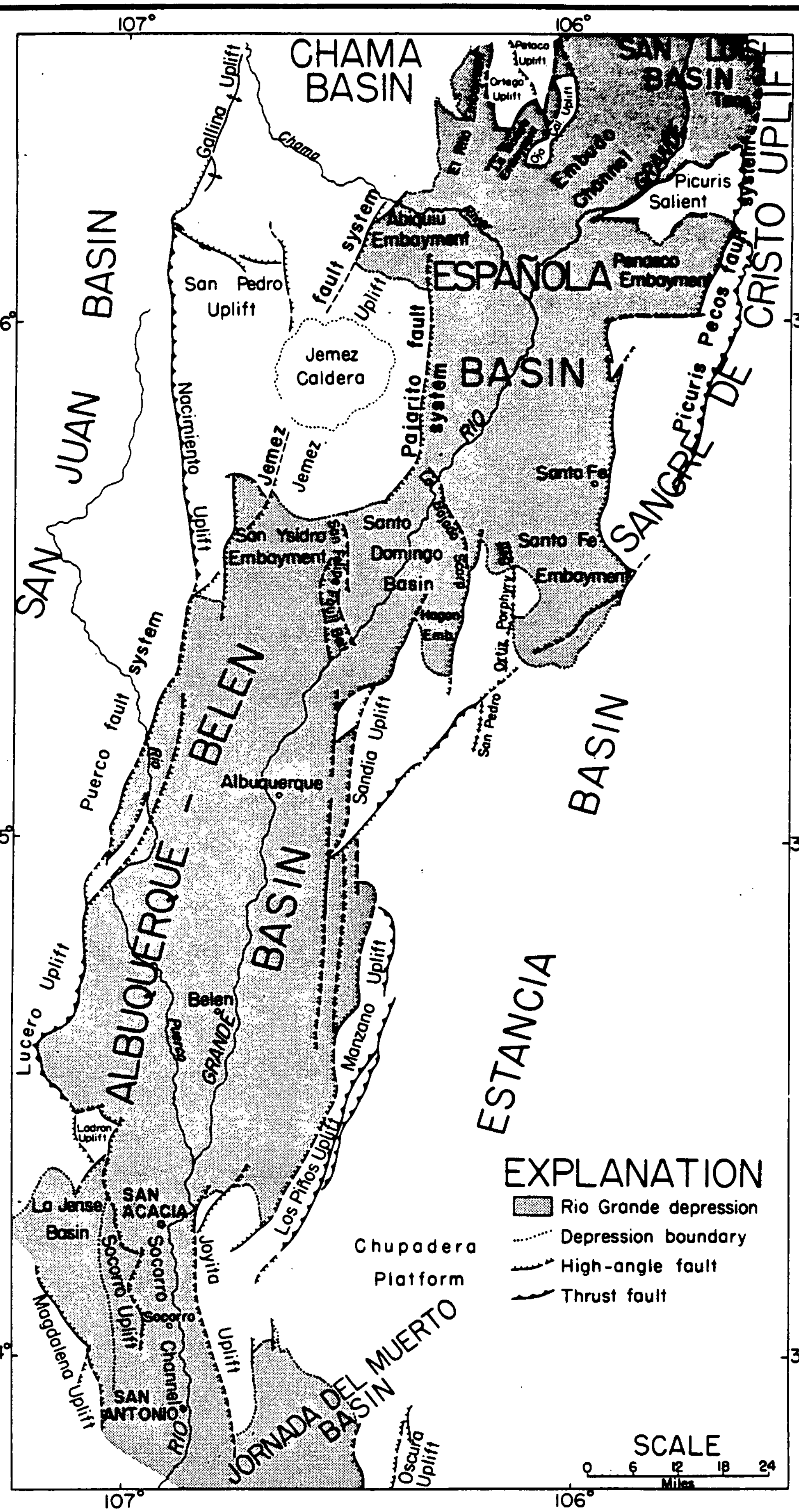
PLATE G-1



Generalized map of the entire Rio Grande Rift (after Chapin, 1971. Arrows indicate apparent direction of movement of continental plates).



Tectonic map of the middle Rio Grande Depression (after Kelley, 1961).

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PLATE G-3

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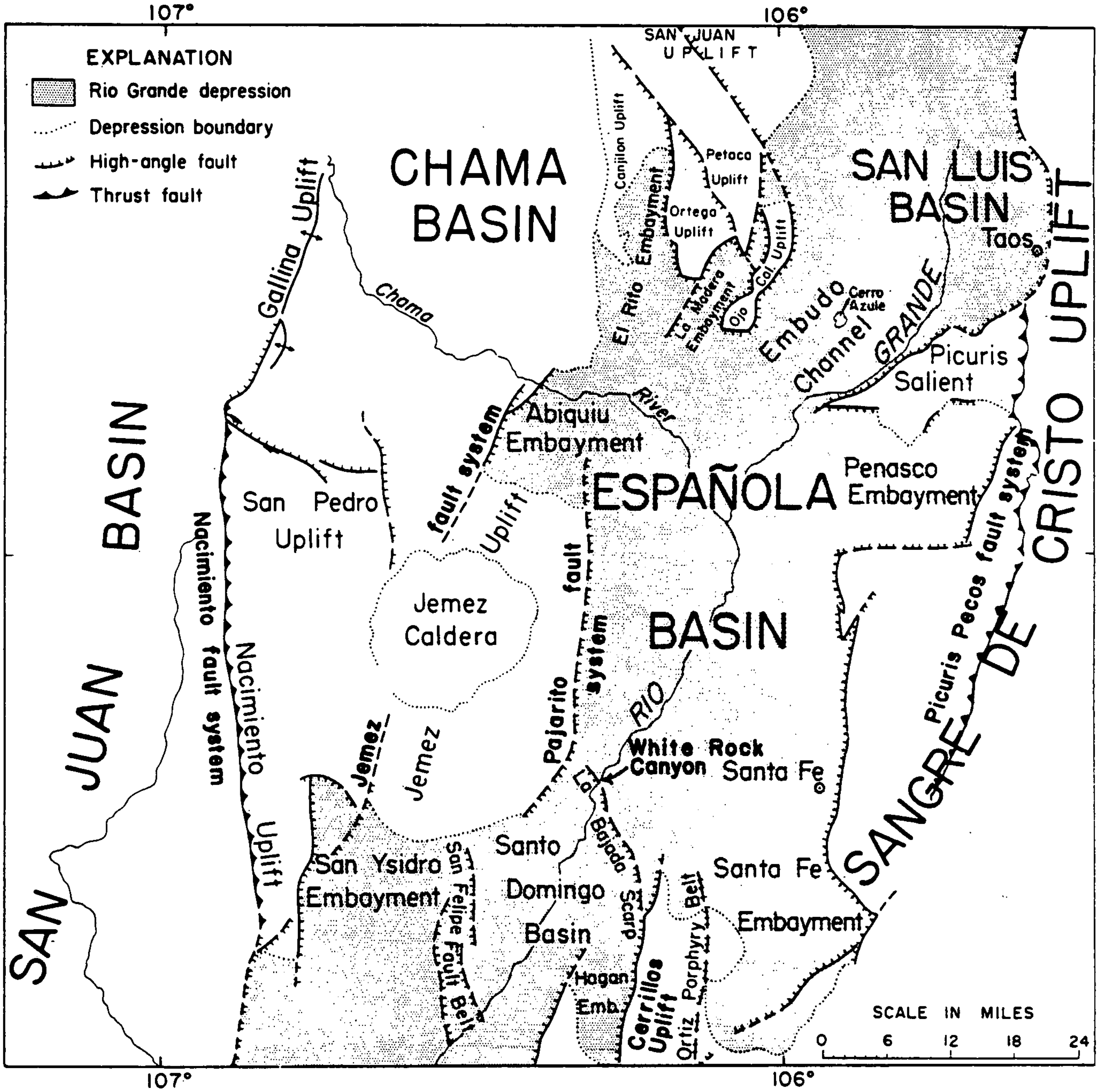
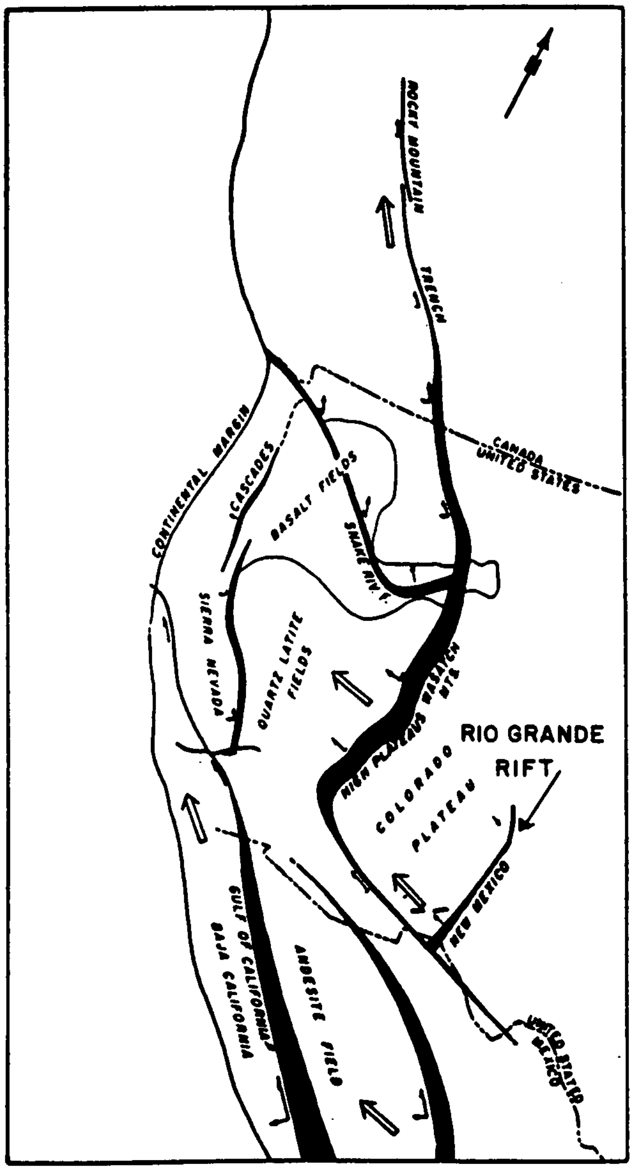


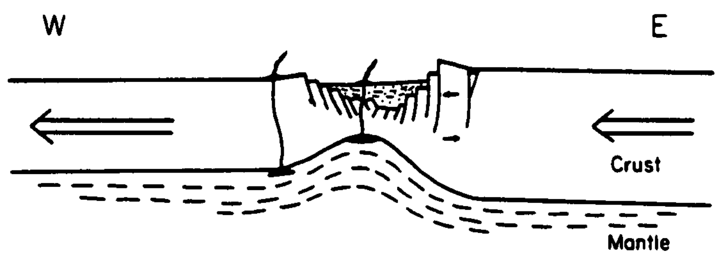
Tectonic Map of the Rio Grande Depression and Adjacent Regions near Los Alamos, New Mexico (after Kelley, 1961).

ERA	SYSTEM OR PERIOD	EPOCH	APPROXIMATE AGE IN MILLIONS OF YEARS
	Quaternary	Recent	0.006
		Holocene	0.018
		Pleistocene	1 - 2
		Pliocene	
			7
		Miocene	
			18
Cenozoic		Oligocene	
	Tertiary		25
		Eocene	
		Paleocene	
			60
	Cretaceous		62
Mesozoic	Jurassic		
	Triassic		
	PERMIAN		230
	CARBONIFEROUS Pennsylvanian Mississippian		
	DEVONIAN		270
Paleozoic			
	Silurian		350
	Ordovician		440
	Cambrian		470
Precambrian			600
			2,500

GEOLOGIC TIME SCALE



Diagrammatic map exploring the concept of extension and drift affecting western North America. Black lines represent amount of expansion as if localized along a few separations. Small arrows represent apparent vectors of movement; large arrows the apparent resultant direction of the movement.



Hypothetical cross-section of the Rio Grande rift. The large arrows indicate direction and relative rate of drift of continental plates. The small arrows indicate a force couple acting on the east shoulder of the rift.

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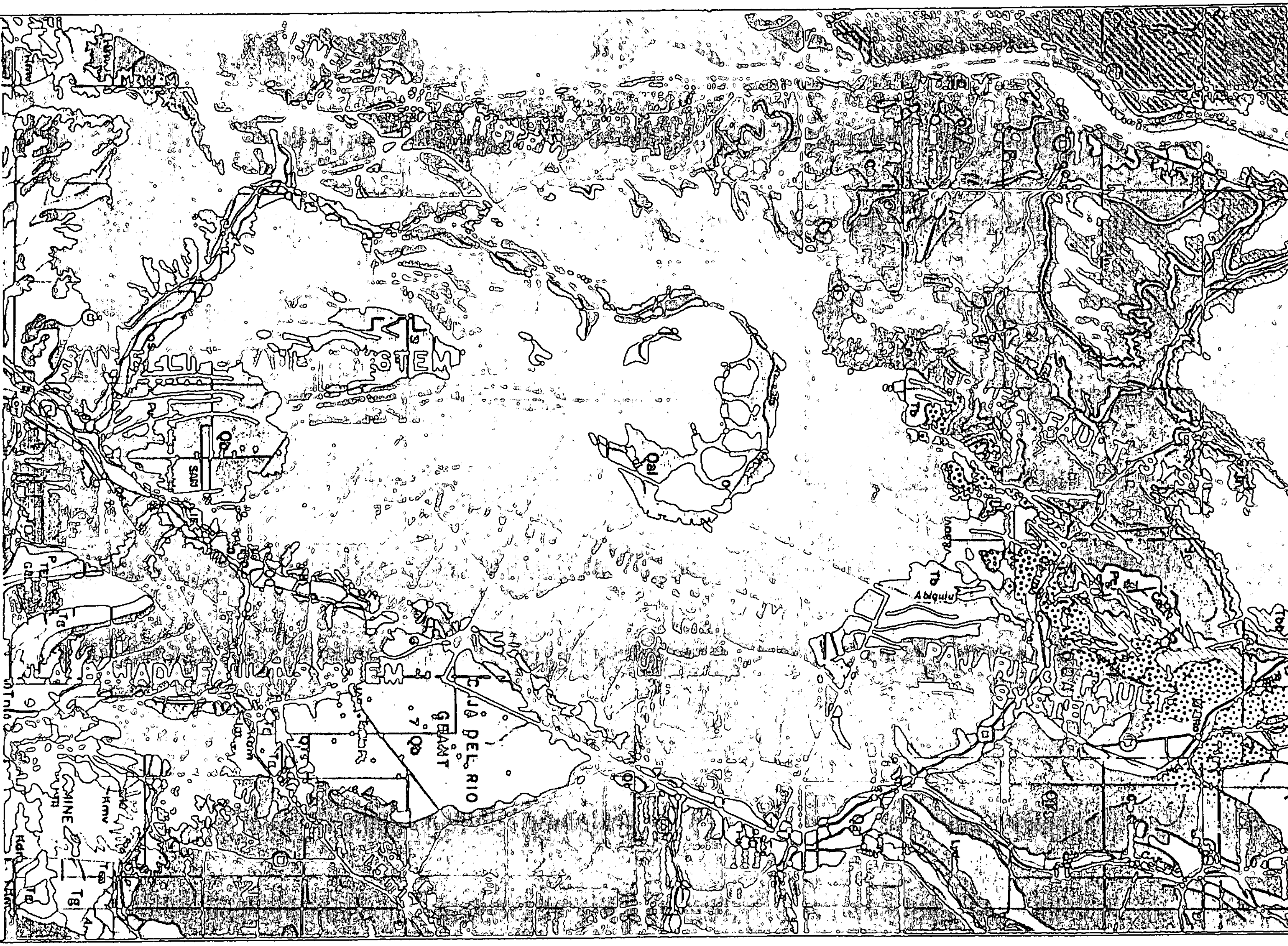

Regional Geologic Map showing area of "Detailed fault Investigation".

PLATE G-7

GEOLOGIC LEGEND FOR PLATE G-7

Era	Epoch	Period	Symbol	Unit
CENOZOIC	PLEISTOCENE AND RECENT	QUATERNARY	Qal	Alluvium
			Ql	Landslides
			Qb	Basalt flows
			Qvr	Valle Rhyolite
			Qr	Bandelier Tuff
			Qct	Cerro Toledo Rhyolite
	PLIOCENE AND PLEISTOCENE	QUATERNARY AND TERTIARY	Qtsf	Upper Santa Fe Group
			QTs	Santa Fe Group undiff.
			Tsa	Lower Santa Fe Group
	PALEOCENE THROUGH MIOCENE	TERTIARY	Tb	Andesite and basaltic andesite flows
			Tes	Espinaso Volcanics
			Tr	Undiff. extrusive rocks
			Tbb	Blanco Basin Fm. and El Rito Fm.
			Tg	Galisteo Fm.
			Tbc	Baca Fm.
			TKr	Raton Fm.
			TKa	Animas Fm.
			Tn	Nacimiento Fm.
MESOZOIC		CRETACEOUS	Kl	Lewis Shale
			K	Undiff. Cretaceous rocks
			Kmv	Mesaverde Group
			Km	Mancos Shale
			Kdm	Mancos Shale and Dakota Sandstone undiff.
			Kd	Dakota Sandstone
		JURASSIC	Jm	Morrison Fm.
			Jsr	San Rafael Group
		TRIASSIC	₹	Undiff. Triassic rocks
PALEOZOIC		PERMIAN	Psg	San Andres Limestone and Glorieta Sandstone
			Pc	Cutler Fm.
			Pa	Abo Sandstone
		PENNSYLVANIAN	IP	Pennsylvanian rocks undifferentiated
			IPms	Madera Limestone and Sandia Fm. undiff.
		MISSISSIPPIAN AND DEVONIAN	MD	Mississippian and Devonian undifferentiated
ARCHAEOZOIC		PRECAMBRIAN	p€	Precambrian rocks undifferentiated

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PLATE G-7A

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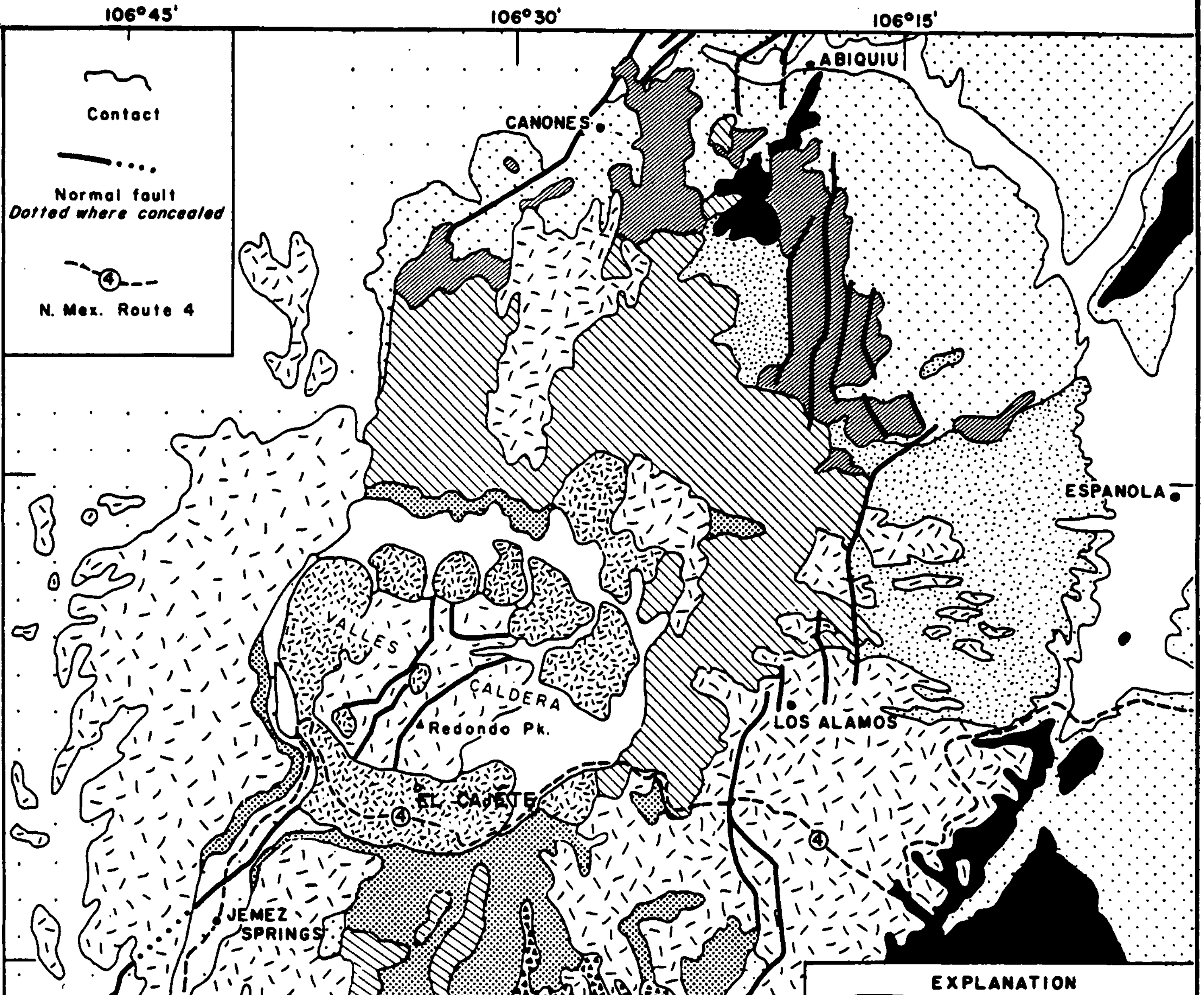

Generalized geologic map of the Jemez Mountains, New Mexico (after Smith, 1961).

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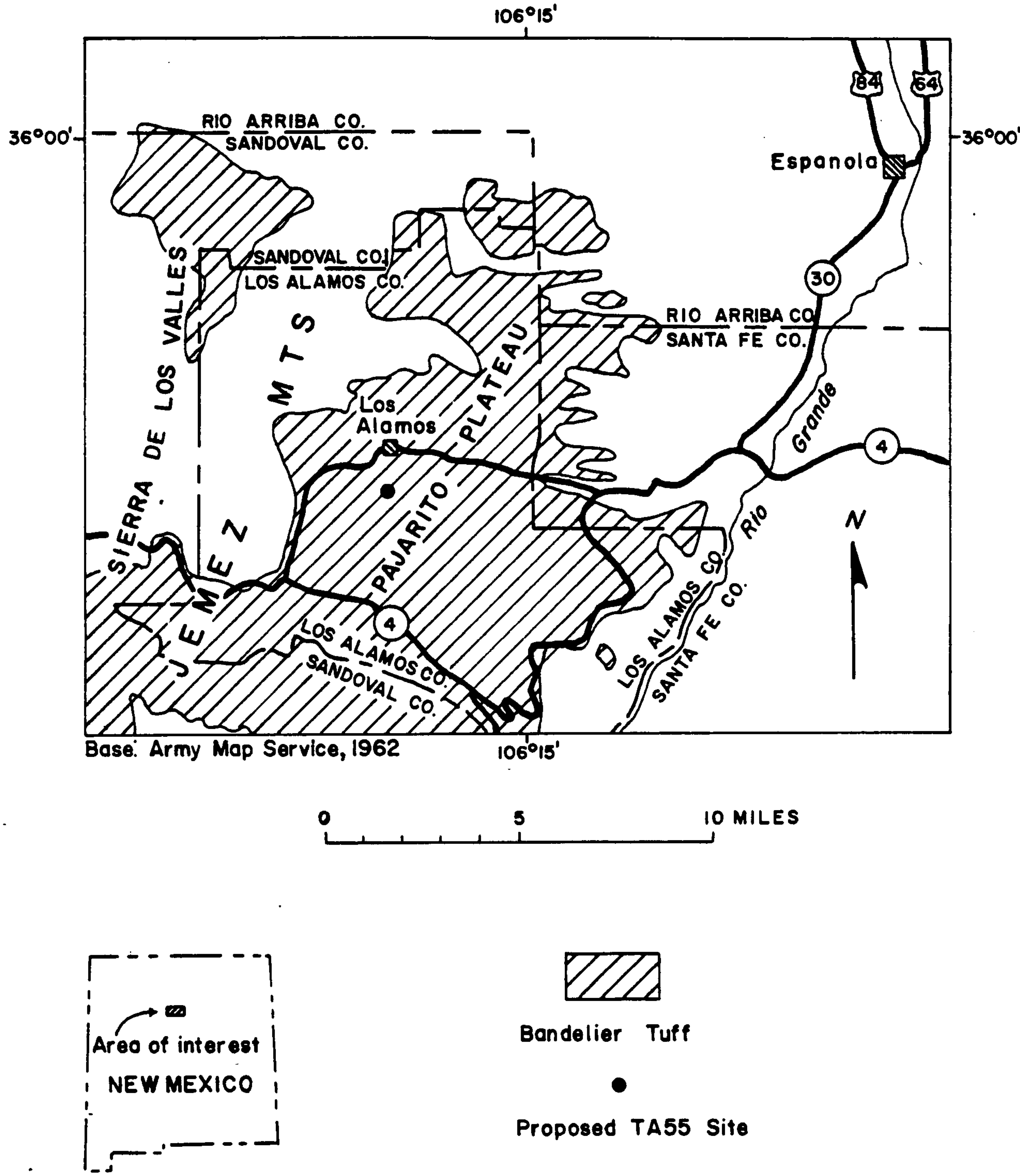
PLATE G-8



Index Map of the Proposed TA-55 Site

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Explanation of Geologic Symbols

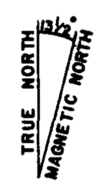
Epoch		Symbol	Unit	Period
HOLOCENE		Qal	Alluvium	QUATERNARY
PLEISTOCENE	BANDELIER TUFF	Qbt	Tshirege Member	QUATERNARY
PLEISTOCENE	BANDELIER TUFF	Qbo	Otowi Member	QUATERNARY
PLEISTOCENE		Qcct	Cerro Toledo Rhyolite Tuffs + Sediments	QUATERNARY
PLIOCENE		QTp	Puye Formation	TERTIARY
PLIOCENE		QTb	Cerros del Rio Basalts	TERTIARY
PLIOCENE		Tt	Tschicoma Formation	TERTIARY
PLIOCENE		Tlb	Lobato Basalt unconformity	TERTIARY
PLIOCENE		Tbi	Bearhead Rhyolite Intrusives	TERTIARY
PLIOCENE		Tpd / Tpa	Paliza Canyon Formation dacites + Andesites	TERTIARY
EOCENE to MIOCENE		Tsf	Santa Fe Formation	TERTIARY
EOCENE to MIOCENE		Tg	Galisteo Formation	TERTIARY

———— - - - Geologic Contact
dashed where approximately located

—┴— - - - Fault
dashed where approximately located
Ball and Bar on downthrown side

12 Structural Attitude of Stratification

Explanation of Base Map Symbols



Approximate Mean Declination 1952

5000 Topographic Contours 20' Intervals

Paved Road (NOT TO SCALE)

Graded Road (NOT TO SCALE)

SCALE
2000 1000 0 1000 2000
1 INCH = 2000 FEET

GEOLOGIC LEGEND FOR PLATES G-10 & G-11

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PLATE G-10-11A

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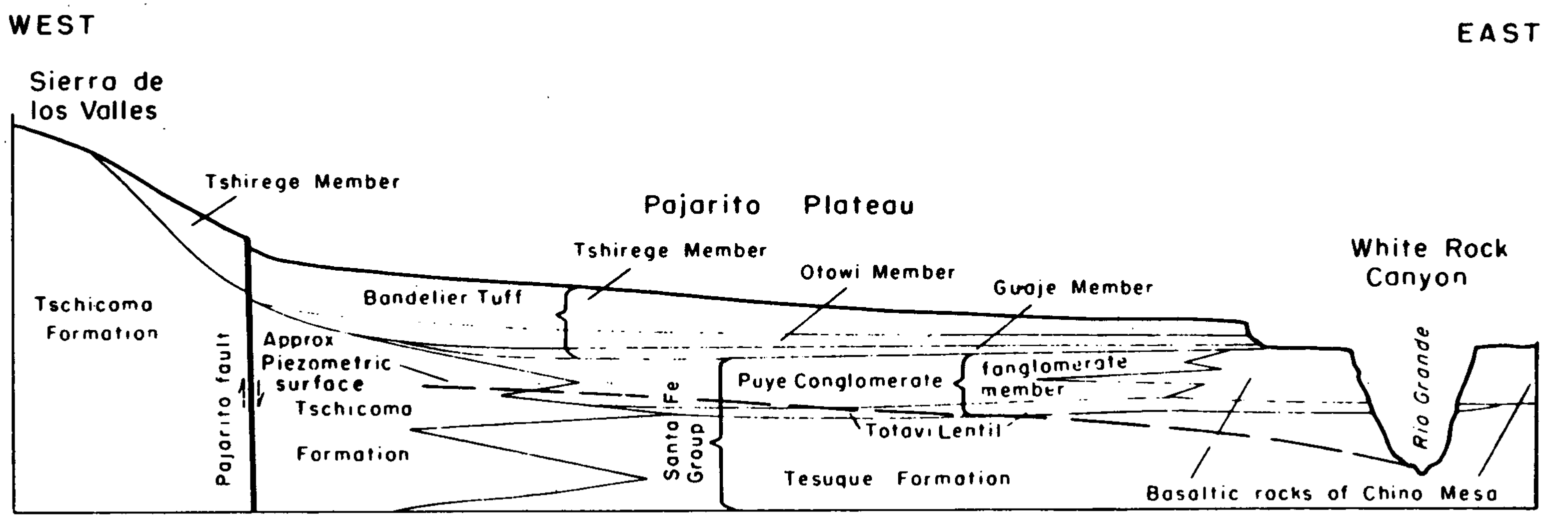


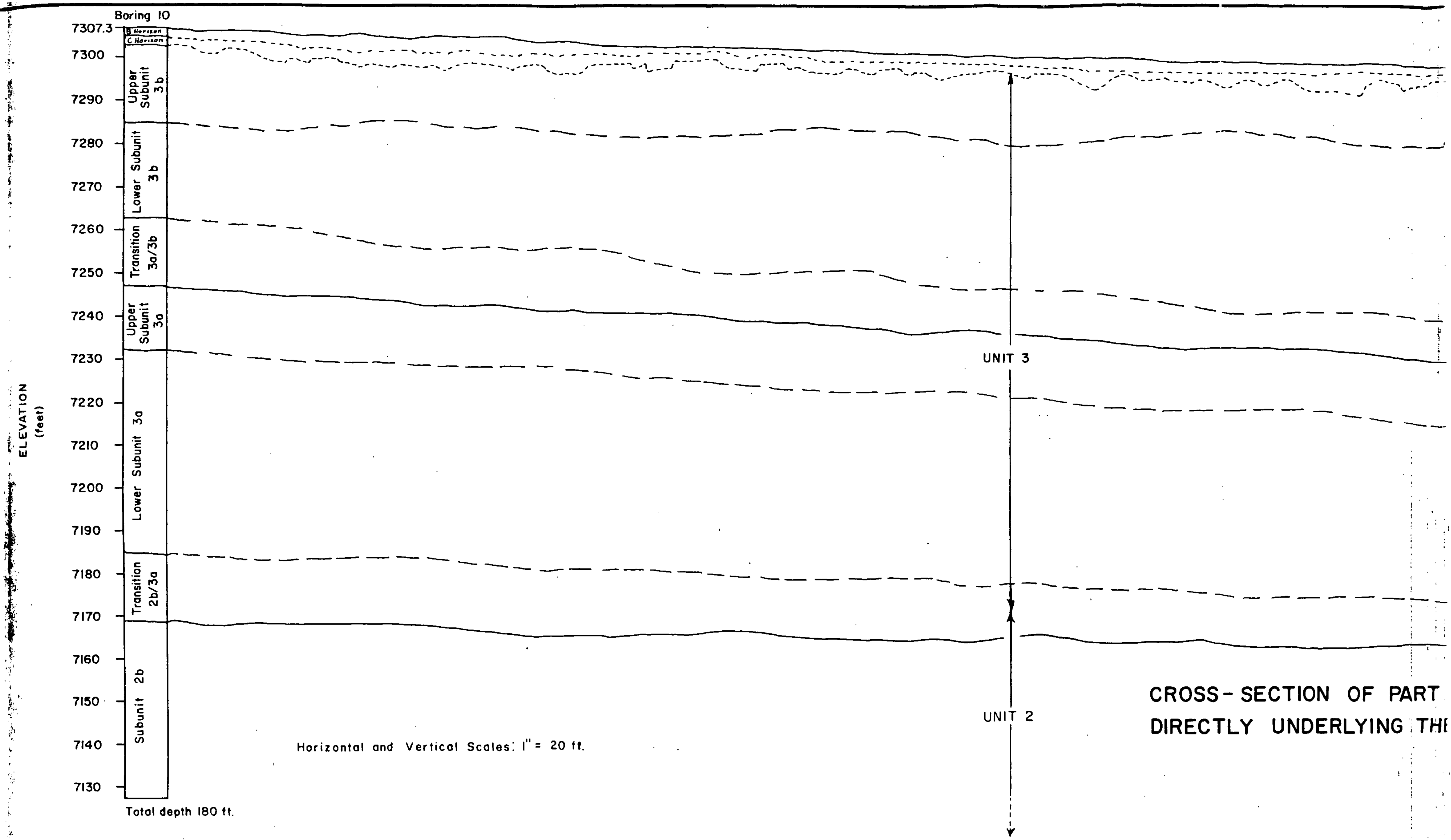
Not to scale

Baltz and others, 1962

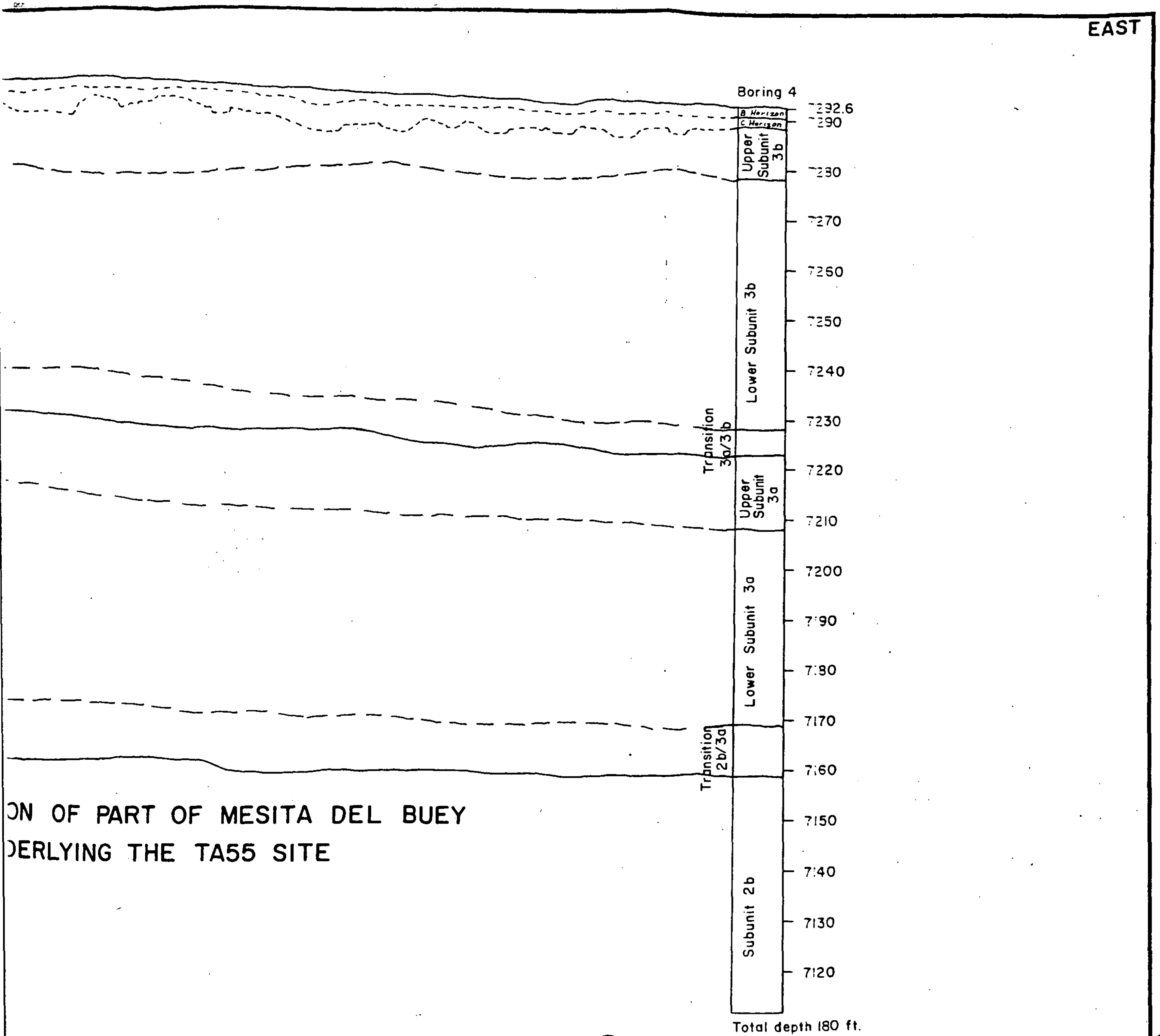
-- Diagrammatic cross section showing generalized stratigraphic relations of the Santa Fe Group, Tschicoma Formation, and Bandelier Tuff in the Los Alamos area **(after Purtymun, 1963)**.

DAMES & MOORE

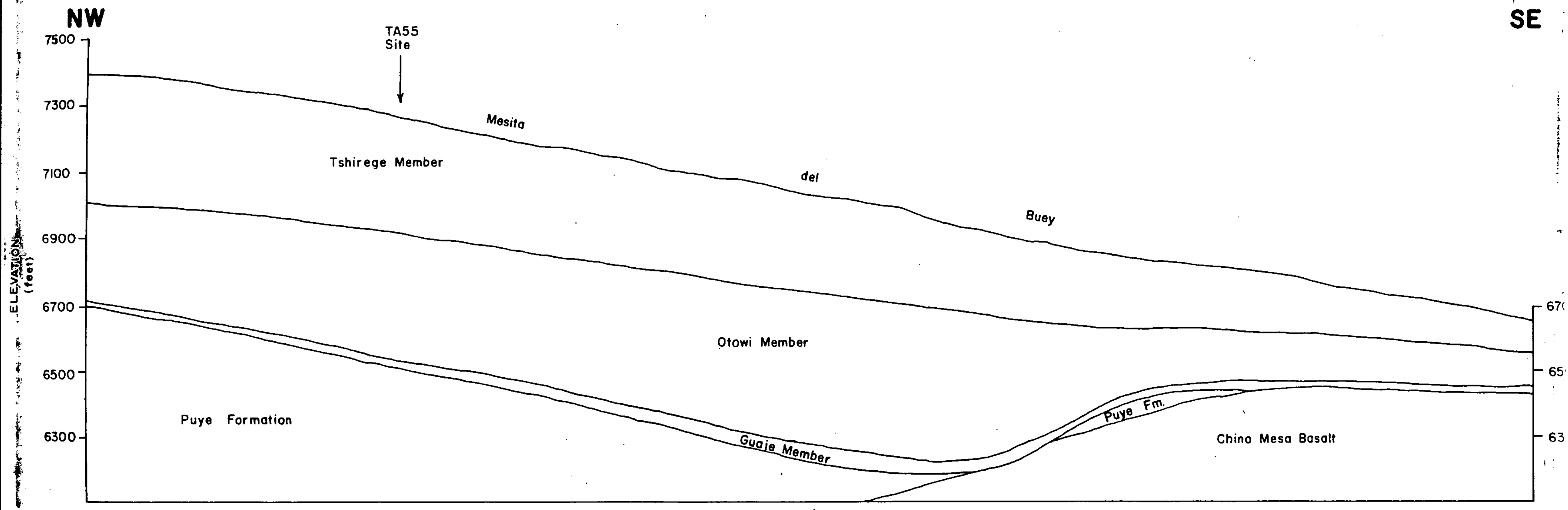
PLATE G-13



CROSS-SECTION OF PART
DIRECTLY UNDERLYING THI

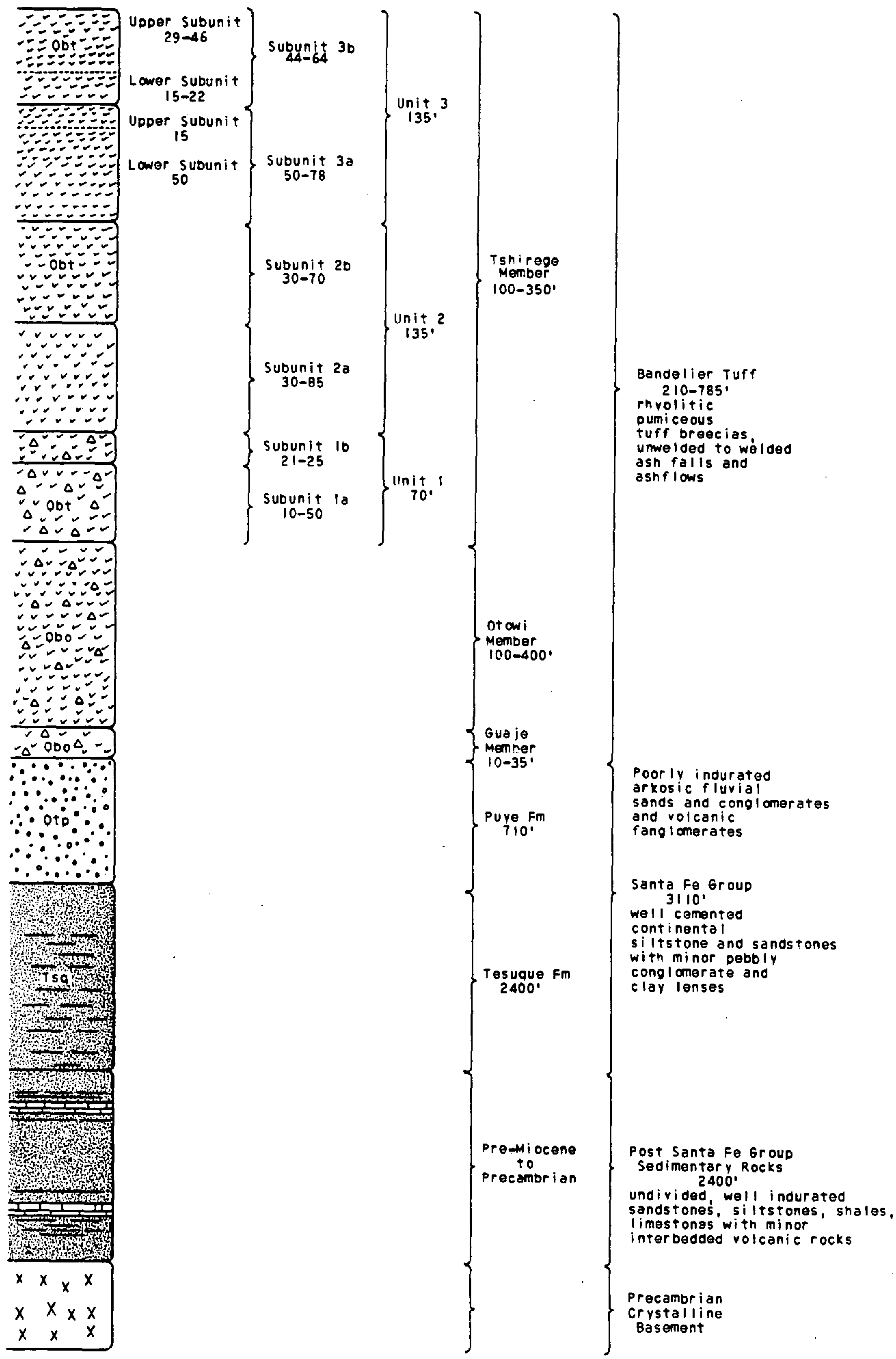


ON OF PART OF MESITA DEL BUEY
DERLYING THE TA55 SITE



GEOLOGIC CROSS-SECTION OF PART OF MESITA DEL BUEY

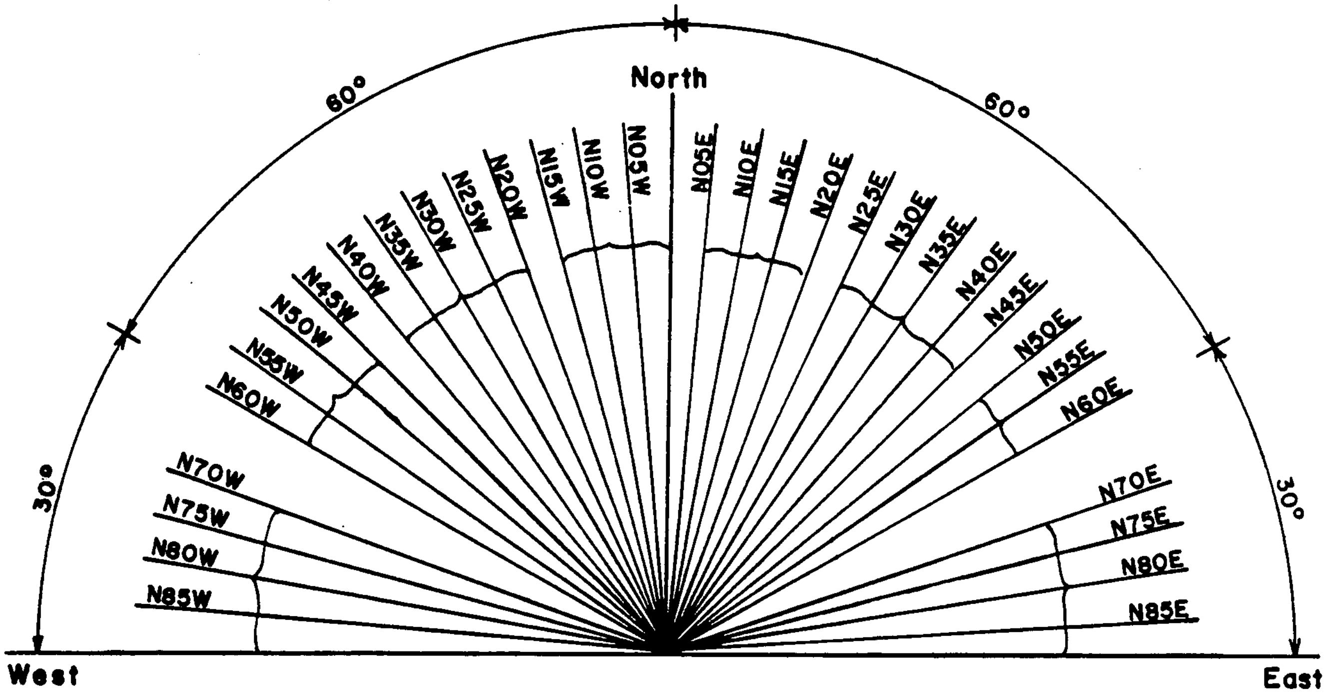
'ertical scale: 1" = 280 ft.
Iorizontal scale: 1" = 1850 ft.



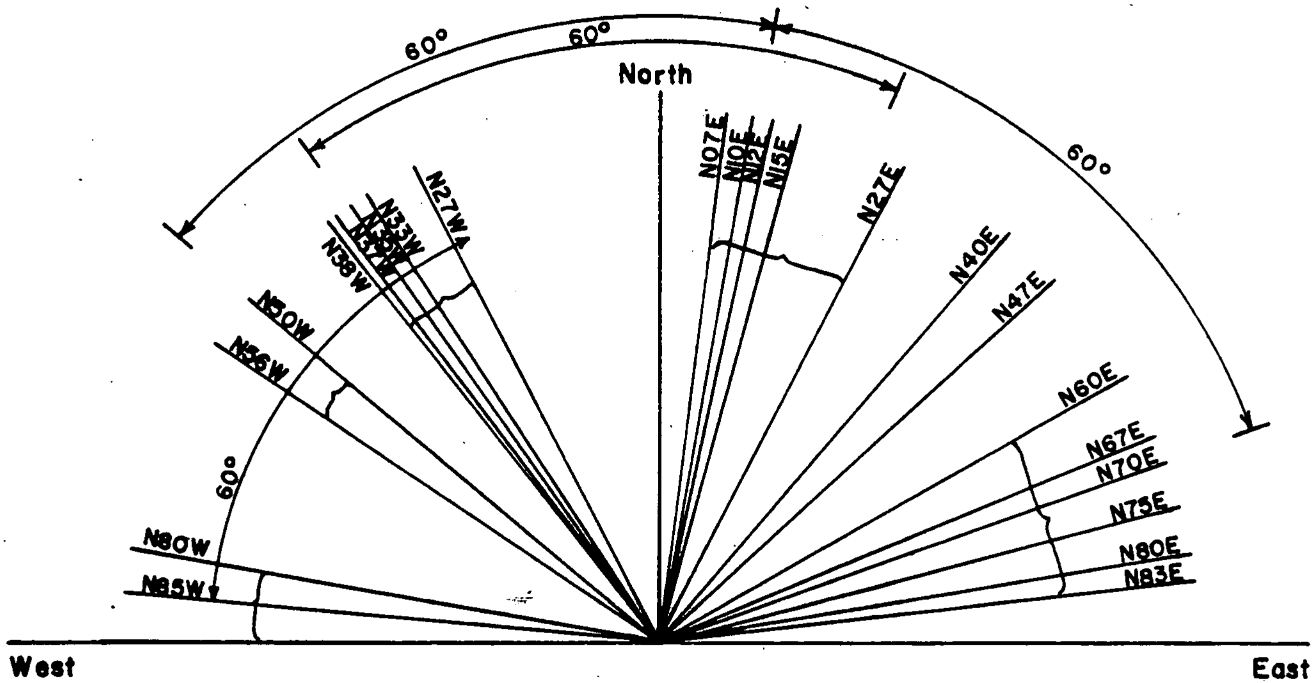
STRATIGRAPHIC COLUMN OF ROCKS UNDERLYING THE PROPOSED TA-55 SITE ON MESITA DEL BUEY

DAMES & MOORE

PLATE G-14

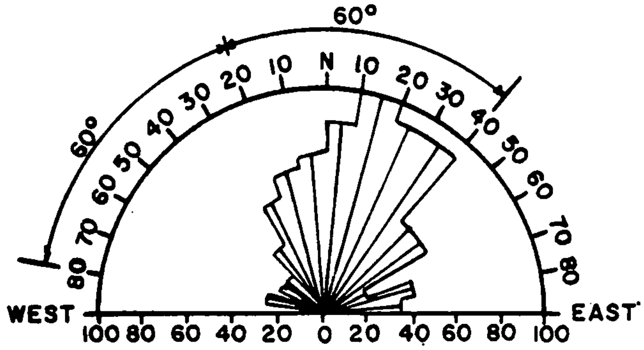


Orientation of some of the master joints in Subunit 3b of the Tshirege Member of the Bandelier Tuff. Sets of similarly oriented joints are bracketed. Each ray represents several joints.

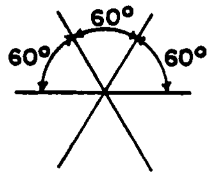


Orientation of some of the master joints in the entire Tshirege Member of the Bandelier Tuff. Sets of similarly oriented joints are bracketed. Each ray represents several joints.

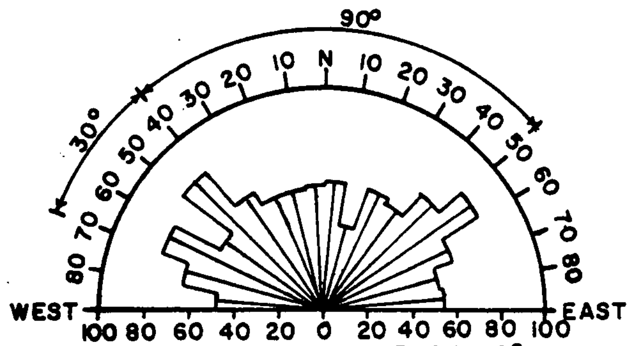
DAMES & MOORE



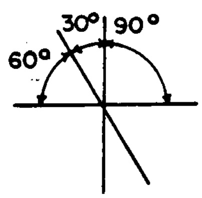
NUMBER OF JOINTS IN EACH 10° SECTOR OF SUBUNIT 3b.



JOINT ORIENTATION OF SUBUNIT 3b (AVERAGE JOINT SETS SHOWN ON ROSE DIAGRAM.



NUMBER OF JOINTS IN EACH 10° SECTOR OF SUBUNIT 2b.



JOINT ORIENTATION OF SUBUNIT 2b (AVERAGE OF THREE JOINT SETS SHOWN ON ROSE DIAGRAM).

Rose diagrams showing the orientation of joints in Subunits 2b and 3b of the Tshirege Member of the Bandelier Tuff.

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PLATE G-18

REVISIONS BY ______ DATE ______

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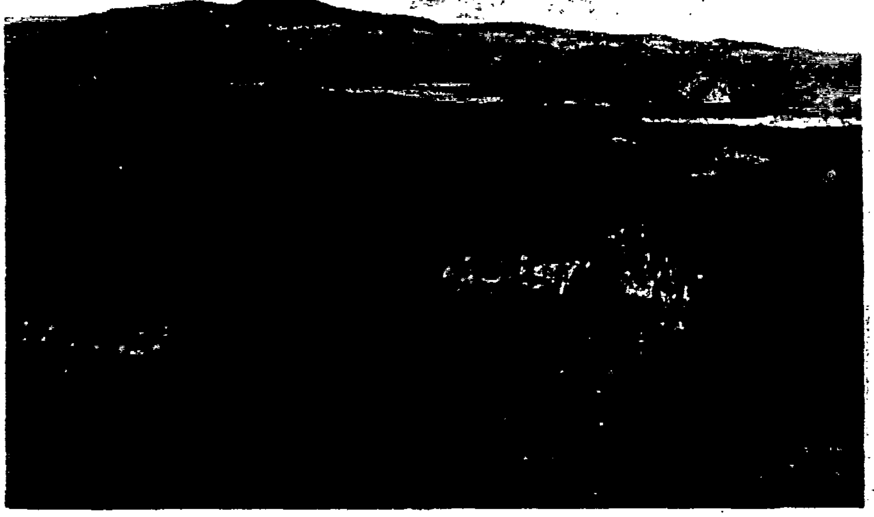
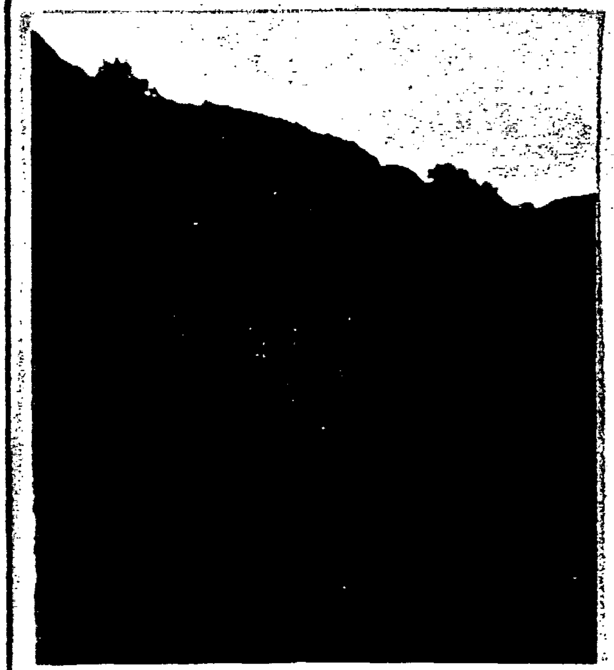
946.7 (REV. 6-61)



PRE-PLIOCENE PLEISTOCENE FAULT MEMBER OF THE JEMEZ FAULT SYSTEM. LOOKING SOUTH AT CANONES MESA.



FAULT CONTRACT BETWEEN PRE-CAMBRIAN ROCKS AND SANTA FE GROUP SEDIMENTS, LOOKING NORTH ALONG THE WEST SIDE OF THE SANGRE DE CRISTO MTNS., NEAR SAN CRUZ DAM.

THE PRE-PLIOCENE/PLIOCENE NACIMIENTO FAULT ALONG THE WEST SIDE OF SIERRA NACIMIENTO LOOKING NORTH.

THE PRE-MIOCENE, PICURIS-PECOS FAULT, ALONG THE EASTERN MARGIN OF THE SANGRE DE CRISTO MTNS, NORTH OF GLORIETA, NEW MEXICO, LOOKING NORTH

DAMES & MOORE

REVISIONS BY ______ DATE ______

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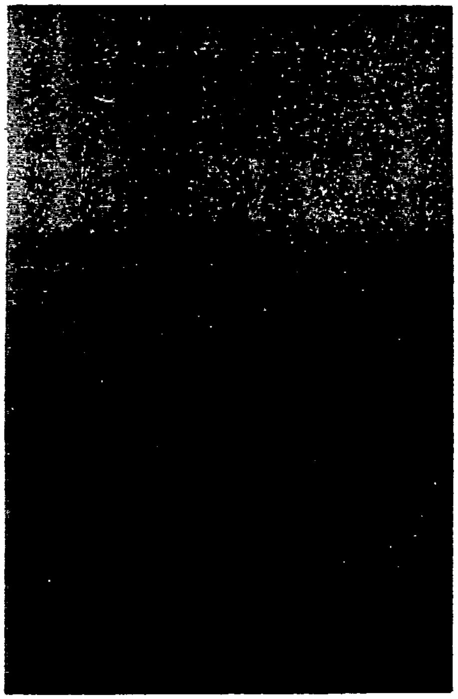
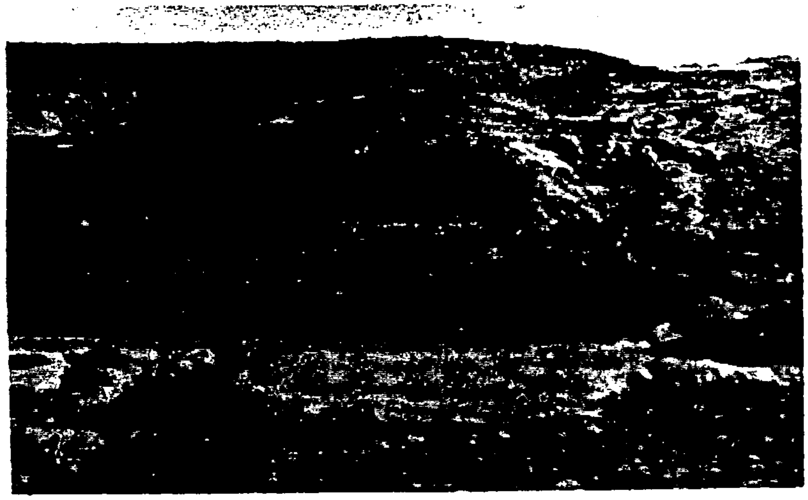
BY ______ DATE ______ CHECKED BY ______



LINEATION OF ALBUQUERQUE VOLCANOES LOOKING NORTH TOWARD SIERRA NACIMIENTO.



RECENT MALPAIS BASALT FLOW, LOCATED EAST OF GRANTS, NEW MEXICO, LOOKING NORTH.

RECENT MALPAIS BASALT FLOW DATED YOUNGER THAN 1000 YEARS, LOCATED EAST OF GRANTS, NEW MEXICO. NOTE LACK OF SOIL DEVELOPMENT.

CLOSE-UP OF QUATERNARY FUMAROLE ALONG WEST SIDE OF SIERRA NACIMIENTO.

QUATERNARY VOLCANIC ALONG THE NACIMIENTO FAULT TRACE ON THE WEST SIDE OF SIERRA NACIMIENTO, LOOKING NORTH.

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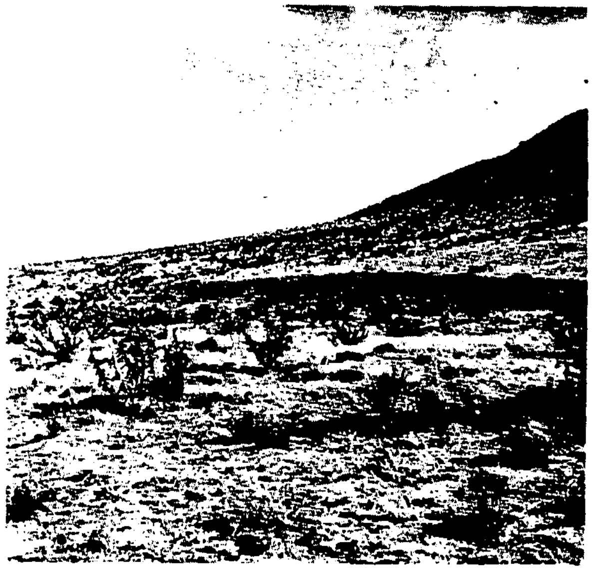
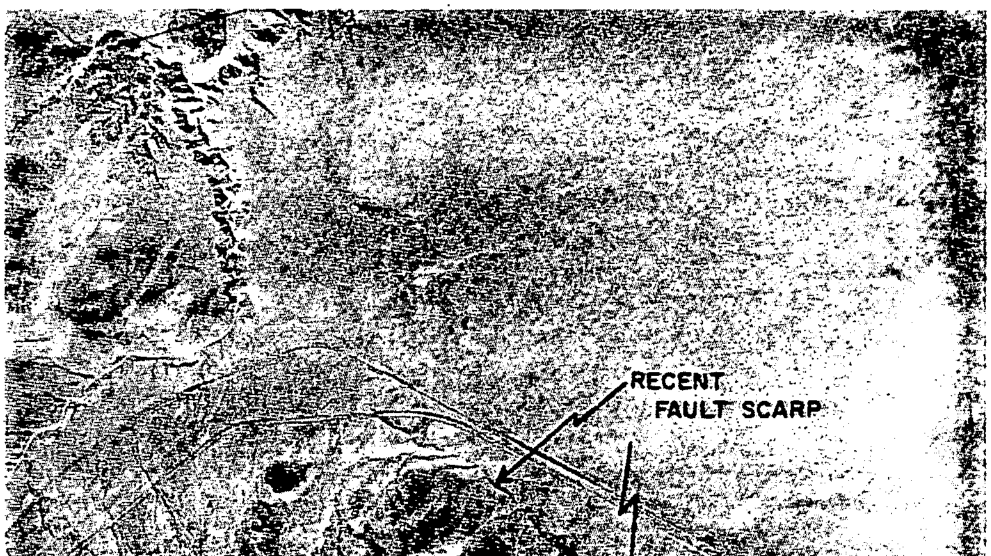
QUATERNARY FAULT SCARP OFFSETTING LOWER VALLE DE PARIDA SURFACE DEVELOPED ON SANTA FE GROUP BEDS, LOOKING AT SOUTH WALL OF SOCORRO CANYON, SW OF SOCORRO.



QUATERNARY FAULT SCARP OFFSETTING ALLUVIAL FAN, LOOKING SOUTH ALONG NORTHEAST SIDE OF MAGDALENA MTNS. AERIAL VIEW SHOWN IN PHOTO BELOW.



RECENT FAULT SCARP IN QUATERNARY ALLUVIAL FAN, LOOKING NORTH ALONG THE NORTHEAST SIDE OF MAGDALENA MTNS.

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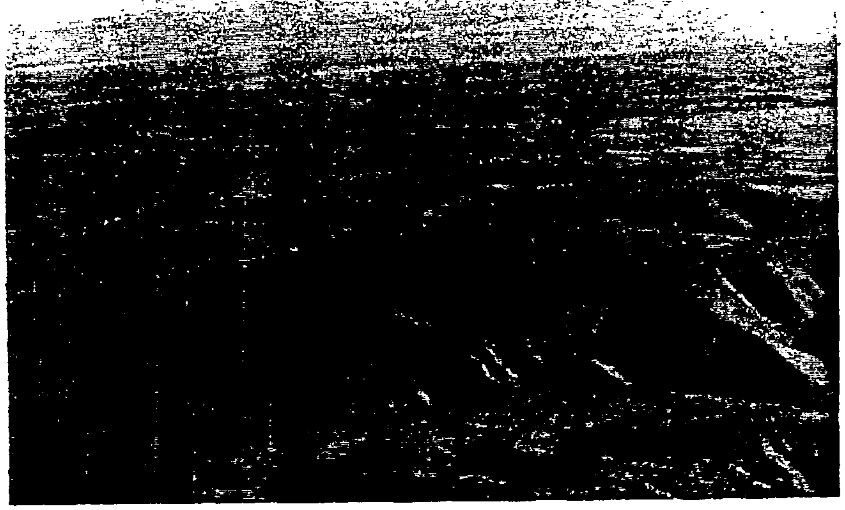
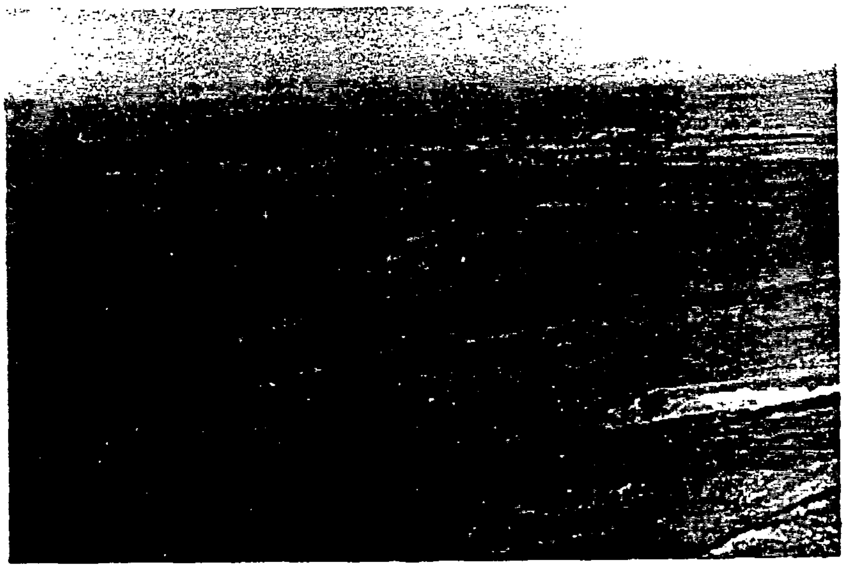


RECENT FAULT SCARP IN QUATERNARY ALLUVIAL FAN, LOOKING SOUTH ALONG EAST SIDE OF SIERRA LA DRONES.

RECENT FAULT SCARP IN QUATERNARY ALLUVIAL FAN, LOOKING SOUTHEAST ALONG EAST SIDE OF SOCCORO MTNS.



UNDISTURBED HOLOCENE "PINNACLES" IN GUAJE CANYON, SUGGESTING LACK OF SIGNIFICANT GROUND ACCELERATION DUE TO RECENT SEISINIC ACTIVITY.

DAMES & MOORE

REVISIONS BY ______ DATE ______

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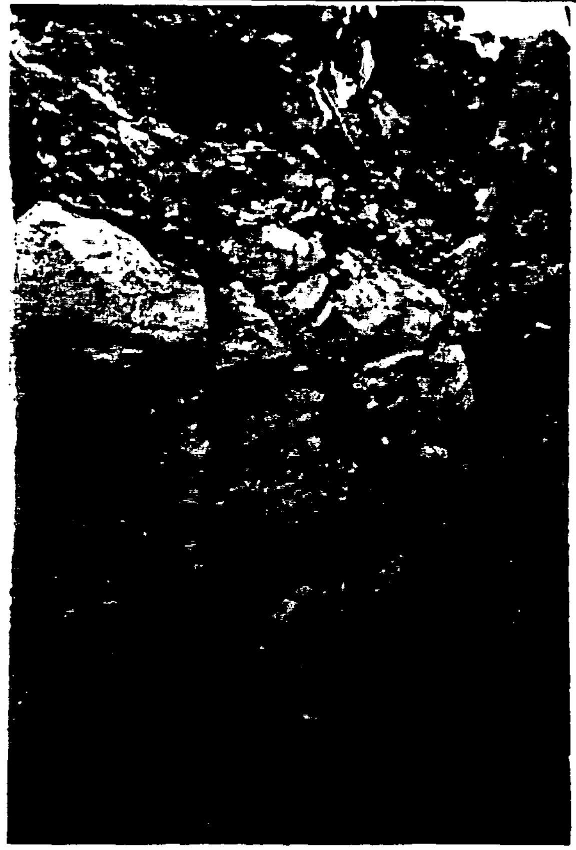
DIFFERENTIAL COMPACTION OF WELDED TUFF OVER NON WELDED ASH FALL ON MESITA DEL BUEY.



B AND C SOIL HORIZONS OVERLYING JOINTED BEDROCK TUFF OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF, ON MESITA DEL BUEY.

DIFFERENTIAL COMPACTION OF WELDED TUFF OVER INTERBEDDED, THIN, NON WELDED ASH FALL ON MESITA DEL BUEY.

"WEST" FAULT MEMBER OF PAJARITO FAULT SYSTEM, OFFSETTING THE TSHIREGE MEMBER OF THE BANDELIER TUFF, ON NORTH WALL OF PUEBLO CANYON

DAMES & MOORE

PLATE G-23

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SEISMOLOGY

VIBRATORY GROUND MOTION

GENERAL

This section discusses vibratory ground motions and includes a presentation of the design earthquakes (Safe Shutdown Earthquake and Operating Basis Earthquake) in light of the following:

- o A review of the geologic background;
- o A study of the seismic history of the region;
- o The relationship of seismicity to geology; and
- o The response of the site to the design earthquakes.

The design earthquakes (SSE and OBE) are presented as recommended smoothed response spectra. Appropriate time histories of ground motion will be presented separately.

The investigation is in compliance with AEC criteria suggested by 10 CFR, Part 100, Appendix A, and Guidelines, American Nuclear Society Document 2.1.

GEOLOGY

General Geology

The proposed site is located within the Rio Grande rift zone on a mesa of the Pajarito Plateau, on the east flank of the Jemez Mountains (Willden & Criley, LA-3728, 1968). The mesa is composed of volcanic tuffs. The rift is related to the southward extension of the Rocky Mountain Front and is a border of the Basin Range Province and Colorado Plateau.

The most recent lava flows of the nearby Valles volcanic locus have been dated as occurring about 42,000 years ago. A younger (800 to 1000 years ago) active volcanic locus, presently dormant, may be presumed near Grants, 80 miles southwest of the site.

Geological conditions of both a regional and local nature which could have a bearing on the vibratory ground motion experienced at the site have been described in more detail in the geologic investigation section of this report.

Faulting

A number of faults are known near the site, which, when taken as a composite group, are known as the Rio Grande rift zone.

The closest of these major faults is the Pajarito fault system. The main trace of the Pajarito fault system passes within 2.7 miles of the site (see Plates G-7, G-10 and G-11). Smaller minor faults of the Pajarito system, the "east" and "west" members, are located closer. Others are the Jemez, San Felipe and La Bajada fault systems.

SEISMIC HISTORY

General

The earthquake history of New Mexico has been neglected until recently, due in part to the lack of instrumentation to record even moderate events, a sparse population except in the Rio Grande Valley, and little requirements for its

Sanford, et al - 1965, 1969, 1972a - gives epicenters of all earthquakes of M = 2.7 and greater, 1962-71.

Willden & Criley, 1868 - a brief review

Sturgul & Irwin, 1971 - tabulation only

Purtymun, 1972 - list only

Sanford, et al, 1972b - south end of Rio Grande Rift

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The only field investigations of note have been of the Socorro swarms (Bagg 1904, Reid 1911) and in the annual "United States Earthquakes (1928 to date)."

The dynamic characteristics of nearby sites have been investigated and reported upon by LASL personnel (Keller and others, 1967, 1968) in connection with the Meson Physics Linear Accelerator Studies. The various Gasbuggy recordings also provide some information on site responses to vibratory excitation. Site dynamics are discussed in later sections of this report.

New Mexico Earthquakes

Over 230 earthquakes originating in New Mexico have been tabulated. This tabulation includes intensities as defined by the Modified Mercalli Intensity (Damage) Scale of 1931.* The tabulation of New Mexico Earthquakes is presented in Table S-II. A small number of additional shocks having origins outside the boundaries of New Mexico have been felt within the state. Of the New Mexico events, Intensity VIII was

* Table S-I

reported 4 times, Intensity VII 6 times, Intensity VI 17 times, and Intensity V 40 times. Due to the incompleteness of the record of smaller events, it is meaningless to attach statistical significance to reports of events with intensities of less than V. The tabulation for Intensity V itself is probably far from complete even for the time span considered, as many communities fail to report such events. An added complexity is in plotting the common location for most of the Intensity VIII events near Socorro which tends to mask the smaller events.

The locations of these events are shown on Plate S-1, New Mexico Earthquakes, 1868-1972. Since many of the smaller events have occurred as swarms near Socorro, no effort has been made for a complete inventory plot in this area. A problem with using an epicenter plot such as this is its lack of uniformity in the coverage of the smaller events. Plate S-2, "Locations 1962-1971," after Toppazada and Sanford, has uniform coverage at the lowest level of perceptibility shown, Richter Magnitude = 2.7. In addition, many smaller events are not shown, although recorded near their stations. The trade-off for the uniform level of perceptibility is that a much reduced time span of only ten years is all that can be shown. The closest moderate event to the site was the August 17, 1952, Intensity V Los Alamos earthquake. Its epicenter may have been about ten miles east-southeast of the proposed site. A tiny shock, Intensity II, was felt in Los Alamos during the evening of February 17, 1971. It was instrumentally recorded but not precisely located. It was probably directely under Los Alamos since it was unreported nearby. The largest nearby earthquake was the May 28, 1918 Intensity VII to VIII, Cerrillos earthquake, 35 miles southwest of the site.* The intensity at Los Alamos for the Cerrillos event was inferred to be VI (Northrop 1949). We believe that Intensity VI may have occurred at the site, making this the highest intensity the site has experienced in historic time. Several Intensity VII earthquakes (1893) have occurred approximately 85 miles south-southwest of the site, and at Dulce (1966) 85 miles northwest of the site. Three Intensity VIII shocks were located approximately 140 miles south-southwest near Socorro in 1906. A fourth Intensity VIII shock was located near Cerrillos in 1918. Other Intensity VIII shocks have been located in the region; however, none are within 200 miles of the site.

It should be noted that the accuracy of location of epicenters before 1962 is limited to "felt" reports which imply a very low accuracy of location. Prior to 1962, instrumental epicenter locations (from Tucson and St. Louis) were probably no more accurate than 1 degree, and then only for the larger shocks. The lack of felt reports is due to the sparse and geographically biased population.

While New Mexico has not generally been considered to be among the most active seismic areas of the United States, Richter (1959), in his seismic regionalization indicated

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*The location of the Cerrillos 1918 earthquake is taken from the "Earthquake History of the United States." However, verbal communication from A. Sanford indicates that the epicenter is probably 35 miles southeast of the site, near Cerrillos.

consideration. This is despite the fact that it is the oldest continuously inhabited area of the United States; it was settled concurrently with the Spanish colonies of Mexico, Panama, and the West Coast of South America.

In contrast, Chile has a well-documented earthquake history dating back 450 years. California's Portola Expedition in 1769 reported what appears to have been many aftershocks of a large earthquake, surface faulting for which has recently been discovered (Bonilla 1972). The Mission records for California have been carefully read for their details of scientific or cultural interest.

New Mexico's earliest known earthquake was in 1849. A swarm of 28 shocks were felt at Socorro in 15 successive months in 1849 and 1850. Only eleven others are known for the entire 19th century.

Improved instrumentation since the early 1960's, and the growing awareness of geotechnical professionals to all forms of geologic hazards has brought to light the seismic activity of the region, which coincidentally follows the concentration of the state's population in the Rio Grande Valley.

In addition to the listing in "The Earthquake History of the United States" (National Ocean Survey, formerly U.S. Coast and Geodetic Survey, Eppley 1965), the following studies are available covering the seismicity of New Mexico:

Northrup, 1949 - a brief survey

damaging motions (including Intensity IX) as occasionally possible for the major portion of the Rio Grande Rift, including the Los Alamos area. Algermissen (1969) included the entire central portion of the Rio Grande Rift as Zone 2 (Intensity VII), but clipped off the area north of Los Alamos and south of Socorro. King (1965), from Woollard's data (1950), indicates an activity of from three to five epicenters per 10,000 square kilometers, which is less than his median classification, worse than the average for the United States, and about equal to northern and eastern California.

Important Earthquakes

Several New Mexico earthquakes are of significance to the project by virtue of being the closest felt event, the closest large event, or perhaps an event on a nearby geologic structure related to the site.

The closest important event is the Intensity V, August 17, 1952, Los Alamos earthquake. It was felt by all and awakened and frightened all in homes. There were some statements of damage to walls of homes. Movable objects shifted. Doors and dishes rattled.

The May 28, 1918 Cerrillos earthquake is most important to the seismic evaluation of the site, since it is the closest large earthquake, and it is associated with Rio Grande rift structure. In addition, it is the only large New Mexico earthquake (Intensity VII to VIII) away from the Socorro swarm area. Its felt area, 7500 square miles, is smaller than the felt area of the 1906 Socorro earthquakes, so the 1918 Cerrillos earthquake is not the largest historical New Mexico shock. Intensity of ground motion at Los Alamos, 35 miles away, was estimated to be VI (Northrup, 1949), the highest the site is believed to have experienced in the last 120 years.

The 1906 Socorro earthquake swarms include the largest events known in the state. Shocks occurred almost daily from July 2, 1906 until well into 1907 (Eppley, 1965, Bagg, 1906, and Reid, 1911). While three of the events were rated as VIII or VII to VIII, the July 16th was the largest, having a felt area of 100,000 square miles and a maximum intensity of VIII. On July 12 and November 15, the intensity was VII to VIII with felt areas of 40,000 and 100,000 square miles, respectively. The July 16, 1906 Intensity VIII earthquake is then, New Mexico's largest known earthquake in the past 120 years.

REGIONAL RELATIONSHIP OF TECTONIC FEATURES TO EARTHQUAKES

The location of most New Mexico epicenters within the Rio Grande Rift is more than coincidental. A direct relationship with the Rift fault system is indicated. Sanford, et al, and Sanford, 1972, have detailed this relationship for the southern section of the Rift and for the Los Alamos region, but have been unable to show a direct correlation between specific faults and seismic events. Epicenters are likely to occur in the middle of the rift zone as well as along the faults which are the two margins of the rift zone.

Microearthquake studies have been conducted principally in the Socorro region. One purpose of these studies was to predict long-term seismicity for the Socorro region. Sanford & Singh (1968) found that estimates of seismicity based on microearthquake activity were substantially lower than indicated by historical reports of earthquakes. Worldwide studies in many other areas also have had difficulty in correlating microseismicity with larger earthquakes and demonstrated tectonic activity. The relationships are not well understood. Difficulties in correlating this data may be explained by anomalously low activity since 1960 or anomalously high past activity. According to Sanford (Sanford et al, 1972) neither explanation is satisfactory. Additional microearthquake studies (Sanford et al, 1972) indicate that microseismicity is most active in the Socorro area and is not uniform throughout the rift zone.

Therefore, sufficient data has not yet been collected. It will be necessary to collect such data in the coming years to serve as a basis for performing a meaningful analysis.

The above documentation is for the area between Socorro and Albuquerque; however, there is no indication that the tectonic structure to the north near Los Alamos is any different. The release of seismic energy at the present time is certainly lower in the Los Alamos area than at Socorro to the south. As discussed in the Geology Section, faulting is more evident to the south, as indicated by recent fault scarps.

SITE RESPONSE TO PAST SEISMIC ACTIVITY

The reaction of the site to past seismic activity was discussed in an earlier section, Seismic History. It is unlikely that earthquake ground motion greater than Intensity VI has been experienced at the proposed site since the date of the first reported New Mexico earthquake in 1849 (Hammond 1852). There is no physical evidence of seismic motion at the site.

RECURRENCE CURVES

The earthquake recurrence rates of New Mexico, the Rio Grande Rift Zone, and the Los Alamos area, are plotted on Plate S-3. These curves have been plotted on a common base to indicate the relative seismic activity of the area of interest. They indicate a measure of the average rate of occurrence of seismic events, based on the historical rate. While an average interval between events may be calculated, no mathematical probability of occurrence should be directly derived from it. The solid portion of these curves are based on the historical record. However, it should be recognized that this record may be too incomplete for statistical significance. Our extrapolation, shown by the dashed line, is arbitrarily extended beyond the data developed from Table S-II.

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Extrapolation to events greater than Intensity VIII is outside the range of New Mexico experience. This indicates that the events are unlikely, or if it is possible that such events do occur, they are so infrequent that none have occurred during the recorded history of the region. With additional data, we believe that the slope or position of the New Mexico curves would change to be more in conformity with Rocky Mountain data, raising the low intensity segment of the curves. The effect would be to rotate the New Mexico curves to make them more parallel with the Imperial Valley curve. The recurrence curve for 1 degree arc of distance (111 km) is centered at the site, and is included for comparitive purposes (Sanford, 1972c).

Similar studies on seismic risk at Los Alamos have been conducted by Dr. A. R. Sanford (1972) in which comparisons are made with the Los Angeles (California) basin. Sanford indicates activity at Los Alamos as one-eighteenth of that of the Los Angeles basin. When two tectonically similar areas are compared, the Rio Grande Rift and the Imperial Valley (Plate S-3) even greater differences in seismicity are noted. The curve for the Rio Grande Rift zone includes only the area within the bordering fault systems. The Imperial Valley data, after Allen, has also been adjusted to assess the seismicity of the area within the bordering active fault zones for comparison to the Rio Grande Rift zone.

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SIGNIFICANT EARTHQUAKES

There are two significant earthquakes with respect to site seismicity:

1. The largest nearby event on site-related structure - the 1918, Intensity VII to VIII, Cerrillos earthquake, and
2. The largest event on the Rio Grande Rift - the 1906 Socorro swarm, which included several Intensity VIII events, the two largest being felt over an area of 100,000 square miles.

ENGINEERING SEISMOLOGY EVALUATION

GENERAL

The cumulative geological, physiographic, tectonic and historic seismological earthquake evidence indicates a potential for moderate future seismic activity. By contrast, however, there are many tall, undisturbed pedestal rocks of the Puye conglomerate along Rendija Canyon. These would certainly indicate a low recurrence rate for damaging events. Conservative practice, however, requires consideration of the possibility of future damaging seismic motions, even though there would be long intervals of time between events.

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Recorded ground motions and damage have been examined for a number of Intensity VIII earthquakes. Measured accelerations for this intensity have ranged from 0.05g to 0.35g. The most analogous and conservative event for which we have a documented acceleration occurred in the Imperial Valley of California in 1940. A strong-motion accelerogram was recorded at El Centro with a single-component acceleration of 0.33g, associated with well documented Intensity VIII damage.

We have had occasion to inspect and verify the 1940 damage and have compared it with other events at both higher and lower levels to confirm the 0.33g-Intensity VIII correlation. Higher intensities were observed in other parts of the Imperial Valley earthquake, along with ground rupture. However, we are equating the acceleration and intensity at El Centro near the recording station, not the maximum for the event.

Consideration was also given to the possibility of seismic events generated by activity of the Valles caldera located eight miles west of the site. It is felt that small premonitory events would provide a warning of volcanic activity well in advance of any subsequent strong-motion seismic activity. Also, distance attenuation would reduce ground motions at Los Alamos to within OBE levels.

Ground motion at the site from distant, large, out-of-state earthquakes is not considered to be a problem. West

Texas (Valentine, 350 miles south-southeast) is the nearest seismogenic zone capable of generating events larger than those considered, and it is adequately distant from the present project to attenuate ground motions to within OBE levels. The largest known earthquake for this region was in Sonora, Mexico in 1887 (375 miles south-southwest). However, we believe that ground motions from a similar future event in Sonora would be attenuated with distance to within OBE levels.

DESIGN EARTHQUAKE VALUES

Operating Basis Earthquake

Operating basis earthquake criteria are intended to indicate those levels of ground motion to which the plant structures might realistically be subjected during their economic life.

On the basis of the seismic history of the area, it appears that the site will be subjected to only moderate levels of seismic ground motion during the life of the plutonium processing facility. It is probable that the maximum level of ground motion experienced in the past century at the site has been no more than Intensity VI. However, the occurrence of an earthquake similar to the 1918 Cerrillos event at Los Alamos, with a site Intensity of VII to VIII, is not improbable. For this condition, the maximum horizontal ground acceleration at the site would probably be on the order of 0.17g. This is the level of ground motion which we recommend for the Operating Basis Earthquake.

Safe Shutdown Earthquake

Based on an evaluation of the degree of ground motion that is remotely possible, considering both seismic and tectonic history and geologic structure, it is possible that horizontal ground motion at the foundation level could reach 0.33g. This level of ground motion would not be exceeded by Socorro-type events occurring at Los Alamos.

Vertical Accelerations

We believe that the design analyses should consider vertical ground motion accelerations of two-thirds of the horizontal, that is, on the order of 0.22g for the SSE and 0.11g for the OBE.

Intensity-Acceleration Relationship

The SSE has been developed with respect to intensity. For purposes of design, the intensity must be equated to acceleration along with a spectral response curve and appropriate time-history accelerogram. Many efforts have been made to correlate intensity with acceleration. General relationships have been given by Gutenberg and by others. However, Herschberger as well as Housner consider that there is too much overlap of empirical data to permit a significant relation between intensity and acceleration.

We have selected an intensity-acceleration relationship which we believe is consistent with field data and conservative with respect to U.S. experience. Accelerograms in areas of Intensity VIII ground motion have been written of the following earthquakes, with maximum accelerations as noted:

Long Beach	1933	0.23g
El Centro	1934	0.26g
Helena	1935	0.12g
El Centro	1940	0.33g
Santa Barbara	1941	0.17g
Olympia	1949	0.32g
Seattle	1965	0.08g

Intensity VIII was reported at the instrument location in each of the above earthquakes.

SUMMARY

In summary, of all the events which can be postulated for the SSE, the maximum level of horizontal ground motion would result from a combination of:

A. The largest Socorro-type earthquake;

B. The epicenter at or near the site;

C. The maximum ground acceleartion being 0.33g, and;

D. A wide area of Intensity VIII shaking.

Subsurface conditions at the Los Alamos site modulate earthquake motions which propagate up from crystalline bedrock to the surface. These site-modified motions, when prepared in response spectra form as presented in the following sections, have been found to exhibit characteristics which will influence the design of all structures and equipment constructed at this site.

From the surface motion response spectra (Plates S-4 to S-7) we find that in the short period range below 0.5 seconds which is typical of most of the proposed buildings, earthquake response is attenuated. This results in lower design forces in these structures than generally expected. On the other hand, in the longer period range from 0.5 to 2.0 seconds, the site conditions tend to amplify the earthquake motions and produce peak structural responses which are larger than the norm. Consequently, any equipment or structural components in this period range will require greater strength to resist an earthquake at this site.

RESPONSE SPECTRA

The unusual characteristics of the Bandelier tuff exposed at the Los Alamos site warrant the development of a site-related response spectra rather than the wide-band spectra normally used for design criteria. The dynamic characteristics of the tuff are discussed in the following section. In general, the tuff attenuates motions in the frequency range above 3Hz.

There are no written acceleration time histories for this site or for sites with similar dynamic characteristics which might be used to produce site-related spectra. Thus, site-dependent surface motions at the base of building foundations were generated from a dynamic analysis of the crystalline bedrock-to-surface geologic column. The analytical methods used follow those developed by Seed and Lysmer (1971). The measured dynamic properties of the site are used in a mathematical model of the elastic soil or geologic column which extends from crystalline bedrock to the ground surface. In the wave propagation analysis, bedrock motions, either recorded or synthetically generated, are fed up through the soil column as upward-propagating shear waves to produce surface motions.

In following the Seed-Lysmer method, a mathematical model was formulated for the Los Alamos site from the dynamic properties of the various sedimentary rock and volcanic tuff layers. These properties were established by performing dynamic triaxial tests and resonant column tests on undisturbed samples and cores taken from the upper 180 feet of site materials. From these tests, shear moduli and damping values were determined as a function of dynamic strain levels in the samples. The values determined from the low strain-level site geophysical studies provided confirmation of the low strain level portions of the laboratory tests. The geophysical tests also provided data for evaluating the dynamic properties of deeper rock layers. The complete site profile from building foundation level down to crystalline bedrock, some 7000 feet, was analytically modeled for the wave propagation analysis. The geologic column and dynamic properties used in the analysis are given on Table S-III. Dynamic properties shown are those computed in the wave propagation analysis at strain levels compatible with the level of actual earthquake motion estimated for the site and calculated layer. These dynamic properties at earthquake strain levels should be used in any future "soil-structure" modeling of the site.

No dynamic laboratory tests were performed on samples from the Puye fanglomerate and Santa Fe Group materials. Therefore, shear wave velocities and damping characteristics were modeled based on test results for similar materials.

Five earthquake motions were used as crystalline bedrock input to the wave propagation analysis. These time-history motions were selected to bound the probable range of acceleration and frequency content which could conceivably be generated in the crystalline bedrock at the Los Alamos site by an Intensity VIII earthquake in the immediate area. Two of these motions were selected from sites with similar bedrock properties at which earthquakes of comparable intensity had been recorded by strong motion accelerographs. The other three are synthetic motions designed to produce intensities of motion similar to that estimated.

The Helena, Montana earthquake of 1935 was recorded with strong-motion instruments at a rock site having dynamic characteristics which very closely approximate the crystalline bedrock conditions at the Los Alamos site. The earthquake closely approximates design requirements for the site. It was a shallow focus event of Intensity VIII with the origin two to five miles from the recording site. It occurred in a similar tectonic province. The peak ground acceleration of 0.12g is less than that suggested for Los Alamos; thus, some scaling of the surface acceleration is required. The Helena site is on Paleozoic limestone, representative of the basement rock below the Bandelier tuff at Los Alamos. There are about five seconds of strong motion in the original Helena record. Upon amplification to 0.33g and modulation by the Los Alamos geologic profile, the duration of strong motion is significantly longer.

The San Francisco earthquake of March 22, 1957 provided an accelerogram on surface rock from an Intensity VIII, shallow focus earthquake with its origin three to five miles from the recording site. The station was located in Golden Gate Park. The record is one of the very few actual time histories written on "rock." In addition, there is some similitude to the Los Alamos design events. Unfortunately, the surface exposure at the Golden Gate Park accelerograph site is a weathered outcrop of the Franciscan formation. Precise thicknesses and characteristics of the Franciscan are not known. The small amount of data available indicates that the shear wave velocities at the Golden Gate Park location are lower than the velocities of the crystalline bedrock at Los Alamos.

In order to get representative crystalline bedrock motions from these two historical earthquake records, the top surface layers were "peeled away" analytically to the bedrock layers having shear wave characteristics comparable to those at Los Alamos. The shear wave propagation analysis was utilized in reverse to take the recorded surface motions down to bedrock to produce a time history motion independent of the geologic profile above the crystalline bedrock. For the Helena, Montana site, competent limestone with shear wave velocities of 9100 feet per second was located 450 feet below the recording station. At Golden Gate Park, competent Franciscan Formation started 200 feet below the recording station and extended down to crystalline bedrock at 9000 feet below the station. The bedrock motion produced almost constant peak spectral velocities over the entire frequency range, which is typical of the theoretical idealization of bedrock motion along a fault zone.

A synthetic bedrock motion developed for the Los Alamos site was generated by a random function computer program to predicted response criteria. In this case, peak spectral velocities were held constant over the frequency range from 0.1Hz to 2.5Hz, which is proported by Kanai to be the idealized behavior of bedrock motion near a causative fault zone. Strong shaking in this synthetic record had a duration of ten seconds.

The remaining two synthetic earthquake motions are the C-1 and C-2 earthquakes developed by Jennings, Housner and Tsai (1968). These synthetic earthquakes were designed to produce spectral response characteristics similar to those from historic surface motions of Intensity VII-VIII.

In the shear wave propagation analysis of the Los Alamos site, all five of the bedrock motions were scaled up in acceleration amplitude in order to produce peak surface accelerations of 0.33g at the building foundation level. This scaling procedure assured strain levels in the site geologic profile which were consistent with the intensity of estimated ground shaking.

The five site-modulated or site-dependent time-history motions generated by the wave propagation analysis were passed through a response spectra computer program. This computed the peak relative displacement, pseudo-velocity, and absolute acceleration for a series of single-degree-of-freedom oscillators of variable frequency and damping characteristics. The resulting spectral values, when plotted in an interrelated manner on tripartite logarithmic graphs, indicate the maximum single mode response for a structure when subjected to each earthquake motion.

Response spectra from the five computed Los Alamos surface motions are given on Plates S-4 through S-7, for 1/2, 2, 5, and 10 percent of critical structural damping. Superimposed upon these spectral plots is the usual wide-band response spectra designed to envelope all probable site conditions. Due to the unique dynamic characteristics of the Los

Alamos site, peak structural response is well above the wide-band spectra in the frequency range from 0.1Hz to 3Hz while it falls below the wide-band spectra above 3Hz. This characteristic response is consistent with geophysical findings on the dynamic behavior of the site. All reported geophysical work finds peaks in the site response near 4 and 5 Hz and in one case, near 2Hz. These peaks are evident in the site-related response spectra.

Design response spectra for the OBE and SSE were established from the five Los Alamos surface spectra by enveloping the spectra for each damping value. The envelope spectra, shown on Plate S-8, contain peaks and valleys which could prove difficult to use in certain design situations where the exact structural period was unknown. To overcome this potential problem, the envelope spectra were smoothed to eliminate the valleys and peaks, resulting in the two smoothed response spectra shown on Plates S-9 and S-10. The OBE spectra has one-half the peak ground acceleration of the SSE. For vertical earthquake design, the OBE and SSE response spectra should be scaled by two-thirds, thus producing peak vertical OBE ground accelerations of 0.11g and peak vertical SSE ground accelerations of 0.22g.

MISCELLANEOUS

DYNAMIC PROPERTIES OF THE BANDELIER TUFF

Several independent geophysical studies have been performed to determine the dynamic characteristics of the volcanic tuff in the Los Alamos area of New Mexico. The first of these studies was by Keller, Foster and Werner, 1967. They studied the site by monitoring heavy traffic vibrations, forced vibration by impact testing, and by high-explosive testing. An independent study was performed by Dames & Moore in August 1972, using explosives and seismic velocity methods. See Appendix S, Geophysical Survey, for a detailed discussion.

In addition to the report of Keller et al, Keller (1968) reports on ground motion measurements at Los Alamos generated by the detonation of Project GASBUGGY, a nuclear test shot northwest of Los Alamos. Last, a dynamic amplification spectra run by Dames & Moore for the Los Alamos site was used to verify the results of the above studies.

The test by Keller, using high explosives, determined a P-or compressional wave velocity in Unit 3 of the Tshirege member to be 1215 meters per second, or 3980 feet per second. In Subunit 2b of this formation, his results for the compressional wave velocity were 1470 meters per second, or 4820 feet per second. He did not determine (or estimate) the shear wave velocity from these results. Dames & Moore's work in 1972 resulted in a P-wave velocity of 3000 feet per second in

Subunit 3b (between about 20 and 60 feet), a P-wave velocity of 2000 feet per second in Subunit 3a (between about 60 and 130 feet), and a P-wave velocity of 4600 feet per second in Subunit 2b (below 130 feet). This last velocity compares well with that of Keller for the same formation. The discrepancy in the data for the P-wave velocity in the upper formation can be ascribed to the fact that Keller considered the first 130 feet as a single layer, whereas the Dames & Moore study treated it as two layers.

The predominant free field ground motion frequency determined by the various reports for this site is 4.5 to 5 Hz. At 5Hz, we found that the ground vibrations did not form a coherent wave train. This implies that although 5Hz may be a predominant frequency for the site under earthquake excitation, the low amplitude of the waves suggests minimal amplification of seismic energy in this frequency range. Keller (1968) arrived at the same conclusion when he stated, "No amplification of signals was noted at any frequency, although the forcing function may be considered repetitive." This is for his test using a truck driving by the site and braking. Keller also reported on microseismic activity at the site. The predominant frequency for the microseisms recorded was again around 5Hz, as determined from Fourier analyses.

The one variation reported is from the Project GASBUGGY results reported by Keller. For this event, he reported an average frequency of 2.6Hz for maximum motions. He did not indicate if this frequency was site-related or a characteristic of the test shot frequency spectrum.

The results of our theoretical amplification spectra confirm the conclusions of Keller and our own field work. That is, for frequencies above 2Hz, there is little, if any, amplification of bedrock motion and some attenuation of the motion at the ground surface. The only amplification was of long period waves, with periods above about 1.5 seconds noted.

SURFACE FAULTING

Consideration has been given to the potential for surface faulting at the site. An extensive investigation was conducted, including trenching across the entire length of the proposed site. The results, presented in detail in the Geology Section of this report, indicate that while surface faulting extends to within a few miles of the site, there is no faulting on the site. It is our opinion that the potential for the formation of a rupture through the site is remote.

VOLCANISM

Various methods have been attempted for the surveillance and prediction of volcanic activity, principally geophysics and geochemistry. Seismic, geodetic, magnetic, and gravity fields near volcanoes have been monitored, as well as the thermal and chemical composition of the fumaroles and hot springs.

Twentieth century studies, reviewed by UNESCO (1972), indicate that most increases in volcanic activity are preceded by a significant change in seismic activity. Therefore, proper surveillance of seismic activity should permit the prediction of an eruption. Surveillance includes both the instrumentation and interpretation programs. The key to most studies has been in the correlation of geodetic changes with changes in activity. Microearthquakes, earthquake swarms, and volcanic tremors must be indentified with respect to time and space relationships. Applicable geodetic techniques include tilt, triangulation (geodimeter), and level measurements.

A volcanic earthquake is defined as "an earthquake which occurs at and around volcanoes at relatively shallow depths." They usually occur within ten kilometers of the crater and have a focal depth of less than ten kilometers. Intense swarms of small events often have preceded an increase in volcanic activity. Large events are not known to be associated with volcanic earthquakes.

Three basic types of volcanic earthquakes can be distinguished. The first occurs near the crater at a focal depth of one to ten kilometers and shows distinct compressional and shear wave components on its seismogram. The second has a depth of less than one kilometer. If it is more than one kilometer away from the crater it will show no distinct P or S waves. The third is the explosion type, which occurs at the time of the eruption directly beneath the crater.

Volcanic tremor is defined as "more or less long duration or continuous vibration of the ground which is generated by magmatic processes." Tremor is more predominant in basaltic volcanoes than andesitic volcanoes. Tremor may be harmonic (continuous and sinusoidal) or spasmodic. A major problem is in distinguishing volcanic tremor from background noise and microseismic activity. Spectral identification is required.

Instrumentation implies a network of continuously recording seismic stations surrounding the volcano. Both visual monitor seismograms for inspection and magnetic tapes for spectral analysis are required. Frequency ranges required are from 1 to 30Hz with gains of from several thousand to tens of thousands. Installations must be made rugged for protection from the elements as well as minimizing maintenance. Successful operation of acceptable systems in remote and severe climates has been accomplished at other locations.

Geodetic methods imply measurements to detect changes in location or attitude of the earth's crust bordering an area of suspected activity. Tiltmeter observations have been the most reliable in previous studies. Levelling (at infrequent intervals) is also important. Geodimeter triangulation has not yet been extensively used but is a vast improvement over conventional geodesy.

We suggest that serious consideration be given to the design and implementation of a surveillance system to monitor activities of the Valles caldera.

ATTACHMENTS

Plate S-1	New Mexico Earthquakes, 1868-1972
Plate S-2	Locations of New Mexico Earthquakes 1962-1971
Plate S-3	Recurrence Curves
Plate S-4	1/2 Percent Damped Response Spectra for Five Los Alamos Ground Motions
Plate S-5	2 Percent Damped Response Spectra for Five Los Alamos Ground Motions
Plate S-6	5 Percent Damped Response Spectra for Five Los Alamos Ground Motions
Plate S-7	10 Percent Damped Response Spectra for Five Los Alamos Ground Motions
Plate S-8	Computed Response Spectra Envelope
Plate S-9	Recommended Smoothed Response Spectra - OBE
Plate S-10	Recommended Smoothed Response Spectra - SSE
Table S-I	Modified Mercalli Intensity Scale of 1931
Table S-II	New Mexico Earthquakes
Table S-III	Site Dynamic Properties
Bibliography	

DAMES & MOORE

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November 29, 1972

Los Angeles, California

TABLE S-I

MODIFIED MERCALLI INTENSITY (DAMAGE) SCALE OF 1931
(Abridged)

I. Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel Scale.)

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel Scale.)

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel Scale.)

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Starding motorcars rocked noticeably. (IV to V Rossi-Forel Scale.)

V. Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale.)

VI. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale.)

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars. (VIII Rossi-Forel Scale.)

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII+ to IX- Rossi-Forel Scale.)

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel Scale.)

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel Scale.)

XI. Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown upward into the air.

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TABLE S-II

NEW MEXICO EARTHQUAKES

DATE	LOCATION	LAT. N°	LONG. W°	DEPTH km	MAX. INTENS. MM 1931	MAG.	FELT AREA SQ.MI.	SITE INTENS.	REFERENCES
1849-1850	Socorro - 28 shocks in 15 successive months								Hammond
1868 Apr 28	Socorro	34.0	107.0		V				EQH
1869 Apr 18	Socorro	34.0	107.0		VII				EQH
1879	Socorro	34.0	107.0		V				EQH
1886 Jul 6	Socorro	34.0	107.0		V				Bagg, EQH
1887 May 3	Sonora, Mex	31.0	109.0		VIII-IX				EQH
1893 Apr 8	Belen	35.6	106.7		VII				Northrup 1961
1893 Jul 12	Albuquerque	35.4	106.4		V				EQH
1893 Sep 7	NM	34.7	106.6		VII				EQH
1895 Oct 7	NM	34.5	106.7		V				EQH
1895 Oct 31	Socorro	34.0	107.0		VI				EQH
1897	Socorro	34.0	107.0		VI				EQH
1904 Jan 9 Sep 10	Socorro	34.0	107.0		V(2)				
1904 Jan 30	Socorro								Reid 1911
1904 Feb 21	Socorro								Reid 1911
1904 Mar 12	Socorro								Reid 1911
1906 Jul 2	Socorro				V				Reid 1911
1906 Jul 12	Socorro	34.0	107.0		VIII(1), VII(2)		40,000		Reid 1911
1906 Jul 16	Socorro	34.0	107.0		VI				Reid 1911
1906 Jul 16	Socorro	34.0	107.0		VIII		100,000		Reid 1911
1906 Nov 15	Socorro	34.0	107.0		VIII		100,000	IV	Reid 1911
1910 Sep 23	NE Ariz	36.0	111.1		VIII		45,000		S&I
1912 Aug 18	Ariz	36.5	111.5		VII		55,000		S&I
1913 Jul 18	Socorro	34.0	107.0		?				EQH
1913 Dec 5	Coconino, Ariz	34.1	106.8						EQH
1918 May 28	Cerrillos	35.5	106.6		VIII		7,500	VI	EQH
1919 Jan 31	Socorro	34.0	107.0		V				EQH
1919 Feb 1	Socorro	34.0	107.0		V				EQH
1924 Aug 12	NM	36.0	104.5		V				
1928 Mar 15	Belen	34.4	106.8		IV				USEQ
1928 Apr 2- May 28	Creede, Co	37.8	107.0		IV-V				USEQ
1928 Sep 29	Holly, Co	38.1	102.1						USEQ

NEW MEXICO EARTHQUAKES

DATE	LOCATION	LAT. N°	LONG. W°	DEPTH km	MAX. INTENS. MM 1931	MAG.	FELT AREA SQ.MI.	SITE INTENS.	REFERENCES
1930 Mar 23	Albuquerque	35.0	106.6		IV				USEQ
1930 Oct 3	Duran	34.5	105.4		VI				USEQ
1930 Dec 3	Albuquerque	35.0	106.5		VI				USEQ, S&I
1931 Jan 27	Albuquerque								USEQ
1931 Feb 4	Albuquerque	35.0	106.0		VI				USEQ, S&I
1931 Feb 12	Las Vegas								USEQ
1931 Apr 7	Socorro								USEQ
1931 Aug 16	W Texas	30.9	104.2		VIII		450,000	III	USEQ
1934 Jan 7	Socorro NM	34.0	107.0		V				USEQ, S&I
1934 Feb 28	Bernardo				IV				USEQ
1934 May 6	Silver City	32.7	108.2		V		200		EQH
1934 May 7	Socorro				III				USEQ
1934 May 7	Magdalena				III				USEQ
1935 Jan 17	Socorro				III				USEQ
1935 Jan 19	Socorro				IV				USEQ
1935 Feb 20	Bernardo	34.5	106.8		VI(2)				USEQ, EQH
1935 Dec 12	Belen								USEQ
1935 Dec 14	Los Lunas								USEQ
1935 Dec 17	Belen	34.8	106.8		VI		2,000		USEQ, EQH
1935 Dec 18	Belen	34.8	106.8		VI				USEQ, EQH
1935 Dec 19	Belen	34.8	106.8		V-VI(16 shocks)				USEQ, EQH
1935 Dec 21	Belen	34.8	106.8		VI(3)				USEQ, EQH
1935 Dec 30	Belen & Albuquerque	34.8	106.8		VI				USEQ, EQH
1936 Jan 7	Carlsbad								USEQ
1936 Sep 9	Albuquerque				(2 shocks)				USEQ
1937 Sep 29	Fort Stanton								USEQ
1938 Mar 22	Las Lunas								USEQ
1938 Apr 15	Albuquerque								USEQ
1938 Sep 17	Gila Nat'l Forest	33.2	108.6		VI-VII		8,000		USEQ

NEW MEXICO EARTHQUAKES

DATE	LOCATION	LAT. N°	LONG. W°	DEPTH km	MAX. INTENS. MM 1931	MAG.	FELT AREA SQ.MI.	SITE INTENS.	REFERENCES
1938 Sep 18- Dec 28	Gila Nat'l Forest	6 widely felt aftershocks							USEQ
1939 Jan 18	Cliff								USEQ
1939 Jan 30	Gila & vicinity								USEQ
1939 Jan 28	Chama				III				USEQ, N 1949
1939 Jan 31	Hillsboro								USEQ
1939 Apr 25	Cliff	2 shocks							USEQ
1939 May 5	Cliff	3 shocks							USEQ, S&I
1939 May 10	Cliff								USEQ
1939 May 21	Cliff	2 shocks							USEQ, S&I
1939 May 23	Cliff								USEQ
1939 Jun 3	SE Ariz	33.0	109.0						USEQ
1939 Jun 3	Clifton								USEQ
1939 Jul 17	SW NM	33.0	109.0						USEQ
1939 Jul 22	Mogollon								USEQ
1939 Jul 28	Mogollon								USEQ
1940 May 16	Grants								USEQ
1941 Aug 4	Socorro								USEQ
1942 Dec 27	Magdalena				IV				USEQ, S&I
1947 Nov 6	San Antonito	34.0	107.0		VI				USEQ, EQH
1947 Dec 14	Chappel/Alten								USEQ
1948 Mar 11	Texas Panhandle	36.0	102.5		VI		50,000		USEQ
1949 Feb 2	Carlsbad								USEQ
1949 May 23	E Vaughn	34.6	105.2		VI				USEQ
1950 Jan 16	Apache Co Ariz	35.5	109.5		VI				USEQ, S&I
1951 Jun 20	Texas Panhandle	35.5	103.0		VI				USEQ
1952 May 21	Dog Canyon				IV				USEQ
1952 Aug 3	Cimarron Area	36.5	105.0		V				USEQ, EQH
1952 Aug 17	Los Alamos	35.3	106.2		V				USEQ, EQH
1952 Oct 7	Northern NM	37.0	106.0		V				USEQ, EQH
1954 Nov 2	Albuquerque Region				IV				USEQ

NEW MEXICO EARTHQUAKES

DATE	LOCATION	LAT. N°	LONG. W°	DEPTH km	MAX. INTENS. MM 1931	MAG.	FELT AREA SQ.MI.	SITE INTENS.	REFERENCES
1954 Nov 3	Albuquerque Region	35.1	106.7		V				USEQ, EQH
1955 Aug 2	SW Colorado	38.0	107.0		VI		2,000		USEQ, EQH
1955 Aug 12	Santa Fe	30.2	104.6		V				USEQ, EQH
1955 Nov 27	Fowler, Co				IV				USEQ
1956 Jan 14	SE Colorado				IV				USEQ
1956 Apr 25	Sandia Mtns				V				USEQ
1957 May 3	Creede Co								USEQ
1960 Jul 22	LaJoya	34.0	106.5		V				USEQ
1960 Jul 23	LaJoya	34.0	106.5		VI		3,000		USEQ
1960 Jul 24	Bernardo	34.0	106.5		V				S&I
1960 Oct 11	SW Colorado	38.3	107.6		VI	5.5	10,000		USEQ
1960 Oct 11	Ouray Co								USEQ
1960 Oct 17	Aspen Co				V				USEQ
1960 Oct 25	Socorro				III				USEQ
1960 Dec 19	Socorro				IV				USEQ
1961 Jan 27	Socorro	33.6	106.9		IV				USEQ
1961 Jul 3	Socorro	33.6	106.9	15	VI				USEQ, H
1961 Nov 26	W Cen Co	39.0	106.1		IV				USEQ
1962 Jan 3	W Cen Co	35.2	103.8	10		3.0			Sanford 1965
1962 Jan 13	Montrose/ Ouray Co				IV				USEQ
1962 Feb 5	SW Co	38.2	107.6		V				USEQ
1962 Jun 14		35°35'	106°52'	10	(III)	2.8			Sanford 1965
1962 Jun 25		34°12'	108°11'	5	(III)	2.6			Sanford 1965
1962 Jun 27		34°02'	107°01'	5	(III)	2.7			Sanford 1965
1963 Feb 22		32°26'	106°59'	10	(III)	2.8			Sanford 1965
1963 Feb 22		32°26'	106°59'	10	(III)	2.9			Sanford 1965
1963 Mar 6		33°40'	107°41'	5	(III)	2.5			Sanford 1965
1963 Jun 2		34°18'	106°37'	5	(III)	2.5			Sanford 1965
1963 Jun 6		36°41'	104°22'	10	(IV)	3.7			Sanford 1965
1963 Aug 19		32°27'	107°08'	10	(III)	2.9			Sanford 1965

NEW MEXICO EARTHQUAKES

DATE	LOCATION	LAT. N°	LONG. W°	DEPTH km	MAX. INTENS. MM 1931	MAG.	FELT AREA SQ.MI.	SITE INTENS.	REFERENCES
1963 Dec 19		35°06'	104°15'	10	(IV)	3.6+			Sanford 1965
1964 Mar 3		35°15'	104°00'	10	(III)	2.6			Sanford 1965
1965 Feb 3	NE NM	35.4	103.4		IV	(3.6,4.2)			S&C 1969,USEQ
1965 Feb 3		32.1	103.0		(IV)	(4.1,3.8)			S&C 1969
1965 Apr 10		34.0	107.1		(III)	(2.7)			S&C 1969
1965 Jul 28		33.9	106.8		(III)	(3.0)			S&C 1969
1965 Jul 28		33.9	106.8		(III)	(2.7)			S&C 1969
1965 Dec 21	Socorro	34.1	106.9		IV(2)				USEQ
1965 Dec 22	Socorro	34.1	106.9		IV(2)				S&I
1965 Dec 29		34.6	105.8		(III)	(2.6,3.1)			S&C 1969
1966 Jan 22	Dulce	37.0	107.0	4	VII	5.5	15,000	III	USEQ, H
1966 Jan 22- Jan 28	USC&GS recorded 119 events - partial list follows (19 other events reportd "felt" through Feb 1966)								USEQ
1966 Jan 22	NM-Co border	37.0	107.0	5	III				USEQ, H
1966 Jan 22	Lumberton	36.9	107.0	5					USEQ, H
1966 Jan 22	Creede Co	37.8	106.9		III				USEQ
1966 Jan 22	Dulce,Lumberton NM; Edith,Co	36.9	107.2		(V)	4.2			USEQ
1966 Jan 23	Lumberton	36.9	107.2		(V)	4.3			USEQ
1966 Jan 23	Dulce,Lumberton NM: Edith,Co	36.9	107.1		(V)	4.5			USEQ
1966 Jan 23	Dulce,Lumberton NM: Edith,Co	36.9	107.0	5	V	4.6			USEQ, H
1966 Jan 25	Dulce,Lumberton NM: Edith,Co	36.8	107.1		V	4.0			USEQ
1966 Jan 27	Dulce,Lumberton NM; Edith,Co	36.9	106.9	5	IV				USEQ, H
1966 Jan 27	Dulce,Lumberton NM: Edith,Co	36.9	107.2		IV				USEQ
1966 Jan 29	Edith, Co	36.9	107.1	5	III				USEQ, H
1966 Jan 31	Dulce	37.0	106.9	5	IV				USEQ, H
1966 Feb 2	Dulce				IV				USEQ
1966 Feb 6	Edith, Co				III				USEQ

NEW MEXICO EARTHQUAKES

DATE	LOCATION	LAT. N°	LONG. W°	DEPTH km	MAX. INTENS. MM 1931	MAG.	FELT AREA SQ.MI.	SITE INTENS.	REFERENCES
1966 Feb 26	Edith, Co	(36.9	107.0)		IV				USEQ, H
1966 Feb 27	Edith, Co	36.9	107.0	5	III				USEQ, H
1966 Mar 8		37.0	107.0	5	III	(2.8,3.2)			USEQ, H
1966 Mar 22		36.9	106.8	5	(III)	(2.5,3.1)			S&C, H
1966 Apr 14		37.0	107.0	5	(III)	(2.7,3.3)			S&C, H
1966 Apr 21		35.4	103.0	5	(IV)	(3.4,3.8)			S&C, H
1966 May 8		36.9	106.8	5	(V)	4.5			S&C, H
1966 May 8		37.0	106.0	5	(V)	3.9			S&C, H
1966 May 9		36.9	106.9	5	(V)	4.2			S&C, H
1966 May 9		37.0	106.9	5	(V)	4.4			S&C, H
1966 May 18	Dulce	37.0	107.2	5	(V)	4.6			USEQ
1966 Jun 1		36.9	107.0	5	(IV)	(2.9,3.5)			S&C, H
1966 Jun 2		36.9	107.6	5	(VI)	4.9			H
1966 Jun 4		36.9	107.0	5	(V)	4.0			S&C, H
1966 Jun 21		36.9	107.0		(V)	4.2			S&C
1966 Jul 24		36.9	107.0	5	(IV)	3.4			S&C, H
1966 Aug 14		32.0	102.6		(IV)	3.4			S&C
1966 Sep 17		32.1	109.4		(IV)	(3.2,3.4)			S&C
1966 Sep 17		35.0	103.9		(IV)	(___,3.6)			S&C
1966 Sep 24	Cimarron	36.5	105.0	18	IV(3)	4.1,3.8,3.4			USEQ, H
1966 Sep 25		36.4	105.1	20	(IV)	3.8			S&C, H
1966 Sep 25		36.5	105.1	20	(IV)	3.6			S&C, H
1966 Oct 2	NM-Co Border	37.4	104.1	10	VI	4.5	15,000		USEQ, H
1966 Oct 6		35.8	104.2		(IV)	(3.1,3.8)			S&C
1966 Dec 16		37.0	107.0	33	(V)	4.2			H
1967 Jan 6		36.9	107.0	33	(V)	4.3			S&C, H
1967 Jan 16		34.5	107.1		(IV)	3.6+			S&C
1967 Jul 29		33.6	108.7		(III)	(___,3.0)			S&C
1967 Sep 9		32.2	107.0		(III)	(___,3.2)			S&C
1968 Mar 9		32.5	106.0	33	(III)	(3.0,3.4)			T&S, H
1968 Mar 9		32.6	106.1		(III)	(3.0,3.4)			T&S
1968 May 2		33.1	105.3		(III)	(2.7,3.0)			T&S
1968 May 12		31.8	106.4		(V)	4.5			T&S

NEW MEXICO EARTHQUAKES

DATE	LOCATION	LAT. N°	LONG. W°	DEPTH km	MAX. INTENS. MM 1931	MAG.	FELT AREA SQ.MI.	SITE INTENS.	REFERENCES
1968 May 19		34.5	108.0		(III)	(___,2.7)			T&S
1969 Jan 29		34.3	106.9	8	V	4.1			USEQ, H
1969 May 12		31.8	106.4		(V)	4.3			T&S
1969 Jun 8		34.3	105.2		(III)	(2.6,2.8)			T&S
1969 Jul 4	Espanola	36.1	106.1	10	IV	4.4			USEQ, H
1969 Aug 23		34.8	108.7		(IV)	3.9			T&S
1970 Jan 12		36.1	103.2	33	(IV)	3.5			T&S, H
1970 Nov 28		35.0	106.7	9	(V)	4.5			T&S, H
1970 Nov 30		36.3	106.2		(III)	(2.7, 3.2)			T&S
1971 Jan 4		35.0	106.7	9	(VI)	4.7			T&S, H
1971 Jan 6		34.2	107.0		(III)	(___,3.0)			T&S
1971 Jan 27		34.1	106.6		(III)	(2.8,2.7)			T&S
1971 Feb 18		36.3	105.7		(IV)	3.7			T&S, H
1971 Apr 28		35.8	105.6	5	(V)	4.0			T&S
1971 May 22		35.4	107.6		(III)	(___,2.8)			T&S
1971 Jun 4		36.3	106.6		(III)	(___,2.9)			T&S
1971 Dec 6		36.1	106.3	5	(V)	4.2			H

NOTES FOR TABLE S-II

DATE: Reported date of occurrence.

LOCATION: Reported location of occurrence.

LATITUDE: Degrees Latitude

LONGITUDE: Degrees Longitude

DEPTH: Focal depth of the event.

MAX. INTENSITY: Intensity of ground shaking as described by the Modified Mercalli Scale, 1931. Numbers in parentheses () following intensities indicate number of shocks of that intensity for the given date. Intensities in parentheses were estimated.

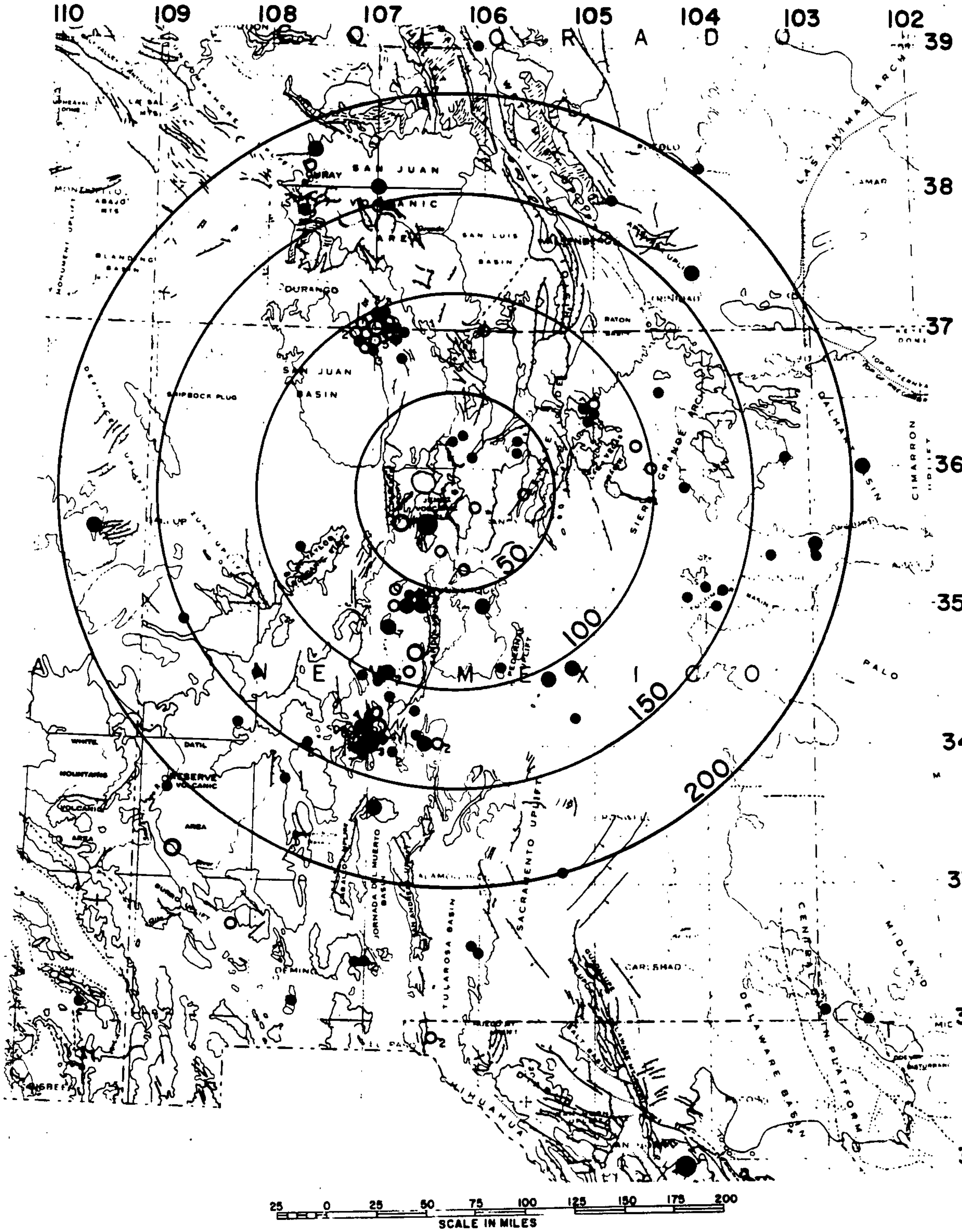
MAGNITUDE: Richter Magnitude for the event. If not in parentheses, it is the magnitude given by the USC&GS or National Earthquake Information Center (NEIC). Values in parentheses are for the Albuquerque and Socorro stations when the magnitude was not determined by NEIC or USC&GS.

(Alb, Soc) - magnitude for both stations
(___, Soc) - for Socorro only, or
($\overline{\text{Alb}}$) - magnitude for Albuqeque only, or for both if they agreed.

FELT AREA: Area reporting the event in square miles.

SITE INTENSITY: Reported intensity at the LASL site.

REFERENCES:
EQH - Earthquake History of the United States
USEQ - United States Earthquakes
S&I - Sturgul & Irwin
S&C - Sanford & Cash
T&S - Toppozada & Sanford
N - Northrup, 1949
H - Hypocenter Data File
A complete list of references is presented in the bibliography.



INTENSITY

Intensity	Symbol
VIII	● (large)
VII	○ (large)
VI	● (medium)
V	○ (small)
I-IV	• (small)

NEW MEXICO EARTHQUAKES

1868-1972

All earthquakes shown for New Mexico and within 200 miles of the site.

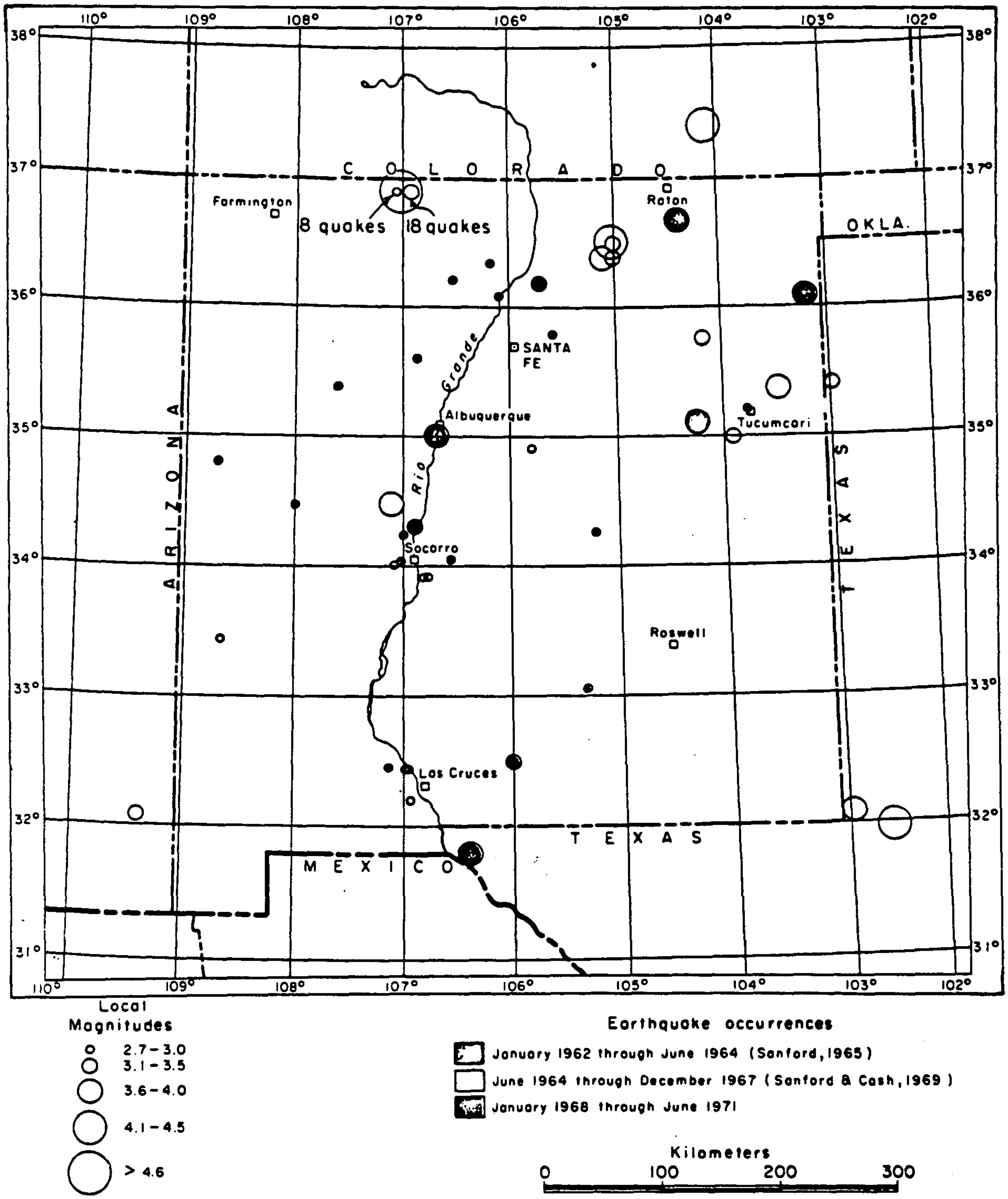
REFERENCE: Tectonic map of the United States USGS/AAPG 1962

DAMES & MOORE

PLATE S-1

BY JTF DATE 9-24-72
CHECKED BY [signature] DATE 11-13
FILE 0651-120
OK to Print [signature] 11-22
REVISIONS
BY ______ DATE ______

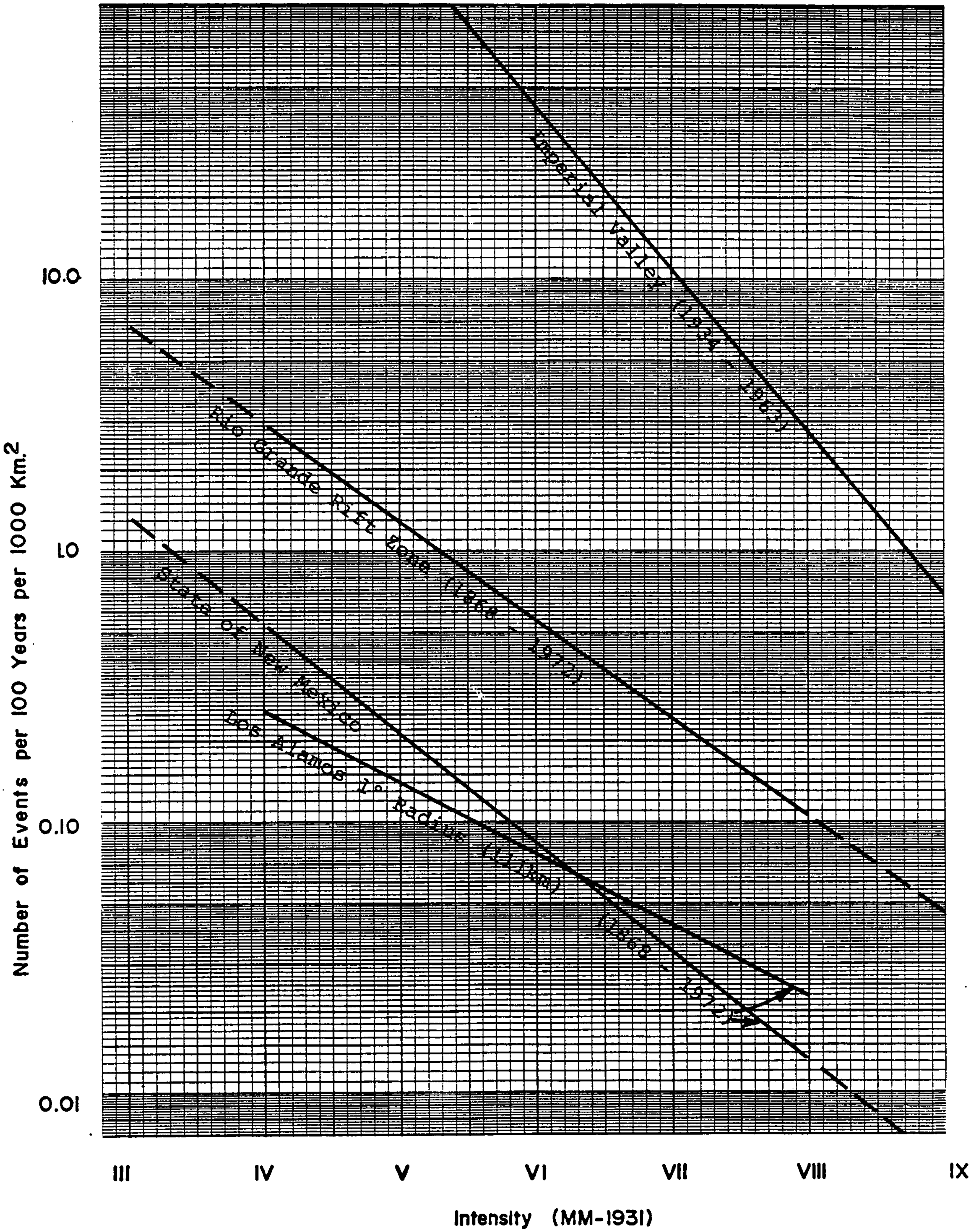
946.7 (REV. 6-61)



Locations of New Mexico Earthquakes having $M_L \geq 2.7$ from January 1, 1962 through June 30, 1971.

Toppozada & Sanford, 1972

BY ___ CHECKED BY ___ DATE ___ FILE ___ REVISIONS BY ___ DATE ___



RECURRENCE CURVES

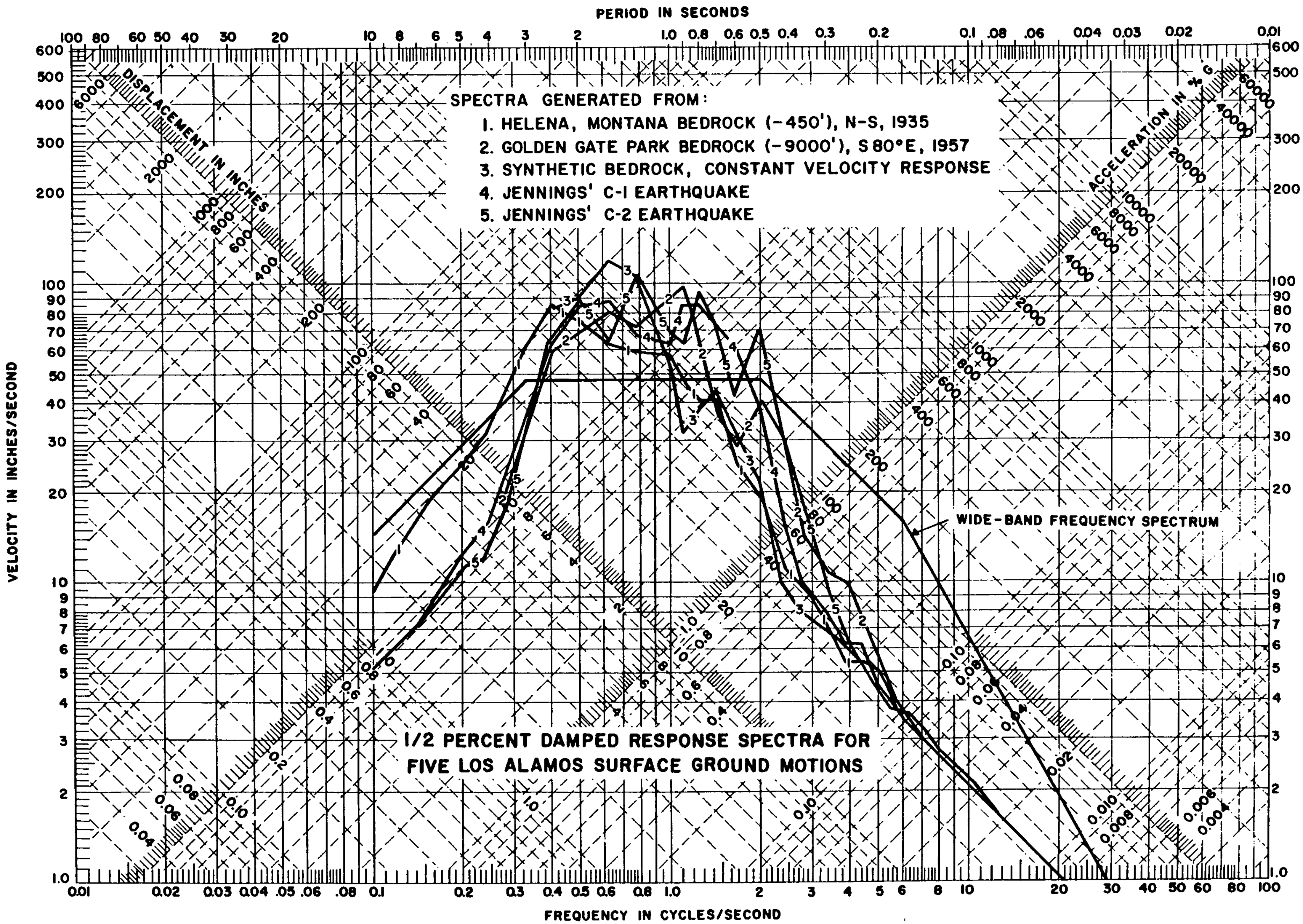
DAMES & MOORE

PLATE S-3

FILE 0651-120
LOS ALAMOS
BY NKS DATE 11-22-72
CHECKED BY RDS DATE 11/21/72

REVISIONS
BY______ DATE______
BY______ DATE______
PLATE______ OF______

Response spectra are for a maximum horizontal ground acceleration of 33 percent of gravity.



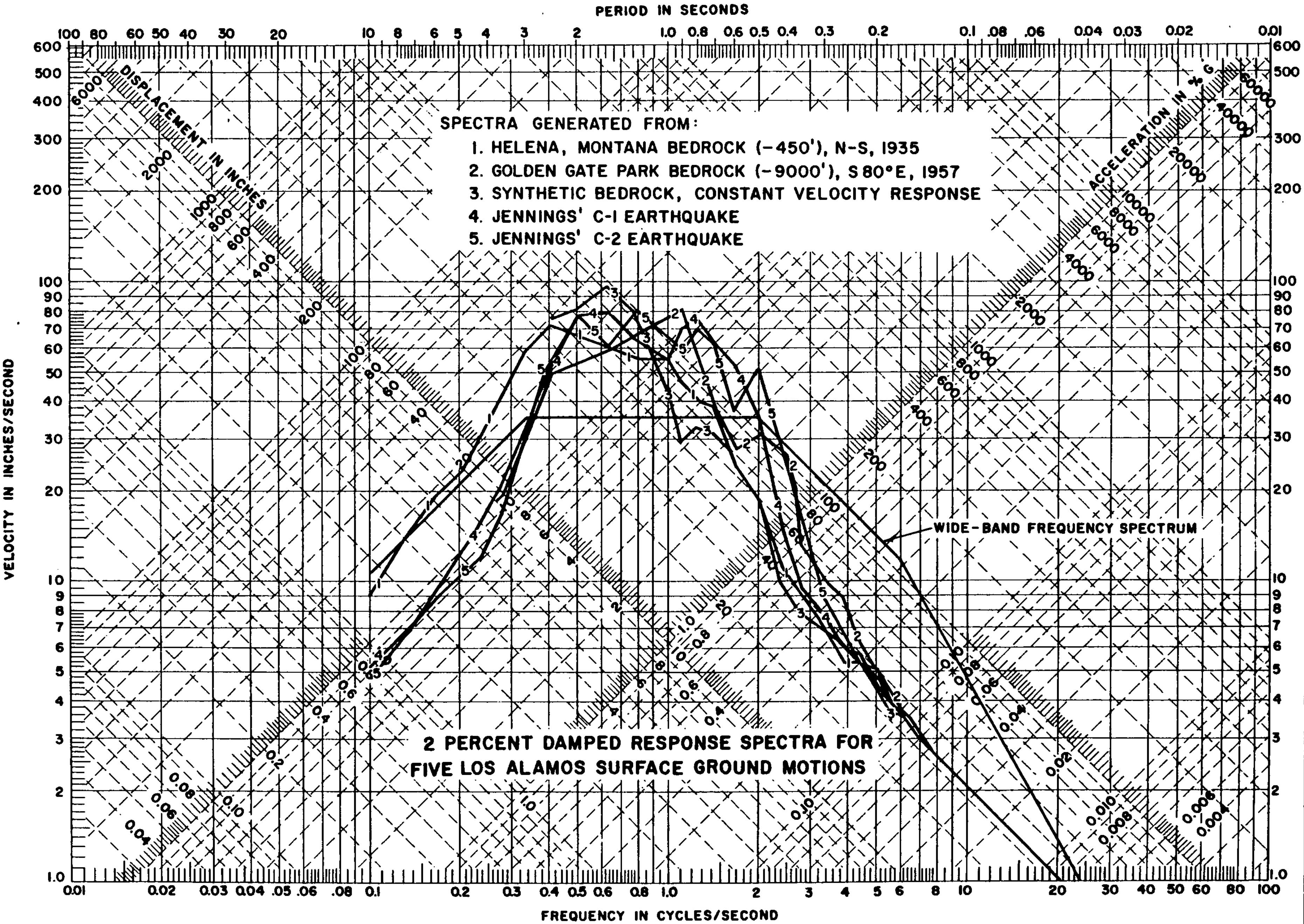
DAMES & MOORE
APPLIED EARTH SCIENCES

PLATE S-4

FILE 0661-120
LOS ALAMOS
BY NKS DATE 11-22-72
CHECKED BY ED[illegible] DATE 1/28/72

REVISIONS
BY________ DATE________
BY________ DATE________
PLATE________ OF________

Response spectra are for a maximum horizontal ground acceleration of 33 percent of gravity.



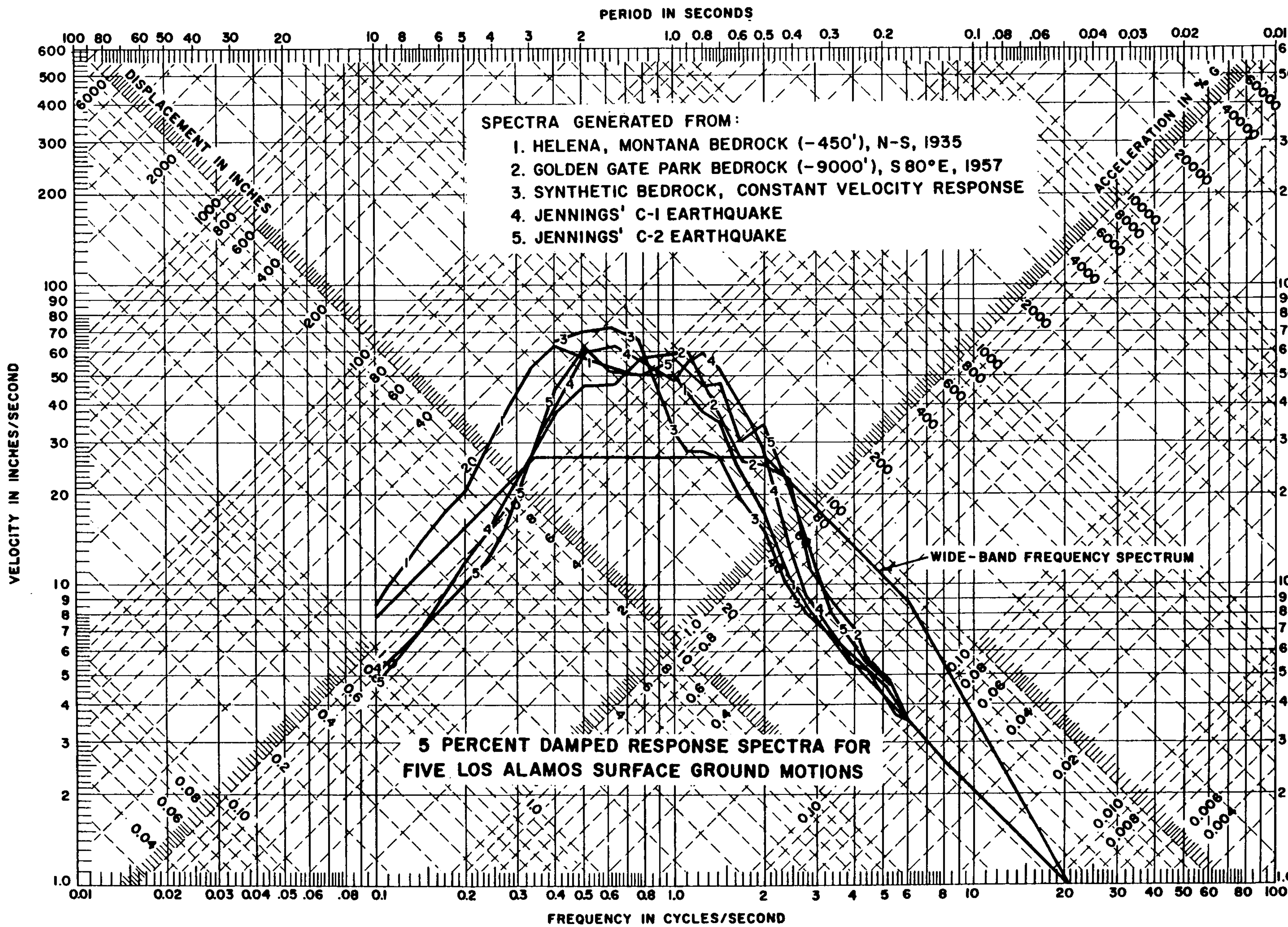
DAMES & MOORE
APPLIED EARTH SCIENCES

PLATE S-5

FILE 0651-120
LOS ALAMOS
BY NKS DATE 11-22-72
CHECKED BY DATE 11/22/72

REVISIONS
BY____ DATE____
BY____ DATE____
PLATE____ OF____

Response spectra are for a maximum horizontal ground acceleration of 33 percent of gravity.



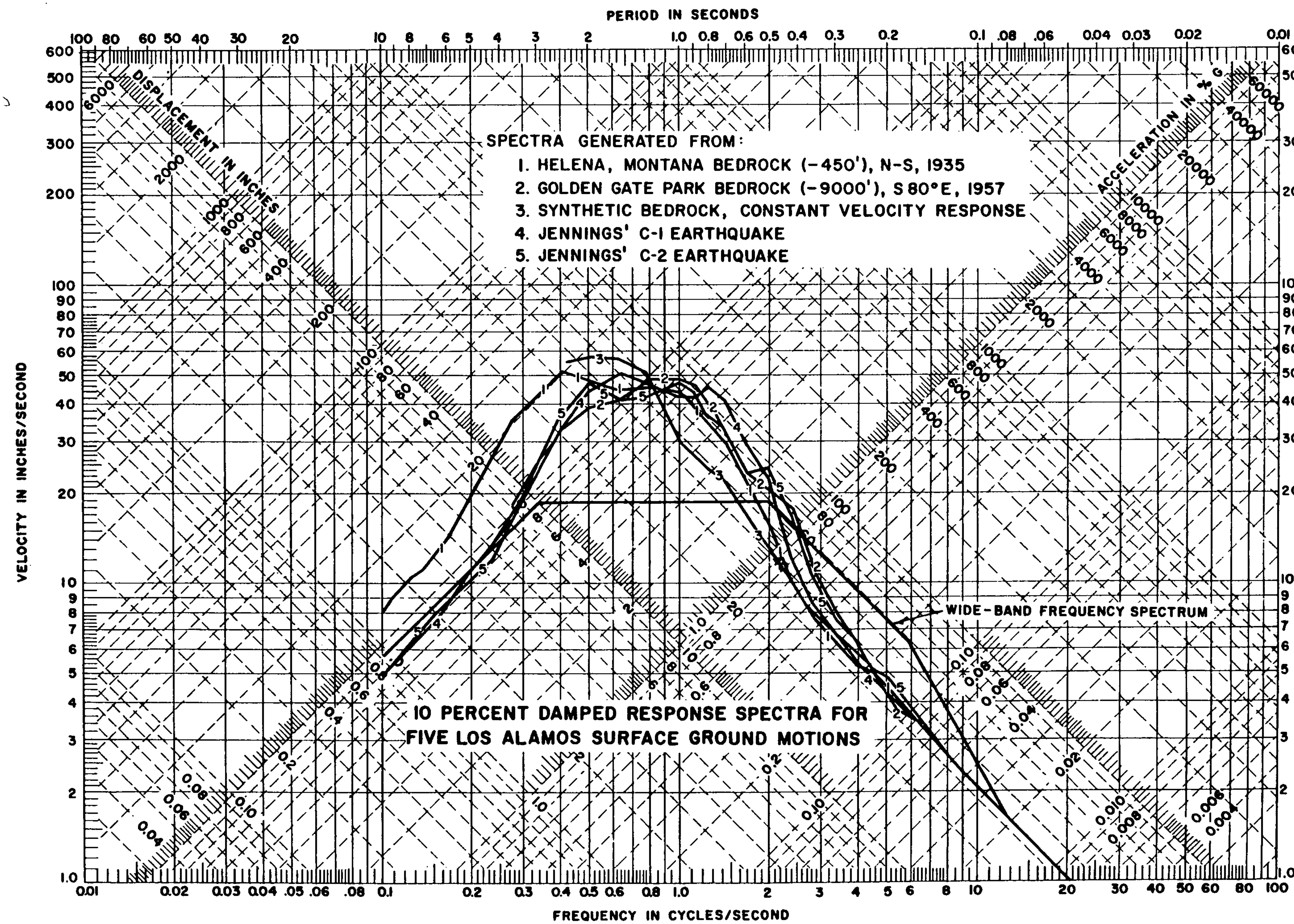
DAMES & MOORE
APPLIED EARTH SCIENCES

PLATE S-6

FILE 0651-120
LOS ALAMOS
BY NKS DATE 11-22-72
CHECKED BY RPS DATE 11/28/72

REVISIONS
BY ______ DATE ______
BY ______ DATE ______
PLATE ______ OF ______

Response spectra are for a maximum horizontal ground acceleration of 33 percent of gravity.



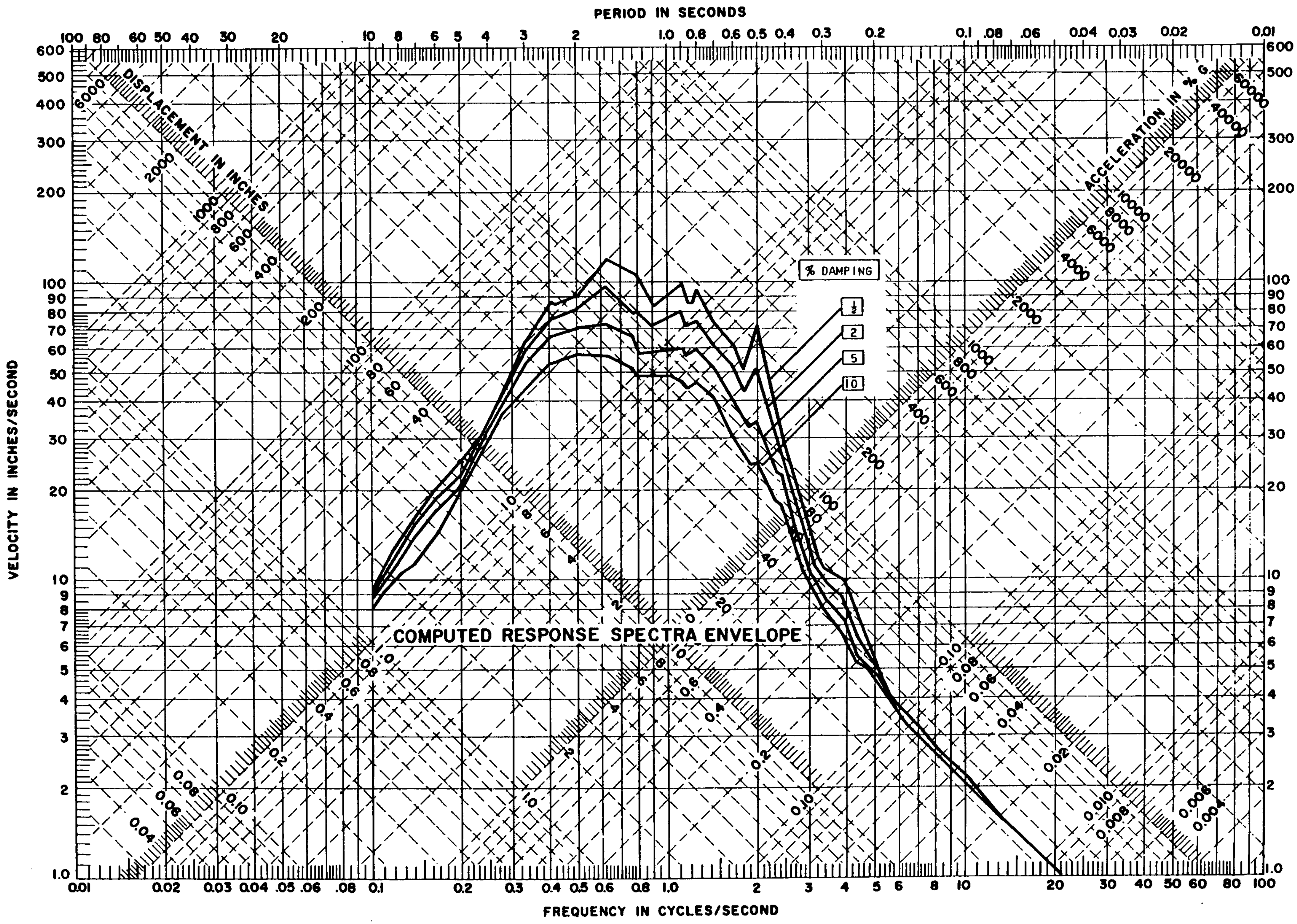
DAMES & MOORE
APPLIED EARTH SCIENCES

PLATE S-7

FILE 0851-120
LOS ALAMOS
BY NKS DATE 11-22-72
CHECKED BY RDS DATE 11/28/72

REVISIONS
BY______ DATE______
BY______ DATE______
PLATE______ OF______

Response spectra are for a maximum horizontal ground acceleration of 33 percent of gravity.



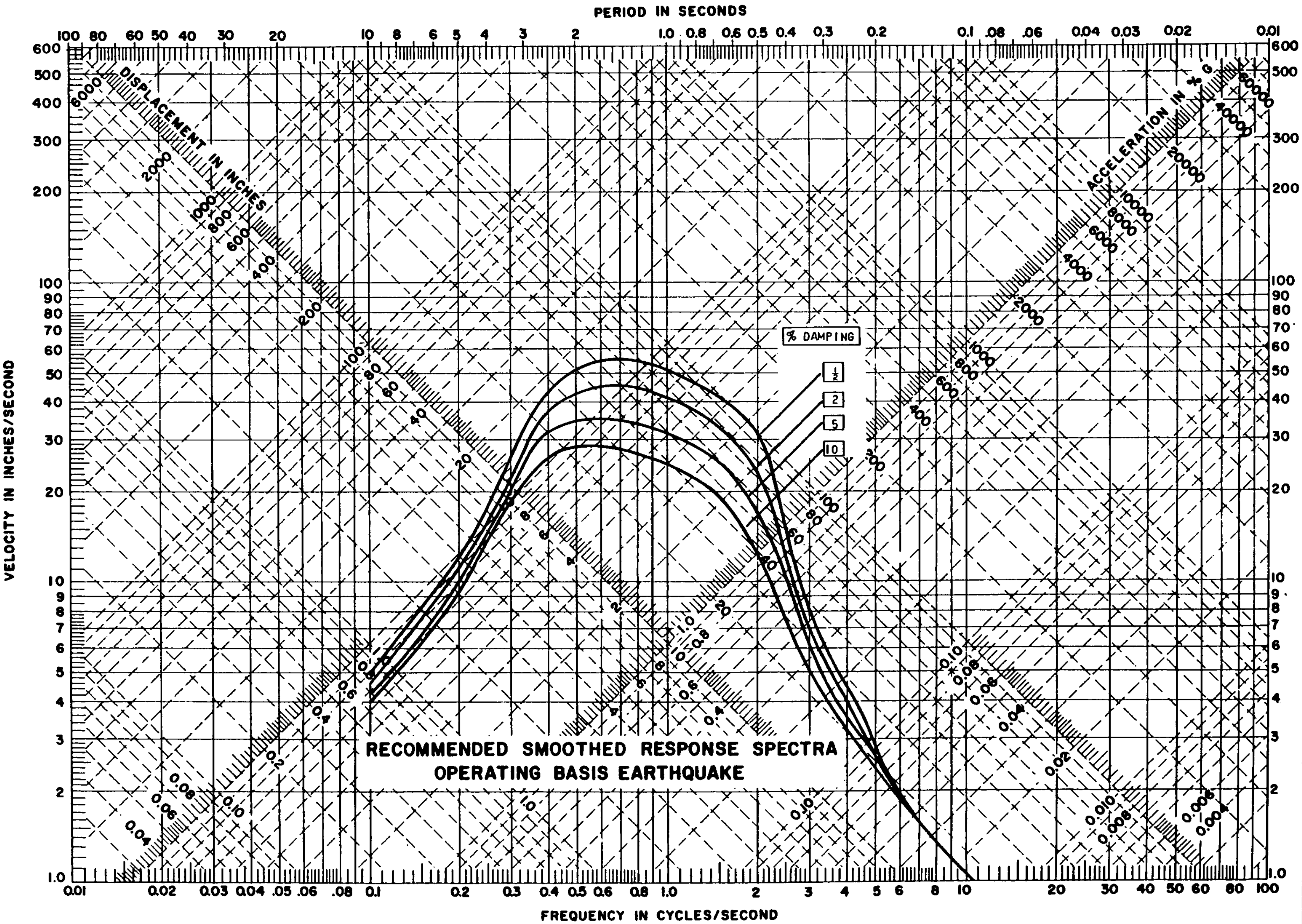
DAMES & MOORE
APPLIED EARTH SCIENCES

PLATE S-8

FILE 0651-120
LOS ALAMOS
BY NKS DATE 11-22-72
CHECKED BY [illegible] DATE 11/28/72

REVISIONS
BY ______ DATE ______
BY ______ DATE ______
PLATE ______ OF ______

Response spectra are for a maximum horizontal ground acceleration of 17 percent of gravity.



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APPLIED EARTH SCIENCES

PLATE S-9

FILE 0651-120
LOS ALAMOS
BY NMS DATE 11-22-72
CHECKED BY ______ DATE ______

REVISIONS
BY ______ DATE ______
BY ______ DATE ______
PLATE ______ OF ______

Response spectra are for a maximum horizontal ground acceleration of 33 percent of gravity.

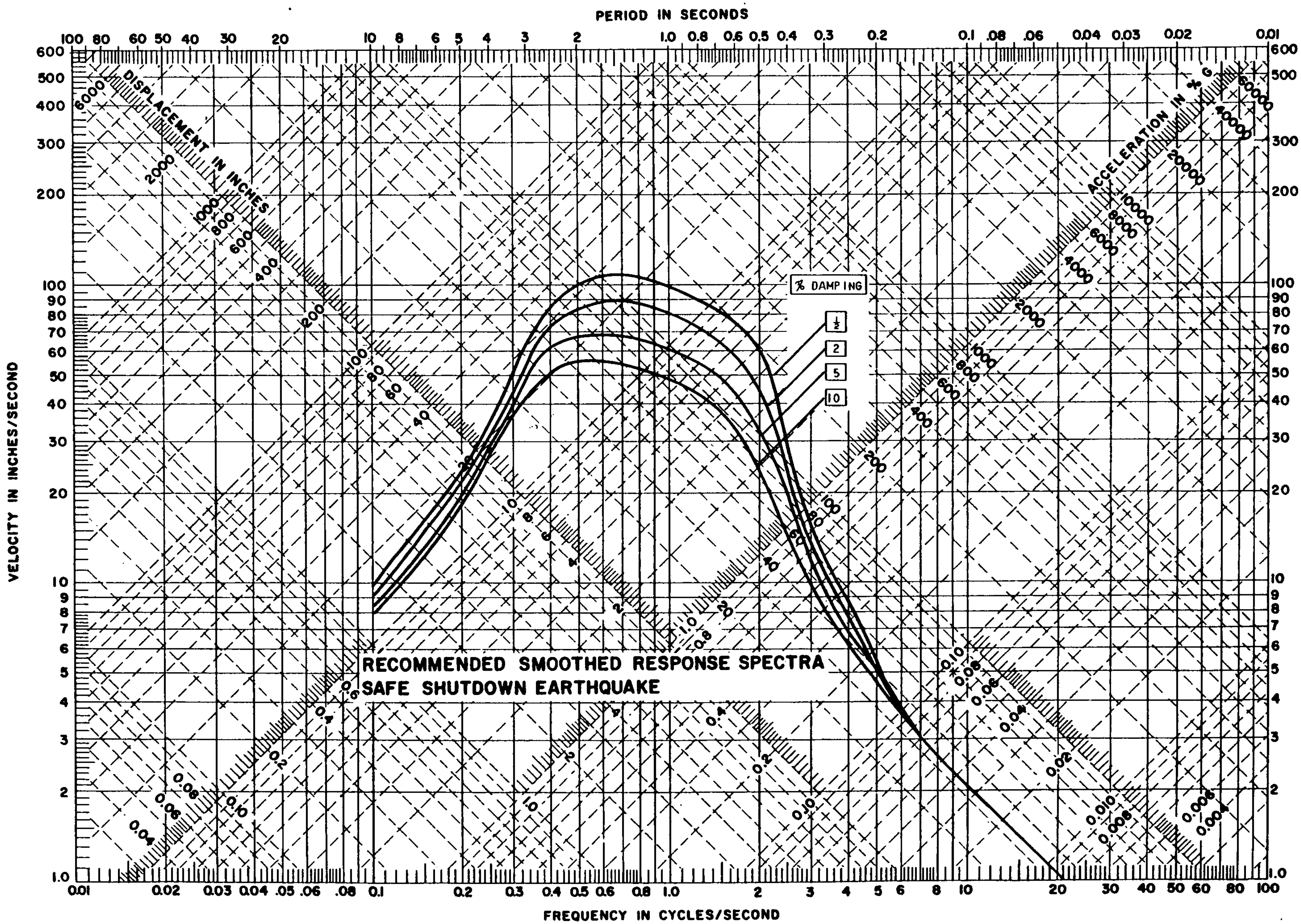

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PLATE S-10

TABLE S-III

SITE DYNAMIC PROPERTIES

LAYER NO.	THICKNESS IN FEET	DESCRIPTION		WET DENSITY (LBS/FT^3)	VALUES AT LOW STRAIN LEVELS+ COMPRESSION WAVE VELOCITY FT/SEC	VALUES AT LOW STRAIN LEVELS+ SHEAR WAVE VELOCITY FT/SEC	VALUES AT DESIGN EARTHQUAKE STRAINS++ SHEAR WAVE VELOCITY FT/SEC	VALUES AT DESIGN EARTHQUAKE STRAINS++ SHEAR MODULUS KSF	VALUES AT DESIGN EARTHQUAKE STRAINS++ DAMPING PERCENT
1	50	Subunit 3b Tshirege	Bandelier Tuff Volcanic Rock	90	3000	1250	979	2696	2.8
2	70	Subunit 3a Tshierge		90	2000*	750	658	1217	9.6
3	230	Unit 2 Tshierge		120	4600	2150	1420	7557	4.3
4	400	Otowi Member		90		2150*	1643	7549	3.9
5	35	Guaje Member		90		2150*	1643	7557	3.8
6	215	Puye Fanglomerate	Santa Fe and Post Santa Fe Sedimentary Rock	130		3000*	2609	27506	7.1
7	500	Puye Fanglomerate		130		3000*	2790	31456	7.4
8	5500	Santa Fe Group		135		4000*	4200	71273	6.8
9	Bedrock at 7000 ft	Crystalline Basement Rock		160		9000			

+ As determined from geophysical testing

++ Computed by wave propagation analysis using strain compatibility relation

* Estimated

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HYDROLOGY

GENERAL

The site is located on the Pajarito Plateau, at Elevation approximately 7200 feet. This plateau is dissected by narrow, steep-walled canyons cut through a cap of tuff by intermittent streams that drain west to east across the plateau. As a result, the country is characterized by long, finger-like mesas between the canyons. The Topographic Map (Plate 1H) shows that the site is located near a drainage divide on top of the mesa between canyons and is not subjected to flooding. Drainage from the site is into Effluent Canyon, which drains into Mortandad Canyon, a tributary to the Rio Grande.

Effluent Canyon receives runoff water from 0.5 square miles of watershed. There is no ground water flow into the canyon. The canyon receives effluent from two technical areas. The floor of the canyon is covered with alluvium which contains a perched ground water body east of the site. The principal aquifer is approximately 1000 feet below the canyon floor. The principal aquifer is unconfined on a regional basis, but in localized areas water is confined beneath tight lenses of clay or silt, or other impervious material.

SURFACE WATER

The stream system of the site region is ephemeral. Runoff is in the season following snowmelt and occasionally during summer thundershowers. The drainage is into the Rio Grande, but in Mortandad Canyon, infrequent runoff in the canyon percolates into the alluvium within a reach three miles downstream from the site. Effluents disposed in Effluent Canyon flow into Mortandad Canyon and are absorbed by the alluvium in the same manner as surface runoff. Owing to the topographic position of the site, there is no danger of flooding. The facility will not use surface water resources, and no water storage reservoirs will be built appurtenant to the facility.

Under operating conditions, all effluent from the facility will be transported by pipeline to Building TA-50.

The nearest municipal use of Rio Grande water is at El Paso, Texas, which is 340 miles downstream. Between the site and El Paso there are two reservoirs, Elephant Butte and Caballo, which are operated by the US Bureau of Reclamation for irrigation projects (see Plate 2H).

GROUND WATER

Ground water in the site region occurs in two separate systems: an upper perched ground water body in the alluvium of Mortandad Canyon; and a deep aquifer about 1300 feet below the site, in the Tesuque and Puye Formations. Test drilling in the area discovered no perched water on top of clay lenses between the canyon floor and the Tesuque-Puye aquifer system. Therefore, water in the alluvial aquifer does not percolate downward through the lower aquifer. Any liquids disposed of at the site would recharge water in the alluvium only.

ALLUVIUM

Mortandad Canyon, as well as many of the deeply incised canyons in the region, is cut into the Bandelier tuff. The floor of the canyon is covered with alluvium. In Mortandad Canyon, the alluvium is discontinuous from the site area downstream, interrupted by basalt outcrops at several places.

In the site area, the alluvium in the bottom of the canyon is entirely granular, composed principally of sand throughout its thickness. Downstream, the lower part of the alluvium grades to sandy silt. The alluvial aquifer is unconfined and has a saturated thickness of six to eight feet near the site. The fine-grained sediments at the base of the alluvium and the Bandelier tuff upon which the alluvium rests, are effective in preventing downward percolation of water from the alluvium into lower formations. The alluvium is of limited extent and is not a source of water to wells.

The alluvium receives recharge from two sources: infiltration of storm runoff and release of industrial effluent. The watershed upstream from Mortandad Canyon is quite small, and there is little runoff. The stream system in the canyon east of the site is poorly defined, indicating that surface flow seldom exists. Effluent is disposed of from two sources: Building TA50, a waste processing facility; and cooling water from Building TA-48. The effluent released into the canyon infiltrates into the alluvium within one mile downstream from the site. Ground water moves eastward through the alluvium. Within three miles downstream from the site, the alluvial water is removed from the aquifer by evapotranspiration of the vegetation on the floor of Mortandad Canyon.

The downstream movement of water is under a gradient of approximately 0.03. The gradient changes slightly from dry to wet seasons. In the general area of the site, the water table varies from a few feet below surface to as much as 60 feet below surface of the canyon floor. The rate of movement of water through the alluvium is on the order of 15 feet per day, on the basis of data available from the files of the Los Alamos Scientific Laboratories. The same file data has shown that dilution in the aquifer occurs on the order of 1 to 4 in a 4000-foot reach 2 miles downstream from the site.

TESUQUE-PUYE AQUIFER

The principal aquifer in the region is about 1300 feet beneath the western margin of the Pajarito Plateau and slopes east to a depth of about 600 feet along the eastern edge. The aquifer consists of the Miocene-Pliocene sequence of rock units designated Tesuque and Puye Formations. The Puye Formation consists of river channel deposits overlain by a fanglomerate member, which is quite pervious. The Tesuque Formation is finer-grained, containing numerous beds of sand, silt and clay and some interbedded basalt. The total thickness of the aquifer has not been penetrated. The deepest penetration of the aquifer has been 2350 feet in the pilot hole of Well LA-1B. On a regional basis, the aquifer system is continuous and unconfined. The sedimentary formation aquifer system in the Rio Grande Valley is shown on Plate 2H. In the Los Alamos area, the aquifer is locally confined beneath lenses of clay, silt, or basalt.

Recharge to the aquifer occurs principally from the west, in the Jemez Mountains, where precipitation is high, and rocks are fractured sufficiently to favor percolation of rainfall and snowmelt. Movement of ground water in the aquifer is to the east. The principal discharge is into the Rio Grande. Discharge occurs through springs into the river and springs and seeps on the canyon wall. The aquifer is too deep for withdrawals by evapotranspiration. Pumpage is from wells in the Los Alamos area, which are shown on Plate 3H.

The average transmissibility of the formation is on the order of 20,000 gallons per day per foot, on the basis of data provided by the US Geological Survey. Permeability is about 30 gallons per day per square foot. The gradient is 140 feet per mile, as indicated on Plate 4H. Velocity of ground water movement in the formation is about 73 feet per year. The nearest municipal well is 3.3 miles away from the site.

When the Los Alamos facilities were opened in 1943, water was derived solely from surface water sources. Water wells were installed as a result of later expansion. Currently the pumpage is approximately 4900 acre-feet per year. A listing of wells is shown in Table IH. The effect on water level gradients by pumpage in the site region has been negligible. Future effects of pumping on the gradient will not result in adverse water supply conditions with respect to the facility.

Water conservation is practiced in the area. Recycled sewage and surface water sources are used to irrigate golf courses and cemeteries. An infiltration gallery at the foothills of the Jemez Mountains is used to supplement the local ground water supply.

LIQUID DISPOSAL EFFECTS

In this section of the report we trace the movement of a hypothetical volume of fluid released at the site. Two conditions are considered:

1. The fluid is released into the subsurface.
2. The fluid is released at the surface.

For a subsurface release of fluid, it is assumed that an excavation with floor dimensions of 100 X 100 feet is 10 feet deep. The excavation would be through the thin soils overlying the Bandelier tuff. Most of the excavation would be in the Bandelier. Studies by the US Geological Survey have shown that capillary infiltration into the Bandelier is at a rate varying between 0.04 and 0.4 gallons per day per square foot. If the hypothetical excavation is filled with fluid, it would require 200 to 2000 days for all the fluid to move into the subsurface. The Bandelier tuff is dry, and the fluid moving into it would be held against gravity by specific retention (0.1 assumed) and would occupy a rock volume of 1,000,000 cubic feet, or 10 times the volume of the hypothetical excavation. It is possible that a minor portion of the fluid would not be retained in the tuff, but might find its way to the stream system along joints. This amount can be expected to be less than five percent of the total volume in the hypothetical excavation. Thus, a fluid released into the subsurface would be essentially contained at the site.

Fluid released at the surface would flow into Effluent Canyon, then into Mortandad Canyon. The released fluid would infiltrate the alluvium in the canyon and subsequently be transpired by plants in the canyon floor. The fluid would not move towards a water well, because there are no wells in the alluvium, and because fluid in the alluvium is precluded from percolating downwards towards the principal aquifer. Because the alluvium would be absorbing the fluid released and subsequently the released fluid would be transpired by plants, there would be no flow of the fluid into the Rio Grande.

CONCLUSIONS

Surface water constitutes a minor element in the hydrologic analysis of the site. The site is high on a plateau and is not subjected to flooding. Surface water is not being used in the operation of the facility. The nearest downstream municipal use is over 300 miles away. Surface drainage from the site infiltrates into alluvial soils of Mortandad Canyon beneath and does not enter the stream system. The main aquifer is insulated from any contamination at the site by the impervious Bandelier tuff. The alluvium in the canyon which receives any fluids from the site is not used by water wells and fluids in the alluvium are totally transpired by native vegetation.

No potable water contamination would result from operating or accident conditions at the site.

ATTACHMENTS

Plate H-1- Topography and Drainage

Plate H-2- Major Aquifers and Reservoirs

Plate H-3- Well Locations

Plate H-4- Piezometric Surface Elevation

Table H-1- Data, Los Alamos Wells

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DAMES & MOORE

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Senior Hydrologist

November 29, 1972

Los Angeles, California

.7 (REV. 6-61)

BY South DATE 9/8/72

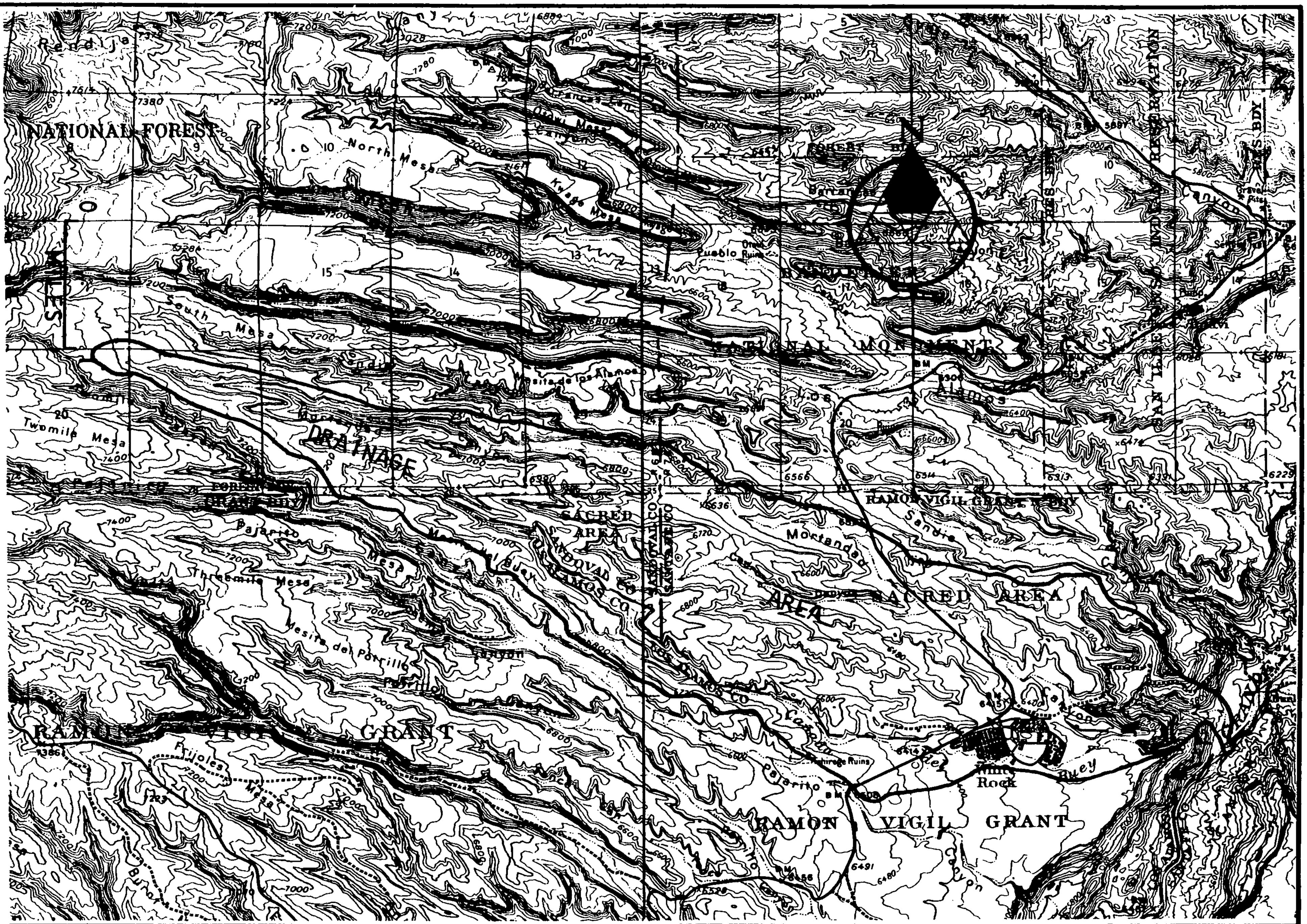
CHECKED BY RMM 11-7-72

FILE 0651-1 Los Alamos

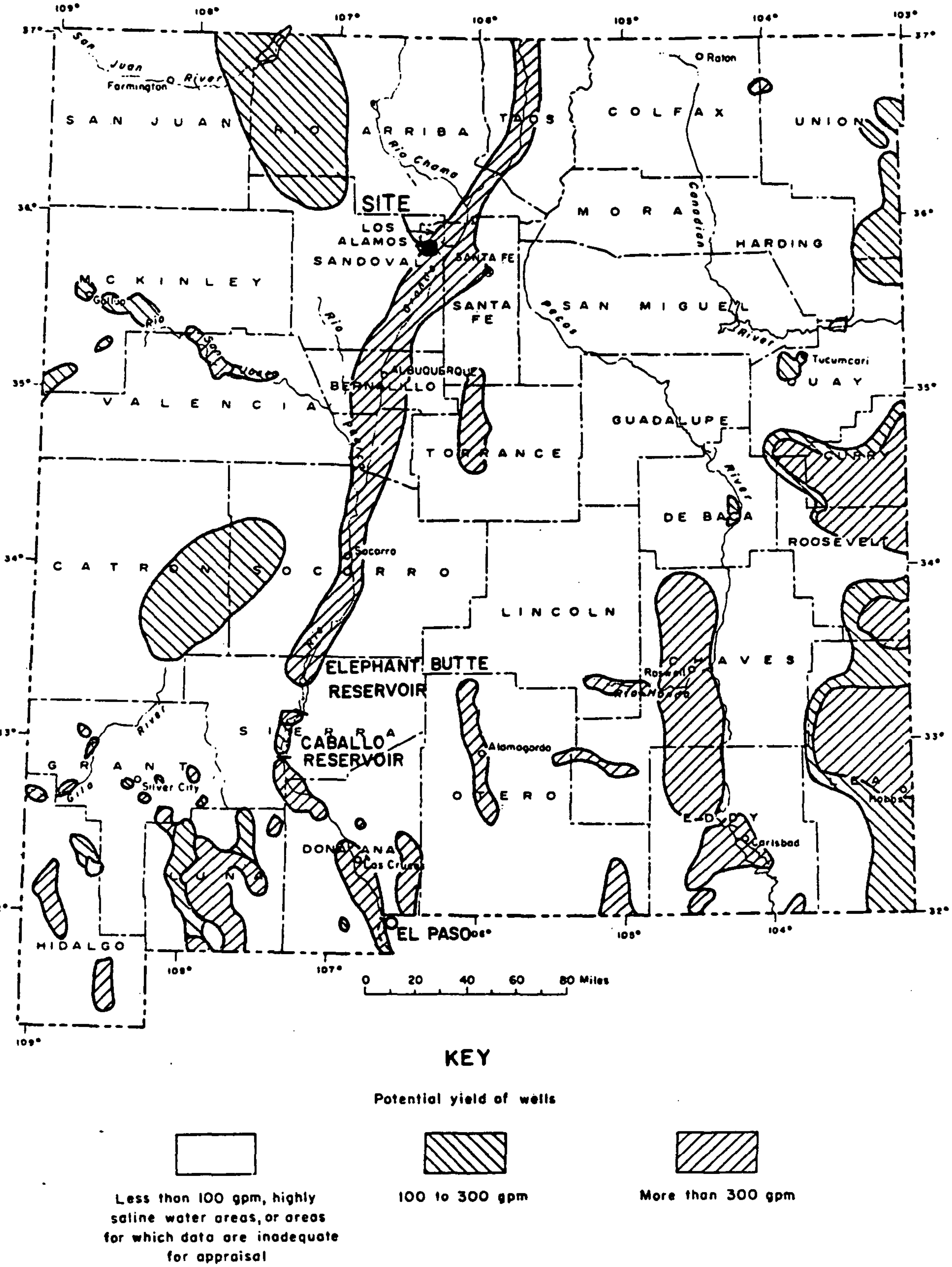
REVISIONS

BY ________ DATE ________

Topography and Drainage (from USGS Quadrangles Espanola and Frijoles, 15' series)



DAMES & MOORE



Major Aquifers and Reservoirs in New Mexico

Source: USBR, 1972

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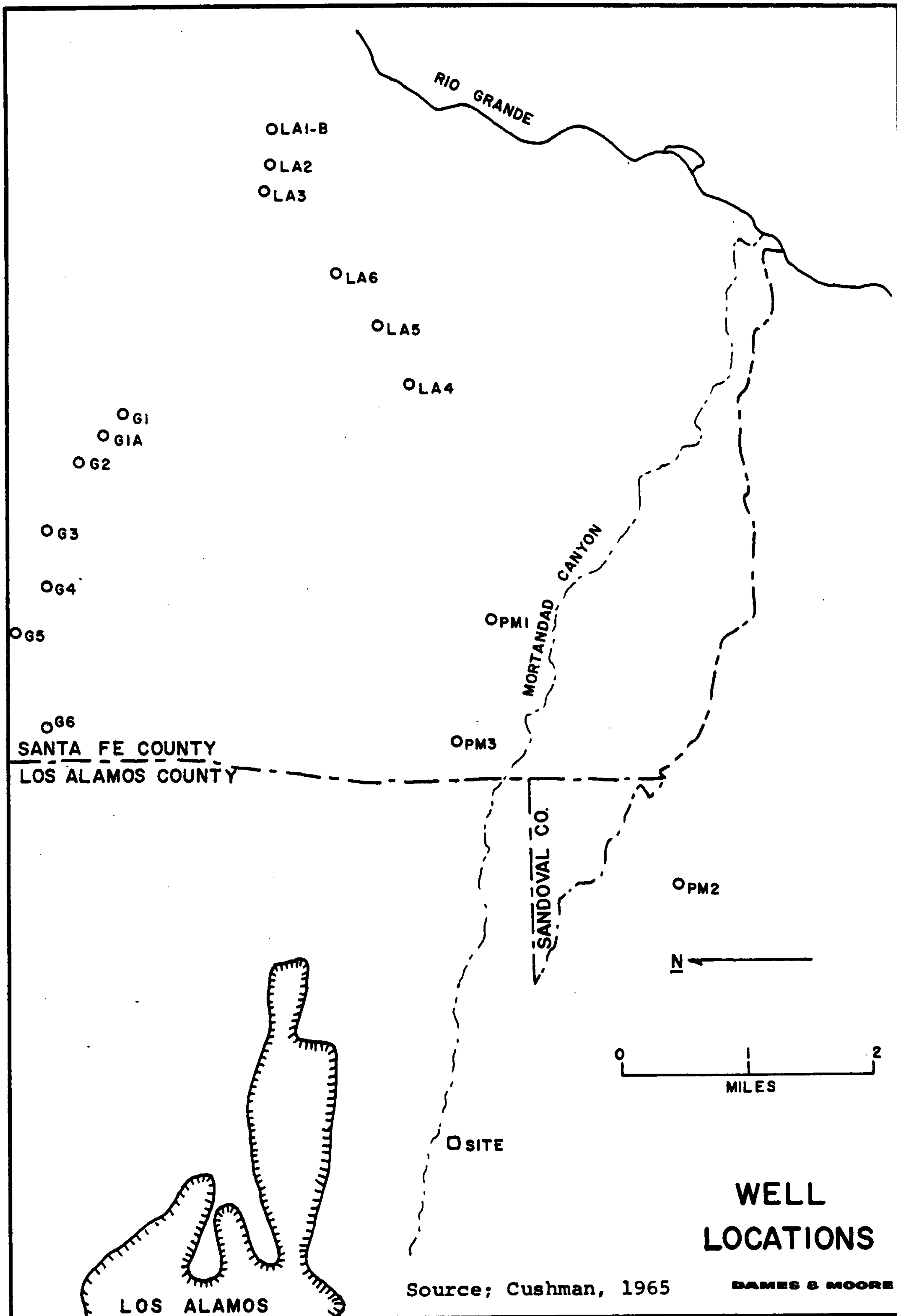

WELL LOCATIONS

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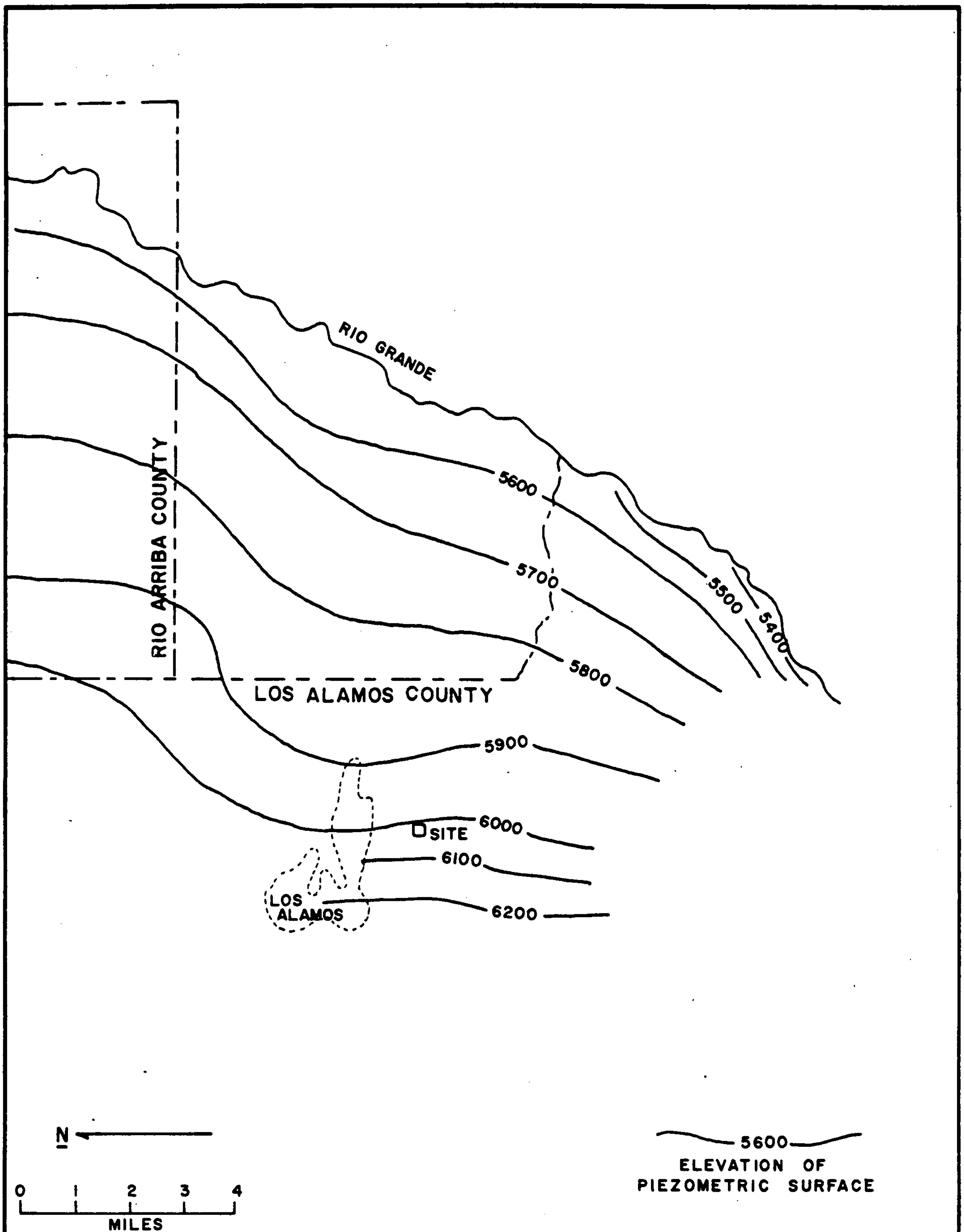

PIEZOMETRIC SURFACE ELEVATION

Source; Titus, 1961

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TABLE H-1

DATA, LOS ALAMOS WELLS

WELL NO. (FIG. 3H)	COMPLETION DATE	LAND SURFACE EL. (FT.)	EL. OF TOP OF UPPER SCREEN (FT.)	EL. OF BOTTOM OF LOWEST SCREEN (FT.)	DEPTH TO STATIC LEVEL WHEN DRILLED (FT.)	DEPTH TO STATIC LEVEL DEC. 1971 (FT.)	WELL YIELD (GPM)
LA-1B	1960	5622	5296	3928	Flowed	25	564
LA-2	1946	5651	5546	4807	Flowed	90	296
LA-3	1947	5672	5567	4786	Flowed	55	296
LA-4	1948	5975	5555	3992	189	290	598
LA-5	1948	5840	5400	4100	71	155	466
LA-6	1948	5770	5016	4011	5	90	556
G-1	1950	5973	5532	4354	192	290	389
G-1A	1954	6014	5733	4096	255	300	563
G-2	1951	6056	5784	4501	259	340	426
G-3	1951	6139	5857	3993	280	330	321
G-4	1951	6228	5766	4476	347	380	213
G-5	1951	6306	5880	4303	411	445	554
G-6	1964	6422	5722	4892	572	560	243
PM-1	1965	6520	5575	4021	722	730	617
PM-2	1965	6715	5711	4415	823	845	1402
PM-3	1965	6640	5684	2552	740	750	1300

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APPENDIX F

FOUNDATION INVESTIGATION

FIELD EXPLORATIONS AND LABORATORY TESTS

FIELD EXPLORATIONS

The subsurface conditions at the site were explored for the foundation investigation by drilling 11 borings at the locations shown on the Plot Plan in the Foundation section of the report, Plate F-1. Originally, 12 borings were planned; however, Boring 7 was eliminated because of the uniformity of the subsurface conditions.

The borings were drilled to depths of about 20 to 50 feet to provide the necessary field data for the foundation investigation. Borings 4 and 10, on diagonal corners of the proposed plutonium building, were extended to 150 feet, with sampling and coring, in order to provide field data for the detailed site geology studies, and to obtain samples and cores for testing to evaluate the dynamic properties of the deeper volcanic tuff. These two borings were further deepened by augering to about 180 feet to assure adequate penetration of Subunit 2b for the geophysical cross-hole and uphole surveys.

The borings were drilled using truck-mounted rotary drilling equipment. The welded volcanic tuff was cored using a 10-foot double-tube NX core barrel. Compressed air was used to cool the core bit and to circulate the cuttings up out of the holes. Tuff Subunit 3a is loosely welded to unwelded, and rock cores could not be recovered. In Subunit 3a, therefore, the holes were advanced using hollow-stem, continuous flight augers, and undisturbed samples were obtained by driving a soil sampler through the augers. Undisturbed samples of the overburden soils were also obtained with a driven sampler.

The field work was supervised by one of our staff geologists who also performed the site geology work. The boring logs are presented on Plates FA-1A through FA-1E. A key to the information presented on the logs is included at the bottom of Plate FA-1A.

The boring locations were staked for us in the field by LASL surveyors, who also provided us with the ground surface elevation at each location.

LABORATORY TESTS

GENERAL

Laboratory tests were performed on selected undisturbed samples and cores of soil and rock obtained from the borings. Static tests were performed to identify the samples as well as to evaluate the static strength and compressibility of the on-site soils and rock. Dynamic tests were performed to evaluate dynamic strengths, shear moduli and damping values of both soil and rock.

STATIC TESTS

MOISTURE AND DENSITY TESTS

Moisture and density tests were performed on selected samples to provide data for calculating stresses versus depth. Moisture and density test results were used in our static and dynamic analyses. Test results are shown adjacent to the sample and core symbols on the Log of Borings, Plates FA-1A through FA-1E.

ATTERBERG LIMIT TESTS

Liquid limit and plastic limit tests were performed on a sample taken from the B soil horizon. This test was performed to help evaluate the potential for expansion of the upper soils. The test was performed in accordance with the A.S.T.M. Test D423-66, Liquid Limit of Soils, and A.S.T.M. D424-59 (1966), Plastic Limit and Plasticity Index of Soils. The sample tested was from Boring 2 at a depth of one foot. The liquid limit and plastic limit were found to be 28.5 and 18.0 respectively. This indicates that this material has low plasticity and low potential for expansion.

EXPANSION TESTS

Expansion tests were performed on undisturbed and remolded samples from the B soil horizon. These tests were performed to assist in evaluating the expansive properties of the upper soils. The tests were performed by installing the sample in a consolidometer, loading to a pressure of 100 pounds per square foot, saturating the sample and measuring the resulting expansion. The samples were then drained, and the shrinkage from saturation to air-dry was measured. One test was performed on a remolded sample compacted to 95 percent of the maximum dry density, or 110 pounds per cubic foot, at 11 percent moisture content. The test results are presented below.

Boring Number	Depth in Ft.	Soil Type	Expansion When Saturated, Percent	Shrinkage Saturated to Air-Dry, Percent
2	1	B Soil Horizon	0.8	0.4
8	1	B Soil Horizon	0.2	0.4
Remolded	1	B Soil Horizon	5.3	1.5

The tests indicate that the natural soil and compacted fill have low potential for volume changes with changes in moisture content.

COMPACTION TESTS

Compaction tests were performed on the upper soils and rock that would possibly be used as compacted fill to determine their compaction characteristics. Tests were performed on representative material from the B soil horizon, C soil horizon, and upper Subunit 3b of the volcanic tuff. The test method used was A.S.T.M. Test Designation D1557, Method A. An additional compaction test was performed on the upper part of upper Subunit 3b using A.S.T.M. Test Designation D1557, Method D.

The method of performing compaction tests is presented on Plate FA-2. The results are presented on Plate FA-3.

DIRECT SHEAR TESTS

Direct shear tests were performed on selected undisturbed samples and remolded samples of soils obtained from the borings. These tests were performed to evaluate the shear strength of the upper soils. Undisturbed samples were tested at their field moisture content. Remolded samples were prepared using representative material from upper Subunit 3b of the volcanic tuff. Remolded samples were compacted to a dry density ranging from 82.5 to 84 pounds per cubic foot and a moisture content ranging from 13.0 to 14.3 percent.

The method of performing these tests is described in more detail on Plate FA-4. The results of the direct shear tests are tabulated on the following page.

DIRECT SHEAR TEST RESULTS ON UNDISTURBED SAMPLES

Boring Number	Depth in Ft.	Soil Type	Normal Pressure Lbs/sq.ft.	Peak Shear Strength Lbs/sq.ft.
1	1	B Horizon	500	2150
1	1	B Horizon	2000	3520
3	1/2	B Horizon	1500	2250
3	1/2	B Horizon	4000	4350
3	3	C Horizon	1000	3520
3	3	C Horizon	3000	5880
6	1	B Horizon	1000	2080
6	1	B Horizon	3000	3670
8	3	C Horizon	2000	3550
8	3	C Horizon	4000	4800

DIRECT SHEAR TEST RESULTS ON REMOLDED SAMPLES OF VOLCANIC TUFF

Test Dry Density in Lbs/cu.ft.	Test Moisture Content in % Dry Wt.	Normal Pressure Lbs/sq.ft.	Peak Shear Strength Lbs/sq.ft.
82.5	13.8	500	1280
84.0	14.3	1000	2200
82.5	13.7	3000	5000
83.8	13.0	5000	5620

UNCONFINED COMPRESSION TESTS

Unconfined compression tests were performed on selected undisturbed cores of bedrock upper Subunit 3b to evaluate their strength, static modulus of elasticity and type of failure. The unconfined compression tests were performed on cylindrical cores approximately two inches in diameter and ranging in height from two inches to five inches. The shorter samples were rebounded and reloaded several times over the range of pressures expected from foundation loads.

The method of performing unconfined compression tests is described on Plate FA-5. The results of these tests are tabulated below:

Boring Number	Depth in Ft.	Ratio of Length Divided By Diameter	Unconfined Compressive Strength Lbs/sq.inch	Strain at Peak Strength, Percent
1	13	2.50	238	1.4
4	42	2.44	543	1.2
5	27	1.19	*	*
5	37	2.37	668	1.4
6	12	2.44	228	1.2
8	9	2.50	315	1.3
9	12	2.50	244	1.2
10	23	1.25	233	0.5
11	40	1.00	774	1.1
11	46	2.25	540	1.2

* Sample not loaded to failure in order to obtain rebound characteristics. Maximum load during test was 465 psi at 0.8 percent strain.

CONFINED COMPRESSION TESTS

Confined compression tests were performed on two soil samples. One test was performed on unwelded Subunit 3a tuff and the other test on a remolded sample of Subunit 3b material. These tests were performed to assist in evaluating the static modulus of elasticity and compression characteristics of the unwelded and remolded tuff. The test results are shown on Plate FA-6, Confined Compression Test Data.

DYNAMIC TESTS

GENERAL

Resonant column and dynamic triaxial tests were performed on selected soil samples and rock cores from Subunits 3b, 3a and 2b. Dynamic tests were performed to evaluate dynamic strengths, shear moduli and damping values. Generally the upper subunit (3b) extends to 55 feet, the middle subunit (3a) from 55 to 135 feet, and the lower subunit (2b) below 135 feet.

RESONANT COLUMN TESTS

Resonant column tests were performed on samples at two to three different confining pressures. Shear wave velocities and damping values were obtained for various strain levels. The tests were performed in the manner described on Plate FA-7. Typical test results are presented on the following page.

RESONANT COLUMN TEST RESULTS

Boring Number	Depth in Ft.	Confining Pressure Lbs/sq.ft.	Shear Strain in %	Dynamic Shear Wave Velocity in Ft./Sec.	Damping in %
4	32	2160	0.010	1976	1.3
4	32	2160	0.016	1943	1.7
4	32	2160	0.022	1891	1.8
10	52	5040	0.023	1549	3.2
10	52	5040	0.030	1549	3.7
10	52	5040	0.037	1549	3.9
10	75	6480	0.075	816	1.4
10	75	6480	0.090	811	1.9
10	75	6480	0.123	803	2.2
10	93	8640	0.037	923	0.8
10	93	8640	0.049	914	0.9
10	93	8640	0.074	914	0.9
4	137.5	11520	0.004	1942	4.0
4	137.5	11520	0.009	1930	5.0
4	137.5	11520	0.015	1803	5.0

DYNAMIC TRIAXIAL TESTS

Strain-controlled pulsating load triaxial tests were performed on samples at confining pressures approximately equal to the in situ overburden pressure of the sample. The tests were performed in the manner described on Plate FA-8. Typical test results are presented on the following page:

DYNAMIC TRIAXIAL TEST RESULTS

Boring Number	Depth in Ft.	Confining Pressure Lbs/sq.ft.	Deviator Stress Lbs/sq.ft.	Axial Strain in %	Dynamic Young's Modulus in KSF	Damping in %
4	32	2160	415	0.009	9715	2.5
4	32	2160	1081	0.026	8275	2.3
10	52	5040	3534	0.052	13526	5.9
10	52	5040	5717	0.086	13219	5.2
10	52	5040	15591	0.261	11935	3.5
10	75	6480	626	0.025	4929	12.7
10	75	6480	1018	0.053	3866	9.6
10	75	6480	1409	0.086	3266	9.4
10	93	8640	689	0.024	5628	8.9
10	93	8640	1174	0.049	4797	7.0
10	93	8640	1722	0.083	4147	7.0
4	137.5	11520	2806	0.026	21553	6.2
4	137.5	11520	4989	0.052	19158	5.3
4	137.5	11520	8315	0.086	19158	3.5

The following plates are attached and complete this appendix:

Plate FA-1A - Log of Borings (Borings 1,2 and 3)

Plate FA-1B - Log of Boring (Boring 4)

Plate FA-1C - Log of Borings (Borings 5,6 and 8)

Plate FA-1D - Log of Borings (Borings 9 and 10)

Plate FA-1E - Log of Borings (Borings 11 and 12)

Plate FA-2 - Method of Performing Compaction Tests

Plate FA-3 - Compaction Test Data

Plate FA-4 - Method of Performing Direct Shear and Friction Tests

Plate FA-5 - Method of Performing Unconfined and Triaxial Compression Tests

Plate FA-6 - Confined Compression Test Data

Plate FA-7 - Method of Performing Resonant Column Tests

Plate FA-8 - Method of Performing Pulsating Load Triaxial Tests

The following plates are attached and complete this appendix:

Plate FA-1A - Log of Borings (Borings 1,2 and 3)

Plate FA-1B - Log of Boring (Boring 4)

Plate FA-1C - Log of Borings (Borings 5,6 and 8)

Plate FA-1D - Log of Borings (Borings 9 and 10)

Plate FA-1E - Log of Borings (Borings 11 and 12)

Plate FA-2 - Method of Performing Compaction Tests

Plate FA-3 - Compaction Test Data

Plate FA-4 - Method of Performing Direct Shear and Friction Tests

Plate FA-5 - Method of Performing Unconfined and Triaxial Compression Tests

Plate FA-6 - Confined Compression Test Data

Plate FA-7 - Method of Performing Resonant Column Tests

Plate FA-8 - Method of Performing Pulsating Load Triaxial Tests

BORING 1

ELEVATION: 7284.1 FEET

Depth (feet)	Soil horizon / unit	Sample data	Symbol	Description
0	B SOIL HORIZON	6.9%- 98 ■ 23	ML	TAN FINE SANDY SILT
	C SOIL HORIZON		ML	TAN FINE SANDY SILT
	SUBUNIT 3b TSHIREGE MEMBER BANDELIER TUFF		U-3b	LIGHT PINKISH GRAY TUFF, MODERATELY WELDED 25-30% VESICLES, 15-20% PHENOCRYSTS, 10% PUMICE FRAGMENTS
10		2.5%- 98 ■ 235		
		(0.4%-104) 20 MIN. - 95%	L-3b	30-35% VESICLES, 25-30% PHENOCRYSTS, 15% PUMICE FRAGMENTS
20				BORING TERMINATED AT 20 FEET 8/10/72

BORING 2

ELEVATION: 7285.3 FEET

Depth (feet)	Soil horizon / unit	Sample data	Symbol	Description
0	B SOIL HORIZON	6.8%- 81 ■ 10	ML	BROWN FINE SANDY SILT
	C SOIL HORIZON		ML	TAN FINE SANDY SILT
	SUBUNIT 3b TSHIREGE MEMBER BANDELIER TUFF	7.8%- 95 ■ 78	U-3b	LIGHT PINKISH GRAY TUFF, MODERATELY WELDED 25-30% VESICLES, 15-20% PHENOCRYSTS, 10% PUMICE FRAGMENTS
10		20 MIN. - 90%	L-3b	30-35% VESICLES, 25-30% PHENOCRYSTS, 15% PUMICE FRAGMENTS
20				BORING TERMINATED AT 20 FEET 8/10/72

BORING 3

ELEVATION: 7287.2 FEET

Depth (feet)	Soil horizon / unit	Sample data	Symbol	Description
0	B SOIL HORIZON	7.4%- 97 ■ 36	ML	BROWN FINE SANDY SILT
	C SOIL HORIZON	9.0%- 80 ■ 106	ML	TAN FINE SANDY SILT
	SUBUNIT 3b TSHIREGE MEMBER BANDELIER TUFF		U-3b	LIGHT PINKISH GRAY TUFF, MODERATELY WELDED 25-30% VESICLES, 15-20% PHENOCRYSTS, 10% PUMICE FRAGMENTS
10		20 MIN.- 12%		
				1 FT. PUMICE LAYER
20		15 MIN.- 0%	L-3b	30% VESICLES, 25% PHENOCRYSTS, 15% PUMICE FRAGMENTS
		■ 300/6"		GRADING TO 20% DARK PINKISH GRAY PUMICE FRAGMENTS
30		15 MIN.- 100%		
				BORING TERMINATED AT 35 FEET 8/9/72
40				

KEY:

A-B ■ C

D-E (F-G) (core run bar)

A	FIELD MOISTURE EXPRESSED AS A PERCENTAGE OF THE DRY WEIGHT
B	DRY DENSITY EXPRESSED IN LBS./CU.FT.
■	DEPTH AT WHICH UNDISTURBED SAMPLE WAS EXTRACTED
C	BLOWS PER FOOT OF PENETRATION USING A 140 LB. HAMMER DROPPING 30"
D	CORING TIME
E	PERCENT RECOVERY
(F-G)	FIELD MOISTURE AND DRY DENSITY FOR ROCK CORES
I	INDICATES DEPTH AND LENGTH OF CORE RUN

U-3b	UPPER SUBUNIT 3b
L-3b	LOWER SUBUNIT 3b
U-3a	UPPER SUBUNIT 3a
L-3a	LOWER SUBUNIT 3a
U-2b	UPPER SUBUNIT 2b

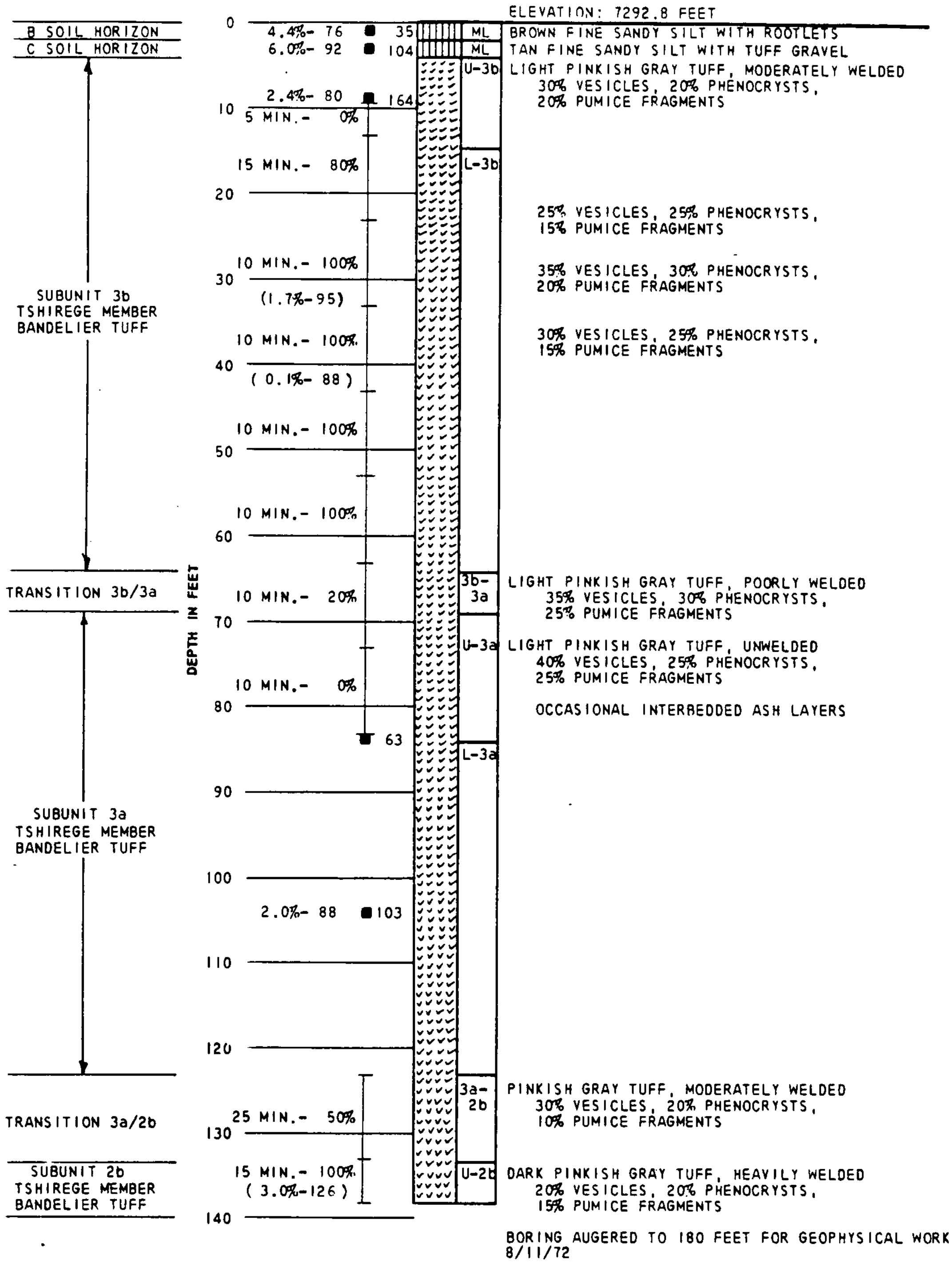
REVISIONS BY ___ DATE ___ BY ___ DATE ___ PLATE ___ OF ___

FILE 0651-120 USAEC LOS ALAMOS BY ___ DATE ___ CHECKED BY [signature] DATE 11-7

LOG OF BORINGS

DAMES & MOORE

BORING 4



LOG OF BORING

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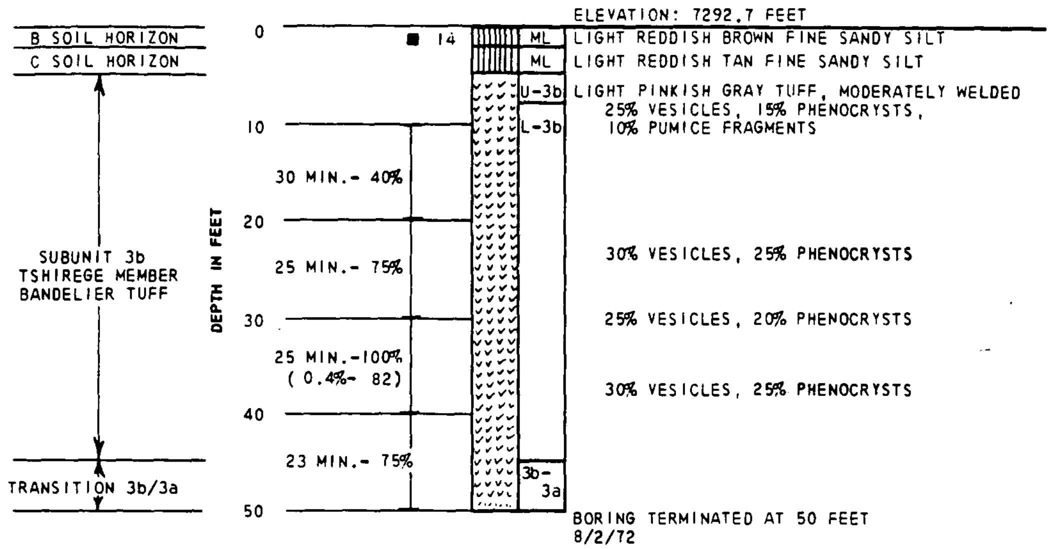
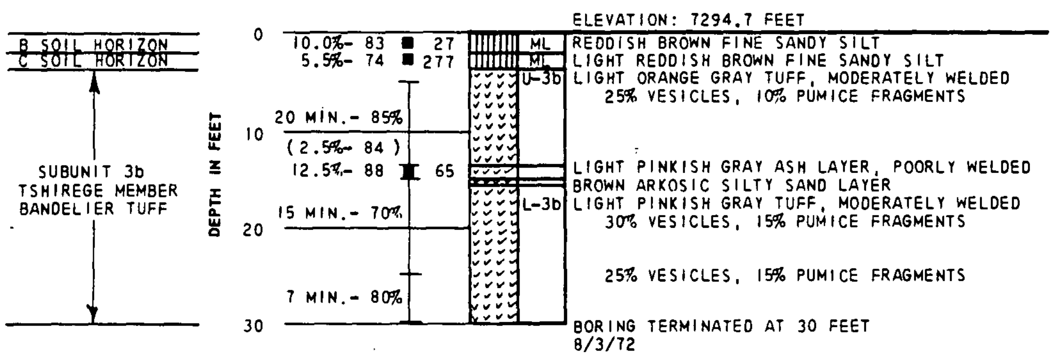
BORING 5



BORING 6



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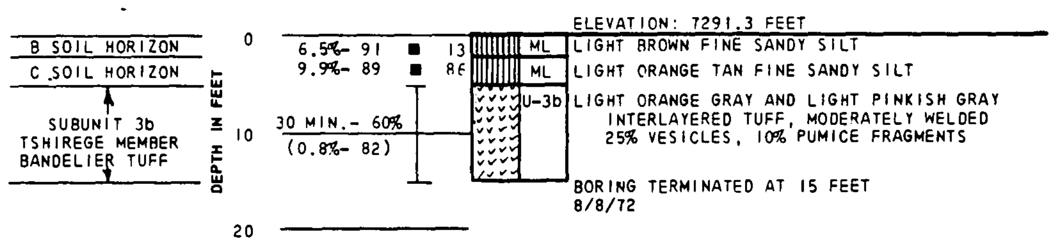
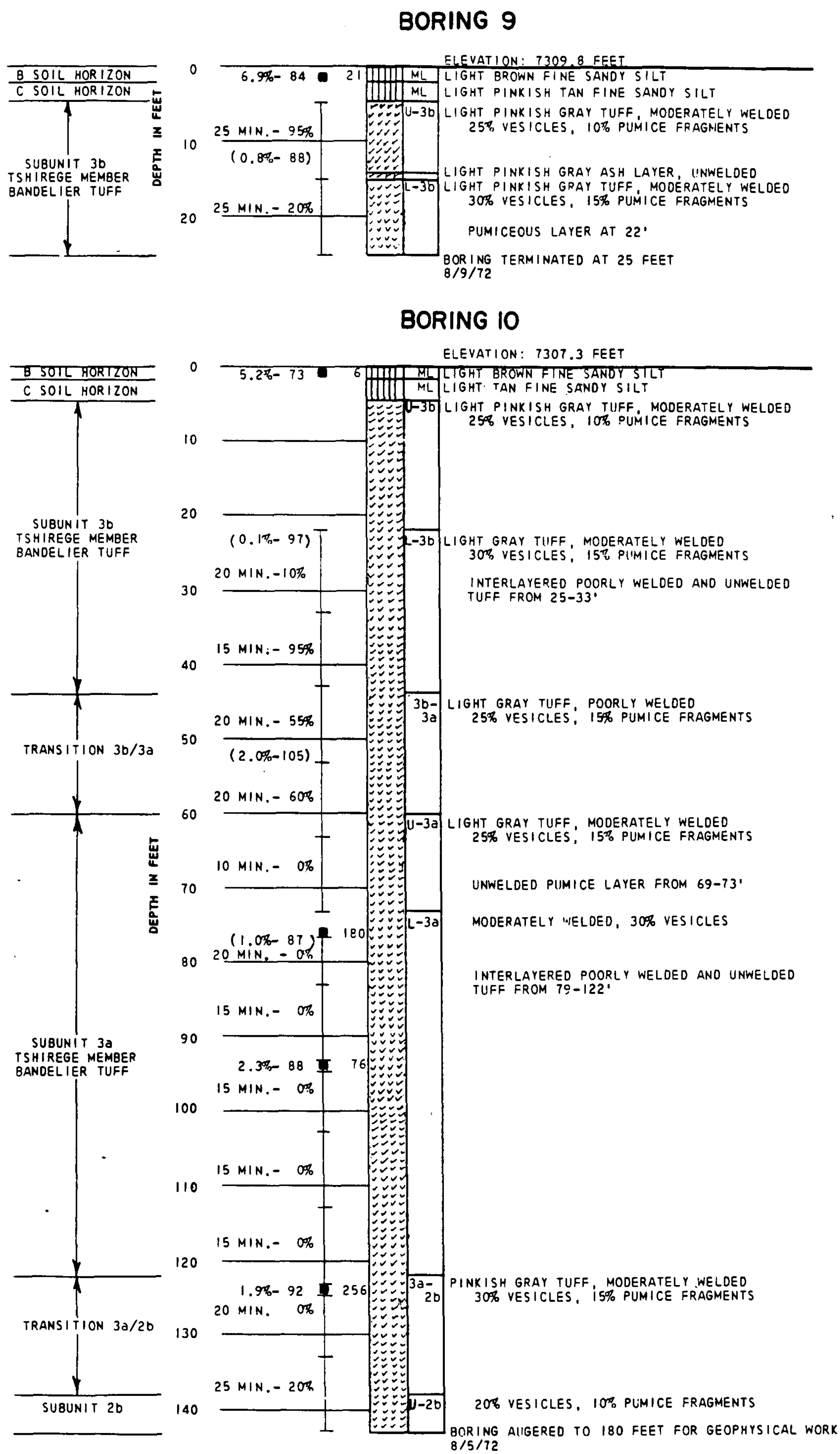


LOG OF BORINGS

DAMES & MOORE



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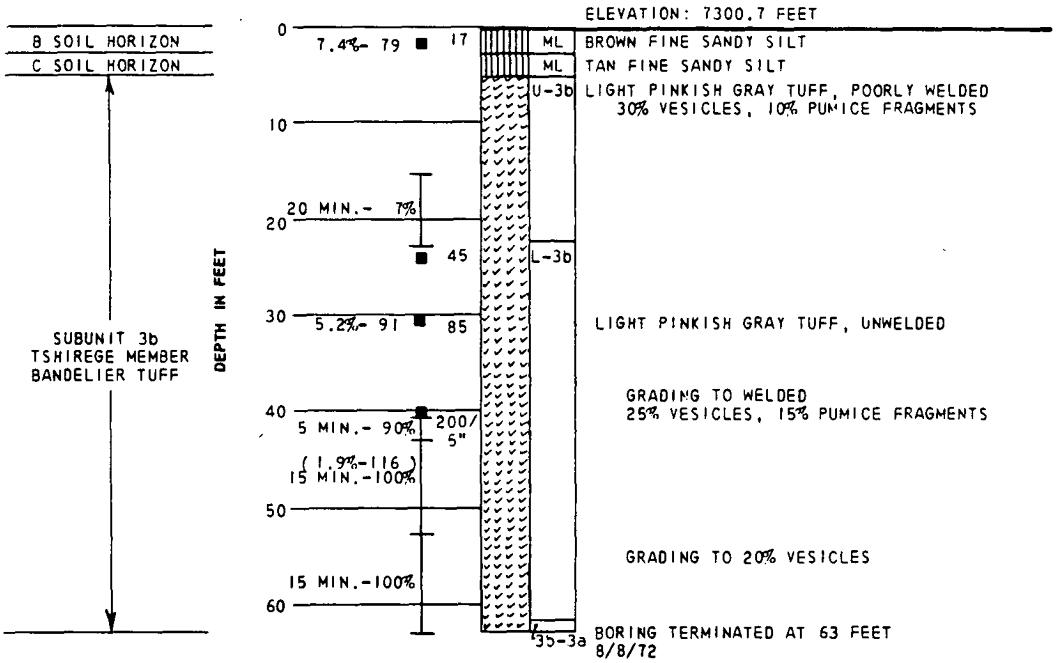
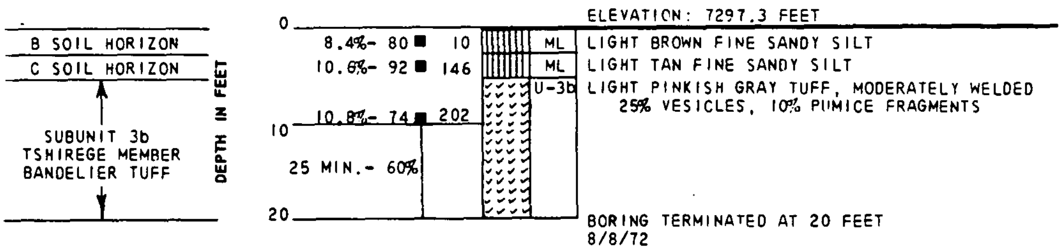
BORING 11



BORING 12

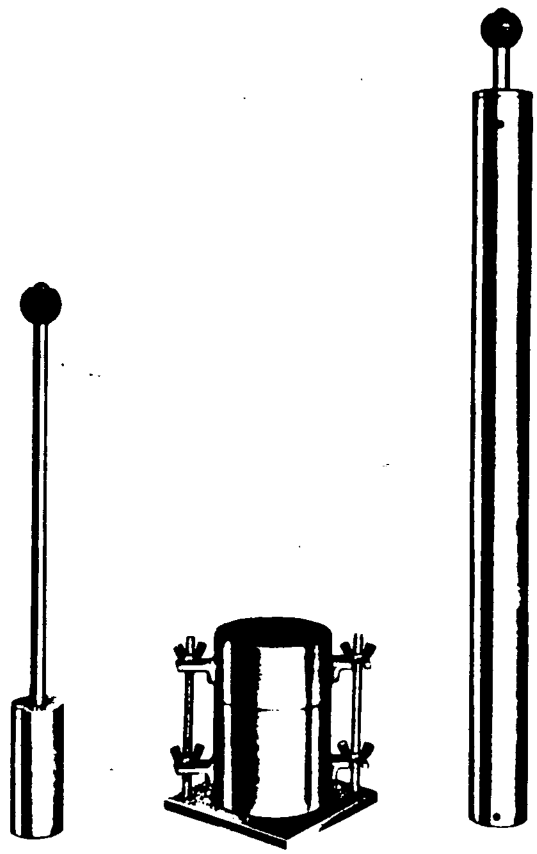


LOG OF BORINGS

METHOD OF PERFORMING COMPACTION TESTS

(STANDARD AND MODIFIED A.A.S.H.O. METHODS)

IT HAS BEEN ESTABLISHED THAT WHEN COMPACTING EFFORT IS HELD CONSTANT, THE DENSITY OF A ROLLED EARTH FILL INCREASES WITH ADDED MOISTURE UNTIL A MAXIMUM DRY DENSITY IS OBTAINED AT A MOISTURE CONTENT TERMED THE "OPTIMUM MOISTURE CONTENT," AFTER WHICH THE DRY DENSITY DECREASES. THE COMPACTION CURVE SHOWING THE RELATIONSHIP BETWEEN DENSITY AND MOISTURE CONTENT FOR A SPECIFIC COMPACTING EFFORT IS DETERMINED BY EXPERIMENTAL METHODS. TWO COMMONLY USED METHODS ARE DESCRIBED IN THE FOLLOWING PARAGRAPHS.



SOME APPARATUS FOR PERFORMING COMPACTION TESTS
Shows, from left to right, 5-1/2 pound rammer (sleeve controlling 12" height of drop removed), 1/30 cubic-foot cylinder with removable collar and base plate, and 10 pound rammer within sleeve.

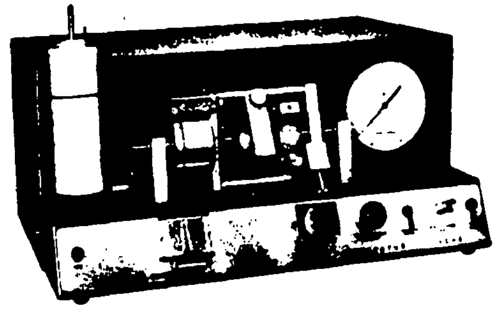
FOR THE "STANDARD A.A.S.H.O." (A.S.T.M. D698-58T & A.A.S.H.O. T99-57) METHOD OF COMPACTION A PORTION OF THE SOIL SAMPLE PASSING THE NO. 4 SIEVE IS COMPACTED AT A SPECIFIC MOISTURE CONTENT IN THREE EQUAL LAYERS IN A STANDARD COMPACTION CYLINDER HAVING A VOLUME OF 1/30 CUBIC FOOT, USING TWENTY-FIVE 12-INCH BLOWS OF A STANDARD 5-1/2 POUND RAMMER TO COMPACT EACH LAYER.

IN THE "MODIFIED A.A.S.H.O." (A.S.T.M. D-1557-58T & A.A.S.H.O. T 180-57) METHOD OF COMPACTION A PORTION OF THE SOIL SAMPLE PASSING THE NO. 4 SIEVE IS COMPACTED AT A SPECIFIC MOISTURE CONTENT IN FIVE EQUAL LAYERS IN A STANDARD COMPACTION CYLINDER HAVING A VOLUME OF 1/30 CUBIC FOOT, USING TWENTY-FIVE 18-INCH BLOWS OF A 10-POUND RAMMER TO COMPACT EACH LAYER. SEVERAL VARIATIONS OF THESE COMPACTION TESTING METHODS ARE OFTEN USED AND THESE ARE DESCRIBED IN A.A.S.H.O. & A.S.T.M. SPECIFICATIONS.

FOR BOTH METHODS, THE WET DENSITY OF THE COMPACTED SAMPLE IS DETERMINED BY WEIGHING THE KNOWN VOLUME OF SOIL; THE MOISTURE CONTENT, BY MEASURING THE LOSS OF WEIGHT OF A PORTION OF THE SAMPLE WHEN OVEN DRIED; AND THE DRY DENSITY, BY COMPUTING IT FROM THE WET DENSITY AND MOISTURE CONTENT. A SERIES OF SUCH COMPACTIONS IS PERFORMED AT INCREASING MOISTURE CONTENTS UNTIL A SUFFICIENT NUMBER OF POINTS DEFINING THE MOISTURE-DENSITY RELATIONSHIP HAVE BEEN OBTAINED TO PERMIT THE PLOTTING OF THE COMPACTION CURVE. THE MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE CONTENT FOR THE PARTICULAR COMPACTING EFFORT ARE DETERMINED FROM THE COMPACTION CURVE.

Method Of Performing Direct Shear and Friction Tests

Direct shear tests are performed to determine the shearing strengths of soils. Friction tests are performed to determine the frictional resistances between soils and various other materials such as wood, steel, or concrete. The tests are performed in the laboratory to simulate anticipated field conditions.



DIRECT SHEAR TESTING
& RECORDING APPARATUS

Each sample is tested within three brass rings, two and one-half inches in diameter and one inch in length. Undisturbed samples of in-place soils are tested in rings taken from the sampling device in which the samples were obtained. Loose samples of soils to be used in constructing earth fills are compacted in rings to predetermined conditions and tested.

Direct Shear Tests

A three-inch length of the sample is tested in direct double shear. A constant pressure, appropriate to the conditions of the problem for which the test is being performed, is applied normal to the ends of the sample through porous stones. A shearing failure of the sample is caused by moving the center ring in a direction perpendicular to the axis of the sample. Transverse movement of the outer rings is prevented.

The shearing failure may be accomplished by applying to the center ring either a constant rate of load, a constant rate of deflection, or increments of load or deflection. In each case, the shearing load and the deflections in both the axial and transverse directions are recorded and plotted. The shearing strength of the soil is determined from the resulting load-deflection curves.

Friction Tests

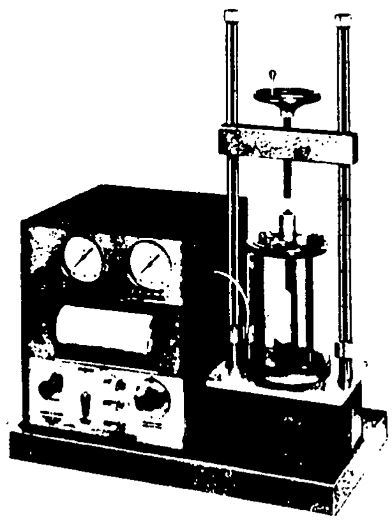
In order to determine the frictional resistance between soil and the surfaces of various materials, the center ring of soil in the direct shear test is replaced by a disk of the material to be tested. The test is then performed in the same manner as the direct shear test by forcing the disk of material from the soil surfaces.

417.1 (Rev. 4-61)

METHODS OF PERFORMING UNCONFINED COMPRESSION AND TRIAXIAL COMPRESSION TESTS

THE SHEARING STRENGTHS OF SOILS ARE DETERMINED FROM THE RESULTS OF UNCONFINED COMPRESSION AND TRIAXIAL COMPRESSION TESTS. IN TRIAXIAL COMPRESSION TESTS THE TEST METHOD AND THE MAGNITUDE OF THE CONFINING PRESSURE ARE CHOSEN TO SIMULATE ANTICIPATED FIELD CONDITIONS.

UNCONFINED COMPRESSION AND TRIAXIAL COMPRESSION TESTS ARE PERFORMED ON UNDISTURBED OR REMOLDED SAMPLES OF SOIL APPROXIMATELY SIX INCHES IN LENGTH AND TWO AND ONE-HALF INCHES IN DIAMETER. THE TESTS ARE RUN EITHER STRAIN-CONTROLLED OR STRESS-CONTROLLED. IN A STRAIN-CONTROLLED TEST THE SAMPLE IS SUBJECTED TO A CONSTANT RATE OF DEFLECTION AND THE RESULTING STRESSES ARE RECORDED. IN A STRESS-CONTROLLED TEST THE SAMPLE IS SUBJECTED TO EQUAL INCREMENTS OF LOAD WITH EACH INCREMENT BEING MAINTAINED UNTIL AN EQUILIBRIUM CONDITION WITH RESPECT TO STRAIN IS ACHIEVED.



TRIAXIAL COMPRESSION TEST UNIT

YIELD, PEAK, OR ULTIMATE STRESSES ARE DETERMINED FROM THE STRESS-STRAIN PLOT FOR EACH SAMPLE AND THE PRINCIPAL STRESSES ARE EVALUATED. THE PRINCIPAL STRESSES ARE PLOTTED ON A MOHR'S CIRCLE DIAGRAM TO DETERMINE THE SHEARING STRENGTH OF THE SOIL TYPE BEING TESTED.

UNCONFINED COMPRESSION TESTS CAN BE PERFORMED ONLY ON SAMPLES WITH SUFFICIENT COHESION SO THAT THE SOIL WILL STAND AS AN UNSUPPORTED CYLINDER. THESE TESTS MAY BE RUN AT NATURAL MOISTURE CONTENT OR ON ARTIFICIALLY SATURATED SOILS.

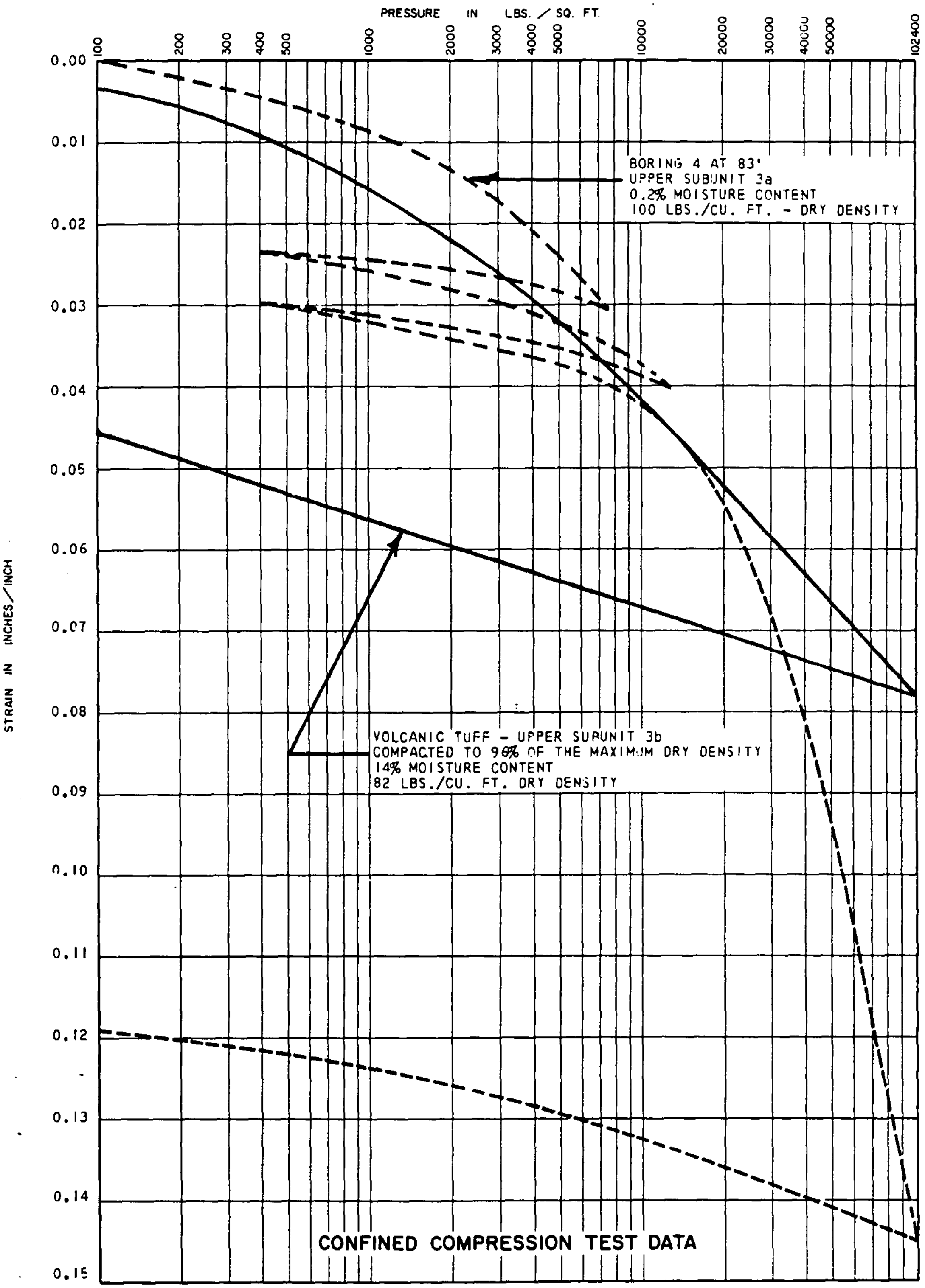
IN A TRIAXIAL COMPRESSION TEST THE SAMPLE IS ENCASED IN A RUBBER MEMBRANE, PLACED IN A TEST CHAMBER, AND SUBJECTED TO A CONFINING PRESSURE THROUGHOUT THE DURATION OF THE TEST. NORMALLY, THIS CONFINING PRESSURE IS MAINTAINED AT A CONSTANT LEVEL, ALTHOUGH FOR SPECIAL TESTS IT MAY BE VARIED IN RELATION TO THE MEASURED STRESSES. TRIAXIAL COMPRESSION TESTS MAY BE RUN ON SOILS AT FIELD MOISTURE CONTENT OR ON ARTIFICIALLY SATURATED SAMPLES. THE TESTS ARE PERFORMED IN ONE OF THE FOLLOWING WAYS:

UNCONSOLIDATED-UNDRAINED: THE CONFINING PRESSURE IS IMPOSED ON THE SAMPLE AT THE START OF THE TEST. NO DRAINAGE IS PERMITTED AND THE STRESSES WHICH ARE MEASURED REPRESENT THE SUM OF THE INTERGRANULAR STRESSES AND PORE WATER PRESSURES.

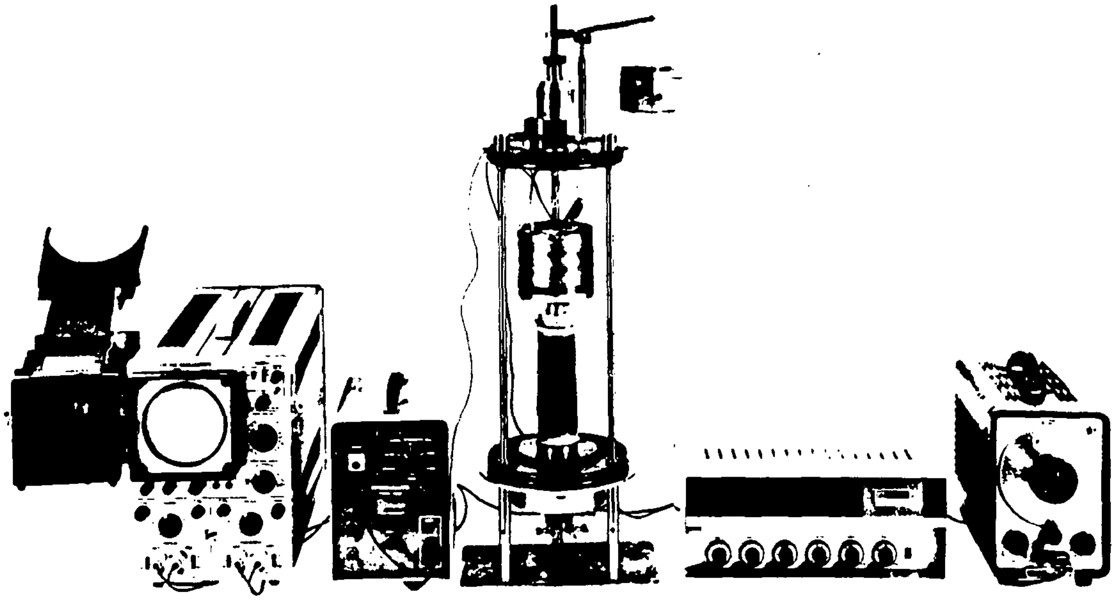
CONSOLIDATED-UNDRAINED: THE SAMPLE IS ALLOWED TO CONSOLIDATE FULLY UNDER THE APPLIED CONFINING PRESSURE PRIOR TO THE START OF THE TEST. THE VOLUME CHANGE IS DETERMINED BY MEASURING THE WATER AND/OR AIR EXPELLED DURING CONSOLIDATION. NO DRAINAGE IS PERMITTED DURING THE TEST AND THE STRESSES WHICH ARE MEASURED ARE THE SAME AS FOR THE UNCONSOLIDATED-UNDRAINED TEST.

DRAINED: THE INTERGRANULAR STRESSES IN A SAMPLE MAY BE MEASURED BY PERFORMING A DRAINED, OR SLOW, TEST. IN THIS TEST THE SAMPLE IS FULLY SATURATED AND CONSOLIDATED PRIOR TO THE START OF THE TEST. DURING THE TEST, DRAINAGE IS PERMITTED AND THE TEST IS PERFORMED AT A SLOW ENOUGH RATE TO PREVENT THE BUILDUP OF PORE WATER PRESSURES. THE RESULTING STRESSES WHICH ARE MEASURED REPRESENT ONLY THE INTERGRANULAR STRESSES. THESE TESTS ARE USUALLY PERFORMED ON SAMPLES OF GENERALLY NON-COHESIVE SOILS, ALTHOUGH THE TEST PROCEDURE IS APPLICABLE TO COHESIVE SOILS IF A SUFFICIENTLY SLOW TEST RATE IS USED.

AN ALTERNATE MEANS OF OBTAINING THE DATA RESULTING FROM THE DRAINED TEST IS TO PERFORM AN UNDRAINED TEST IN WHICH SPECIAL EQUIPMENT IS USED TO MEASURE THE PORE WATER PRESSURES. THE DIFFERENCES BETWEEN THE TOTAL STRESSES AND THE PORE WATER PRESSURES MEASURED ARE THE INTERGRANULAR STRESSES.


PRESSURE IN LBS. / SQ. FT.
100
200
300
400
500
1000
2000
3000
4000
5000
10000
20000
30000
40000
50000
102400
STRAIN IN INCHES / INCH
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
BORING 4 AT 83'
UPPER SUBUNIT 3a
0.2% MOISTURE CONTENT
100 LBS./CU. FT. - DRY DENSITY
VOLCANIC TUFF - UPPER SUBUNIT 3b
COMPACTED TO 96% OF THE MAXIMUM DRY DENSITY
14% MOISTURE CONTENT
82 LBS./CU. FT. DRY DENSITY
CONFINED COMPRESSION TEST DATA

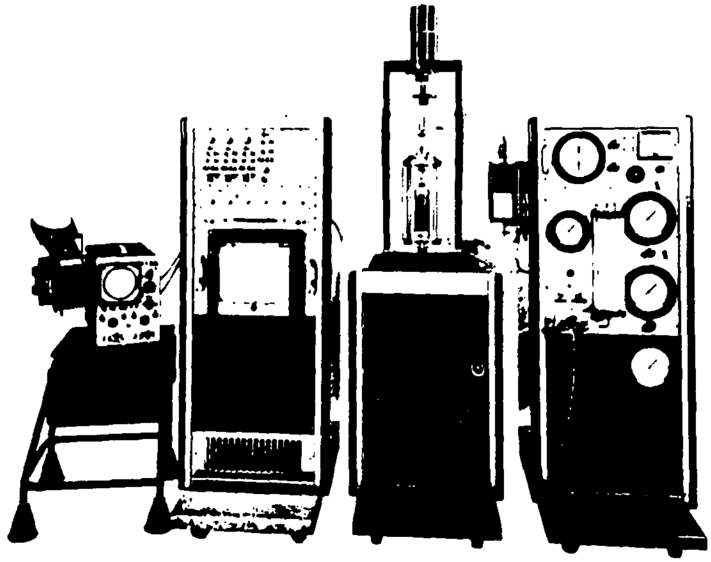
Methods Of Performing Resonant Column Tests



Resonant column tests are performed to evaluate the dynamic properties of the soil or rock samples. Utilizing the resonant column apparatus, a cylindrical column of soil or rock is subjected to a steady state sinusoidal forcing function, which stresses the sample in torsion. The frequency of the applied force is varied until the resonant frequency of the soil apparatus system is obtained. The resonant frequency is that which produces the maximum amplitude of output recorded. The resonant frequency thus obtained is related to the torsional shear modulus of the material tested.

Resonant column tests are performed on undisturbed or reconstituted cylindrical samples of soil approximately 6 inches in length and 2½ inches in diameter. The samples are encased in a rubber membrane and placed in a test chamber. The tests may be performed confined or unconfined on soils at field moisture or on artificially saturated samples. The apparatus employs a vibration excitation device, powered by a variable frequency sine wave genfrator which applies a forcing torque to the free end of the specimen. The resulting vibrations are measured by an accelerometer which produces a calibrated output that is a measure of the angular acceleration of the free end of the specimen. The sinusoidal voltage used to produce the forcing torque and the output of the accelerometer are displayed on the X-Y axes of the oscilloscope resulting in elliptical configurations for associated frequencies. These elliptical loops are photographed and evaluated to determine the damping characteristics of the samples tested.

METHODS OF PERFORMING PULSATING LOAD TRIAXIAL TESTS



PULSATING AXIAL LOAD TESTS ARE PERFORMED TO EVALUATE THE DYNAMIC PROPERTIES AND THE LIQUEFACTION POTENTIAL OF THE SOILS UNDER SIMULATED ANTICIPATED FIELD LOADING CONDITIONS.

PULSATING LOAD TESTS ARE STRESS CONTROLLED AND ARE PERFORMED ON UNDISTURBED OR RECONSTITUTED SAMPLES OF SOIL APPROXIMATELY 6 INCHES IN LENGTH AND 2½ INCHES IN DIAMETER. THE SAMPLES ARE ENCASED IN A RUBBER MEMBRANE, PLACED IN A TEST CHAMBER AND SUBJECTED TO CONFINING PRESSURE THROUGHOUT THE DURATION OF THE TEST. THE TESTS MAY BE RUN ON SOILS AT FIELD MOISTURE CONTENT OR ON ARTIFICIALLY SATURATED SAMPLES. THE TRIAXIAL EQUIPMENT ACTING THROUGH A BELLOFRAM SYSTEM APPLIES A PULSATING AXIAL LOAD. THE CYCLING SPEED OF THE LOAD CAN BE VARIED BETWEEN ½ TO 5 CYCLES PER SECOND TO SIMULATE THE FIELD LOADING FREQUENCY.

DYNAMIC PROPERTIES DETERMINATION

TO EVALUATE THE DYNAMIC PARAMETERS, THE SOIL SAMPLE IS LOADED IN CYCLIC COMPRESSION. THE LOAD AND DEFLECTION ARE RECORDED ON TWO CHANNELS OF A RECORDING OSCILLOGRAPH. BY TAPPING THE OUTPUT OF THE LOAD AND DEFLECTION TRANSDUCERS AND APPLYING THESE TO VERTICAL AND HORIZONTAL PLATES, RESPECTIVELY, OF A CATHODE RAY OSCILLOSCOPE, A HYSTERESIS LOOP IS PRODUCED. THIS LOOP IS PHOTOGRAPHED, AND THE PHOTOGRAPH IS USED TO EVALUATE THE DAMPING VALUE PRESENT. THE PROCEDURE IS REPEATED AT VARIOUS STRAIN AMPLITUDES TO EVALUATE THE DYNAMIC PROPERTIES IN THE RANGE OF INTEREST ON A PARTICULAR SAMPLE. THE LOAD AND DEFLECTION VALUES OBTAINED FROM THE OSCILLOGRAPH ARE USED TO EVALUATE THE DYNAMIC MODULI OF ELASTICITY.

LIQUEFACTION POTENTIAL

TO EVALUATE THE LIQUEFACTION POTENTIAL, THE SOIL SAMPLE IS SUBJECTED TO AXIAL CYCLIC LOADING. THE MAGNITUDE, FREQUENCY, DURATION AND SEQUENCE OF LOADING IS DETERMINED ON THE BASIS OF PAST EARTHQUAKE RECORDS. THE LOAD, DEFLECTION, AND PORE PRESSURE ARE RECORDED ON THREE CHANNELS OF A RECORDING OSCILLOGRAPH. THESE RECORDS ARE USED TO EVALUATE THE LIQUEFACTION POTENTIAL FOR THAT PARTICULAR SOIL TYPE UNDER THE TEST CONDITIONS.

the geophones to the ground. As a result, the time-distance plots are based largely upon secondary cycles of the compressional wave train. These secondary cycles generally show a consistently lower apparent velocity than the true first arrival of the wave train would show. This is due to the shift towards lower frequencies for the secondary cycles as the distance from the shot increases.

It can also be seen from the results of the uphole survey that the site contains a layer of lower-velocity material sandwiched between two layers of higher-velocity material. This low-speed layer cannot be detected by the seismic refraction method; consequently, there is no reliable information available about this layer or anything below it from the seismic refraction survey. Depth calculations cannot be made for the deeper high-speed layer.

The accuracy of the computed compressional-wave velocities is considered to be $\pm$ 15 percent.

CROSS-HOLE SURVEY

The cross-hole method was used to determine shear-wave velocities. Special three-component bore hole geophones (Mark Products L1-3DS, 4.5Hz) were placed in Borings B-10 and B-4. Explosive charges were detonated at in-line distances of 1000 and 1500 feet from these borings (Plate SA-1). The resultant seismic energy was recorded at successive 25-foot intervals in each boring. Each shot was recorded with the

the geophysical surveys is presented below. The locations of these surveys are shown on Plate SA-1.

UPHOLE SURVEY

An uphole velocity survey was performed in Boring B-4 to provide a check on the compressional-wave velocities determined from the seismic refraction survey. The boring was uncased and dry.

Explosive charges were placed in drill holes to depths of 7 feet. These drill holes were offset from the boring at distances of 15 to 30 feet. The seismic energy released by each explosive charge was detected in the boring by 12 geophones, spaced 25 feet apart, affixed to a special cable. The seismic energy detected by the geophones was recorded by an Electro-Tech Lab M4-E seismic amplifier coupled with an SDW-100 recording oscillograph. Some check shots were made in this hole using the vertical trace of a Mark Products L1-3DS, 4.5Hz geophone.

The data points on Plate SA-2 show a wide scatter on both sides of the interpreted best-velocity values. The cause for this wide scatter of data is the extreme absorption of seismic energy near the explosive charges. It is believed that the velocity values shown on the figure are reasonably good even though each individual data point is highly questionable.

SEISMIC REFRACTION SURVEY

A seismic refraction survey was performed on the site to evaluate compressional-wave velocities of the various materials. The survey was conducted along two intersecting seismic lines for a total length of 1600 lineal feet. The seismic lines were positioned to crisscross the proposed facility, while avoiding the possibility of damaging any underground utilities with the explosives. The lines are shown on Plate SA-1.

The seismic energy used in this survey was produced by the detonation of explosive charges placed in drill holes. The drill holes ranged in depth from 15 to 20 feet. The energy released by the explosives was picked up by verticially-oriented geophones fitted with a spike for coupling with the underlying soil. The geophones, manufactured by Electro-Tech Labs, have a natural frequency of 14Hz.

The energy picked up by the geophones was recorded by the same equipment used in the uphole velocity survey.

The compressional wave velocities were evaluated by plotting arrival times of the seismic energy at each geophone against the distance of each geophone from the energy source. The time distance data for each seismic line are shown on Plates SA-3 and SA-4.

The character of the near-surface materials and the lack of a water table at this site cause extreme absorption of seismic energy near the explosive charges and poor coupling of

APPENDIX S

GEOPHYSICAL SURVEYS

INTRODUCTION

The purpose of the geophysical surveys performed was to obtain in situ measurements of the compressional and shear-wave velocites of the materials at the site and to obtain other pertinent site parameters for use in earthquake design analysis of the proposed plutonium processing facility. The following geophysical surveys were performed at the site:

1. A seismic refraction survey to evaluate the compressional wave velocities of the various site materials,
2. An uphole velocity survey to further define the compressional wave velocities,
3. A cross-hole velocity survey to evaluate shear-wave velocities of the various site materials,
4. A surface wave survey to evaluate near-surface, shear-wave velocities and to determine site parameters such as characteristic site frequency and surface wave types.

FIELD WORK

The field work was performed from August 8 to August 15, 1972, under the direction of a geophysicist, who recorded and interpreted the field data. All explosives were handled, stored, and detonated by a licensed powderman. A description of each of

FILE 0651-120
LOS ALAMOS
BY JSF DATE 11-13-72
CHECKED BY DATE

REVISIONS
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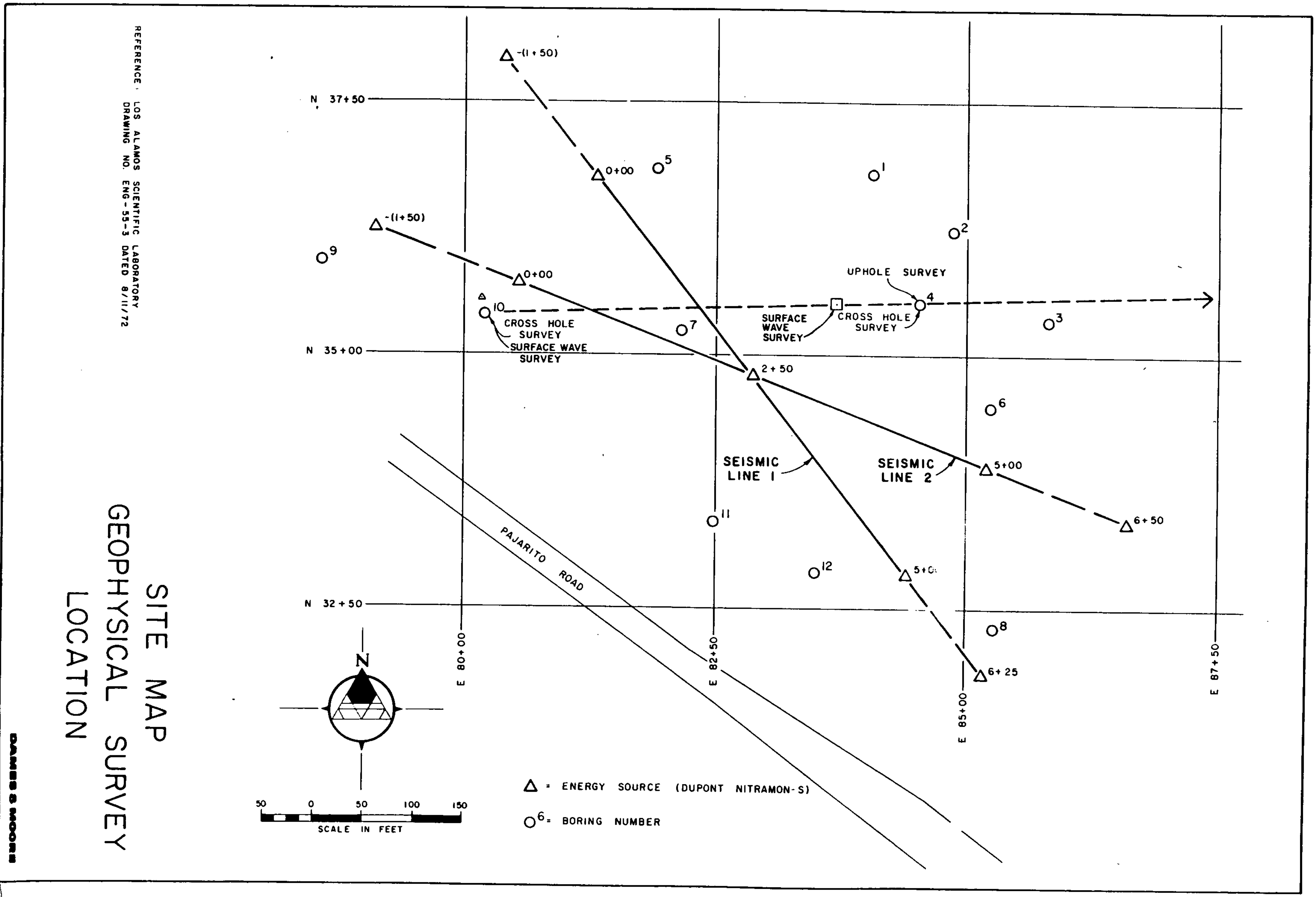
PLATE OF



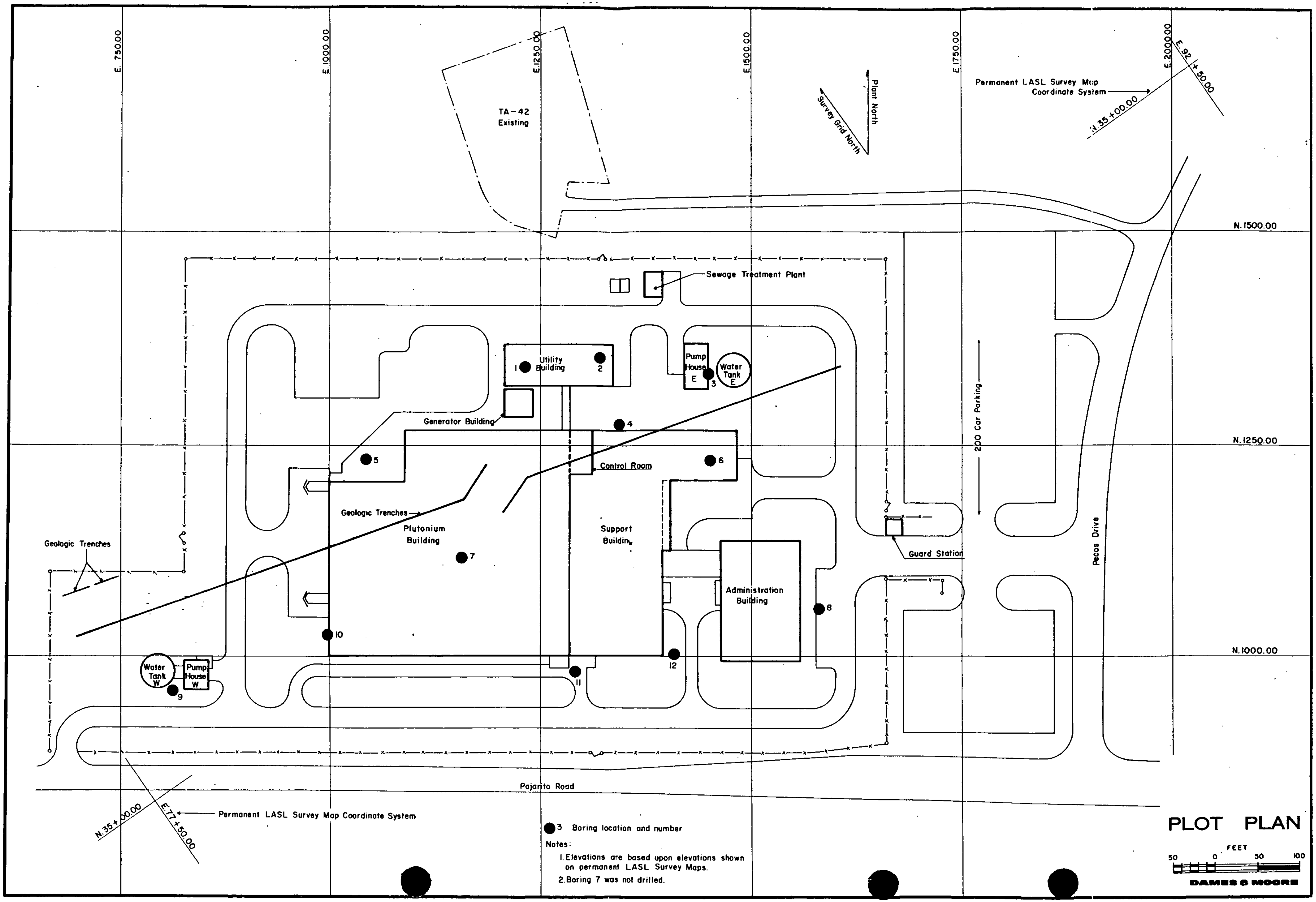

E 750.00
E 1000.00
E 1250.00
E 1500.00
E 1750.00
E 2000.00
E 92 + 50.00
N 35 + 00.00
Permanent LASL Survey Map Coordinate System
TA - 42 Existing
Plant North
Survey Grid North
N. 1500.00
N. 1250.00
N. 1000.00
Sewage Treatment Plant
Utility Building
Pump House E
Water Tank E
Generator Building
Control Room
Geologic Trenches
Plutonium Building
Support Building
Administration Building
Guard Station
200 Car Parking
Pecos Drive
Water Tank W
Pump House W
Pajarito Road
N. 35 + 00.00
E. 77 + 50.00
Permanent LASL Survey Map Coordinate System
3 Boring location and number
Notes:
1. Elevations are based upon elevations shown on permanent LASL Survey Maps.
2. Boring 7 was not drilled.
PLOT PLAN
FEET
50 0 50 100
DAMES & MOORE

PLATE F-1

FOUNDATION INVESTIGATION

PROPOSED CONSTRUCTION

The major structures to be included in the facility are shown on the Plot Plan, Plate F-1. They include both Class 1 and Class 3 structures, as tabulated below:

Class 1 Structures	Class 3 Structures
Plutonium Building	Support Building (Except Control Room)
Control Room	Administration Building
Generator Building	Utility Building
Pump Houses (2)	Sewage Treatment Plant
Water Tanks (2)	Guard Station

The Class 1 structures will be designed for all combinations of normal loading and the Operating Basis and Safe Shutdown Earthquakes. All of the Class 1 structures except the pump houses and water tanks will also be designed for the AEC M1 Tornado.

The Class 3 structures will be designed for all normal loads and for UBC Zone 2 earthquake criteria.

The structures will be interconnected by a system of asphaltic concrete roads, and there will be a 200-car asphaltic concrete parking lot east of the guard station.

The plutonium building will be a two level reinforced concrete structure approximately 265 by 285 feet in plan dimensions. Lateral seismic loads will be resisted by floor slab and roof slab diaphragms transmitting the forces to vertical shear walls. There will be basically six of these shear walls, the four exterior walls, and one interior wall in each direction. They will be supported by continuous wall foundations designed to support vertical loads by bearing on the rock foundation material and designed to resist lateral forces by shear through the rock parallel to and acting along the bottom and the two sides of each wall foundation.

Vertical wall loads will range from 10 to 35 kips dead load and 1 to 10 kips live load per linear foot of wall. The lateral seismic loads will range from 20 to 50 kips per linear foot of shear wall.

Interior columns for the plutonium building will be supported by shallow spread foundations carrying one or two columns each. Loads for single columns will be approximately 60 to 70 kips dead load 60 to 70 kips live load. Columns on combined footings will have loads of approximately 300 kips dead load and 125 kips live load per column.

A common foundation will be used where the control room and support building abut the plutonium building.

The generator building and control room will be small single-story reinforced concrete structures with roof diaphragms and shear walls. They will be supported by continuous wall foundations; the vertical wall loads will be about 5 to 10 kips per linear foot dead load and up to 1.0 kip per linear foot live load. The lateral seismic loads will be about 3 kips per linear foot.

All other buildings, except the guard station, will be single-story reinforced concrete block buildings with floor slabs poured at grade, roof diaphragms, and shear walls. Vertical wall loads will range from about 1 to 2 kips per linear foot dead load and up to 1.0 kip per linear foot live load. Individual column loads in the support building and administration building will be light, as will the lateral seismic loads for these single story structures.

The guard station will be a light building of prefabricated metal panel construction. The water tanks will be steel tanks approximately 40 feet in diameter and 20 feet high supported on crushed rock pads and concrete ring walls. The sewage treatment plant will consist of a low reinforced concrete tank.

PURPOSES

The purposes of the foundation investigation were to:

1. Explore the subsurface conditions at the site to the depths which will be significantly influenced by the proposed construction.
2. Provide recommendations regarding site preparation and grading, including:
   a) Stripping.
   b) Ease of excavation of volcanic tuff.
   c) Use of excavated materials for fill.
   d) Criteria for placing and compacting fill.

3. Recommend foundation types and provide criteria for design of foundations, including:
   a) Allowable bearing pressures for vertical loads.
   b) Estimated settlements.
   c) Allowable shear values for lateral loads.
4. Recommend lateral active and passive pressures on walls and foundations.
5. Provide recommendations for tank foundations.

The field explorations and laboratory tests performed for the foundation investigation are described in Appendix F.

SITE CONDITIONS

The surface of the site slopes gently downward towards the north and northeast, ranging in elevation from 7310 at the southwest corner to 7270 along the northerly side. The site is blanketed by a relatively thin cover of residual soil formed by in-place weathering of the underlying volcanic tuff. The thickness of the soil is about four feet. There is no apparent A soil horizon and the vegetation is sparse. The B soil horizon consists of tan sandy silt with some gravel; the C soil horizon is similar but is coarser and contains more gravel, cobbles, and larger sized pieces of the underlying rock.*

The underlying volcanic bedrock consists of various units and subunits of the Tshirege member of the Bandelier tuff. These units are described in the text and on the cross sections in the geology section of this report.

The excavation for the plutonium building will be mostly within upper Subunit 3b of the Tshirege member; it will penetrate down to lower Subunit 3b in a few spots. More detailed descriptions of the subsurface strata are presented on the Log of Borings, Plates FA-1A through FA-1E in Appendix F.

The following conclusions were reached concerning the site conditions:

1. There is no ground water within the depth that will be influenced by the proposed construction.
2. According to local sources, the depth of frost penetration at the site is about 2-1/2 feet.

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* A, B, and C soil horizons are soil science terms used to describe the agricultural soil profile. The A horizon lies at the surface and is characterized by high biotic activity and the accumulation of organic matter. The B horizon comes next and includes layers in which deposition from above, or even from below, has taken place. It is the zone of accumulation of colloidal materials. The A and B horizons together are called the "solum," that is, the portion of the profile developed by soil building processes as distinguished from the parent material immediately below. The C horizon is the relatively unaltered or parent material.

3. The B horizon and the C horizon soils were found to have a low potential for expansion or contraction with changes in moisture content. Therefore, they would be classified as slightly expansive. This should not be a problem in design of the proposed facilities.
4. There is not a substantial change in the strength characteristics of the tuff or of the soil with changes in moisture content.
5. There will be no significant change in strength or compressibility characteristics of the foundation materials due to earthquake motions.
6. There is no evidence of landsliding, erosion, sinkholes, depressions, subsidence, or other undesirable features on the site.

DISCUSSION AND RECOMMENDATIONS

GRADING

Stripping

The site should be stripped only to the extent necessary to remove the sparse surface vegetation and the majority of the roots. There is no layer of organic topsoil that requires stripping. It is estimated that the average depth of stripping required will be less than three inches. The stripped material is not suitable for compacted fill but may be used for landscaping.

Excavation

The basement excavation for the plutonium building will extend to about Elevation 7280, a depth of 10 to 25 feet below existing grade. Except for the 3- to 5- foot soil overburden, the excavation will be in the volcanic tuff rock. The tuff can be easily excavated by ripper, scraper, backhoe, or other conventional equipment. Blasting will not be required.

We recommend overexcavation, and replacement with select compacted fill, under floors and foundations where required to provide a uniform thickness of compacted fill under the floors and foundations and thus avoid discontinuities that might result in differential settlement. The need for this depends on the relationship between existing grades, planned grades, and the rock surface. Guidelines for evaluating the need for such overexcavation and replacement are summarized in the

Foundation Design Data section later in this report.

Use of Excavated Materials

The excavated soil and rock will be suitable for use as fill and backfill, either separately or mixed together. The rock will break up when excavated and can be further crushed by construction traffic and compaction equipment. The soil and crushed rock materials can be most readily compacted by sheepsfoot or vibratory compaction equipment.

Treatment of Overexecavated Areas

Areas that may be inadvertently overexcavated should be replaced by compacted fill or by lean concrete depending on where it might occur. (This does not apply to areas that are intentionally overexcavated.) If the overexcavation is for foundations and in rock, we recommend replacing it with lean concrete. In soil or compacted fill, it should be replaced with compacted fill. Compacted base course material, sand or compacted fill could be used to replace minor thicknesses of overexcavation under floors or pavements.

Part of the site was overexcavated when the geologic trenches were dug during our investigation. The locations of the trenches are shown on the Plot Plan, Plate F-1.
The main trench was about three to four feet wide and eight feet deep with essentially vertical sides. The supplementary, shorter trenches at the west end of the site were about 15 to 20 feet deep, and also three to four feet wide.

Compaction tests on samples of the crushed rock show a fairly flat compaction curve which indicates that the density achieved for a given compactive effort is not highly sensitive to variations in moisture content of a few percent. It is suggested that crushed rock fill be placed and compacted at a moisture content three to five percent dry of optimum in order to minimize problems that could be encountered when the rock breaks down into smaller particles with continued working and compaction. As reported by Mr. Roland A. Pettitt of the Zia Co.*, the maximum density increases and the optimum water content decreases as the particles get smaller.

As discussed in the referenced paper, the addition of about two percent cement might be considered to lower compaction requirements in some instances, such as in backfilling utility trenches.

The results of compaction tests performed on the two soil horizons and the rock to be obtained from the plutonium building excavation are presented on Plate FA-3 in Appendix F. Additional compaction tests should be performed during construction on the mixtures of these materials actually being used for fill and backfill. It is suggested that the procedures for testing the compacted fill outlined in the referenced paper be followed for this project.

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*Pettitt, Roland A., "Cement Stabilization of Volcanic Materials," Journal of the Construction Division, ASCE, Vol. 93, No. CO1, Proc. Paper 5149, March, 1967, pp. 11-25.

The trenches were loosely backfilled upon completion. This backfill will be removed in some areas by site grading. Where the site grading does not extend below the bottoms of the geologic trenches, the loose backfill should be removed and replaced with lean concrete or compacted fill according to the above criteria. This should be done as a part of the construction contract for the project.

Filling and Backfilling

Cut surfaces in soil should be surface rolled and compacted in all areas that will support foundations, floors, pavement, sidewalks, or other structures. This should also be done prior to placing fill in fill areas, except where the thickness of fill is five feet or more. The surfaces should be watered to bring the soil to optimum moisture content and compacted, to a depth of 12 inches, to at least 95 percent of the maximum dry density*.

Rock used for fill should be crushed during the excavation, placement, and compaction operations so that no pieces exceed 3 inches in diameter and so that at least 50 percent of the fill material passes the No. 4 sieve, after compaction. All structural fill and backfill behind walls should be placed in lifts 6 to 8 inches in loose thickness and compacted to at least 95 percent of the maximum dry density. Utility trench backfill also should be compacted to the same requirements.

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*In this report, the maximum dry density refers to that determined by ASTM compaction test designation D 1557.

velocity is calculated. The resultant shear-wave velocities are presented on Plate S-4 of the Seismology Section.

SURFACE WAVE SURVEY

A surface-wave survey was conducted along a 2300-foot line. Explosive charges were detonated at distances of up to 2300 feet from the surface-wave recording locations shown on Plate SA-1. The dashed line indicates the in-line direction of the shot locations. The resultant energy was recorded by two Sprengnether Engineering Seismograph geophones. These geophones simultaneously record ground motions in three directions. The amplified output of these geophones was recorded by an Electro-Tech Labs- SDW-100 recording oscillograph. The geophones were placed 350 feet apart for this survey.

No large amplitude surface waves were generated by the use of explosives at this site. The amplitudes of all of the secondary arrivals are no more than two or three times larger than the first arrival compressional waves. This indicates that no appreciable amplification of seismic energy occurs at this site when it is excited by explosives detonated at shallow depths.

Two low-amplitude, high-frequency waves are generated at the site with apparent velocities between 2000 and 2400 feet per second and with frequencies of about 25Hz. These waves are not well developed, and their wave trains are only about two or three cycles long. They are probably trapped or bore hole geophones maintained at the same elevation in the respective bore holes. The resultant seismic energy was recorded by the same instrument system that was used for the uphole and seismic refraction surveys.

The resultant field records are analyzed for compressional-wave arrivals and shear-wave arrivals. Shear-wave arrivals are often masked by compressional-wave arrivals or by large-amplitude motion induced by surface wave systems, or a combination of both.

It is often necessary, in analyzing the field records, to align all the records in the sequence shot. This aids in defining continuity of a seismic event from the first record to the last record. After continuity of a specific seismic event is established, then each event on each record is analyzed. This analysis takes into account the frequency content, the cyclic phase of motion and the amplitude of the seismic energy received on each trace. These factors, coupled with a knowledge of the site geology and geometry, will yield the characteristics of the shear and surface-type wave arrivals. Knowledge of these characteristics is then applied to each trace on each record in the selection of the best pick of shear arrival. The time of the best pick of shear arrival, as determined from the analysis, is applied to wave path diagrams determined for the site. Differential distances and arrival times are computed for each geophone, and the shear-wave major broken rock zones are encountered. Some broken rock zones were encountered in our geologic trench, particularly west of the proposed plutonium building. These zones generally do not exceed 12 feet in depth below the existing ground. They can be expected to occur at random locations anywhere on the mesa, so the excavation should be closely inspected as it is made and the slopes flattened if necessary.

Permanent Cut and Fill Slopes

Permanent cut slopes in the rock can be the same as for temporary cuts; they would probably be cut flatter for aesthetic reasons.

We recommend that permanent cut and fill slopes in the natural soil or compacted fill be constructed at 1-1/2 horizontal to 1 vertical or flatter. On fill slopes, if the required degree of compaction (95 percent) cannot be attained by rolling on the sloped surfaces, the slopes should be overfilled and then cut back until the compacted inner core is exposed.

Measures should be provided to control erosion on the slopes. We understand that good slope erosion control methods have been developed locally from experience.

FOUNDATION DESIGN DATA

Recommended Foundation Types

We recommend that the proposed structures be supported on spread foundations which include continuous wall foundations and single or combined column foundations. The foundations may be established on the rock, on compacted fill or on natural soil depending on the loads and the relationships between existing grades, planned grades and the rock surface.

The type of foundation support should be uniform for each structure. We recommend overexcavation and replacement with compacted fill under floors and foundations, where required to provide a uniform thickness of compacted fill under floors and foundations. Guidelines for evaluating where to establish foundations and overexcavation and replacement under foundations, floors, and tanks are summarized below:

1. Where the final grades for a structure are such that foundations at a uniform depth would be partially on rock and partially on soil, then all the foundations for that structure should be established on the rock.
2. Except for very light buildings, such as the guard station, foundations should not be placed in the natural soil, because this might result in foundations for a structure being partially on natural soil and partially on compacted fill. In these cases, the natural soils should be overexcavated and replaced with fill compacted to at least 95 percent of the maximum dry density. The overexcavation should

extend to a depth of three feet below the bottoms of the foundations, and the excavations should be at least twice the width of the foundations.

3. Unless they are on rock, ground floor slabs should be underlain by at least two feet of compacted fill. It may be necessary to over-excavate under portions of some floors to accomplish this.

4. The water tank bottoms, as well as the ring walls, should have uniform support. Unless the entire tank bottom is on rock, the tank area should be leveled and then raised to the desired grade by placing compacted fill to result in a minimum thickness of five feet of compacted fill and base course under the tank bottom.

Minimum Width

Foundations for heavy structures on rock or soil should be at least two feet wide. Foundations for light buildings and tanks should be at least one foot wide.

Frost--Minimum Depth

The depth of frost penetration and the grain size of the soils would make foundations susceptible to frost heave if there were a source of water. We recommend that the site be graded, or other measures taken, to assure that there will be no ponding of surface water adjacent to structures that might seep under foundations. This will prevent frost heave under foundations, and the exterior foundations will not necessarily need to be installed below frost depth. We recommend that all foundations be installed at least 18 inches below the lowest adjacent grade.

Foundation Installation

Care must be exercised during construction to prevent intrusion of water into foundation and basement excavations. We suggest using temporary berms or ditches around the plutonium building basement excavation to keep surface runoff from flooding the excavation during rains. Rock, natural soil, or compacted fill material that might become softened to a depth of a few inches by ponded water should be removed prior to placing concrete for foundations or floors.

The foundation excavations should be inspected to assure that all loose material is removed prior to placing concrete.

Bearing Pressures, Class 1 Structures

Spread foundations on the volcanic tuff rock can be designed using an allowable bearing pressure of 12,000 pounds per square foot. On compacted fill or natural soil, we recommend an allowable bearing pressure of 5,000 pounds per square foot. These are gross pressures; the weights of the foundations should be included when computing dead loads. The recommended bearing pressures apply for the total of dead load plus live load and are for a calculated factor of safety of 3.0. They may be increased by 25 percent when considering operating basis earthquake loads or by 50 percent when considering safe shutdown earthquake or tornado loads.

Bearing Pressures, Class 3 Structures

Spread foundations can be designed using an allowable gross bearing pressure of 12,000 pounds per square foot on the rock or 5,000 pounds per square foot on compacted fill or natural soil. These values apply for the total of dead load plus live load and are for a calculated factor of safety of 3.0. They may be increased by 20 percent when considering UBC earthquake loads.

Estimated Settlements

Estimated settlements of foundations are small and should not be a problem. It is estimated that settlements of the plutonium building foundations, designed in accordance with our recommendations, will be 1/4 of an inch or less. Settlements of lighter buildings on rock foundations will be even smaller. Foundations on compacted fill or natural soil, such as the control room foundations, will be on the order of 1/3 of an inch or less. The settlements will essentially be elastic and will occur as the loads are applied.

Lateral Seismic Loads

Lateral seismic loads on foundations in rock can be resisted by shear through the rock along the bottom and the two sides of the foundation parallel to the direction of loading. We recommend an allowable shear value of 3500 pounds per square foot for Class 1 structures (SSE loads) and 2800 pounds per square foot for Class 3 structures. The recommended values are for factors of safety of 4 and 5 respectively.

The shear along the bottom of foundations applies as long as there is no theoretical uplift on the foundation. The shear should be assumed to be independent of the bearing pressure on the bottoms of the foundations, as long as the pressure is positive downward (no uplift). This is because the major portion of the shear strength of the rock is due to welding and not "internal friction."

To develop this shear, the sides and bottoms of the foundation excavations should be sufficiently rough or irregular so that the shear failure would be forced to act through the rock rather than along a smooth plane between the concrete and rock. In our judgment, the excavation surfaces can be considered sufficiently rough or irregular if there is the equivalent of a one-inch key or notch for each foot of length along the excavation. It will be important to make the intent of this requirement clear in the plans and specifications so that the bidders do not get the impression that a lot of hand work or "sculpturing" of the rock will be required. It is considered that the desired results can be achieved by the excavating equipment. The foundation excavations should be inspected carefully prior to placing the concrete to confirm that the surfaces are sufficiently rough or irregular and that no major zones of broken rock are present.

The foundation excavations should be cut with vertical sides and the concrete placed neat without forms. It will be important to vibrate the concrete into place thoroughly and to place it at the proper water-cement ratio, and possibly with an additive, to minimize shrinkage of the concrete during curing.

Lateral passive pressure on the sides of foundations perpendicular to the direction of loading would also provide resistance to lateral forces. For foundations poured neat in sound rock, a pressure of 8000 pounds per square foot can be used for design. Because of differing mechanics of failure, the lateral pressure and shear values should not be combined.

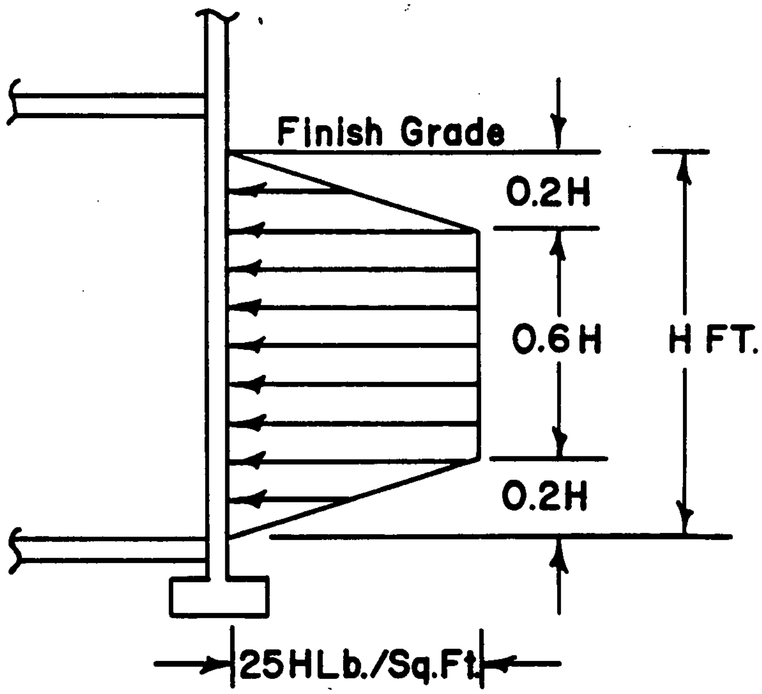
Lateral loads on foundations in compacted fill or natural soil may be resisted by friction under the foundations and/or by passive pressure on the sides of the foundations. If the friction and passive pressure are used together, one of them should be reduced by one-half. For Class 1 structures, we recommend a coefficient of friction of 0.55 and a passive pressure equal to that exerted by an equivalent fluid weighing 400 pounds per cubic foot. These values are for a factor of safety of about 1.25. For Class 3 structures, we recommend a coefficient of friction of 0.45 and a passive pressure equal to that exerted by an equivalent fluid weighing 330 pounds per cubic foot; these values are for a factor of safety of about 1.5.

MISCELLANEOUS

Lateral Earth Pressure

The plutonium building basement walls and other walls that will retain compacted backfill will be subjected to lateral earth pressures.

Lateral earth pressures recommended for design of the basement wall are illustrated below:



Tank Foundations

The proposed concrete ring walls for the steel tanks will prevent edge cutting. They can be designed using the foundation design data presented previously. We recommend using a compacted crushed rock base course at least six inches thick under the bottoms of the tanks.

Floors

Floor slabs can be poured directly on the rock, on compacted fill, or compacted natural soil. A moisture-proof membrane or spray should be applied before placing the concrete to prevent the soil and rock from absorbing moisture from the concrete before it has a chance to cure.

Asphaltic Concrete Pavements

Smooth rock surfaces and compacted fill or natural soil can be considered as good to excellent subgrade materials, provided that the drainage is planned so they do not become saturated. We understand that the planned pavement will consist of six inches of rock base and two inches of asphaltic concrete. This design has proved successful for pavements at Los Alamos and will be satisfactory for this project.

V-Ditches

Shallow V-ditches in compacted fill and natural soil can be unlined if the flow velocities are three feet per second or less.

INSPECTION

Inspection of site grading and foundation excavations is important, and should be performed by an engineer or qualified testing laboratory experienced in such work.

ATTACHMENTS

The attached Plate F-1 completes this section of the report. The field and laboratory work are described in Appendix F.

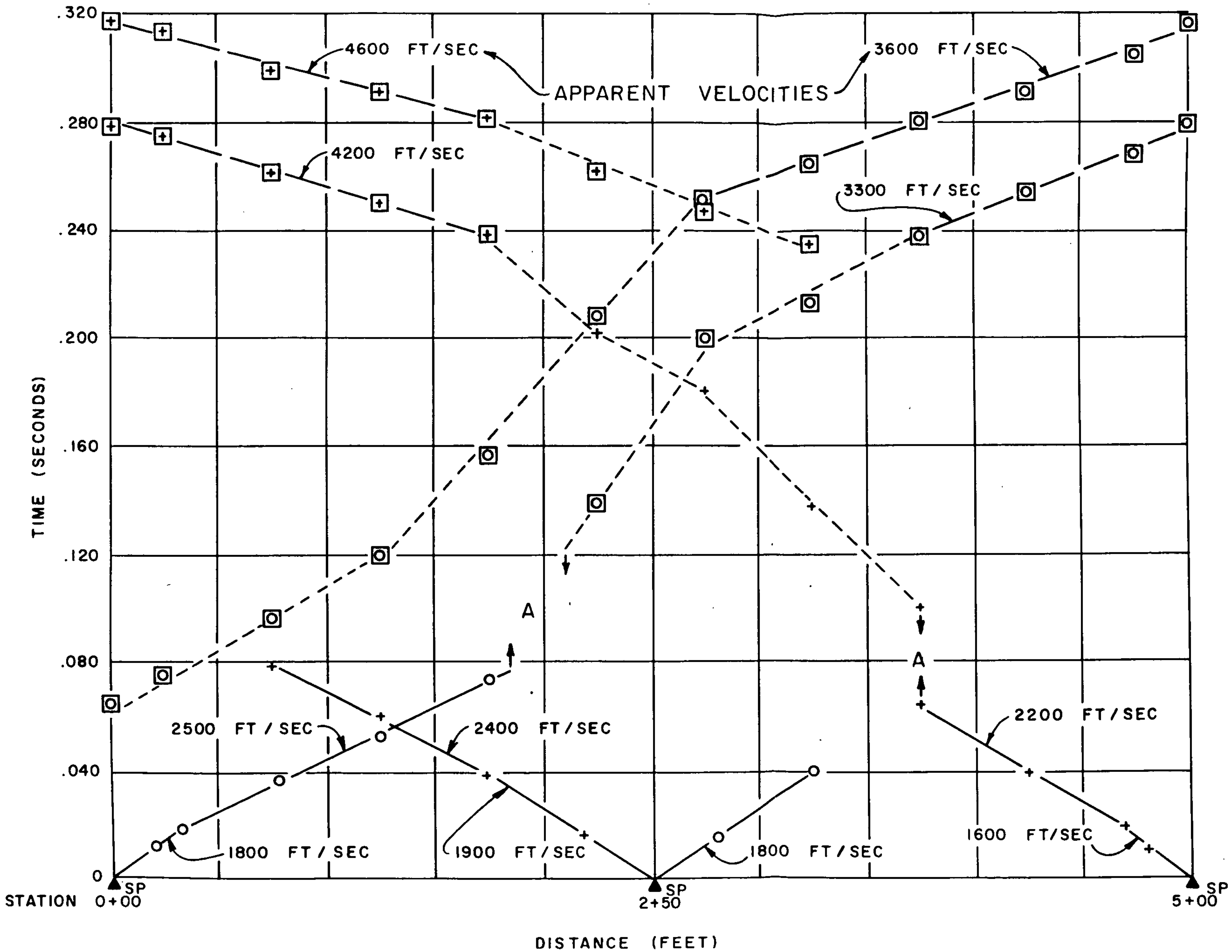
DAMES & MOORE

Robert M Moline

Robert M. Moline
Senior Engineer

November 29, 1972

Los Angeles, California



NOTES:

▲SP = ENERGY SOURCE (DUPONT NITRAMON-S)

TIME DISTANCE PLOTS SHOW INFORMATION COLLECTED FROM SHOT POINTS MADE AT SEVERAL LOCATIONS ALONG A SEISMIC LINE. FOR CLARIFICATION, TWO PLOT SYMBOLS HAVE BEEN USED TO INDICATE THE ORIGIN OF THE ENERGY: FROM THE LEFT (O) AND FROM THE RIGHT (+).

A: TIME PICKS OF SECONDARY EVENTS ARE INDICATED BY ⊡ OR ⊞. THE GAPS SHOWN AT LOCATIONS MARKED A ARE NOT REPRESENTATIVE OF FAULTING, BUT ARE BASED ON TIME DIFFERENCES BETWEEN PRIMARY AND SECONDARY EVENTS.

SEISMIC REFRACTION LINE 1

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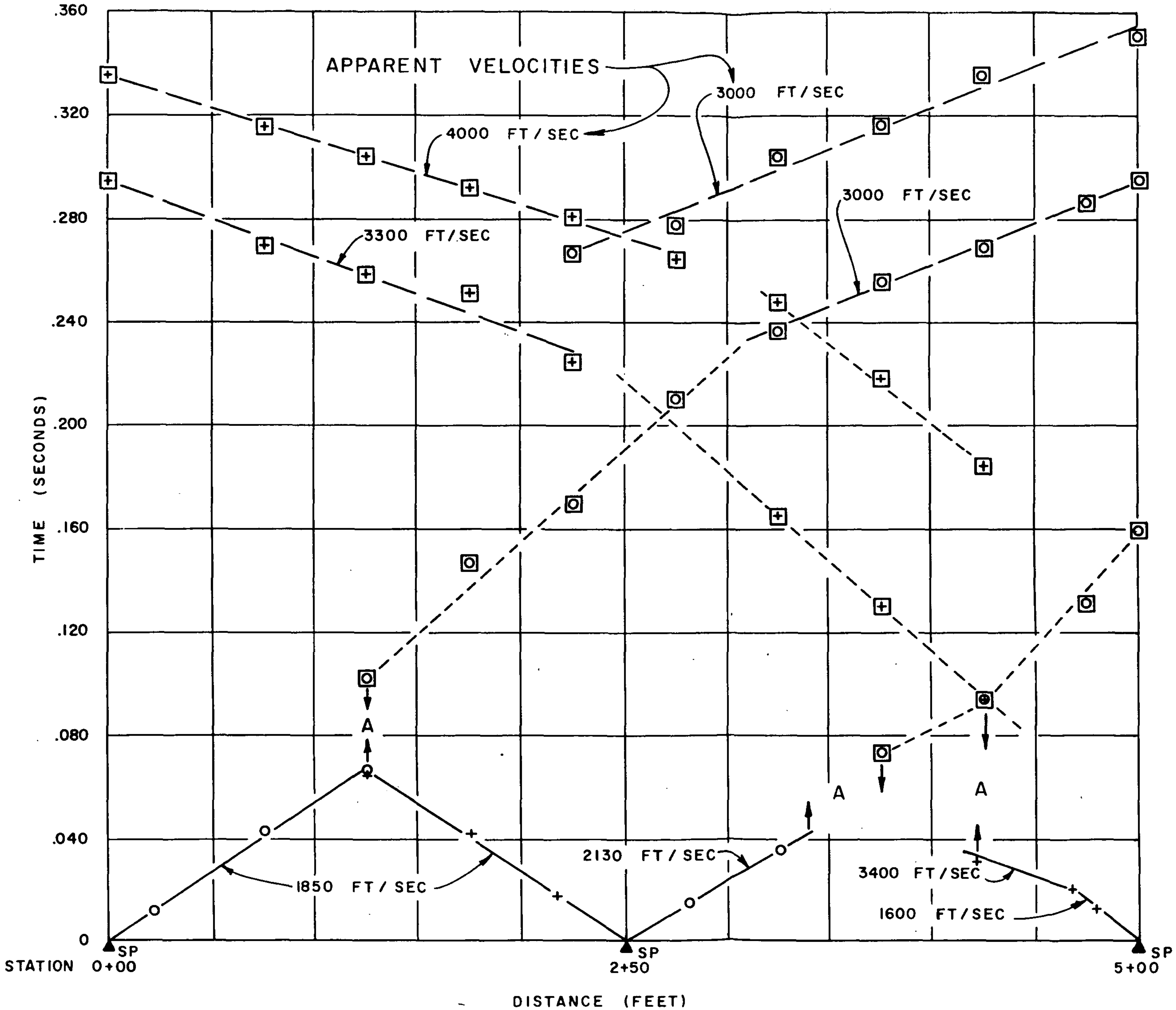
PLATE SA-3

LOS ALAMOS
BY JTE DATE 11-13-72
CHECKED BY [illegible] DATE [illegible]

BY ___ DATE ___
BY ___ DATE ___
PLATE ___ OF ___

LOS ALAMOS
BY JTF DATE 11-13-72
CHECKED BY [illegible] DATE [illegible]



NOTES:

▲SP = ENERGY SOURCE (DUPONT NITRAMON-S)

TIME DISTANCE PLOTS SHOW INFORMATION COLLECTED FROM SHOT POINTS MADE AT SEVERAL LOCATIONS ALONG A SEISMIC LINE. FOR CLARIFICATION, TWO PLOT SYMBOLS HAVE BEEN USED TO INDICATE THE ORIGIN OF THE ENERGY: FROM THE LEFT (O) AND FROM THE RIGHT (+).

A: TIME PICKS OF SECONDARY EVENTS ARE INDICATED BY ⊡ OR ⊞. THE GAPS SHOWN AT LOCATIONS MARKED A ARE NOT REPRESENTATIVE OF FAULTING, BUT ARE BASED ON TIME DIFFERENCES BETWEEN PRIMARY AND SECONDARY EVENTS.

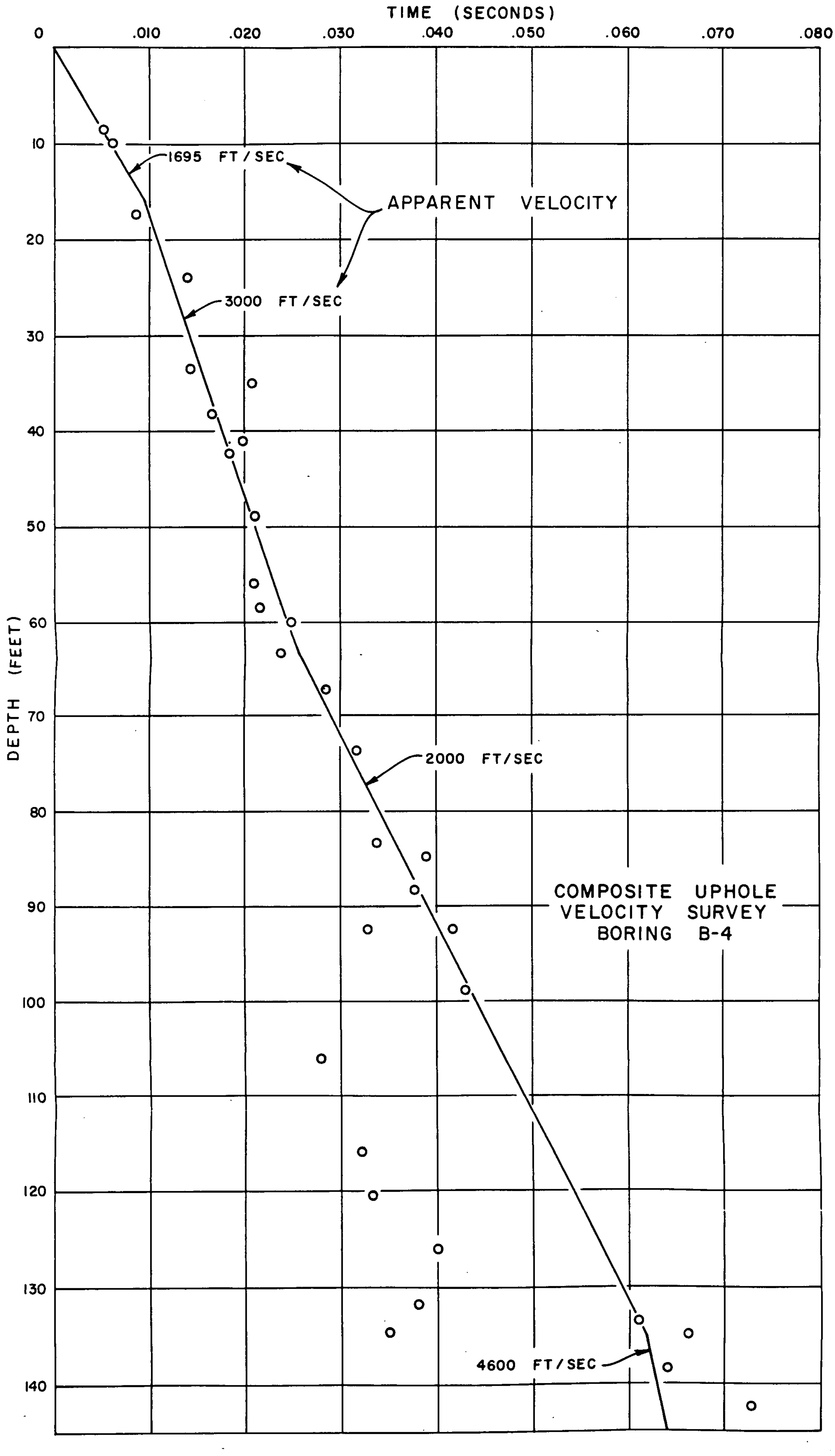
SEISMIC REFRACTION LINE 2

DAMES & MOORE

PLATE SA-4

FILE 0651-120
LOS ALAMOS
BY JTF DATE 11-13-72
CHECKED BY RMM DATE 11-13

REVISIONS
BY ______ DATE ______
BY ______ DATE ______
PLATE ______ OF ______



DAMES & MOORE
PLATE A-2

A P P E N D I X G

GEOLOGY

DETAILED DESCRIPTION AND ANALYSIS
OF THE REGIONAL TECTONIC STRUCTURES
AND
EVALUATION OF THE AGE OF FAULT MOVEMENT IN
THE AREA SURROUNDING THE PROPOSED
PLUTONIUM PROCESSING FACILITY
LOS ALAMOS, NEW MEXICO

PHYSIOGRAPHIC SETTING

The southern Rocky Mountain Province extends southward from Colorado about 100 miles where it is terminated by the Basin and Range Province (Plates G-1 and G-2). The southern Rocky Mountain Province is characterized by various types of complex mountains and intermontane basins.

The site of the proposed plutonium facility lies within this Province, west of the Rio Grande river in the north-central portion of New Mexico. The site is situated on the Pajarito Plateau along the eastern flank of the Jemez Mountains. The Pajarito is characterized by numerous finger-like mesas. These mesas are dissected remnants left by eastward-flowing streams which intermittently descend from the western Jemez Mountains to become tributaries of the Rio Grande.

MAJOR TECTONIC PROVINCES

The Jemez Mountains and associated Pajarito Plateau lie along the northwestern margin of the Rio Grande tectonic trough. The Rio Grande trough is a "graben," formed during Cenozoic tectonic activity in New Mexico; it is thus likely to have the greatest potential for developing surface faulting in conjunction with substantial seismicity (Sanford, et al, 1972). The Colorado Plateau and Great Plains provinces, which lie to the west and to the east of the Jemez Mountains respectively, are tectonically and seismically less significant, (Kelley, 1961; Sanford, et al, 1972).

The Rio Grande tectonic trough extends from the head of the San Luis Valley in southern Colorado at least 450 miles southward, for the length of New Mexico, to near El Paso, Texas (Plate G-2). Sedimentological evidence suggests that the depression extends further south into northern Chihuahua, Mexico (Chapin, 1971). In a broad regional sense, the Rio Grande trough is part of a much larger series of intermontane depressions extending the full length of the eastern Rockies of Colorado and New Mexico. In effect, it divides the southern Rocky Mountain orogenic belt into a western and an eastern chain of uplifts.

From a tectonic point of view, these bordering uplifts must be considered part of the tectonic trough structure or rift zone. The uplifted and outward-tilted margins of the rift zone are generally 10 to 30 miles in width. The outer edges of these marginal uplifts are marked by a sharp inflection line where the structural slope changes and becomes more gentle (Chapin, 1971).

Numerous faults, small folds, and local downwarps occur along the lines of inflection. These smaller structures parallel the rift and were formed contemporaneously with it. In consequence, the width of the total structure--including the bordering uplifts--is often twice that of the intervening graben (Chapin, 1971).

From a regional point of view, the major north-trending grabens or fault troughs of New Mexico are arranged en echelon, north-northwesterly along the Rio Grande and are separated from each other at the "offsets" by structural constrictions or narrow salients from adjoining uplifts (Plates G-2 and G-3). The form and internal structure of the depressions are neither homogeneous nor simple. The structural deformations within individual grabens do not appear to have been synchronous. Likewise, the geologic histories of the individual basins appear to vary considerably, although generally their initial development throughout the entire intermontane tectonic trough seems to have begun shortly after the Laramide Orogeny and to be continuing at present (Kelly, 1952).

STRUCTURAL DEVELOPMENT OF THE RIO GRANDE TECTONIC TROUGH

Plates G-1 and G-2 show that the Rio Grande tectonic depression is a major rift zone. The rift structure is expressed in a series of linked, apparently en echelon, structural depressions flanked by a series of uplifted, northward-trending structural blocks (Kelley, 1952; Chapin, 1971).

The fault patterns within the graben are of the same structural complexity as those observed in the adjacent uplifted blocks. The major faults express a predominantly northward trend, and although discontinuous, they develop en echelon zones of closely spaced parallel faults. Dip slip displacement on these northward-trending faults does not always reflect the basic graben structure. Field observations indicate that many individual blocks within the rift zone are anomalous intergraben horsts thrust upward from the floor of the broader, down-dropped trough. The movement along the major faults does not always appear to be primarily vertical. Stratigraphic dissimilarities of formational thicknesses and facies along the two margins of the graben, together with local drag effects, suggest that there may be horizontal displacements of as much as several miles (Kelley, 1952-1956).

The oldest rocks exposed in the outer uplifted blocks are Precambrian in age and are overlain by Carboniferous, Permian, Triassic, and Cretaceous strata (see Plate G-5). Volcanic and sedimentary rocks of early Tertiary age are also present and locally extend into parts of adjacent troughs. Paleontological data indicate a predominantly Eocene age for the Galisteo, Raton, El Rito, and Baca formations. The geographic and stratigraphic position of these formations indicate that what is now the Rio Grande rift zone must have been the site of one or more great sedimentary basins after the Laramide orogenic activity of the late Mesozoic era. It was the Laramide Orogeny which developed the complexly folded and faulted deformation belts presently flanking the Rio Grande graben.

The pre-Tertiary and early Tertiary rocks exposed in the present series of linked structural basins or troughs were largely overlain by a thick sequence of alluvial sediments derived from the bordering highlands. These sediments are now known as the Santa Fe Group and consist of a series of fanglomerates, conglomerates, sandstones, and mudstones. In geologically recent times they have been interbedded with and have been dominated by Pleistocene volcanic debris, especially in the northern portion of the Rio Grande trough near Los Alamos. The maximum thickness of the Santa Fe Group has been estimated from gravity data to be in excess of 5,000 feet. A 21-million year K-A date was obtained from an interbedded andesite flow in the Popatosa Formation, one of the lower units of the Santa Fe Group. Fossil evidence from basal alluvial fill materials indicates an age of 18 million years (early Miocene) for the lower formations of the Santa Fe Group (Chapin, 1971). Together, these data indicate a late Oligocene or early Miocene date for the initiation of the development of the Rio Grande graben.

Along the edges of the Rio Grande graben, Santa Fe Group sedimentary rocks generally are in fault contact with older rocks. However, local outcrops of Santa Fe Group sediment and rocks overlap the rims of the graben and rest unconformably on older rocks. Gravity data have identified en echelon faults along the western margin of the Sangre de Cristo Mountains near Santa Fe (Plate G-4) which have offset older Santa Fe strata, but which have been overlain by undisturbed, younger beds of the Santa Fe Group. This suggests a history of faulting penecontemporaneous with late Tertiary or early Quaternary sedimentation.

Together, the data suggest that the present Rio Grande trough has been superimposed upon a linked series of earlier basins of deposition whose outlines partially conformed to the present structural outline of the trough and its margins.

Recent volcanism has occurred primarily along the medial axis and west side of the Rio Grande trough. Present-day hot spring activity also has a similar distribution. Assuming that the problems of inadequate sampling and/or bias distribution have been avoided, volume calculations of volcanic and volcaniclastic rocks indicate that volcanism within the depression became more prominent about five million years ago, and that the rate of volcanism has increased over the geologic span of some 20 millions of years (Chapin, 1971), though it is presently dormant.

A summary of the development of the Rio Grande tectonic trough has been suggested as follows:

1. The southern Rocky Mountains were beveled by an erosion surface of moderately low relief in the late Eocene.

Inferring an average elevation of 2,000 feet for the late Eocene erosion surface, minimum uplift was approximately 5,000 to 12,000 feet during late Tertiary time for ranges east of the rift, and minimum subsidence was 4,000 to 24,000 feet within the rift. Numerous fault scarps cutting late Quaternary surfaces indicate that the differential movement is continuing.

2. The bounding uplifts were the source areas for the thick accumulation of late Tertiary sediments (Santa Fe Group) which filled the intervening graben. The relative absence of Tertiary deposits to the east may be attributed to uplift and erosion in the late Tertiary, rather than to nondeposition.

3. Undifferentiated and uncontaminated tholeiitic flood basalts have erupted within the graben to the northeast of Los Alamos, near Taos, at the same time that alkalic, crustally contaminated basalts were being erupted on either side.

4. In general, basalts within the southern portion of the depression near Las Cruces and west of the depression near Grants are relatively undifferentiated in comparison to basalts east of the depression, including those at Carrizozo (see Plate G-1).

The underlying cause for the development of the rift may be sought in the intrusion of a pillow-shaped magma body near the level of the Mohorovicic discontinuity in the crust. This bulge caused a stretching or arching of the overlying rocks and created the stress field necessary for the formation of normal faults. The orientation of the greatest principal stress was vertical, while the least principal stress was directed W-E to NW-SE. This caused the earth's crust to fail in a pattern of normal faults, which dominate the structure of the rift (Plate G-6).

The strike of these faults is N to NE; their distribution and direction of movement are complex, with step faults and antithetic faults offsetting individual blocks in the graben.

Combined vertical displacements along these faults dropped the graben blocks from 2000 to 7000 meters with respect to the sides of the rift, at the same time further raising the shoulders.

Assuming a dip of 60° for the main graben faults and an average width of 50 kilometers for the Rio Grande rift zone, the bounding faults will intersect at a depth of 43 kilometers, well below the earth's crust. Thus it is likely that the volcanism that accompanied rifting utilized these faults as channel ways for magma from the mantle to reach the surface.

Budding and Sanford's inference (1972) that in general the most seismically active portion of the graben is in the middle of the graben and that the oldest faulting and seismic activity occurred along the flanks supports the suggestion of a magmatic spreading center below the Rio Grande tectonic trough.

DESCRIPTION OF THE RIO GRANDE TECTONIC TROUGH AND SURROUNDING AREA IN THE VICINITY OF THE JEMEZ UPLIFT

CHAMA BASIN

The proposed site of the facility at Los Alamos lies on the eastern flank of the Jemez uplift. The Jemez uplift is bounded on the north by the late Paleozoic and Mesozoic sedimentary rocks of the Chama Basin, which lies as a reentrant between the Rio Grande tectonic trough to the east and the northward extension of the Nacimiento uplift to the west (Plates G-2 and G-4). The northern part of the Jemez volcanic plateau overlies and conceals the relationship between the southeastern part of the Chama Basin and the junction of the two bounding structures. To the south and east the upturned edges of pre-Tertiary rocks are overlain by Tertiary and Recent volcanic rocks and sediments (Plate G-7). The southeastern part of the Chama Basin exhibits a gentle northwestward plunge and is displaced by several northeast and north-trending normal faults. Many short faults with relatively small displacements are found within the basin. In addition, faults with lengths of up to 6 miles and with stratigraphic throws of 200 feet or more are present. Many faults exhibit branching near their ends, and owing to this bifurcation, the stratigraphic throw becomes distributed over a number of smaller faults, which in turn terminate in incompetent beds.

Much of this faulting seems to have been related to differential movements between the Chama Basin floor to the west and the Brazos uplift in the Tosas Mountains, 15 miles to the east (Plates G-2 and G-4). These movements apparently generated a tensional-stress field between the basin proper and the adjacent uplift which resulted in normal faulting of the sedimentary fill. Some of the fault zones are filled with basaltic dikes whose irregular displacements suggest late Tertiary adjustments to the sinking of the Rio Grande tectonic trough (Budding, et al, 1960).

The Chama Basin is separated from the San Juan Basin on the west by a low sill which marks the position of the Archuleta arch (Plates G-4 and G-7). According to Kelley (1955), this arch forms a connection between the Nacimiento uplift in New Mexico and the San Juan Dome in southwestern Colorado.

NACIMIENTO UPLIFT

The Nacimiento uplift bounds the Jemez Mountains on the west (Plate G-4). Both the Nacimiento and Brazos uplifts are old structural elements that can be traced back to Pennsylvanian time (Read and Wood, 1947). Both uplifts, however, attained their present elevated position as a result of the late Mesozoic Laramide Orogeny and the subsequent Tertiary fault adjustments.

The Sierra Nacimiento is a rather narrow but long uplift characterized by a steep reverse fault of that name, developed in response to Laramide compressional forces (Kelly, 1952; Plate G-19). The Nacimiento fault offsets only Mesozoic rocks. Undisturbed Pliocene and Pleistocene terrace and pediment boulder and gravel deposits overlie the Nacimiento fault near the Nacimiento copper mine, just east of Cuba (Woodward, 1971). These "high level" sediments once formed an extensive contiguous veneer but are now preserved as discontinuous erosional remnants 200 feet above present drainage. The north-south lineation of the Albuquerque volcanoes (Plate G-20) which lie between the Nacimiento fault zone to the north and coincident trace of the Precambrian escarpment along the Joyita uplift to the south (Plate G-3), and the position of the circular hot springs along the Nacimiento fault trace on the west side of Sierra Nacimiento indica indicate that the pre-Pliocene/Pleistocene faults of the Nacimiento fault zone served as feeder channels for Quaternary volcanic emanations.

JEMEZ FAULT SYSTEM

The Jemez fault system (Plates 3 and 4) approximately defines the eastern structural margin of Sierra Nacimiento. A product of mid-Tertiary tensional forces, the Jemez fault system is a series of northeast-trending, en echelon, normal faults dominantly down-thrown to the east. The zone extends from just west of Jemez Pueblo in the south to beyond Canoes in the north (Plate G-7). The southern segment of this system,

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between the southeast corner of Sierra Nacimiento and Jemez Springs, is defined primarily by the Jemez fault, which juxtaposed sediments of the Santa Fe Group on the east in high-angle contact with pre-Tertiary rocks on the west.

Older fault members within this system are overlain by undisturbed Bandelier tuff on Virgin Mesa. Younger en echelon fault members offset Bandelier tuff not only on Virgin Mesa, but also the southeast tip of Cebolleta Mesa, and on the northwest edge of San Juan Mesa. Several of these younger en echelon fault members are overlain by the undisturbed Banco Bonito and Battleship Rock members of the Valles Rhyolite and are covered by Recent stream gravels of the Jemez River (see USGS Misc. Geol. Map 1-571). The Banco Bonito and Battleship Rock members have been approximately dated as 100,000 years old (Smith and Bailey, 1968).

The Jemez fault system cannot be traced into the Jemez Caldera (Plate G-4), but the alignment of it with graben structures within the caldera suggests that it may have continued into the caldera and predetermined the position and orientation of the grabens.

Northeastward from the caldera, the Jemez fault system is again sharply delineated by several en echelon faults which bring the Abiquiu tuff of the Santa Fe Group, dated at 15 million years, down to the southeast against Jurassic rocks in the vicinity of Canones and the Abiquiu Dam,

(Plate G-7). The older set of fault members on Canones Mesa are overlain by undisturbed Pliocene-Pleistocene Tschicoma Formation which contains the Hinsdale andesite, dated at one to two million years (Plate G-19). A younger set of en echelon faults also occurs on Canones Mesa and to the southeast on La Grulla Plateau which do offset the Tschicoma Formation.

Thus, the spatial and temporal distribution of faults within this system indicates pre- as well as post- Tschicoma time movement. Younger and older fault traces on the northeast flank of the Jemez Mountains are overlain by undisturbed Holocene landslide deposits and terrace gravels, indicating that the Jemez fault system in the vicinity northeast of the caldera has been dormant since Holocene time. However, numerous epicenters in this region might indicate otherwise.

Kelly (1952), as well as Smith and Bailey (1968) suggest that the Jemez volcanic rocks erupted along the pre-existing Jemez fault system. Its geographic position and the inferred structural relationship to Tertiary and Quaternary volcanism suggest that the Jemez fault system and its possible continuation under the Jemez volcanic plateau define the western margin of the Rio Grande tectonic trough.

The Jemez fault system appears to be en echelon with the Puerco fault system whose northern extension lies just five miles southeast of San Ysidro (Plates G-3 and G-7).

PUERCO AND LUCERO FAULT SYSTEMS

The Puerco and Lucero fault systems define the western margin of the Albuquerque-Belen basin. The Puerco fault system is a broad zone of complex normal faults, forming a belt of grabens and horsts, but with dominantly downward displacement to the east on the side of the Rio Grande depression.

The Lucero uplift, the eastern margin of which may be in part a southern continuation of the Puerco fault system, as also shown on Plate G-3, was thrust from west to east in relatively early Tertiary time; it subsequently sustained one or more episodes of normal faulting in late Tertiary time (Kelley, 1961).

Many of the earlier faults, including the Picuris-Pecos fault within the Sangre de Cristo uplift northeast of Espanola (Plate G-3) were rejuvenated in late Tertiary time. This second phase of displacements, however, was not always of the same magnitude nor in the same direction as the previous movement (Kelley, 1961). One can infer from this a long history of faulting and repeated reactivation of old zones of structural weakness within the Rio Grande tectonic trough.

SAN YSIDRO EMBAYMENT AND THE SAN FELIPE FAULT SYSTEM

The San Ysidro embayment, of late Tertiary age, and the Santo Domingo basin bound the Jemez Mountains on the south and mark the area where the Rio Grande depression emerges from the Southern Rocky Mountain Province into the Basin and Range province (Plates G-1 and G-4). In this vicinity the Rio Grande depression is offset to the west about 20 miles.

The western and eastern margins of the San Ysidro embayment are contained by the Nacimiento uplift and the San Felipe fault system, respectively. The San Felipe fault system consists of one or more grabens extending from the Jemez uplift southward towards the Sandia uplift on the east side of the Albuquerque-Belen Basin, (Plate G-3). This system appears to be en echelon with the fault margins of the eastwardly titled Sandia, Manzano and Los Pinos uplifts which define the eastern margin of the Rio Grande graben.

This system of small, north striking, en echelon faults was initiated prior to the Pliocene, but continued seismic activity offset Pliocene-Pleistocene basalt flows and tuffs in the vicinity of San Felipe, on Santa Ana Mesa, and on the southern flank of the Jemez Caldera (Plate G-7). In general, these faults have tilted and displaced downward, to the east, the older rocks of the volcanic pile.

The volcanic vents on Santa Ana mesa are aligned parallel to the post-eruption fault pattern, suggesting that the fault system existed prior to the volcanic eruptions. The fault scarps are well preserved in the basalts but are obliterated in the incompetent Santa Fe sediments. Northward, the en echelon faults of this system appear to have been active for a considerably longer time, although there is no evidence of movement after deposition of the Otowi member of the Bandelier tuff, approximately 1.4 million years ago.

Sediments exposed within the San Ysidro embayment belong for the most part to the Zia Sandstone of Miocene age, to the Santa Fe Formation and to the Pliocene Cochiti Formation. The surface exposures of Mesozoic rocks in the broad Puerco fault system to the southwest (Plate G-3) suggest that pre-Tertiary sedimentary rocks underlie the Tertiary sequence at the northern margin of the Albuquerque Basin. Pre-Tertiary rocks are also exposed in the Hagan embayment of the Santo Domingo basin. In the vicinity of Santa Fe, Pennsylvanian rocks are locally exposed in the Santa Fe fault system, along the eastern margin of the Espanola basin. This also suggests, but does not prove, the presence of at least a local sedimentary sequence intervening between the Precambrian and the Tertiary strata in the Rio Grande trough.

In early Pleistocene time, a widespread erosional surface developed across the Albuquerque-Belen Basin and extending on to the adjoining uplifts. Remnants of this surface are prominent on both sides of the Rio Grande trough and can be correlated with an erosional surface in the Santo Domingo and Espanola basins, which could be the equivalent of the Ortiz surface. The Pliocene-Pleistocene Puye Formation and basalts of Santa Ana mesa predate the Ortiz surface. The age of the younger Valle

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de la Parida surface, established by vertebrate fossils, indicates that the Ortiz surface is older than 400,000 years.

These and other surfaces, which probably are roughly equivalent in age, presently are exposed at markedly different altitudes. This is due to initial variation in the rates of erosion, to differences in gradients, and to subsequent tilting and faulting. Topographically lower and younger surfaces are present, but stratigraphic correlation of these lower surfaces outside or within the basin is very uncertain (Kelley, 1952).

SANTO DOMINGO BASIN AND THE LA BAJADA FAULT SYSTEM

The Santo Domingo Basin (Plates G-3 and G-4) is defined by the San Felipe fault system on the west and by the La Bajada escarpment or constriction on the east. To the south the basin is limited by the Hagan embayment. The Santo Domingo basin is a small feature which should be considered an embayment of the Albuquerque-Belen Basin.

The surface rocks of the Santo Domingo Basin are entirely Cenozoic and chiefly consist of the Miocene-Pliocene Santa Fe Formation. As in the Espanola basin, the beds west of the Rio Grande are rich in alluvial and pyroclastic volcanic materials. Along the northern edge of the basin, isolated exposures of the Otowi member of the Pleistocene Bandelier tuff crop out.

The western and northern margins of the Santo Domingo basin are continuations of the Pajarito fault and the Jemez uplift (Plate G-4). Santa Fe strata are tilted 5 to 15 degrees south-southwesterly along the Jemez uplift, while they are only slightly deformed beneath Quaternary erosional surfaces in the center of the Santo Domingo basin and tilted 5 to 25 degrees east-northeasterly in the more southerly Hagan embayment.

The La Bajada fault zone separates the Santo Domingo basin from the Cerrillos uplift (Plate G-4). The latter consists of Mesozoic and early Tertiary sediments and of middle Tertiary volcanic rocks intruded by several porphyry masses (Ortiz porphyry belt). These laccolithic and stock-like intrusive masses were apparently emplaced along the trend of the Laramide Picuris-Pecos fault system prior to the deposition of the Santa Fe Group.

The displacements of the La Bajada fault system are predominantly downward on their western sides and may have been initiated in Pliocene or earlier time. Nonetheless, this fault zone offsets the Ortiz surface of river gravels and later sands and gravels of the early Pleistocene Ancha Formation. The faults also offset the basalts of Santa Ana mesa, and basaltic dikes were subsequently injected along the faults in some places. Northward, at the base of the Jemez uplift, just east of the Rio Grande river, the faults disrupt the Pleistocene "basaltic andesite of Tank Nineteen" which is stratigraphically equivalent to the Bandelier tuff (USGS Misc. Geol. Map 1-157). Broad downwarping of the Bandelier tuff over the western end of the escarpment near the Jemez uplift also indicates movement along the fault after deposition of the tuff. The La Bajada scarp is concealed beneath Holocene fan and landslide deposits along the southwestern margin of the Cerros del Rio volcanic field, near La Bajada mesa (USGS Misc. Geol. Map 1-157).

Northwest of the La Bajada escarpment (Plate G-4), the Ortiz surface has been severely eroded but only slightly warped since its development. Southwest of La Bajada, however, the Rio Grande depression has been sharply lowered along the La Bajada fault, as well as along a synclinal sag which more or less parallels the Rio Grande. It is possible that the faulting and downwarping movements which began in post-Ortiz time (post 400,000 years) may still be continuing along the Rio Grande in the vicinity of Santo Domingo basin. Although the Rio Grande may have deposited material for a time along the post-Ortiz surface sag in the Santo Domingo basin, in recent time it has breached the sag to a depth of about 300 feet. One consequence of this erosional process has been the formation of lower stream terraces; these terrace deposits have been called Pena Blanca or Cochiti.

ESPANOLA BASIN AND THE PAJARITO FAULT SYSTEM

The Espanola basin bounds the Jemez Mountains on the east (Plate G-4). The western margin of the basin is defined by the Pajarito fault escarpment. This fault system which lies between the basin and the Jemez uplift has offset members of the Pleistocene Bandelier tuff and of the stratigraphically equivalent Cerro Toledo rhyolite; it has also brought early and middle Tertiary volcanic rocks of the Jemez uplift into juxtaposition with late Tertiary and early Quaternary rocks of the Santa Fe and Puye Formations at many places along the eastern base of the uplift.

The Pajarito fault system displaces the Bandelier rhyolite tuff 40 feet to as much as 400 feet, but displacements in the underlying Pliocene dacitic rocks exceed 1,000 feet and indicate fault activity over a long period of time. North of Santa Clara Canyon, along the eastern edge of Lobato mesa (Plate G-7), the fault zone continues as a series of an echelon faults that displace the Pliocene-Pleistocene Lobato basalts but are overlain by undisturbed beds of the Pliocene-Pleistocene Puye Formation and by undisturbed Holocene alluvium. In places near Abiquiu these north-trending faults meet the northeast-trending faults of the Jemez fault system.

Northeast of Los Alamos, between the trace of the Pajarito fault and the Rio Grande (Plate G-7), a north-south trending zone of an echelon normal faulting has developed a complex series of grabens and horsts which offset both members of the Pleistocene Bandelier tuff. These faults may have an en echelon structural relationship with the Pajarito fault system.

The fault characteristics of the San Felipe-Pajarito and Jemez fault systems differ in several important ways. The faults in the Jemez fault zone generally show normal displacement downward to the east and bound blocks that are tilted westward. The faults in the San Felipe and Pajarito systems commonly are en echelon and bound blocks that are tilted eastward. The faults of the two more easterly systems also show considerably greater syn-volcanic and post-volcanic displacement than those in the Jemez fault system. Episodes of faulting and volcanic eruptions along all three fault zones suggest that volcanism and faulting occurred intermittently since the initial formation of the Rio Grande tectonic trough.

The stress distribution pattern of the present surface expression of the Pajarito fault system suggests that it was affected by the presence of the caldera. The post-caldera movement of the fault zone is believed to be structurally and tectonically related to the older, pre-Bandelier tuff, precaldera fault movement responsible for the several thousands of feet of displacement of the underlying pre-Pleistocene rocks. The entire fault system showing recurrent movement is probably structurally related to the northern extension of the La Bajada fault system and to the Labato mesa expression of the Pajarito system.

The eastern margin of the Espanola basin is also the eastern edge of the Rio Grande tectonic trough; it is defined by the resistant Sangre de Cristo uplift which rises abruptly from the softer Tertiary strata of the basin (Plate G-3).

The rocks of the Sangre de Cristo uplift are almost entirely of Precambrian and Pennsylvanian age. These rocks have been complexly folded, overthrust eastward, and offset along large tear faults during intense Laramide deformation. The present fault scarp along the western edge of the uplift was, however, caused by late Tertiary en echelon normal faulting. Most of the normal faulting occurred after deposition of the Santa Fe Group. In places the Santa Fe Group overlapped the older structural basin; field observations show that several large footwall blocks of Santa fe sediments have been caught up along some of the bounding faults of the Sangre de Cristo escarpment and elevated several hundred feet above the general surface of the present basin (Plate G-19).

Gravity data along the western margin of the Sangre de Cristo escarpment in the vicinity of Santa Fe indicate that the main en echelon fault system occurs west of the present margin of the uplift and that faulting was also in part penecontemporaneous with deposition of the Santa Fe sediments. Unfaulted, unconformable depositional contacts of younger Santa Fe strata against the uplifted pre-Tertiary rocks exist in many places along the eastern boundary of the basin and also in the Picuris embayment.

The fault traces along the western margin of the Sangre de Cristo uplift appear not to disrupt Pleistocene-Holocene alluvial deposits.

The Sangre de Cristo uplift is crossed by the north-south trending Picuris-Pecos fault which juxtaposes Precambrian and Pennsylvanian rocks (Plate G-19). There has been a 23-mile, right-lateral, strike-slip separation of Precambrian units during Precambrian time. The present structural features of the uplift developed during Laramide time as the Precambrian faults were rejuvenated. Late Mesozoic, early Tertiary movements involved vertical dip slip displacements with no rotation of the fault plane from the vertical attitude established during Precambrian time (Miller, Montgomery, and Sutherland, 1963).

The Picuris-Pecos fault is concealed beneath undisturbed Miocene Picuris tuff which is stratigraphically equivalent to the Abiquiu tuff of the lower part of the Santa Fe Group. West of Rodarte, north of Espanola, the fault is overlain by Pliocene-Pleistocene Ancha Formation of the upper part of the Santa Fe Group and by Recent alluvium. It is thus apparent that this fault has not experienced any post-Miocene movement.

The rocks of the Espanola basin are predominantly

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those of the middle Miocene to middle-to-upper Pliocene Tesuque and Chamita Formations of the Santa Fe Group. The sediments of the Santa Fe Group in the basin consist chiefly of alluvial fan and aeolian deposits, including conglomerates, loosely consolidated sandstones, siltstones, volcanic ash, bentonites, tuffaceous deposits, conglomeratic sandstones, intraformational breccias, concretions of various kinds, calcareous and cherty strata and a small amount of clay. Interbedded volcanic flows are few and of small extent.

All along the eastern half of the Espanola basin the Santa Fe members are tilted westward 5 to 10 degrees against the Sangre de Cristo fault scarp; it appears that at least some of the western tilt of the Santa Fe is due to late and post-Santa Fe movement on the fault. The most westerly exposures of the Santa Fe beds are found in the bottoms of youthful canyons cut into the Pajarito mesa, along the west base of the Jemez uplift. These strata generally have a low westerly dip (2 to 3 degrees) and define a broad monoclinal tectonic structure of Tertiary strata projecting under the Pajarito Plateau.

The Santa Fe sediments around the Jemez uplift contain fragments of Jemez volcanics and a small amount of material from the Sangre de Cristo and northern areas. It is apparent that the central drainage of the basin, which shifted intermittently during Santa Fe time in accordance with variations in the influx of materials and tilting of the subsiding floor, determined the separation as well as intertonguing of the east and west facies of the group (Galusha and Blick, 1971).

The minor pyroclastic and sedimentary volcanic materials in the western facies of the Santa Fe Group indicate volcanic activity in the area of the Jemez uplift during Santa Fe time. The general coarseness of the western Santa Fe materials indicates the persistence of an uplift in the Jemez area during much of Santa Fe time. It thus appears that the Espanola basin subsided recurrently in relation to the adjoining uplifts instead of being downthrown by a single, short-lived tectonic event occurring at the end of the Pleistocene. Termination of much of the Santa Fe deposition appears to be marked by a long period of quiescence; this allowed widespread beveling of the deformed strata, especially along the eastern side of the Espanola basin. However, deposition of Santa Fe type of sediment in the Rio Grande trough is still in progress today in response to the persistence of the adjacent highlands.

The northern boundary of the Espanola basin is taken arbitrarily along the irregular Embudo constriction where an arcuate series of Precambrian horsts rise above the Tertiary sediments of the Cerro Azul structural channel, which is the principal structural link between the Espanola and the San

Luis basins. The Cerro Azul Channel lies between the Ojo Caliente uplift and the Picuris salient (Plate G-4).

From the vicinity of Dixon at the eastern edge of the Picuris salient, northward to Taos in the southernmost part of the San Luis basin (Plate G-8) the Precambrian exposed in the canyons of the Rio Grande are directly overlain by the Santa Fe beds. The existence of a Precambrian inlier at Cerro Azul, nearly half way between the Dixon area and the margin of the Petaca and Ortega Mountains in the vicinity of Ojo Caliente, (Plates G-3 and G-4) suggests that the Precambrian is also directly overlain by the Santa Fe in the northern part of this basin.

If the Santa Fe Group does indeed rest on Precambrian rocks at the northern end of the Espanola basin and on Mesozoic rocks in the northwest end of the Albuquerque-Belen basin (Plate G-3), there must be either a stratigraphic or structural change in the pre-Tertiary sequence, somewhere between the two latitudes.

Much of the late structural and geomorphic history of the Espanola basin is due to the numerous volcanic eruptions which began in late Santa Fe time in the Cerros del Rio, just east of the Rio Grande, but west of the city of Santa Fe (Plate G-7). The tilting and beveling of the Santa Fe beds along the margins of the basin began and were largely developed before these basaltic eruptions. Tributary channels which had been cut into tilted Santa Fe strata were filled by basalt along the course of the Rio Grande, where many of the eruptions occurred. Elsewhere, away from the main river channel, flows are interbedded with sediments of Santa Fe type. North of the lava flows, lacrustrine clays accumulated in the impounded waters and some of the lavas which poured into the lake formed pillow structures. In addition, toward the end of the Pliocene and generally prior to basaltic eruptions renewed uplift of the Jemez block caused the spreading of alluvial fans (Puye gravel) over the slightly deformed earlier Santa Fe strata. These fans extended as far east as the Rio Grande. Volcanic activity also occurred in the Jemez uplift during Puye time (Pliocene-Pleistocene), as indicated by lenses and thin beds of pyroclastic pumice within the Puye gravel.

Following the spread of the Puye gravel and most of the basaltic eruptions of the Cerros del Rio, the La Bajada fault system again became active and developed its present escarpment. The Rio Grande flowed out of the impounded lake west of its present channel, around the basalt field, and over the rising La Bajada escarpment. After the river had partly dissected the elevated escarpment, great eruptions of rhyolite tuff from the Jemez uplift engulfed the river and completely filled its channels. Some slight rise of the escarpment appears to have continued after these eruptions of the Bandelier tuff. The Rio Grande, forced eastward--almost to the site it had occupied during late Santa Fe time--carved a channel through Pliocene-Pleistocene beds during the late Pleistocene and Recent time, and developed the present gorge of White Rock Canyon (Plate G-4). The Santo Domingo and Espanola basins east of the Jemez uplift are connected by the White Rock Channel. This structural linkage lies between the buried northern end of the Cerrillos uplift and a small salient at the southern edge of the Jemez uplift.

REGIONAL AND HISTORICAL GEOLOGY OF THE JEMEZ UPLIFT

The Jemez uplift lies just west of Los Alamos and the Pajarito fault and constitutes a complex accumulation of Tertiary and Quaternary volcanic rocks, with a geomorphic expression of a maturely eroded, central mountainous mass surrounded by more youthfully dissected plateaus and mesas. In the midst of the volcanic mountain is the Valles or Jemez caldera, a sub-circular volcanic depression 12 to 15 miles in diameter, 500 to 2,000 feet deep, and surrounded by peaks that rise to altitudes exceeding 10,000 feet.

The volcanic rocks of the Jemez uplift unconformably overlie igneous, metamorphic and sedimentary rocks ranging in age from Precambrian to late Tertiary. On the west, the volcanic rocks overlie dominantly Paleozoic and Mesozoic sedimentary rocks that form the eastward-dipping blackslope of the Sierra Nacimiento (Plate G-4). On the north, east and south they overlie the Miocene Abiquiu tuff and the middle and upper Tertiary sediments of the Santa Fe Group, a Miocene to Pliocene sequence of conglomerates, arkosic sands and silts.

Volcanic activity in the Jemez uplift probably started in earliest Miocene. Subsequent early Pliocene volcanism (about ten million years ago) formed the basalt fields in the vicinity of Chamisa and Borrego mesas, approximately 16 to 18 miles south of the center of the Valles caldera. These basaltic eruptions formed separate, scattered, overlapping shield volcanoes. Stratigraphic and structural evidence indicate that these eruptions did not occur until some time after the initiation of the Rio Grande tectonic trough as a structural feature.

About a million years after the eruption of the basaltic shield volcanoes, cogenetic eruptions of rhyolitic domes, flows, and tuffs formed small stratovolcanoes within the center of the older basalt field. (Smith, et al, 1970, Canovas Canyon Rhyolite).

A younger volcanic center formed about ten miles south of the center of the Valles caldera. The first magmas erupted were of basaltic composition which were sequentially followed by a differentiated sequence of andesites, dacites, and rhyodacites (Smith, et al, 1970, Paliza Canyon Formation). About two and one-half million years later, cogenetic eruptions or rhyolitic domes, flows, and tuffs again formed small stratovolcanoes near the center of the older basalt pile.

The youngest volcanic center formed about six million years ago, in late Pliocene time. This locus of volcanic activity produced the Lobato basalts and sesequently formed two giant calderas: an older Toledo caldera which was all but destroyed by the later and well-preserved Valles or Jemez caldera. About five million years elapsed from its initiation before a sequence of differentiated magmas culminated with Pleistocene eruptions of rhyolitic ash flows and ash falls, which produced the Valles caldera (Plate G-8).

These pyroclastic eruptions, now known as the Bandelier tuff, unconformably overlie all the older volcanic rocks and sediments which constitute the pre-caldera edifice of the Jemez volcanic locus. The Bandelier tuff is composed of two members, the Otowi and Tshirege members, dated 1.4 and 1.0 million years old, respectively (Smith and Bailey, 1961). The tuff underlies the Pajarito and Jemez plateaus on the east and west and Mesa de Medio on the north (see USGS Misc. Geol. Invest. Map I-571). It covers an area of nearly 400 square miles, locally attaining a thickness of up to 1000 feet and represents the accumulation of more than 50 cubic miles of ash and pumice.

As a result of the culminating pyroclastic activity, the two calderas of slightly different ages were formed. The older Toledo Caldera was destroyed by the younger with the only remaining remnant of its structure preserved near the head of Santa Clara Canyon (see USGS Misc. Invest. Map I-571). The younger and larger caldera, the Valles caldera, formed when the roof of the magma chamber collapsed along circular tensional fractures as the result of resurgent magmatic pressures which developed subsequent to the eruption of the Bandelier ash flows. A structural dome, known as the Redondo Dome, emerged within this central ring-fracture zone as the result of post-collapse uplift of the caldera floor, rather than differential collapse of the caldera block. This was probably the consequence of a resurgence of new magma from below, with accompanying intrusion of a stock or laccolith; or, possibly it was due to hydrostatic readjustment of the viscous magma that remained in the chamber following eruption of the late sequence of Bandelier ash flows.

During and subsequent to the gradual rise of this structural dome, large quantities of viscous rhyolite were extruded from the peripheral ring-fracture zone, resulting in a nearly continuous ring of volcanic domes which now surround Redondo Mountain. These Pleistocene rhyolite domes are the youngest volcanic rocks in the Jemez Mountains, having been dated at 0.7, 0.5, and 0.4 million years B.P. The youngest of these eruptive centers is El Cajete (see USGS Misc. Geol. Invest. Map I-571). It is of particular interest because it is the source vent of the welded tuff of Battleship Rock in upper San Diego Canyon, the "popcorn" pumice surrounding El Cajete crater, and the obsidian flow of Banco Bonito. The welded tuff and glass flow have been estimated to have formed 100,000 years before present) as they post date ash flows which have been dated in 0.43 million years old, but predate an ash flow which has been dated at 42,000 years B.P. (Bailey, et al, 1969).

The ring fault bounding the subsided caldera block is for the most part covered by these younger rhyolitic volcanics and alluvium. Nevertheless, existing exposures indicate that it constitutes a complex fracture zone two to three miles wide.

The location of the Jemez volcanic locus, athwart the western margin of the depression at a point where its north-south trend is offset by a series of en echelon faults, suggests that the tensional environment associated with this offset may have established the zone of weakness which provided the outlets for volcanism. However, it is difficult to determine of the faulting and volcanism are causally related.

EVIDENCE OF RECENT FAULTING AND VOLCANISM WITHIN THE JEMEZ UPLIFT

STRATIGRAPHIC EVIDENCE FOR FAULTING

There is abundant evidence of Quaternary faulting in the Jemez Mountains. The younger en echelon fault member of the Jemez fault system on the southwest flank of the mountains have a post-Bandelier tuff age (post-1,000,000 years), although none have been active since eruption of the upper members of the Valles rhyolite 100,000 years ago. All the younger fault members of the Jemez fault system on the north-east flank of the mountains have a post-Tschicoma Formation age (post-Pliocene-Pleistocene), but existed prior to Bandelier tuff time. Furthermore, the Jemez system is known to fracture, but not displace, the much younger Valles rhyolite exposed within the Valles caldera. This is clearly shown on thermal infrared photographs. The rhyolite body has been dated as 0.4 to 0.1 million years (verbal communication, Smith, 1972).

The faults within the Pajarito system have a pre- as well as a post- Bandelier tuff age (post-1,000,000 years). Movement along the fault members in the northward extension of this system in the vincinity of Lobato mesa, occurred before deposition of the Puye Formation (pre-Pliocene-Pleistocene).

The Pajarito fault system disrupts the geomorphic surface of the Pajarito Plateau. Perhaps not more than 50 to 500 feet of loose ejecta was removed from a slightly undulaing plateau top by sheet erosion before the more resistant underlying welded tuffs and rhyolitic domes became exposed. Following this beveling, the mesa-like top was incised by stream erosion.

Present-day stream erosion rates suggest that this Canyon system could not have been formed in Recent times. The incision probably occurred during one or more of the pluvial periods of the Pleistocene or at the latest between the end of the Pleistocene and the beginning of the last thermal maximum (18,000 to 26,000 years ago or during the Holocene). It is thus probable that the original beveling occurred during a previous interglacial age, before the arrival of the pluvial conditions associated with the last period of glaciation. In our judgment the degree of incision suggests it was a late Pleistocene to Holocene event. This implies that the youngest fault displacement within the Pajarito fault system may have occurred during the late Pleistocene, for it was also noted that fault scarps on the plateau which displaced the beveled surface generally have undergone little erosion.

Both of the two major fault systems which affect the Valles caldera consist of older and younger en echelon fault members which evidence a long history of recurrent fault movement. The Pajarito fault system and the Jemez fault system experienced several thousand feet of displacement in the pre-Bandelier tuff time.

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from the uplifts. The El Rito, Baca, Galisteo and Raton Formations were the first Tertiary deposits laid down in the late Laramide structural basins.

In about middle Tertiary time, volcanic extrusions of rhyolitic to andesitic rocks occurred on an enormous scale, were accompanied by minor eruptions of basalt, and were concentrated along the western half of the Rocky Mountain uplift belt and in the adjacent Colorado Plateau. Little or no compressional deformation accompanied this volcanism, but there is evidence of tensional deformation and resultant high-angle faulting, both during and subsequent to the igneous activity. The Abiquiu tuff, the Picuris tuff and the Espinaso volcanics are products of this first stage of volcanism.

The middle Tertiary flows, pyroclastics and volcanic alluvial beds accumulated over broad areas and overlay earlier nonvolcanic sediments with only slight unconformities or discordances. The intense fracture belts and prominent tilted blocks and trough-like structural basins characteristic of the Rio Grande depression and adjoining uplifts developed subsequent to this mid-Tertiary deposition.

Development of the <u>present</u> Rio Grande structural depression probably began about 18 to 21 million years ago in early Miocene time and culminated in what may be termed the Cascadian orogeny toward the end of Pliocene time. Deformation formed the series of isolated en echelon basins which broadly represent

In the last 1,000,000 years there has been greater fault displacement within the Pajarito system than in the Jemez system, with Bandelier tuff having been offset up to 500 feet within the Pajarito system, as compared to 100 to 200 feet in the Jemez system (verbal communication, Smith, 1972). Movement post-dating the development of the plateau surface has occurred within both systems. This movement may have occurred between 500,000 and 100,000 years ago.

Most en echelon displacement along the fault members of the Pajarito fault system is ascribed to pre-Tshirege member (Bandelier tuff) movement. Some apparent displacements of the Tshirege member are the result of local differential compaction of poorly welded or unwelded pyroclastic units overlying welded units or buried topographic highs of basement rock.

The 400,000 to 100,000 year old Valles rhyolite in the center of the caldera is not offset by faults, although it is tectonically fractured. It should be noted, however, that this does not preclude the possibility of fault movement during or after Valles time in areas which lack outcrops of that formation.

Faulting in both the Pajarito and Jemez zones predates the Holocene alluvial fan and landslide deposits within the Jemez uplift; nevertheless, the above information indicates that both of these major fault systems are geologically

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active. Furthermore, more than one period of faulting occurred within both systems between 500,000 and 10,000 years ago and are therefore to be considered "active" according to AEC criteria. Both fault systems are considered to be structurally and tectonically related, differing only in the dates of their initial activity and in the local distribution of their stress field.

CRITERIA FOR "CONTROL WIDTH" FAULTING

In our opinion, the Pajarito and Jemez fault systems thus define a broad, 25-mile wide zone of "active" faulting. The approximate "control width of faulting," (as set forth by AEC regulations, Supra, P. 22604) for both of the individual fault systems is listed below:

FAULT ZONE	"CONTROL WIDTH"
Pajarito	8 miles
Jemez	4 miles

According to AEC specification, the width of the zone "requiring detailed faulting investigation" is twice the "control width." Since the proposed plutonium facility lies within the Pajarito fault zone, the width of the zone required for the detailed study is 2 X 8 miles, or 16 miles. The length of this zone is 20 miles, extending 10 miles along the fault trend in both directions from the proposed site. The boundaries of this zone are indicated on Plate G-7.

SEISMIC EVIDENCE FOR RECENT FAULTING

The fault with the greatest length and displacement is the Pajarito fault west of the proposed facility. We may assign a length of nine miles to the section of this fault nearest to the site; the maximum stratigraphic displacement in the nearly horizontal Bandelier tuff is 430 feet. From historical earthquake data (Iida, 1956), Iida has obtained an average displacement-to-length ratio of 10^{-4}. Thus, repeated movements must have taken place along the Pajarito fault system.

If we use Iida's ratio of $\frac{D}{L} = 10^{-4}$, then 83 displacements of $L = 14.4 \times 10^{+5}$ cm. and $D = 144$ cm. may have occurred. In this calculation, it is assumed that fault movement is due entirely to earthquake activity and that creep along the fault has been negligible.

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Since the Pajarito fault displaces the Tshirege member of the Bandelier tuff, it has a maximum age of one million years. Dividing this age by 83 events would give one significant event every 12,000 years.

If 83 displacements along this fault were distributed evenly over the last million years, then 42 displacements would have occurred during the last 500,000 years. According to AEC criteri , this fault system may thus be considered "active," on this basis alone, having undergone two or more movements within the last 500,000 years.

In the area of interest, an average yearly movement of 0.13 millimeters is indicated on the Pajarito fault zone. This value compares with vertical movements of 0.5 to 1 millimeter per year, as reported from the borders of the upper Rhine graben in West Germany (Malzer H., 1967).

GEOMORPHIC EVIDENCE FOR FAULTING

In Quaternary time, probably early Pleistocene time, regional climatic fluctuations produced periods of erosion alternating with periods of alluviation throughout the Rio Grande tectonic trough. An extensive series of geomorphic features developed on Santa Fe and older sediments. Pediments were cut locally along the flanks of mountain ranges during periods of erosion; gravels were deposited on the pediments during periods of alluviation. Each successive period of pedimentation tended to destroy the older gravel-capped surfaces. Remnants of younger surfaces generally can be found at lower elevations. The oldest of the pediment surfaces, that known as the Ortiz surface, is about 430 feet above the present drainage of the Albuquerque-Belen Basin. The youngest and lowest surface is called the Canada Mariana surface and lies 40 to 90 feet above the level of the present drainage. Several faults downdrop these surfaces as much as 50 feet, thus leaving Quaternary fault scarps as evidence of the most recent faulting within the Rio Grande tectonic trough near Socorro (Sanford, et al, 1972). The age of these scarps has been estimated to be 400,000 to 10,000 years old. The scarps occur both north and south of Los Alamos.

One hundred and fifteen to one hundred and fifty miles southwest of Los Alamos, Quaternary fault scarps are preserved in fanglomerate and alluvium east and southeast of Ladron Mountains, northeast of Magdalena Mountain, and southeast of Socorro Mountain (Plates G-2, G-21, and G-22). These faults generally trend north-northeast, with their eastward sides downthrown toward the trough axis. Different magnitudes of offsetting between older and younger terrace surfaces indicate recurrent and differential displacement along these Quaternary faults. One of the faults, exposed in Socorro Canyon, southeast of Socorro Mountain, offsets the lower Valle de Parida pediment surface and is overlain by an undisturbed Recent river terrace situated approximately ten feet above the present and adjacent river channel. Present-day rates of stream erosion indicate that this Quaternary fault has not been active in the last 100 years.

One hundred and eighty miles north-northeast of Los Alamos, in the San Luis Valley of Colorado, about 14 miles south of Salida in the vicinity of Villa Grove (Colorado, San Luis Valley, Plate G-2). Quaternary faults displace Pleistocene sediments which include alluvium, stream terrace remnants, and landslides.

During the late Pleistocene (Wisconsin) time in Colorado, glaciers deposited morainal material in high cirque basins and canyons of the Sangre de Cristo Range, the Bonanza volcanic field, and the southern Sawatch Range. Outwash fans representing several stages of glaciation were deposited along the steep western front of the Sangre de Cristo Range. Periods of erosion between episodes of fan deposition partially removed the earlier fan systems.

Subsequent to and probably during the deposition of these Pleistocene outwash fans along the Sangre de Cristo Range, the pre-Quaternary Sangre de Cristo fault system was reactivated and displaced Pleistocene gravels by as much as 20 to 25 feet. This Quaternary fault system bifurcates in the vicinity of Valley View Hot Springs. One branch continues north-northwest along the front of the Sangre de Cristo Range; the other trends more northwestward toward the town of Villa Grove.

Faults along the front of the Sangre de Cristo Range at the north end of the Rio Grande trough in Colorado displace the heads of several alluvial fans. Fault displacements along the northwest branch decrease to the northwest and finally die out altogether north of Villa Grove. Along the central portion of this branch the faults have partially dammed ground water circulation, forming marshy and densely vegetated areas on the upslope side of some faults. Displacement along both fault branches is predominantly up on the east.

The north-northwest fault branch apparently reflects recurrent movement along the pre-Quaternary Sangre de Cristo fault system. The northwest fault system roughly outlines a subsidiary graben within the major part of the Rio Grande depression. Gravity data indicate the presence of a second narrow, intratrough graben south and east of Villa Grove. Recurrent movement along the border of this graben had displaced Quaternary gravels. North of the graben the thicknesses of Quaternary deposits decrease rapidly.

In Holocene time, small alluvial fans and mud or debris flows formed, commonly at the base of pre-existing or erosional scarps. In one area, north of Steel Canyon, a recent mud flow has been disrupted by a range-front fault.

Thus, the numerous fault scarps cutting Pleistocene surfaces and Recent alluvial fans of the Rio Grande tectonic trough, both north and south of Los Alamos, indicate that this major tectonic structure is still undergoing structural development.

Quaternary "gravity" faulting along the entire Rio Grande depression is also represented by "torevas." Torevas are landslide masses generally located along the margins of mesas, which form when underlying incompetent material (usually the Santa Fe group) fails, and the overlying, more competent rocks (usually Quaternary basalts) are broken and rotated as they slide downslope. These slide masses form characteristic hummocky relief with irregular blocks on their top surfaces. It is quite possible that solifluction and landsliding became active under the periglacial conditions of the Pleistocene.

EVIDENCE OF ACTIVE VOLCANISM

Late Pleistocene and Recent volcanism in the general vicinity of Los Alamos also suggest late Quaternary tectonism. Fifteen miles west of the proposed plutonium site, rhyolite flows and ash eruped 100,000 years ago. Vestiges of volcanism continue today, as evidenced by solfataric and hot spring activity within the caldera, notably at Sulfur Springs some 18 miles west of the proposed site and outside the caldera at several localities in San Diego Canyon, along the present course of the Jemez River.

The repose period between large eruptions appears to have increased in the development of each of the major eruptive centers within the Jemez volcanic locus. Approximately 300,000 years elapsed between the eruption of the lower and upper Bandelier tuff members and those from the youngest center. Other eruptive sequences of similar type and magnitude within the volcanic complex have a periodicity ranging from 200,000 to 500,000 years. This would indicate that there should have been another eruption of Bandelier tuff-type materials about 600,000 years or two "periods" ago; the fact that a million years have passed without a Bandelier-type eruption suggests that the probability of such an event occurring again in this cycle of volcanism is very small.

There is a mechanical or physical continuum between the Bandelier tuff eruptions and the later Valles rhyolite eruptions of lesser magnitude. The Valles rhyolite eruptions comprise intrusive rhyolitic domes which were preceded by violent but relatively small ash fall eruptions within 50,000 years of the initial collapse of the caldera. The repose period between these eruptions is only about 100,000 years. Since the last of these eruptions (Banco Bonito flow and

El Cajete tuff) occurred only 100,000 years ago, there is a much stronger probability of a future small El Cajete-type eruption than of a giant Bandelier-type eruption.

The nearly complete structure of ring eruptions indicates, however, that this sequence of eruptions must be nearly finished. The spatial distribution of these intrusive domes and explosive tuffs indicates that there is room for one more eruption, between Cerro del Medio and South Mountain, approximately ten miles west of the proposed site.

The fact that the volcanic activity which produced the Bandelier tuff and the Valles rhyolite eruptions is slowing down does not indicate that the volcanic center is extinct, nor does it preclude the possibility of a new cycle of volcanic activity. The eruptive center which produced these eruptions is considered to be geologically active, but in a current state of dormancy.

Geological data on the volume of the magma chamber, heat flow, and solidification rates, and geothermal gradients may be interpreted to indicate that there may still be magma within the magmatic reservoir (verbal communication with R. Smith, 1972). The attitude and topographic position of the denuded ring structure indicate that the top of the magma chamber is 10,000 to 15,000 feet below the ground level of the caldera. Several thousand feet below the surface, the geothermal termperatures reach between 100°F and 200°F.

Structurally and tectonically related flank eruptions of basaltic magma represent the greatest probability of another volcanic event.

Approximately 35 miles southwest of the proposed site, Recent volcanic hot springs occur along the trace of the Nacimiento fault (Plate G-20). Two recent basalt flows have erupted along the margins of the Rio Grande rift zone about 95 miles southwest and about 165 miles south-southeast of the proposed site, near Grants and Carrizozo, respectively (Plates G-2 and G-20). A Recent basalt eruption has occurred within the rift zone 270 miles south of Los Alamos, near Las Cruces. These eruptions are so recent that the flows lack a soil horizon. Enclosed Indian artificats within the Malpais basalt flow east of Grants date the flow as younger than 1000 years.

In comparison to other rift valleys, the alluvial fills in the Rio Grande depression were relatively free of interbedded volcanic rocks until about five million years ago, when volcanism appears to have become more prominent (Chapin, 1971). Published K-Ar dates, supplemented by archaeological dates and geomorphic estimates on very young flows suggest that the rate of volcanism associated with the Rio Grande tectonic trough has increased through geologic time.

RELATIONSHIP BETWEEN EARTHQUAKE EPICENTERS AND THE RIO GRANDE GRABEN STRUCTURE

Sanford et al (1972) studied the seismicity of a portion of the Rio Grande rift zone extending from Santa Fe in the north to Socorro in the south (Plates 2 and 3). Analysis of historical reports and recent instrumental studies indicated that most of the seismic activity along this segment of the rift occurs south of Albuquerque, with the most intense activity concentrated between Bernardo and Socorro.

According to their results, current microearthquake activity is not uniformly distributed within the rift area; it tends to be concentrated in relatively narrow zones. These seismic zones appear to be geographically unrelated to the large fault systems between the basins and their marginal uplifts. Many of the fault-defined boundaries between basins and highlands are nearly aseismic. The seismic zone near Socorro cuts obliquely to the northeast, across the north-trending rift structure.

If the observed distribution of seismic activity is an accurate representation of the stress distribution within the studied area, the general lack of correlation between zones of microearthquake activity and graben faults may indicate:

1. A recent shift of tectonic stresses

or

2. That the microearthquake zones represent areas where relatively minor stress concentrations are being relieved.

If Item 2 is the case, large stress concentrations may yet exist along the major rift faults; such stress concentrations would have to be relieved by strong shocks, which are relatively rare in the region. One could thus infer that the areas which are likely to produce large earthquakes may presently have little or no microearthquake activity.

It should be emphasized that the regional tectonic and structural framework of the Rio Grande rift zone causally relates all seismic activity occurring within it.

SYNOPSIS OF REGIONAL GEOLOGY

Geomorphic, stratigraphic, structural and historical geologic data are essential to an analysis of the tectonic character of the Rio Grande rift zone.

The Rio Grande rift was formed by two distinct periods of deformation, one prior to the initial deposition of the Santa Fe Group (pre-Oligo-Miocene) and the other after much of the Santa Fe Group had been deposited (post-Pliocene-Pleistocene). The geographic boundaries of deformation generated by tectonic activity during these two periods nearly coincide.

Toward the end of Cretaceous time, compressive Laramide tectonic forces were active along the entire length of the New Mexico Rocky Mountains. The uplifts resulting from these compressional forces appear to have been paralleled by flanking downwarps which became filled with erosional debris the present outline of the Rio Grande tectonic trough. With the development of the graben basins, between 4000 to 10,000 feet of sediments of the Santa Fe Group began to accumulate. Santa Fe Group sediments are typically alluvial fan deposits and their compositions in large part reflect the rock types which were exposed in the adjoining uplifts. In fact, the superposition of local members roughly reflects, in reverse order, the stratigraphic superposition of the adjoining uplifts.

The Santa Fe deposits are relatively free of volcanic debris, but in many places along the west side of the depression (especially near the Jemez uplift) coarse fragments may be almost exclusively volcanic. Basaltic flows are characteristic of the Santa Fe Group and are interbedded sparingly but repetitively throughout the section.

Stratigraphic and structural relationships indicate that extensive volcanism at the site of the Jemez uplift began in early Pliocene time. The area now occupied by the Jemez uplift was then a basin of sedimentation situated between the Sangre de Cristo Range on the east and the Nacimiento Mountains (probably a subdued upland) on the west. Volcanism commenced along the western slope of the basin and was accompanied and followed by faulting along the Jemez fault system. After a period of quiescence and erosion, eruptions of rhyolitic ash flows and development of calderas occurred and continued until about one million years ago. Subsequent intrusions and extrusions formed a ring of rhyolitic domes and ash falls within the existing Jemez caldera between 900,000 and 100,000 years ago. Current volcanic activity within the Jemez volcanic uplift is restricted to solfataric and hot spring activity.

By the end of the Pliocene, renewed structural deformation occurred. The tectonic pattern of this late Tertiary - early Quaternary deformation is dominated by closely spaced, en echelon, normal strike faults with northerly to northeasterly trends. This deformation resulted in integration of the previously isolated sedimentary basins along the original structural depression, via a through-flowing perennial river -- the ancestral Rio Grande. Tremendous volumes of sediments were removed from the Rio Grande depression, and the present complex geomorphology of the Santa Fe Group remains as a fragmentary record of important Pleistocene tectonic events. The Pleistocene deformation is especially apparent in the eastern Espanola basin where renewed movement of the pre-Quaternary Sangre de Cristo fault system has offset Santa Fe Group strata.

Pliocene-Pleistocene deformation was evidenced in the Jemez uplift by renewed movement along the Jemez and San Felipe fault systems and by initiation of the Pajarito fault system. The Jemez and Pajarito systems have post-Bandelier tuff movement (post-1,000,000 years) and post-plateau surface development movement (post-early Pleistocene). Regional geological analysis indicates that these two fault systems are

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structurally related and define a zone roughly 25 miles wide and 30 miles long within which faulting occurred intermittently during the last 1,000,000 years. Numerous fault scarps offsetting both Pleistocene sediment surfaces (estimated to be 400,000 to 10,000 years old) and Holocene alluvial fans and recent seismicity within 200 miles of the Jemez uplift indicate that differential movement within the Rio Grande tectonic trough is continuing.

The dominant structure of the Rio Grande depression is similar to the tensional deformation structure of the basin and range type. Along the length of the Rio Grande structural belt Kelley (1956) has suggested that there may be evidence of horizontal shifting. The depression should thus be considered a great rift zone which has been subjected to both tensional and compressional forces.

The forces which have given rise to the present system of fractures may be explained by principles of plate tectonics. The Rio Grande tectonic trough may be viewed as consequent to the "splitting away" of the Colorado plateau block from the continental interior, the latter resulting from tensional crustal fragmentation subsidiary to movement between underlying segments of lithosphere or from convection currents across a magmatic rise.

As applied to the Rio Grande rift zone, the concepts of rifting and plate tectonics account for the release of compressive forces to form structural grabens by gravity impetus, as well as for the development of tangentially directed forces which would produce lateral shear, horizontal displacement, and en echelon structures. The faults which bound the uplifts are generally steep to vertical and dip toward the depression. The development of both high-angle thrusts and gravity faults is compatible with an hypothesis of extension and rifting, and field evidence gathered along many of the bounding faults indicates that in many instances both kinds of movement have occurred on the same fault.

The geologic history of this region indicates repeated deformation from Laramide to Recent times. Recent seismic and volcanic activity within the Rio Grande tectonic trough suggest that the deep-seated rifting which started in middle Tertiary time (and which was responsible for the development of the present en echelon basins and uplifts) is currently in progress. Continued widening of the Rio Grande rift, the result of extension and drift of crustal plates, also appears to have accelerated volcanism, especially along the western boundary.

SITE GEOLOGY INVESTIGATION

PURPOSE AND SCOPE

The regional studies determined that the site of the proposed plutonium processing facility at Los Alamos lies along the flank of the geologically active, but presently dormant, Jemez volcanic locus and within the geologically active Pajarito fault system. The presence of the proposed site within the Pajarito fault system established the boundaries of the area, requiring detailed fault investigation as specified by the Atomic Energy Commission in 10CFR100, Appendix A. This study presents the results of the detailed investigation of the site.

The scope of the investigation included:

1. Meetings with representatives of the US Geological Survey in Washington, D.C., whose published work on the area was used as the basis of our geological studies. The purpose of the meetings was to determine their current theories on the geologic history of the area and their evaluation of the age of faulting and of volcanic activity in the area, preparatory to site geological investigations.
2. Field examination and mapping of the orientation and displacement of all surface fault members within the detailed investigation zone (16 X 20 mile area, Plates G-10 and G-11, scale 1" = 2000 feet).

3. Determination of which faults in excess of 1000 feet in length and ranging within 5 miles of the site are to be considered active.
4. Construction of a detailed geologic map and stratigraphic column of the proposed site, including a discussion of the local stratigraphy and geologic structure with notes on relevant engineering considerations (Plate G-12, scale 1" = 200' and Plate G-14).
5. Excavation of a trench 965 feet long, 3 to 4 feet wide, and 6 to 8 feet deep across the proposed site to allow detailed geologic mapping of the bedrock and to substantiate the lack of any fault tectonic fracture system extending through the site. The mapping included the recording of all attitudes of the volcanic joints and indications of any displacement due to differential compaction of tuff or to block adjustments due to gravity impetus. An orientation diagram (Plate G-17) and two rose diagrams (Plate G-18) of the structural attitudes of the volcanic joints were made. These diagrams helped to distinguish between the volcanic and tectonic fractures and permitted an analysis of the structural significance of

the tectonic fracture pattern exposed east of the site. Two additional trenches (15 feet long, 30 inches wide and 15 to 18 feet deep) were excavated to insure that discontinuous platey fracturing of bedrock previously observed to extend within six feet of the C soil horizon was, in fact, of nontectonic origin.

6. Construction of a detailed geologic cross section from data gathered in two 180-foot foundation investigation test borings which were also used for geophysical studies at the site (Plate G-15).
7. Construction of a large-scale geologic cross section of a part of Mesita del Buey (Plate G-16).

RESULTS OF CONFERENCES WITH THE US GEOLOGICAL SURVEY

Messrs. R. Smith and R. Bailey of the US Geological Survey, Washington D.C., authorities of considerable repute on the geology of the Los Alamos area, agree that the Pajarito and Jemez fault systems are structurally and tectonically related, and that both are geologically active.

They also agree that the eruptive center which produced the Bandelier tuff, the Valles caldera and the associated intrusive Valles rhyolite is geologically active; and that the Quaternary tectonism of the Rio Grande rift zone is currently active, as stated in the section on regional geology.

STRATIGRAPHY IN THE "ZONE REQUIRING DETAILED FAULT INVESTIGATION"

The results of field-checking our photogeologic interpretations of infrared photographs and the geological map of Smith et al (Misc. Geol. Invest. Map 1, 1970) were compiled on the Guaje Mountain and Frijoles Canyon 7-1/2-minute topographic maps (Plates G-10 and G-11). These two topographic maps together approximately cover the 16 X 20 mile zone of detailed fault investigation. All local geological field data pertinent to the design and safety analysis of the proposed facility are included on this map.

Faults which have been classified as "active" according to AEC criteria and which come within 5 miles of the proposed site and are 1000 feet long are specifically designated on Plates G-10 and G-11.

The geologic units used in the legend and the geologic contacts on the map are essentially the same as those published in Smith's map (Smith, et al, 1970).

Plate G-13 is a diagrammatic geologic cross section of the upper part of the Pajarito plateau, showing the generalized stratigraphic relations of the Santa Fe Group (in ascending order: The Tesuque Formation - Tsq -, the Puye conglomerate - QTp -, composed of the Totavi lentil and a fanglomerate member, the interbedded basaltic rocks of Chino Mesa Formation - QTb -), of the stratigraphically younger

Tschicoma Formation - Tt -, and of the overlying Bandelier tuff. (Undifferentiated Guaje and Otowi members - Qbo - and Tshirege member - Qbt -.) These stratal units crop out within the zone requiring detailed investigation (see Plate G-7).

Within this zone, the Pliocene Tesuque Formation is about 2400 feet thick and unconformably overlies about 2800 feet of sedimentary and volcanic rocks chiefly of Eocene to Miocene age, but which may include some Mesozoic and Paleozoic strata. These pre- Santa Fe Group strata extend down to Precambrian crystalline basement rocks at an elevation of about 250 feet above sea level.

The Tesuque Formation is composed of well-cemented beds of siltstone and sandstone with some pebbly conglomerate and clay lenses. These sedimentary rocks represent alluvial fan and flood plain deposits which are interbedded with rocks of the Tschicoma Formation. The Tesuque Formation is overlain disconformably by the basalt member of the Puye conglomerate throughout most of the plateau; in the Los Alamos area, however, the contact is conformable. The middle to late Pliocene Puye conglomerate consists of two members. The lower member is called the Totavi lentil, consisting of about 70 feet of poorly consolidated arkosic river channel fill composed of sand, pebbles, cobbles, and boulders of rhyolite, latite, quartz latite, pumice, granite, and quartzite. In the eastern part of the plateau, the Totavi lentil is overlain by the thick basalt flows of Chino mesa. To the west, the Totavi lentil is conformably overlain by a 640-foot fanglomerate member composed of latite, quartz latite, and andesite debris. On the surface, the fanglomerate is interbedded with the basaltic rocks and intercalated sediments of the Chino Mesa Formation. The Chino Mesa Formation overlies the main body of the Puye Formation, and only a thin section of the Puye fanglomerate overlies the basalts.

In the western part of the plateau, the fanglomerate of the Puye Formation and the rocks of the Tesuque Formation of the Santa Fe Group are interbedded in the subsurface with the middle to late Pliocene Tschicoma Formation. Here the Tschicoma, composed of thick massive flows and domes of porphyritic dacite, rhyodacite and quartz latite, has an aggregate thickness of over 3000 feet.

The youngest rocks within this area are a Pleistocene sequence of rhyolitic ash flows and ash falls called the Bandelier tuff. The total thickness of these rocks ranges from about 1000 feet on the eastern flank of Sierra de los Valles (the western edge of the Pajarito plateau) to about 50 feet along the banks of the Rio Grande, thinning westward away from the source vents.

On the eastern flank of the Sierra de los Valles, the basal member of the Bandelier tuff conformably overlaps the Puye and Chino Mesa Fromations and unconformably overlies the Tesuque and the Tschicoma Formations.

The Bandelier tuff consists of rhyolitic ash flows and ash falls that draped over the topographic irregularities of the older rocks, forming a smooth shield-like appearance. The Bandelier Formation was first subdivided by Griggs (1964) into three members, in ascending order: the Guaje member (50 feet maximum thickness), the Otowi member (400 feet maximum thickness), and the Tshirege member (500 feet maximum thickness).

The Guaje member is a bedded pucice fall deposit with a thin layer of water-laid pumiceous tuff. This member has an average thickness ranging from 20 to 35 feet, with a maximum thickness of about 50 feet. The Otowi member is conformable with the underlying Guaje member, ranges in thickness from less than 50 feet to 400 feet and is composed of massive nonwelded to slightly welded pumiceous tuff breccia of ash flow origin, with local, thin, upper units of water-laid ash. The Tshirege member unconformably overlies the Otowi member and comprises a cliff-forming series of welded pumiceous ash and tuff breccia flows, with one water-laid bed near the top reaching an aggregate thickness ranging from 50 to 800 feet. Nonwelded ash flows in the lower part of the Tshirege member may be as much as 200 feet thick near the center of the plateau. Individual moderately welded and welded ash flows in the upper part of the Tshirege member range from 20 to 120 feet thick.

Although this three-fold subdivision was suitable for mapping the Los Alamos area (see Plate G-13), subsequent work by Smith et al (1966, 1969) has shown that the Bandelier Formation may be more naturally subdivided into two stratigraphic and genetically equivalent units, each consisting of a basal pumice fall overlain by a petrologically related succession of ash flows. This data is summarized as follows:

Griggs (1964)	Smith and Bailey (1966)	Smith and Bailey (1969)	
Tshirege member	"upper member"	Tshirege member	Ash-flow units -------------- Tsankawi Pumice Bed
Otowi member ------------ Guaje member	"lower member"	Otowi member	Ash-flow units --------------- Guaje Pumice Bed

FRACTURING IN THE "ZONE REQUIRING DETAILED FAULT INVESTIGATION"

The proposed site lies near the southward strike projection of the tentatively named "East" and "West" fault members of the Pajarito fault system (see Plates G-10 and G-11).

The displacement on the "active" en echelon fault members of the Pajarito fault system is predominantly dip slip. North and south of the site, the fault blocks are generally downthrown to the west and to the east, respectively, forming a complex series of normal faults which bound structural blocks that are generally tilted eastward.

The dip separation of what is apparently post-Tshirege displacement of the Bandelier tuff approaches 300 feet 10 to 15 miles to the north and to the south of the proposed site. West of the site, along the main trace of the Pajarito fault, maximum post-Tshirege displacement appears to be 430 feet.

Along the West fault member, a 50-foot dip separation of the zonal contact between vitric and devitrified tuff of the Tshirege member, exposed in Pueblo Canyon, dissipates rapidly southward; there is no evidence of surface faulting along the north wall of Los Alamos Canyon, one and one-half miles north of the proposed site (see Plate G-23).

The maximum apparent dip separation along the West fault member appears to be about 100 feet. West of Guaje Mountain, just east of the cemetery where Bandelier tuff is juxtaposed with Tertiary Tshicoma latite, a fault zone of brecciated latite is approximately 200 feet wide. This fault zone contains at least three or four auxiliary fault members, secondary to the main fault plane. Slickensides indicate only minor conccomitant horizontal displacement.

Along the East fault member, the dip separation of stratigraphic contacts indicate a maximum displacement of about 100 feet and a minimum displacement of 10 feet, occurring along the west side of Guaje Mountain. This dip separation likewise dissipates southward and is not exposed along strike projection near the north wall of Pueblo Canyon, two miles north of the proposed site.

Possible southward and northward continuation of these East and West fault members as tectonic fracture zones with no associated dip separation is limited to several hundred feet. Three geomorphic lineations on the aerial photos, possibly associated with the faulting and involving anomalous north-south bends in the east-west oriented stream channels, were examined in the field. Two of these lineations, in the northern part of Section 28, T 19N, R 6E, (0.4 miles south of the site) which have northeasterly, nearly coincidental trends involve erosion along the dominant volcanic joint planes within the topmost tuff unit (Subunit 3b). Dominant joint planes do not extend more than a few feet into the underlying tuff (Subunit 3a) before becoming irregular and dying out 50 to 70 feet below the surface of the plateau. These two lineations, as well as other minor geomorphic lineations detected within a ten-mile radius of the site, are definitely surface features resulting from weathering and erosion, and do not extend into the subsurface.

A third distinct lineation, between Sections 22 and 27, T 19N, R 6E, approaches to within 1000 feet east of the site, trends approximately N 15-20 W, and comprises at least five closely spaced en echelon members. This lineation represents a structural fracture zone, roughly en echelon with the East fault member of the Pajarito fault system. The southeast trend of the lineation terminated within Pajarito mesa, just south of Pajarito Canyon; the northwest trend of the lineation does not reach the north wall of Sandia Canyon, but ends within the mesa between Mortandad and Sandia Canyons.

Tectonic fractures within the zone of detailed investigation can be distinguished from volcanic joints by:

1. The subparallel orientation of the major (tectonic) fractures (N 0-20 W, commonly 10-15 W) to the N 5-25 W trending volcanic joints.
2. The dip of major fracture planes, although generally similar to that of existing volcanic joint surfaces (90-80°) is usually slightly less (85-80°) and occasionally as low as 75 to 60°, whereas volcanic joints rarely dip less

than 75°. There is usually a slight curvature in the vertical plane to the tectonic fracture plane that is less commonly observed along volcanic joint planes.

3. Density of tectonic fracture planes is higher (five to ten feet average spacing) than the dominant volcanic joint planes in the surrounding area (10-15 feet average spacing, with occasional secondary joints at 5-foot spacings).
4. Tectonic fractures generally truncate volcanic joint planes and are much more continuous along strike than neighboring joint surfaces. The tectonic fracture planes also tend to form en echelon patterns with 3 to 150 feet horizontal separation between planes, distinct from the discontinuous polygonal volcanic joint patterns. Volcanic joint planes intersect other volcanic joint planes, but do not offset them, nor do they offset tectonic fracture planes.
5. Tectonic fracture planes always offset subhorizontal parting planes from several inches to several feet. Volcanic joints only rarely offset the parting surfaces, the result of differential settlement.

6. The presence of obliquely oriented slickensides on the clay gouge along tectonic fracture planes indicates minor horizontal movement. These clay zones are thin (1/8 to 1/2 inch thick) and generally much thinner than the sedimentary clay fill (1/4 to 2 inches thick) between volcanic joint blocks; the latter is generally the result of the filtering down of the surface soils and never exhibits a slickenside texture.
7. Small graben structures with offsets of from several inches to several feet typically develop along narrowly-spaced fractures (1 to 3 feet separation). These small graben structures are not generally developed along similarly spaced volcanic joint surfaces.

Most of the evidence of post-Tshirege time fault movement within the detailed fault investigation zone is geomorphic in nature, and consists of offsets of plateau surface, fault lines, and fault scarps which occasionally have anomalous vegetation cover. There is difficulty in distinguishing real and apparent post-Tshirege time fault movement, due to differential compaction of the tuff where it overlies buried topographic irregularities of pre-Bandelier rock (see Plate G-23). One of the best examples of apparent displacement is exposed in Pueblo Canyon; there the elevation and structural attitude of a zonal cooling and welding unit between a lower vitric (glassy) tuff unit and an upper devitrified (crystalline) tuff unit varies across the canyon, in response to a change in the topographic position and shape of a partially buried Tertiary latite body. The zonal unit is not a stratigraphic unit, but roughly contours the outer perimeter of the existing "basement" rock. As much as 50 feet of apparent displacement of this zonal unit is seen along the north wall of Pueblo Canyon near the junction with Acid Canyon; this is the result of a depositional buttress contact of upper Bandelier tuff with what is thought to be a large landslide mass of latite.

Most of the pronounced *en echelon* fault displacement within the 16 X 20 mile zone occurs within pre-Tshirege member rocks. The width and degree of brecciation of fault zones within these rocks is much greater than in the overlying Tshirege member, attesting the long history of recurrent fault movement along en echelon fault members of the Pajarito fault system.

The intensity of fault deformation within Tertiary latite along the West and East fault members is much greater than that within the overlying Bandelier tuff, suggesting that older branches of the two faults may continue southward, toward the proposed site, under the undisturbed Bandelier tuff.

DETAILED SITE GEOLOGY

GENERAL

The proposed site is on the northwestern part of Mesita del Buey, located between Effluent Canyon to the north and Two Mile Canyon to the south. The canyon floors are 200 to 300 feet below the surface of the mesa. Effluent and Two Mile Canyons are tributary to Mortandad and Pajarito Canyons, respectively.

The north walls of these canyons are generally steep, composed of bare rock with scanty vegetation; the south walls are less steep and exhibit a thick talus and soil cover with relatively dense growth of deciduous shrubs and conifers. The differential erosion of the canyon walls has previously resulted at least in part from the differences in vegetation cover, caused in turn by differences in the amounts of solar radiation received by the north and south-facing walls.

STRATIGRAPHY AND PETROLOGY

Plate G-12 is a detailed geologic map of the proposed site. A stratigraphic column of the rocks underlying the proposed site on Mesita del Buey is given on Plate G-14. The stratigraphic units of the Tshirege member of the Bandelier tuff shown in the legend of Plate G-12 are those first developed by Wier and Purtymun (1962), and later modified by Baltz and others (1963). The upper unit (Unit 3) was subdivided by the authors into Subunits 3a and 3b, and each subunit was divided into a lower and upper interval (see Plate G-15).

The rocks exposed on the surface of the mesa at the proposed TA-55 site belong entirely to Subunit 3b of the Tshirege member of the Bandelier tuff. Due to the structural attitude of stratigraphic units and to the proposed foundation elevation (7284 to 7280 feet), the foundation of the proposed TA-55 Building will be entirely within Subunit 3b. Because of the importance of this and associated stratigraphic units, they are described in detail below.

Some of the subsurface rocks underlying Subunit 3b crop out along the walls of the adjacent canyons. In Effluent and Two Mile Canyons, stratigraphic Subunits 3a, 2b, and 2a are exposed. From these exposures, from exposures in Mortandad, Sandia, Los Alamos, and Pajarito Canyons, and from augering, coring, and sampling to depths of 180 feet below the surface at the TA-55 site, the following descriptions of these units were completed:

Subunits 1a and 1b

The lower part of the Tshirege member consists of two ledge-forming units of pumiceous tuff breccia, similar in lithology but slightly different in color, degree of welding and in weathering characteristics.

The lower Subunit 1a overlies the reworked sediments at the top of the Otowi member. The thickness of this member varies because of the irregular erosion surface, ranging from 20 to 30 feet at the western part of the mesa and thinning within two miles to less than 10 feet at the eastern part of the mesa.

The unit ranges from nonwelded to moderately welded tuff, and weathers to a steep slope with a case hardened outer rind one to three inches thick; this protects the unweathered rock from severe erosion. It consists of a light orange-brown, pumiceous tuff breccia ash flow. It contains numerous pumice fragments ranging to six inches in length, small quartz crystals, and zenoliths of latite, rhyolite, and obsidian in a fine glassy ash matrix.

Subunit lb conformably overlies Subunit la and is slightly less resistant to erosion; it forms a ledge set back from the lower unit along a narrow bench. At some places both layers form nearly vertical cliffs, and the subunits can then be distinguished by an unwelded bed of pumiceous tuff at the base of the upper one which erodes to form a persistent notch.

The thickness of this lower part of the Tshirege member is fairly uniform, ranging from 21 to 25 feet. Subunit lb is a moderately welded, gray-brown, crystal-fragment tuff breccia with a fine-grained ash matrix, similar to la. The tuff contains more and larger quartz crystal fragments (granule-sized), but fewer and smaller fragments of pumice, latite, and rhyolite.

Subunits 2a and 2b

Unit 2 of the Tshirege member conformably overlies Subunit lb and appears to grade into it. The unit consists of two subunits, a lower slope-forming pumiceous tuff separated from the overlying ledge-forming crystal-fragment tuff by an erosional unconformity. This is commonly marked by a six-inch thick, shaley bedded, fine-to coarse-grained tuffaceous sandstone.

Subunit 2a consists of two ash flows or ash falls of moderately to nonwelded tuff; this weathers to form a casehardened rind several inches thick and erodes to form a steep, smooth slope set back from Subunit 1b.

Along the western part of the mesa, the upper part of Subunit 2a is moderately welded, but grades eastward into a nonwelded pumiceous ash fall with minor reworked tuff. From the eastern to the western part of the mesa, Subunit 2a ranges in thickness from 85 to 30 feet, respectively. This subunit consists of a pumiceous devitrified ash matrix containing fragments of pumice, dense rhyolite and latite fragments as large as three to four inches long, but which decrease in size toward the top of the unit. Minor quartz chrystal fragments are present.

Subunit 2b consists of at least two ash flows that cooled as a single unit. The contact between these two flows is marked by an increase in the size and number of pumice fragments and by minor inclusions of reworked tuff. The two flows are pink-gray, brown weathering crystal tuffs, resistant to erosion and forming ledges and benches above the steep rounded slopes of basal Subunit 2a.

The thickness of Subunit 2b ranges from 70 to less than 30 feet and occasionally exhibits columnar jointing in the form of hexagonal prisms 10 to 20 feet in height and from 5 to 8 feet in diameter.

Subunit 2b has the following model analysis:

Phenocrysts	20.0%	(coarse sand to granules)
Sanidine	17.0%	(blocky habit)
Quartz	3.0%	(nondipyramidal habit)
Clinopyroxene	< 0.5%	
Magnetite	< 0.5%	
Pumice fragments	10.0%	(1-20mm in size)
Mesostasis	40.0%	(fine-grained devitrified ash)
Xenolithic fragments	≤ 1.0%	(latite, minor rhyolite) (pebble sized, up to 1/2-inch long)
Vesicular cavities	30.0%	

Subunits 3a and 3b

Unit 3 of the Tshirege member conformably overlies Subunit 2b and grades into it, marked by a 5 to 15-foot ledge-forming transition zone. The transitional crystal-fragment tuff is modally and texturally similar to the overlying Subunit 3a, but differs in that it has a corase fragment size and a mottled color appearance. Unit 3 also contains numerous irregular, thin (two-inch to three-foot) layers and lenses of unwelded air fall tuff, composed of ash-, pebble-, and cobble-sized pumice fragments.

Examination of cores from test holes indicates that the degree of welding of Unit 3 varies locally -- both vertically and horizontally. Vertical and lateral gradation from moderately welded to unwelded tuff within Unit 3, within a distance of several hundred feet is not uncommon. There is also a regional trend toward increased welding laterally within individual flows as source vents are approached, and a decrease in welding eastward across the Pajarito plateau.

Vertical variation in welding characteristics occurs within individual flows or within a series of flows that have cooled as a single unit, with the greatest degree of welding generally occurring near the center, rather than near the upper or lower contacts of the flow or cooling unit.

Subunit 3a is a pinkish or whitish gray, nonwelded to slightly welded pumiceous tuff breccia which weathers to form a case hardened rind several inches thick, and erodes to form soft, rounded slopes.

Subunit 3a has a maximum thickness of 64 to 78 feet in the western part of the mesa, thinning eastward to 50 or 60 feet thick. It comprises two pumiceous tuffs which differ only in the size of pumice fragments and in the percentage of phenocrysts and vesicular cavities (i.e., degree of welding). The lower subunit averages about 45 feet thick and has the following mode:

Phenocrysts		(coarse sand to granule size)
Sanidine	15.0%	(blocky habit)
Quartz	3.0%	(dipyramidal habit)
Clinopyroxeme	< 1.0%	
Magnetite	< 0.5%	
Pumice fragments	15.0%	(1 to 0.10mm in size)
Mesostasis	40.0%	(fine-grained devitrified ash)
Xenolithic fragments	≤ 1.0%	(latite, minor rhyolite and obsidian)
Vesicular cavities	30.0%	

The upper subunit averages about 15 feet thick and has the following mode:

Phenocrysts	25.0%	(coarse sand to granule size)
Sanidine	20.0%	(blocky habit)
Quartz	5.0%	(dipyramidal habit)
Clinopyroxene	< 1.0%	
Magnetite	< 0.5%	
Pumice fragments	20.0%	(15 to 40mm in size)
Mesostasis	20.0%	(fine-grained devritified ash)
Xenolithic fragments	≤ 1.0%	(latite, minor rhyolite and obsidian)
Vesicular cavities	35.0%	

Subunit 3b conformably overlies Subunit 3a and grades into it within a transition zone tuff which is modally and texturally similar to the upper subunit of 3a, but which is more welded and exhibits few preserved vesicular cavities.

This transition tuff is only slightly to moderately welded and contains a few irregular layers of unwelded ash fall. Subunit 3b forms the foundation rock for the TA-55 facilities. It is moderately welded, moderately resistant to erosion and forms flat mesas benches with steep sides. The thickness of the subunit ranges from 44 to 64 feet. The subunit consists of two tuffs which differ in the type of pyroxene, the size of the pumice fragments, and in the percentage of phenocrysts and vesicular cavities. The lower and upper subunits are separated by a thin (less than 12-inch) discontinuous and irregular tuffaceous, medium-grained arkosic sandstone.

The lower subunit ranges in thickness from 22 to 40 feet and has the following mode:

Phenocrysts	30.0%	
Sanidine	25.0 - 27.0%	
Quartz	3.0 - 5.0%	
Clinopyroxene	1.0%	
Magnetite	0.5%	
Pumice fragments	15 %	(1-15 mm in size)
Mesostasis	25 %	(fine grained devitified ash)
Xenolithic fragments	1 %	
Vesicular cavities	30 %	

The upper subunit ranges in thickness from 29 to 46 feet and has the following mode:

Phenocrysts	15.0 - 20.0%
Sanidine	12.0 - 15.0%
Orthopyroxene	1.0%
Clinopyroxene	trace
Magnetite	0.5%
Biotite	trace
Pumice fragments	10.0% (1-15mm in size)
Mesostasis	44 - 99% (fine grained devitrified ash)
Xenolithic fragments	1.0%
Vesicular cavities	25%

Both the lower and upper intervals of Subunit 3b are petrologically similar. Both intervals have interbedded, irregular and discontinuous layers (4 to 18 inches thick) of unwelded, pumiceous, highly porous ash falls. Both the lower and upper intervals have layers of more pumiceous (20% pumice fragments, generally 15-10mm in size) and crystal-rich (up to 40% phenocrysts) ash flows, with 30-35% vesicular cavities. These intercalated flows are thin (one to two feet thick) and only slightly welded. Both the lower and upper intervals have similar color, texture, and petrographic characteristics. The following description is applicable to both the upper and lower intervals.

Color:	Light pink-gray
Texture:	Pumiceous, vitroclastic, porphyritic, moderately welded

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Constituents:

Phenocrysts:

Sanidine	Tabular to blocky, anhedral to subhedral equant crystals and fragments (some appear to be pitted). Crystal habit is only slightly elongate parallel to c axis and flattened parallel to side pinacoid (010); b and c axes are nearly equal. Irregular zones of secondary feldspar crystallization around sanidine phenocrysts indicate deuteric (or hydrothermal) crystallization. Clear to milky white in color. Sizes range from 1-2-3-4mm with many fragments < 2mm.
Quartz	Dipyramidal, euhedral to subhedral; microphenocrystic; 1-2-3mm in size; light smokey gray to clear, minor milky white inclusions and yellow weathering strain.
Orthopyroxene	Dipyramidal, subhedral crystals and tabular to prismatic fragments. 1-2mm in size; green-brown to yellow-green in color, possibly hypersthene(?) Crystal fragments predominate over intact crystals.
Clinopyroxene	Equant crystal fragments < 2mm in size, green in color; possibly aegirine - augite (?)
Magnetite	Octahedral, shiny metallic anhedral to subhedral crystals. 1/4 to 1mm in size. Minor association intergrown with pyroxene
Biotite	Hexagonal; equant blocks and crystal fragments appear altered. Brown micaceous masses. Brown-black in color, 1/4 - 1/2mm in size.

Pumice fragments:	Blocky to rectangular; juvenile and accessory (?) fragments; elongate planar cellular structure of glass froth. Brown to dark gray, less commonly purple and red-gray. Generally unaltered to partially altered, less commonly completely devitrified to light brown crypto-crystalline mineral aggregates commonly 1-15mm in size, rarely 20-30mm.
Mesostasis:	Fine grained ash groundmass (mesostasis), devitrified ash fragments (shards are plate-like, spherical, and irregular in shape); rarely are ash shards unaltered. Divitrification (deuteric crystallization - alteration, or gas phase reaction of metastable glass) chiefly produced crypocrystalline intergrowths (aggregate texture) of cristobalite and feldspar (K-spar?) with minor brown clay-like material, probably montmorillonite (which appears near to exceed 15% of the groundmass volume).
Xenolithic fragments:	Accidental fragments of gray, microphenocrystic latite predominant, with minor gray to red-gray rhyolite and rare andesite. Sizes are typically from 1-3-10mm, less commonly from 15-30mm, rarely 30-40mm, generally subrounded (never angular).
Vesicular cavities:	Mostly interconnecting, high permeability within cavities, deuteric, plate-like crystals of tridymite, equant sanidine, and slender needles of hornblende; also within radial groups of tridymite and feldspar. Along joints jematite mineralization, possible hydrothermal.
Name:	Pumiceous rhyolitic tuff.

For density, moisture content, temperature and dynamic parameters of Unit 3, refer to Keller, (1968.) Purtymun and Koopman (1965) also have data on the thermal conductivity, bearing capacities, and chemical analyses of the moderately welded tuff of the Tshirege member. Estimates of erosion rates of Unit 3 on Mesita del Buey are given by Purtymun (1971).

Plate G-15 is a geologic cross section showing the detailed stratigraphic relationships of Subunits 2b, 3a and 3b underlying the proposed TA-55 site.

The average composite thickness of the Tshirege member of the Bandelier tuff underlying the TA-55 site is summarized below:

Unit 3:	135 feet
Unit 2:	135 feet
Unit 1:	70 feet
Total:	340 feet

The average composite thickness of the three members of the Bandelier tuff underlying Mesita del Buey, from a point about one mile northwest of the TA-55 site to a point about three miles southeast of the site, is summarized on the following page and shown in the geologic cross section, Plate G-16 (partially constructed from Figure 3, Purtymun, 1971).

	NW	SE
Tshirege member	350 feet	100 feet
Otowi member	400 feet	100 feet
Guaje member	35 feet	10 feet
Total: Bandelier tuff	785 feet	210 feet

Soil

Soil zones B and C are developed on the surface of Mesita del Buey (Plate G-23). Soil zone B is typically one and one-half to three feet thick along the axis of the mesa, but thins toward the canyon rims. This light brown, silty-sandy soil with a minor clay fraction is derived from the in situ weathering of the underlying tuff in soil zone C. The predominant soil constituents are quartz and sanidine feldspar with the clay minerals montmorillonite and illite.

Soil zone C typically ranges in thickness from two to four feet and is composed chiefly of angular, blocky fragments of tuff with a distinct planar fabric caused by the development of subhorizonal parting surfaces roughly parallel to the existing ground surface. Downward infiltration of B horizon soil and the development of autochthonous clay and silty soil along parting and joint surfaces contributes 5 to 15% (by volume) of the material within the C soil horizon.

The lack of a soil zone A and a deep soil profile is attributable to both the youth of the bedrock and to the way the exposed surface of nonwelded tuff becomes "case hardened." During the process of weathering, moisture is absorbed due to the porosity of the tuff, and some minerals are dissolved. The dissolved minerals are precipitated at the surface by evaporation as the tuff dries out and form a protective rind of impure caliche which resists both wind and water erosion and further weathering.

Alluvium overlies the weathered tuff and soil profile in the stream channels north and south of the mesa. Generally, the alluvium is thickest near the axial part of the stream channel and becomes thinner toward the edges, reflecting the shape of the stream channel which was cut in the Bandelier tuff before the alluvium was deposited.

The alluvium in the two adjacent canyons (Effluent and Two Mile) probably ranges from 3 to 30 feet in thickness and may be only a few inches thick in places.

Deposition of alluvium is presently occurring, and small fans of coarse detritus are accumulating at the bottom of the adjoining steep canyon walls and along the stream channels of adjacent canyons. Thin veneers of blocky and angular talus with intermixed silty-sandy soil are slowly creeping down the canyon walls toward the canyon bottoms, contributing alluvial material to the intermittent streams.

The alluvium in the stream channels directly overlying the tuff generally is a sandy silt - clay unit derived from in situ weathering of the tuff. The upper part of the alluvium consists of sand-size quartz and sanidine crystals and crystal fragments of latite, rhyolite and pumice, derived from erosion of the Tshirege member of the Bandelier tuff.

GEOLOGIC STRUCTURE

The proposed site lies on a gently dipping homocline; the gently undulating surface is part of the broad radial structural apron of the Jemez volcanic locus. The gentle southeastward dip (2 to 3 degrees) of the Tshirege member probably reflects an initial dip resulting from deposition and concomitant thinning of individual units away from their source vents in the Valle Grande region west of the Pajarito plateau.

The Bandelier tuff as a whole also thins eastward, principally as the result of the underlying basalts which acted as a partial buttress to these eastward-drifting ash falls. The older basalts originated from vents to the east. Flow direction from these basaltic centers was north and west into the area of investigation. A topographic high was formed before the tuff was laid down, which acted as a partial barrier to the distribution of the tuffs.

Well data on Mesita del Buey indicates that the structure of the underlying Otowi member is not quite the same as that of the Tshirege member, due to sharper eastward thinning of the Otowi against the Chino mesa basalts. Well data on Frijoles mesa, about three miles south of the proposed

TA-55 site, also indicate that the base of the Bandelier tuff and the base of the Puye conglomerate are structurally lower in the central part of the plateau than they are at the eastern edge; this suggests that the plateau was partly eroded to form topographic irregularities prior to deposition of the Puye conglomerate and prior to deposition of the Guaje member.

At places south of White Rock about six miles southeast of the TA-55 site, Unit 1a of the Tshirege member dips gently west; probably the result of the westward slope of the underlying basalt rocks.

Plate G-16 is a geologic cross section of the part of Mesita del Buey extending from an area about one mile northwest of the TA-55 site to about three miles southeast of the site (see location of cross section on Plate G-11). The cross section shows some of the structural relationships mentioned above.

As indicated on Plage G-12 and on the infrared photographs, no fault branches or tectonic fracture zones pass directly through the proposed TA-55 site. Since neither the Bandelier tuff nor the geomorphic surface developed on the tuff has been offset, it has been inferred that there has been no faulting at the site in the last 1,000,000 years. This does not preclude the possibility that older, pre-Bandelier tuff faults or fracture zones underlie the site along the strike of or en echelon with a possible southern continuation of the surface expression of these faults north of Los Alamos Canyon.

A tectonic fracture zone, with maximum dip separation generally amounting to only several inches, lies about 1000 feet east of the site and roughly en echelon with the East fault member of the Pajarito fault system. Much of the apparent dip separation may be due to differential settling of linear blocks of tuff between the en echelon members after fracturing.

To substantiate the detailed surface geological mapping which indicated a lack of faults or tectonic fractures disrupting the Bandelier tuff in the immediate area of the proposed TA-55 site, a 1000-foot-long trench was excavated to expose four to five feet of unweathered bedrock directly under the site. The position of this trench is indicated on Plate G-11 and the discussion of the trench is given on pages GA-88 to GA-90. The geological map of the north wall of the trench was provided under separate cover.

Examination of the trench showed that no faults or tectonic fractures passed through the site and that the dominant structure within the Bandelier tuff is volcanic jointing, caused by shrinkage (tension) during cooling. The joints were examined and mapped carefully within the trench and along the adjacent canyon walls in order to distinguish them from tectonic fractures and to evaluate their influence on the direction of tectonic fracturing and faulting.

The pre-existing master joint pattern appears to have had little influence in determining or affecting the direction of faulting within the tuff north of Los Alamos Canyon. However, the orientation of some volcanic joints (N 0-20 W) appears to have had some influence, although still slight and difficult to quantify with respect to the direction of tectonic fracturing.

The joints are classified as master and minor joints. Master joints are numerically predominant, most persistent in length, and may pass through one or more ash flows within a single cooling unit. Master joints are vertical or nearly vertical (80° - 90° dip) and tend to be perpendicular to the layering of the Tshirege member. The vertical trend of the master joint is generally straight, but may be slightly curved along part or all of its length. The dip is deflected slightly when the joint enters a layer with a different density or degree of welding.

Minor joints dip at angles slightly less than major joints (70° - 80°, occasionally ranging as low as 40°) and are not continuous as major joints. Some of the shorter joints have much more pronounced local curvature than do the major joints, and they do not persist as they intersect the master joints.

Joint densities vary between stratigraphic units with different degrees of welding. The number of joints varies directly with the degree of welding, decreasing with a decrease in the temperature of deposition. The joint density within a specific unit or subunit of the Tshirege member will also vary laterally with different degrees of welding. Purtymun (1971) reports an average joint density of about one master joint for every seven feet of horizontal exposure of welded Subunit 2b. A joint density of about one master joint for every ten feet of horizontal exposure of moderately welded Subunit 3b was recorded during this investigation.

However, the spacing of joints is irregular. At many places individual joints intersect or are only a few inches or a few feet apart, whereas at other places the joints are several yards apart. The average joint density for the Tshirege member of the Bandelier tuff seems to be about one joint per square yard.

The orientation of the major joints appears to vary slightly between the major units 1, 2 and 3 of the Tshirege member. The major joints of older units do not appear to continue more than a few feet into overlying units. Master joints may, however, pass through one or more ash flows comprising a single cooling unit, with the joint pattern of the older layer(s) or subunit tending to govern the orientation of the joints in the younger layer(s) or subunit.

The orientation of some of the master joints is shown on Plate G-17. The lower diagram (Purtymun, 1963) shows the orientation of master joints for the entire Tshirege member. The upper diagram shows the orientation of master joints within Subunit 3b of the Tshirege member. Sets of similarly oriented joints are bracketed, each ray represents many parallel joints. The available data suggest a grouping of several sets of nearly parallel joints (as shown by the brackets) with about 60 degrees of separation between their respective orientations; this suggests that some of the sets are conjugate tension joints.

Plate G-18 shows rose diagrams for the orientation of joints in Subunit 2b (Purtymun, 1971) and Subunit 3b (this report). One thousand seventy-eight and 888 orientations were plotted in the construction of the diagrams for Subunits 2b and 3b, respectively. These diagrams show an average of three joints intersecting at angles of 60 degrees for Subunit 3b and 30 and 90 degrees for Subunit 2b. The three-joint sets for Subunit 2b are: N 30° W to N 50° W, N 60° W to N 80° W, N 40° E to N 60° E. The three-joint sets for Subunit 3b are: N 70° W to N 90° W, N 10° W to N 30° W, and N 30° E to N 50° E. Forty percent of all joints measured in Subunit 2b and Subunit 3b belong to the respective sets shown.

A joint traced vertically through an ash flow may be closed in some places and open in others; the opening may thus range from hairline cracks to fissures several inches wide. Most joint openings, however, are less than one-quarter inch wide.

Many joints terminating in the base of the soil zone or in exposed tuff along the canyon walls are filled with light brown alluvial or surficial clay and silt; this fill extends to depths of three to five feet below the surface. Below this surface fill, the joint openings are filled or plated with a light gray montmorillonite clay derived from in situ weathering of the tuff and of secondary minerals precipitated along the joint surfaces. Within and below the zone of secondary clay mineralization, pink to red hematitic clay, probably of deuteric origin, may also occur; its distribution is much more sparse and sporadic than the secondary clay mineral. It should be noted that joint openings are likely to extend below the surface and may provide channels for infiltration of surface water at the site.

Joints divide the tuff into multitudinous irregular and polygonal blocks, many of which are prismatic or columnar. The dimensions of blocks formed by joints within Subunit 3b typically range from 5 X 12 X 15 feet to 10 X 15 X 20 feet; the surface area of these blocks, however, ranges from a few feet to as much as 500 square feet.

Geologic Trench

Excavation of the trench revealed irregular and discontinuous zones of broken rock. The length of the zones ranges from 1 inch to 200 feet. The depth of the zone of broken rock ranges from 6 to 12 feet below the surface of the ground. To ascertain the depth and nature of these zones, two additional trenches, both north of and parallel to the original trench, were excavated to a depth of 15 to 20 feet, opposite the 900-foot and 965-foot intervals of the original trench.

The broken rock zones appear to be unrelated to faulting, tectonic fractures, and volcanic joints. These zones do not extend more than 12 feet vertically, appear to extend laterally no more than 200 feet and have a length which must be quite limited and variable, as many of the smaller zones do not extend from one side of the trench to the other. The fragmentation has taken place after the development of the volcanic joints and occurs without regard to the local density of joints.

The degree of fragmentation varies, developing "major" and "minor" zones of broken rock, but the size of the fragments is the same in both the major and minor zones of broken rock. The size of tuff fragments ranges from one-quarter inch to six feet, but typically they have surface measurements of one inch by one inch to three inches by four inches. The shape of the fragments is angular and irregular to rectangular. The arrangement of the block fragments within the zone has a vague planar fabric, subparallel to the soil horizon profiles and the ground surface.

Gravity filtering of sand, silt and clay from the overlying soil horizons has filled the interstices among the tuff fragments.

The zones of broken rock are probably related to a near-surface phenomenon, perhaps involving differential compaction of underlying ash fall beds (discontinuous beds and lenses of unwelded ash up to two feet thick have been mapped in the trench), exfoliation, or other surficial weathering processes.

GEOLOGICAL HAZARDS

In accordance with 10 CFR 100, Appendix A, the potential geological hazards at the proposed site have been identified. The most significant hazards, listed below, have been discussed in detail within the geology appendix and seismology sections, and have been evaluated on pages G-1 through G-4.

(1) Seismic activity, with and without accompanying surface rupturing related to tectonic and/or volcanic forces.

(2) Reactivation of surface faulting along the Pajarito fault system.

(3) Renewed volcanism within the Jemez volcanic locus.

Geologic hazards of less significance in the vicinity of the proposed site are:

(1) Landslides. These are virtually nonexistent in the immediate Los Alamos area, and are expected to pose no significant problem since topographic and climatic conditions conducive to landslide development have not been common in the geologically recent past. The Bandelier tuff is a nearly flat-lying cohesive unit with low specific gravity, and imposes a relatively small load on the underlying formation. Furthermore, the water table is deep and the tuff mesas are generally dry to a depth of several hundred feet below the canyon bottom. The probability of rock falls and small isolated gravity block slides of jointed tuff along mesa-rim cliffs is high however, but these will not endanger the proposed site.

(2) Severe erosion is not considered a significant geological hazard except directly along mesa-rim cliffs. Calculated rates of erosion for the Bandelier tuff (Purtymun, 1965) indicate that the tuff is relatively resistant to wind and water erosion.

(3) Ground Compaction due to withdrawal of water is not expected to be a significant geologic hazard because pumping at the present time has significantly lowered the water table only in the vicinity of the well fields. There are no records of perched water within the Tshirege member of the Bandelier tuff. The water table is about 1000 feet beneath the proposed TA-55 site. The aquifers are silty sandstones, sandstones and conglomerates not particularly susceptible to compaction when water is withdrawn.