EL LLANO AND VICINITY GEOTECHNICAL STUDY

FINAL REPORT

VOLUME I

Prepared for:

Office of Military Affairs
Civil Emergency
Preparedness Division
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Prepared by:

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New Mexico Bureau of Mines and Mineral Resources
Socorro, New Mexico 87801

28 June 1985

New Mexico Bureau of Mines & Mineral Resources
Socorro, NM 87801

A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

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June 28, 1985

Mr. Bill Rives
Office of Military Affairs
Civil Emergency Preparedness Division
P.O. Box 4277
Santa Fe, NM 87501

Dear Mr. Rives:

The New Mexico Bureau of Mines and Mineral Resources is pleased to submit this final report on the findings of our El Llano geotechnical investigation.

We are providing you with five (5) copies of the report. Additional copies are being provided to those on the distribution list at the end of the report (Vol. 1). The report is being placed on open-file at the New Mexico Bureau of Mines and Mineral Resources and a copy is being given to the Española Public Library so that it is readily available to the public.

If you have any questions regarding the report please call me.

Sincerely,

Gary Johnpeer

Gary Johnpeer
Engineering Geologist

GJ:lm

EL LLANO GEOTECHNICAL STUDY
FINAL REPORT

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INTRODUCTION

The following is the final report on the studies conducted by the New Mexico Bureau of Mines and Mineral Resources and its subcontractors between November 30, 1984, and June 28, 1985. The studies were done in response to Executive Order 84-76 (signed by Governor Toney Anaya in December 1984), which declared southern Rio Arriba and northern Santa Fe Counties within the Santa Cruz Grant a disaster area due to settling ground (collapsible soil) that heavily damaged public buildings, utilities, and some private structures. Most damage centered in the El Llano, New Mexico, area (Fig. 0-1).

The purpose of this report is to make available all data gathered so that recommendations for soil stabilization can be made. The data gathered for this report bear on civil engineering needs elsewhere in New Mexico where similar problems exist.

This multi-faceted study drew expertise from a number of disciplines including:

- engineering geology
- geotechnical engineering
- structural engineering
- environmental geology
- hydrology
- historical archaeology
- geophysics
- surveying
- earthquake engineering and

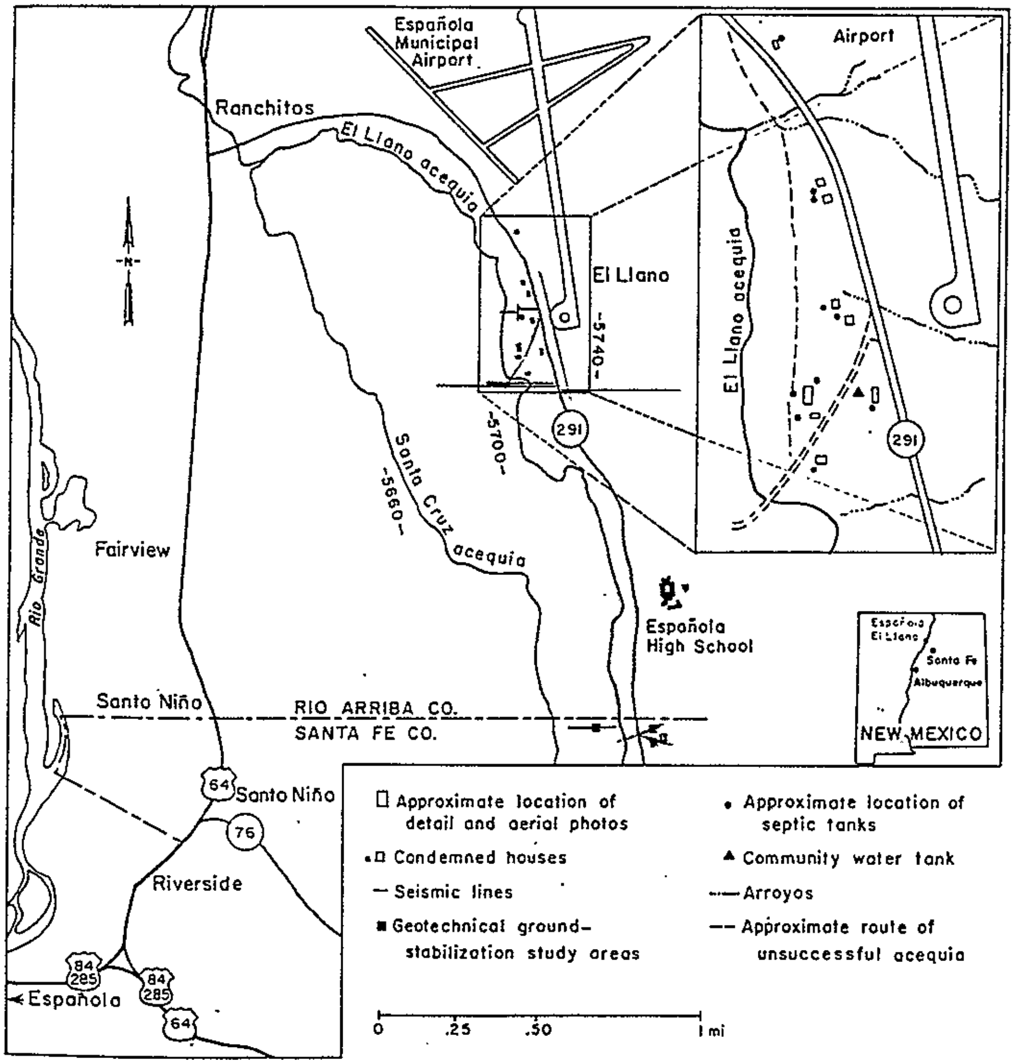

Figure 0-1. Location map of El Llano and vicinity.

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o remote sensing.

The data provided by these disciplines were synthesized to meet the goals of the project. Work is now 100% complete.

After considering several possible alternative explanations, the most likely cause of damage is collapsible soils. Collapsible soils significantly reduce in volume subsequent to wetting and are a well-known cause of structural damage in other parts of New Mexico as well as in the central and western U.S. Numerous accounts of damage due to collapsible soil have been reported worldwide. As used in this report, soil is defined as the naturally occurring superficial deposits overlying bedrock (ICBO, 1982).

It is likely that ground settlement in the area would not have occurred so rapidly and on such a large scale if it were not for human development. In its natural or undisturbed condition, soil consolidation is a slow process, perhaps measurable in inches per few thousand years. In contrast, certain areas in the El Llano vicinity have settled a few feet in a few months.

Measures to stabilize the ground in areas not yet affected and, more importantly, in areas already affected were studied. Recommendations are given in Section 13.0 to reduce the wetting phenomenon, which would thereby lessen the resultant settlement damage. These preventive and mitigative recommendations center on readily available and relatively inexpensive techniques the layman can use. They include measures to provide positive drainage away from structure foundations, landscaping, sheetwash control, utility line maintenance, and fundamental changes in sewage disposal methods.

The data developed are relevant to civil engineering needs elsewhere in New Mexico. The techniques utilized and developed for this study can be used to assess other areas, which otherwise may be developed without sufficient regard for the geologic hazard posed by collapsible soils. Selected recommendations made here should be considered for implementation to existing State building codes.

1.0 PURPOSE

The purpose of this report is to summarize the findings of our geotechnical investigation into the nature of ground subsidence that has damaged utilities and public and private structures in El Llano and vicinity (Fig. 0-1). The primary goal is twofold: 1) to make recommendations for stabilizing ground in areas already developed and in areas not yet developed and 2) to provide data that are applicable to civil engineering needs elsewhere in New Mexico where similar problems exist.

This comprehensive report includes all data gathered and reduced during the course of the investigation. It is based on approximately seven months of intensive field work combined with laboratory analyses, literature searches, report reviews, and data analyses. The conclusions are now deemed final and affected agencies and individuals can utilize the accompanying data for immediate input into possible remedial measures.

It should be noted that this was not a site-specific study. The report should not be used in the design of remedial measures at particular sites. However, it may be a useful supplement to additional site-specific work that is ultimately required. Such site-specific work is beyond the scope of this study because the Bureau does not perform private consulting or do site-specific work for private individuals.

1.1 Disclaimer

A field log was prepared for each activity by our geologists and technicians. The logs contain such information as boring methods, samples attempted and recovered, indications of the presence of various materials, and ground-water observations. They also contain the field representative's interpretation of the soil conditions between the recovered samples. Therefore, these logs contain both factual and interpretive information. Copies of the logs are on file in our office.

The final logs (Appendix I) and maps represent our interpretation of the contents of the field logs, laboratory examinations, and results of tests on the field samples. We must emphasize that our recommendations and conclusions are based on the contents of the final logs and the information contained therein and not on the field logs.

The analyses, conclusions, and recommendations contained in this report are based on site conditions that existed at the time of our investigation. If a substantial amount of time elapses between the submission of this report and the start of any remedial measures, or if conditions change due to natural causes, we urge that the report be reviewed to determine the applicability of our final conclusions and recommendations.

2.0 BACKGROUND

At the request of Mr. Tom Closson, Office of Civil Emergency Preparedness, Santa Fe, the New Mexico Bureau of Mines and Mineral Resources (NMBM&MR) was requested to survey utility damage, structural damage, and ground subsidence in the El Llano area (Fig. 0-1). On November 30, 1984, NMBM&MR Environmental Geologist David Love and Engineering Geologist Gary Johnpeer visited the area. They observed numerous structural cracks (in both public and private buildings), a disrupted water line, saucer-shaped ground depressions, and stressed gas and electric lines. They thought there were a number of possible causes (Sec. 7.0), but that the most likely was "geological."

A topographic survey was made of the area west of the Moya residence on December 4, 1984 (Appendix XVII), which determined the configuration of the surface that was apparently subsiding. Features such as roads, utilities, ground cracks, and damaged buildings were included within the survey area to document the extent of damage.

On December 6, 1984, at the request of Mr. John Ramming, the Governor's authorized representative, and Mr. Tom Closson, geologists from NMBM&MR (Love and Johnpeer) met at the Governor's Conference Room with representatives from the Construction Industries Division (CID), New Mexico Highway Department, other state agencies, the Red Cross, and with residents of El Llano. The purpose was to discuss the initial findings of the state agencies and to determine the future course of action. It was concluded that the damage to public utilities posed a hazard to some residents. Mr. Ramming designated NMBM&MR the "lead agency" to conduct a geologic investigation of the affected area. NMBM&MR geologists were to work under the direction of the Office of Civil Emergency Preparedness and with the New Mexico State Highway Department to develop a plan for geotechnical investigations. The consulting services of Dr. Robert L. McNeill were utilized throughout the study to assure that all procedures, tests, and activities were conducted in accordance with state-of-the-art geotechnical practice. Pertinent reports by Dr. McNeill are included in Appendix VIII.

On December 13, 1984, Governor Toney Anaya signed Executive Order 84-76, which declared southern Rio Arriba and northern Santa Fe Counties within the Santa Cruz Grant a disaster area. That declaration made disaster relief funds available for this study.

Since December 13, 1984, NMBM&MR staff have been conducting the emergency geotechnical study. A total of approximately 6,500 hours have been spent on the project by NMBM&MR personnel to date. Work is now 100% complete. On April 15, 1985, a four-volume interim report was completed and distributed to a number of state agencies and individuals (Johnpeer et al., 1985). It contained all data available as of that date and presented our preliminary conclusions and recommendations. Since April 15, NMBM&MR geologists have completed a number of important additional tests, drawn final conclusions, and made final recommendations. This report is mainly an update of work conducted since April 15, 1985. The discussions and conclusions of this report supersede those of the interim report.

3.0 SCOPE

The scope of this investigation was outlined in a letter to the Office of Military Affairs on December 16, 1984, and in subsequent discussions with Mr. Pete Mondragon, Mr. Tom Closson, and Mr. Bill Rives. The scope of work was further defined at a hearing called by the CID on February 4, 1985, in Española.

Work performed during the study is listed below:

- literature review (maps, aerial photos, reports)
- acquiring new aerial photographs, which were used to produce maps, at a scale of 1 inch equals 200 feet (with contours at 5 foot intervals)
- acquiring new stereo infra-red color photographs at a scale of 1 inch equals 833 feet
- aerial photo analyses
- geologic mapping
- drilling
- sampling
- lab testing
- age dating
- geophysical studies
- ground-vibration monitoring
- geotechnical ground-stabilization studies
- settlement monitoring
- ground-water-level monitoring
- water quality analyses
- surveying
- computer modelling
- acequia history research

- trenching
- photographic documentation
- acquisition of monthly and daily weather records
- scanning electron microscopy and
- report writing.

Identification of field samples generally followed the American Society for Testing and Materials procedure for description of soils (ASTM, 1984) and the Unified Soil Classification System (USCS, Fig. 3-1).

The literature review consisted of acquiring reports describing subsidence phenomena elsewhere. Special emphasis was placed on acquiring case history reports describing approaches to studying subsidence and the mitigative measures taken. The bibliography of pertinent articles compiled is presented as Appendix XIV.

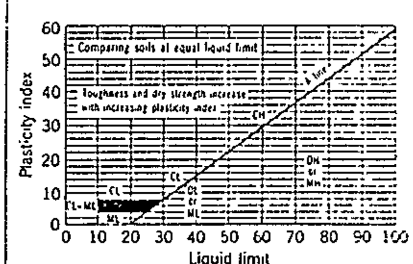
One finding of the literature study was that no recent detailed aerial photographs or topographic maps existed for the study area. To fill this need, a contract was let to Koogle and Pouls Engineering, Inc. of Albuquerque to acquire new black and white, vertical, stereo, aerial photographs at scales of 1:24,000 and 1:20,000. These were enlarged to a scale of 1 inch equals 200 feet and overprinted with contour lines at 5-foot intervals. These enlarged photographs were used as the bases for the maps in Appendix XII.

In addition to the aerial photographs, infra-red (IR) color photography also was obtained at a larger scale (1:10,000). The purpose of the IR color photography was to identify areas of

Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights)				Group Symbols [a]	Typical Names	Information Required for Describing Soils	Laboratory Classification Criteria
Coarse-grained soils. More than half of material is *larger* than No. 200 sieve size[b] (The No. 200 sieve size is about the smallest particle visible to naked eye)	Gravels. More than half of coarse fraction is larger than No. 4 sieve size (For visual classification, the ¼ in. size may be used as equivalent to the No. 4 sieve size)	Clean gravels (little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes	*GW*	Well graded gravels, gravel-sand mixtures, little or no fines	Give typical name; indicate approximate percentages of sand and gravel; maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbols in parentheses	$C_U = \frac{D_{60}}{D_{10}}$ Greater than 4; $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
			Predominantly one size or a range of sizes with some intermediate sizes missing	*GP*	Poorly graded gravels, gravel-sand mixtures, little or no fines	For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics	Not meeting all gradation requirements for *GW*
		Gravels with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures see *ML* below)	*GM*	Silty gravels, poorly graded gravel-sand-silt mixtures		Atterberg limits below "A" line, or *PI* less than 4 — Above "A" line with *PI* between 4 and 7 are *borderline* cases requiring use of dual symbols
			Plastic fines (for identification procedures, see *CL* below)	*GC*	Clayey gravels, poorly graded gravel-sand-clay mixtures		Atterberg limits above "A" line, with *PI* greater than 7
	Sands. More than half of coarse fraction is smaller than No. 4 sieve size	Clean sands (little or no fines)	Wide range in grain sizes and substantial amounts of all intermediate particle sizes	*SW*	Well graded sands, gravelly sands, little or no fines	Example: *Silty sand*, gravelly; about 20% hard, angular gravel particles ½-in. maximum size; rounded and subangular sand grains coarse to fine, about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (*SM*)	$C_U = \frac{D_{60}}{D_{10}}$ Greater than 6; $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
			Predominantly one size or a range of sizes with some intermediate sizes missing	*SP*	Poorly graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for *SW*
		Sands with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures, see *ML* below)	*SM*	Silty sands, poorly graded sand-silt mixtures		Atterberg limits below "A" line or *PI* less than 5 — Above "A" line with *PI* between 4 and 7 are *borderline* cases requiring use of dual symbols
			Plastic fines (for identification procedures, see *CL* below)	*SC*	Clayey sands, poorly graded sand-clay mixtures		Atterberg limits below "A" line with *PI* greater than 7

Laboratory Classification Criteria (coarse-grained soils): Use grain size curve in identifying the fractions as given under field identification. Determine percentages of gravel and sand from grain size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse grained soils are classified as follows: Less than 5% — *GW*, *GP*, *SW*, *SP*; More than 12% — *GM*, *GC*, *SM*, *SC*; 5% to 12% — *Borderline* cases requiring use of dual symbols.

Fine-grained soils. More than half of material is *smaller* than No. 200 sieve size	Identification Procedures on Fraction Smaller than No. 40 Sieve Size	Dry Strength (crushing characteristics)	Dilatancy (reaction to shaking)	Toughness (consistency near plastic limit)	Group Symbols	Typical Names	Information Required for Describing Soils
	Silts and clays liquid limit less than 50	None to slight	Quick to slow	None	*ML*	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	Give typical name; indicate degree and character of plasticity, amount and maximum size of coarse grains; colour in wet condition, odour if any, local or geologic name, and other pertinent descriptive information, and symbol in parentheses
		Medium to high	None to very slow	Medium	*CL*	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remoulded states, moisture and drainage conditions
		Slight to medium	Slow	Slight	*OL*	Organic silts and organic silt-clays of low plasticity	
	Silts and clays liquid limit greater than 50	Slight to medium	Slow to none	Slight to medium	*MH*	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Example: *Clayey silt*, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (*ML*)
		High to very high	None	High	*CH*	Inorganic clays of high plasticity, fat clays	
		Medium to high	None to very slow	Slight to medium	*OH*	Organic clays of medium to high plasticity	
Highly Organic Soils		Readily identified by colour, odour, spongy feel and frequently by fibrous texture			*Pt*	Peat and other highly organic soils	



Plasticity chart for laboratory classification of fine grained soils

From Wagner, 1957.

[a] *Boundary classifications.* Soils possessing characteristics of two groups are designated by combinations of group symbols. For example *GW–GC*, well graded gravel-sand mixture with clay binder.

[b] All sieve sizes on this chart are U.S. standard.

Field Identification Procedure for Fine Grained Soils or Fractions

These procedures are to be performed on the minus No. 40 sieve size particles, approximately 1/64 in. For field classification purposes, screening is not intended, simply remove by hand the coarse particles that interfere with the tests

Dilatancy (Reaction to shaking):

After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (Crushing characteristics):

After removing particles larger than No. 40 sieve size, mould a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun or air drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Toughness (Consistency near plastic limit):

After removing particles larger than the No. 40 sieve size, a specimen of soil about one-half inch cube in size, is moulded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eighth inch in diameter. The thread is then folded and re-rolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line.

Highly organic clays have a very weak and spongy feel at the plastic limit.

Figure 3-1. Unified soil classification system.

contrasting rock and soil units based upon the vegetation patterns they exhibit. Because of its high absorption of photographic IR radiation, healthy vegetation has a red signature. Rock outcrops of the Santa Fe Formation appear as shades of yellow. An advantage of IR color photography is that damp ground may be recognized by its darker signature.

Analyses are being conducted on all aerial photographs. The following list shows the dates of the photographs that have been obtained and any enlargements made for use in this study.

Date	Original Scale	Enlarged Scale
1935	1:20,000	1:7,600
1949	1:21,000	1:5,000
1951	1:28,400	1:7,600
1954	1:54,000	not enlarged
1962	1:20,000	1:5,000
1973	1:31,680	1:8,300
1976	1:29,000	not enlarged
1980	1:24,000	1:12,000;1:6,000;1:2,400
1982	1:12,000	not enlarged
1985	1:20,000	1:2,400
1985	1:10,000 (IR color)	1:2,532

The imagery in these photographs covers a span of 50 years and clearly depicts the growth of the area (Sec. 5.0). The growth of the area is also obvious when comparing enlargements of these photographs with modern oblique photography (Photographs 1 and 2). The photographs are particularly useful in mapping the geology (Sec. 6.0) and in assessing the influence of man-made

PHOTOGRAPH 1—Vertical aerial view of El Llano taken in 1949. Note lack of development east of El Llano acequia (arrow) and extensive irrigation west of the acequia. The box represents approximate location of photograph 2.

PHOTOGRAPH 2—Oblique aerial view of El Llano, New Mexico, showing area of most concentrated geotechnical activities (view to the east). Note the increase in housing and other development as compared to the same area in photograph 1 (see box).

structures such as acequias, roads, dams, and buildings.

Geologic mapping of major units was conducted using drill hole data, existing literature, (see Bibliography in Appendix XIV), and by field mapping. Special emphasis was given to delineation of surficial units and to suspected faults. The geologic maps that were produced are presented in Appendix V and geologic cross sections are presented in Appendix X.

To gain insight into subsurface conditions and to verify results of the geophysical profiles, 102 geotechnical drill holes were completed. Most were drilled with a CME-55 drill rig using hollow-stem auger techniques (Photograph 3). The holes range in depth from 10 to 125 feet. Both disturbed (split-spoon) and undisturbed (thin-wall and continuous sampler) samples were retrieved. A total of 560 disturbed and 397 undisturbed samples were obtained. The tests conducted on these samples are discussed in Section 9.0.

The purpose of the drill holes varied and some were drilled for multiple purposes. The majority were drilled primarily to gain geotechnical information on subsurface conditions. Preliminary geotechnical information was obtained from blow-counts, drilling rate, and field descriptions. Additional information was obtained from the suite of laboratory tests later conducted on each sample.

Eleven drill holes were installed to gain information on depth to groundwater and to obtain ground-water samples. These holes were lined with 2-inch perforated-PVC pipe so that ground-water levels can be monitored and sampled. In addition, soil samples were obtained for laboratory testing.

PHOTOGRAPH 3—Equipment used for drilling geotechnical wells and obtaining laboratory samples. Note damaged house in background.

PHOTOGRAPH 4—Exploratory trench that was used for visual examination and sampling of near-surface soils.

Undisturbed and disturbed sampling was conducted carefully, generally at intervals of 5 feet or less in all drill holes. The undisturbed samples were labeled with drill hole number, project number, depth, date, and measured recovery. They were kept in a vertical position and transported daily to a secure location where they would not freeze or become disturbed. Subsequently, they were transported vertically to various laboratories in specially constructed wooden or cushioned cardboard boxes. The disturbed samples were obtained with a split-spoon sampler. The samples were logged and then sealed in plastic bags to retain their moisture content. Bags were labeled with drill hole number, project number, depth, blow count, and date. Both undisturbed and disturbed samples were laboratory tested in the most expedient manner consistent with quality testing procedures.

To expedite testing, samples were tested in the following three laboratories: NMBM&MR, Fox and Associates of New Mexico, Inc., and New Mexico Highway Department. Laboratory testing of the samples is now complete.

Laboratory tests were chosen for their ability to help identify the cause(s) of subsidence and to help quantify subsurface soil parameters. The standard tests conducted include:

1) Atterberg limits
2) gradation
3) density (wet and dry)
4) moisture and
5) consolidation.

Additional tests conducted on selected samples include X-ray diffraction and scanning electron microscopy (SEM). These tests are discussed in more detail in Section 9.0 and the results of tests completed are included in Appendix III.

An important field test conducted during disturbed sample acquisition is the blow count or N-value test. The N-value is a measure of the energy required to drive a 2-inch sampler 12 inches into the soil using a 140 lb weight, which free falls 30 inches.

Eleven trenches, ranging in depth from 7 to 12 feet, were excavated, shored, gridded, and logged in detail to characterize shallow subsurface conditions and to investigate the nature of cracks at depth (Photograph 4). The logs of the trenches are presented in Appendix II. In places, the trench logs show a relationship between cracks and animal burrows (krotovina) and typically show the inactive character of most cracks at depth. The implications of these fundamental findings are discussed in Section 10.11.

In the course of drilling, trenching, and geologic mapping a number of samples were collected that were suitable for age-dating using carbon-14 methods and were submitted for age-date analyses (see Appendix XII and Sec. 6.0). The purpose of acquiring the age dates was to confirm the age of the collapsible soils and to date possible faulting in the area (Secs. 7.6 and 10.6).

Thirty-seven drill holes were made to install two types of settlement-monitoring equipment. Seven wells consisted of a 3/4-inch metal water pipe, which extended from the bottom of the well to ground level. The pipes are lined with 1 1/2-inch diameter PVC to minimize skin friction from backfill material. In the event the soils settle or otherwise compact, the pipe will extend above the ground surface. The remaining thirty wells consisted of corrugated 3- and 4-inch diameter compressible tubing (Sondex casing). The tubing has stainless steel rings soldered at approximately 5-foot intervals. When installed, a special probe can be lowered inside the casing to measure ring separation (Photograph 5). Any changes in ring separation are a measure of soil settlement. All settlement holes were checked regularly throughout the study.

Geophysical studies consisted of seismic reflection and seismic refraction surveys (Appendix VII). The surveys were conducted by Charles B. Reynolds and Associates of Belen, New Mexico. They were conducted in key areas to investigate the subsurface units in more detail than could be done by drilling. Of primary interest was the determination of the thicknesses of surficial low-velocity layers that may correlate with collapsible soils. Also of interest were detection of ground-water levels in the area and delineation of buried faults.

Ground-vibration monitoring was an important task conducted during the initial 10 weeks of the investigation. Two model ST-4 seismic-triggered seismographs were leased from Dallas Instruments, Inc., and they were operated continuously in two of the condemned houses in El Llano. The automatic instruments were set to activate at a predetermined trigger level and to record on magnetic tape the triggering event and all subsequent motion

PHOTOGRAPH 5—Equipment used for monitoring ground settlement.

PHOTOGRAPH 6—Equipment used for monitoring in situ moisture and density conditions.

associated with the event. Of particular interest was the peak particle velocity associated with the triggering events. The results of the vibration-monitoring study are discussed in Sections 7.1 and 10.1.

Geotechnical ground stabilization studies (GGSS) were conducted in four areas south of Española High School on property owned by Mr. Richard Cook. Three areas are east of the El Llano acequia and one is west of the El Llano acequia (see maps, Appendix XX, and Fig. 0-1). These sites were deemed more favorable than other sites in El LLano for a number of reasons. First, the large undeveloped area assured that no underground utilities or surface structures would become adversely affected as a result of the study. Second, the relatively thin soils of the area facilitated the study. Third, field observations and drilling data indicated the soils were similar to El Llano in that surface subsidence pits and cracked structures were present. This was confirmed with drilling and later laboratory data. Therefore, with the written permission of Mr. Richard Cook, property owner (Appendix XXIII), the studies were conducted. The main purpose of the GGSS was to demonstrate the relationship between soil wetting and ground settlement. A second purpose was to develop, if possible, a system to induce settlement of existing structures to make them more stable. Each of the research areas consisted of one or more wells where water was injected continuously. Several additional wells were drilled for monitoring settlement and soil moisture changes (Photographs 5 and 6). In addition to the settlement-monitoring wells, ground settlement was monitored by surface-based surveying techniques using a theodolite. The investigations at GGSS-Areas 1, 2, and 3 were designed to simulate addition of a point-source of moisture such as a septic tank or leaking utility line. The aim of the experiment at GGSS Area-4 was to devise a technique to induce uniform settlement beneath a foundation. At GGSS-Area 3 noticeable settlement was detected after only seven days of wetting (Photograph 7 in Section 12.0). Ultimately, settlement at GGSS-Area 3 produced a circular depression approximately 2.5 feet deep and 25 feet in diameter. Significant settlement also occurred, as expected, in GGSS-Areas 1 and 4 (Photographs 8, 9, and 10 in Section 12.0). No measurable settlement occurred at GGSS-Area 2 which was located west of El Llano acequia. Results and conclusions from the four GGSS areas are presented in Section 12.0. Detailed maps of all four GGSS areas showing cracks and topography are presented in Appendix XX.

Settlement monitoring of the wells described above was conducted on a bi-weekly or more frequent basis. The locations of the monitoring wells are shown in Appendix XX.

Ground-water-level monitoring also was conducted on a bi-weekly or more frequent basis. Monitoring did not reveal any changes in ground-water level. A map showing ground-water elevation has been included (Appendix XI). The implications drawn from the ground-water-level observations are discussed in Sections 6.5, 10.3, and 10.4.

Soil and water samples taken from selected wells have been tested for water quality by the Environmental Improvement Division (EID). The data available from these analyses are discussed in Section 6.0 and Appendix XXII.

Topographic surveys have been conducted in a number of important localities. These were resurveyed every month and sometimes more frequently. The equipment used in the surveys consisted of a Lietz TM20H theodolite and stadia rod. Data were reduced with in-house computer programs at NMBM&MR.

The subsidence depression west of the Moya residence has been resurveyed five times. Three of the geotechnical ground-stabilization areas south of the high school were resurveyed four times. In each area, rebar driven into the ground was reoccupied during subsequent surveys. The survey results are discussed in Section 4.0 and the maps and data generated are presented in Appendices XVII and XX.

Computer numerical modeling studies to support remedial measures were conducted by Dr. Dan Stephens and Robert Knowlton of the New Mexico Institute of Mining and Technology (New Mexico Tech), Socorro. The objectives of the study are:

1) to compare predicted soil consolidation with observed consolidation in a controlled field experiment.

2) to calibrate an existing numerical model to predict consolidation using known field behavior.

3) to apply the results to remedial measures.

The results of their studies are presented in appendix XXI.

The history of acequias (irrigation ditches) in the area was deemed important to understanding settlement mechanisms. Charles Carrillo, an historian from Albuquerque, was contracted to document the history and use of acequias as they related to this study. The month-long study consisted of an extensive in-depth literature review supplemented by field interviews with knowledgable individuals. His findings are summarized in his consulting report to NMBM&MR (Appendix XVI).

Photographic documentation of structural damage due to differential settlement and of the general field operations was provided by Mr. Neil Hollander of the New Mexico Corrections Department and the staff of NMBM&MR. The numerous photographs, which were taken to document the extent of damage and field operations, are filed at NMBM&MR and CID. Twelve photographs were selected for inclusion in this final report.

Monthly weather records for the last 90 years were compiled to ascertain the effect of intense rainfall. The data were summarized with graphs and are discussed in Section 10.7.

Finally, a number of samples were analyzed using the scanning electron microscope at New Mexico Tech. The results of the scanning electron microscopy study and representative photographs (Photographs 11 and 12) are presented in Section 9.10.

4.0 TOPOGRAPHIC SETTING

The study area is located in the Española Valley at elevations from 5,600 to 5,800 feet (Figs. 0-1, 4-1). To the west are the Jemez Mountains and the eastward-sloping, dissected Pajarito Plateau. To the east are the southern Sangre de Cristo Mountains and the dissected foothills sloping westward from Truchas and Chimayo. The Rio Grande forms the lowest part of the Española Valley and slopes to the south with a gradient averaging about 11 feet per mile. The Rio Grande floodplain is about 1 mile wide. The Rio Chama joins the Rio Grande from the northwest. The Santa Cruz River joins the Rio Grande from the east with an average gradient of about 50 feet per mile. River terraces occur discontinuously along both the Rio Grande and Santa Cruz Rivers near San Juan Pueblo, east of the river, and from La Plaza south to Española west of the river. The study area lies along the eastern side of the Española Valley north of the Santa Cruz River. El Llano occupies the upper-to-middle portion of the eastern valley border. The valley border slopes to the west with gradients ranging from 65 to 125 feet per mile. Farther to the east, bluffs of less erodible rocks form steep slopes and range up to 350 feet above the valley border.

Acequias run subparallel to the Rio Grande from north of San Juan Pueblo to the agricultural areas of the Rio Grande floodplain. Two acequias from the Santa Cruz River, the Santa Cruz and El Llano acequias (Fig. 0-1), trend northwest and distribute water to the lower and middle valley border from Santa Cruz to Ranchitos.

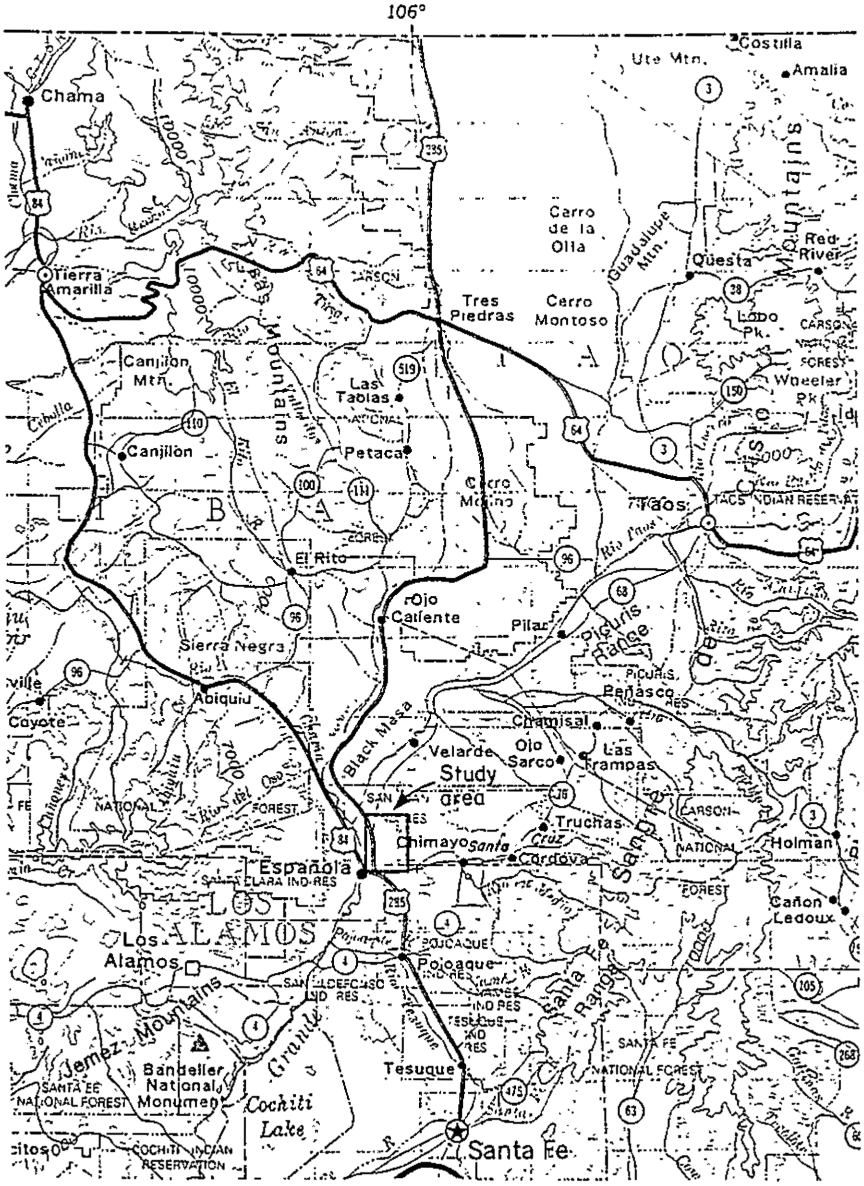


Figure 4-1. Regional topographic map.

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5.0 CULTURAL SETTING

The growth and development of the El Llano area was researched to assess the impact of human activity on the area. Of particular interest was the relationship between growth of the area and increased use of water.

Two methods were utilized to document this growth. The first was to study aerial photographs taken during the past 50 years. The second was to research the acequia systems, which represent a significant source of water. The following is summarized from the acequia report by Charles Carrillo (Appendix XVI).

Earliest reports of Spanish explorers in the region date to 1539. By the late 1500's, permanent settlements had been established, although there are no indications of any settlements in El Llano. The Spanish population apparently continued to grow at a slow rate during these early years and there are some indications that then-existing Pueblo Indian irrigation systems were utilized; it is probable that new acequias also were constructed. It appears that acequias in the El Llano area (El Llano and Santa Cruz) may have been in existence since the 1630's.

In addition to the older acequias, a relatively young, but unused, acequia extends from the Rio Grande south into El Llano. The remains of this acequia are apparent on all aerial photographs used in this study. Even on the oldest photograph (1935) the acequia is abandoned. Indications are that it may have been built by Mormons sometime during the early 1900's. Apparently, it was never used because of numerous washouts at arroyo crossings north of El Llano. Mr. Carrillo reports that additional research would be required to establish, with more certainty, the history of this acequia.

The development of the area in recent years is particularly interesting and may have contributed to the settlement damage. Hispanic tradition has established tracts of land perpendicular to major water courses. These strips of land typically extended from an acequia to a river bank and thus, each strip of land had dependable water sources. Because the Hispanic custom in New Mexico is to divide land equally among male and female children, these strips of land became narrower as they were subdivided each generation.

The aerial photographs illustrate this pattern of subdivision well. In particular, they show a large increase in the number of houses in recent years (Fig. 5-1). Most of these houses are not yet connected to a central sewage system. Waste is disposed of in septic tanks; most tanks are not pumped on a regular basis and fluid is absorbed into the soil in leach fields.

The community water well apparently was installed sometime between 1936 and 1949. By 1949, there was a windmill attached to the well with an accompanying small reservoir tank. The 1954 aerial photographs show the new tank much as it appears today. Residents have reported that the tank has periodically overtopped, allowing water to saturate the foundation materials and flow westward toward the El Llano acequia. The tank has settled and leaned signficantly and may have ruptured water pipes leading to and from it. Just west of the tank, increased

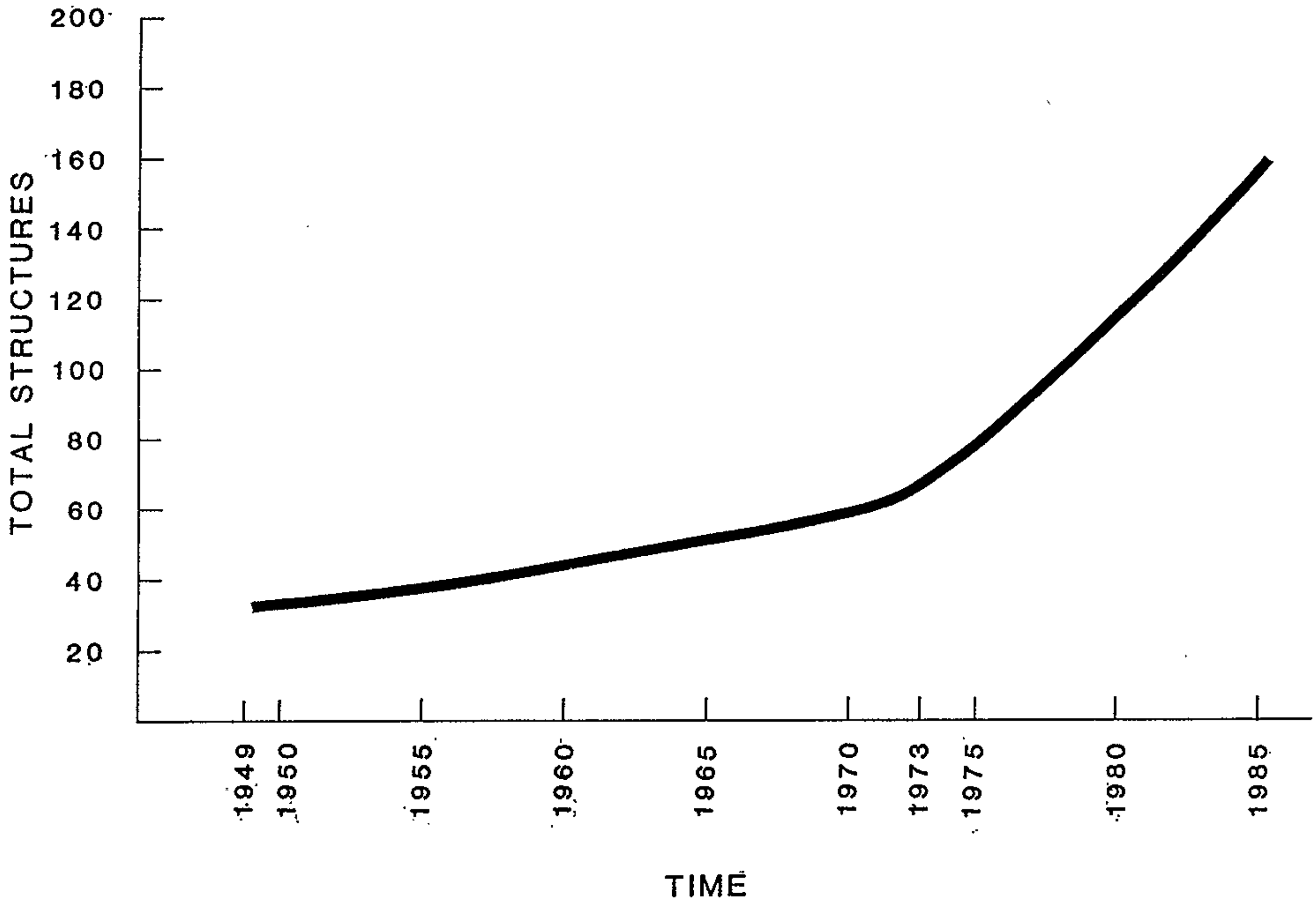

Figure 5-1. Total number of structures in El Llano.

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moisture was encountered to a depth of 56 feet in one of the wells drilled for this study (drill hole ESPDH-4).

Most houses in the El Llano area are not landscaped to accommodate surface runoff effectively. For example, Mr. A. Vigil reports that, because of road work on Middle Road, recent rain water was diverted into his lawn and garage, which are at a lower elevation. Few houses have rain gutters and downspouts that would direct water away from footings. Dripping eaves allow water to saturate foundation materials and this may enhance settlement. Some residents sprinkle their lawns regularly during summer months. It is noteworthy that four houses with lawns are significantly cracked (Cook, Manzanares, Vigil, and Voight).

The high school was repaired recently because of differential settlement, reportedly due to wetting of foundation materials. The technique used to stabilize the foundation there was to replace irrigated areas (watered lawns) peripheral to the building with concrete slabs.

6.0 GEOLOGIC AND HYDROLOGIC SETTING

The El Llano area is located in north-central Española Basin, a major structural depression between two mountain highlands, the southern Sangre de Cristo range on the east and the Jemez Mountains on the west. Most of the regional uplift surrounding the basin and differential movement between mountain and basin areas has occurred in the past 10-12 million years.

The Sangre de Cristo Mountains are a southeastern prong of the Rocky Mountains, and, east of Española they mainly consist of very ancient crystalline rocks (>1 billion yrs old). These rocks and an overlying thick sequence of sedimentary strata dip gently westward beneath the central part of the Española Basin. The western margin of the basin is covered by the thick pile of volcanic rocks that forms the bulk of the Jemez Mountains. Younger sedimentary deposits that partly fill the central structural basin (Santa Fe Group basin fill) are abruptly terminated by a north-trending fault zone that includes the Pajarito fault at the west edge of the Pajarito Plateau near Los Alamos. Volcanic activity in the Jemez Mountains probably continued until about 100,000 years ago within the central vent zone of the Valles caldera (Valle Grande) at the summit of the Jemez Mountains. However, volcanism has not occurred in the area east of the mountains since emplacement of the Bandelier Tuff in the Pajarito Plateau area about 1 to 1.5 million years ago.

Current studies by geologists and geophysicists indicate that deep-seated processes, including structural deformation and geothermal activity, still play an important role, particularly when landscape evolution is considered over very long spans of time. However, there is no historical evidence (post-1598 A.D.) of major geologic events, such as large earthquakes, that have caused significant deformation of earth materials or surficial features in the area.

The main geomorphic (landscape-forming) process affecting the area in the past one million years (most of the ice age or Quaternary period) has been the erosive action of the Rio Grande and its tributaries. The ancestral Rio Grande originally flowed near the level of the high tablelands (mesas) and benches that form the outer rim of the Española Valley. The valley itself is mainly a product of stream erosion. The inner valley, which includes the modern Rio Grande floodplain and alluvial aprons constructed by tributary streams, is flanked by lower terraces that are remnants of former valley-floor deposits. Geologic research throughout the Rio Grande Valley of New Mexico shows that the river cut its valley in several major stages, each separated by long spans of time when valley cutting essentially ceased and local aggradation of valley floors occurred. Changes in climate from cold ice-age conditions to relatively warm-dry intervals like the present have been very important factors controlling long-term cycles of river-valley cutting and partial backfilling. Structural deformation also played a subordinate, but locally significant, role in development of valley landforms.

Detailed review of the geologic history of the area is beyond the scope of this report. However, there are a number of recent publications that provide an excellent introduction to the Española Basin area. A broad overview of the geology of north-central New Mexico is offered by books on the Rio Grande rift compiled by Baldridge and others (1984), Hawley (1978), and Riecker (1979). These publications include reports on specific geologic and geophysical topics, review articles, correlation charts, a variety of maps, and field trip guides with road logs. Maps that illustrate the distribution and ages of major geologic formations and the history of structural deformation and volcanism during the past 20 to 30 million years have been prepared by Smith and others (1970), Galusha and Blick (1971), and Kelley (1978).

The major concern of this study is with very young geologic features of the El Llano area. The younger valley fill is mostly of post-glacial and late glacial age (<15,000 years old). It includes buried channel deposits of a late-glacial Rio Grande and an overlying wedge-shaped layer of alluvium that forms the bulk of the surficial deposits in the El Llano area. That latter unit was deposited primarily as alluvial fans by tributary arroyos heading in valley-flanking uplands. The character of these sediments and the occurrence of ground water in younger valley fill near El Llano is discussed in more detail in Sections 6.1 - 6.5. These sections deal with broader relationships that have been observed throughout the region.

Ancestral Rio Grande deposits were emplaced by a large perennial stream with average and peak discharges equal to or exceeding measured flows of the Rio Grande over the past 100 years. Deposits are primarily coarse grained (sand and gravel) with local lenses of silt and clay. The buried surface of these ancient river beds, when not deeply eroded, should approximate the gravel bar and swale topography of the present channel and floodplain area west of Fairview and Ranchitos (Fig. 0-1). The deposits are and always have been near the water table and are mostly saturated with ground water. These deposits have relatively high bearing strength and should not be susceptible to much additional consolidation under normal structural loads.

The main geologic unit considered in this study is the apron of alluvial-fan deposits emplaced by tributary stream systems over the older river beds. The communities in the El Llano area are built on these deposits, and it is this area that includes most of the reported sites affected by recent subsidence features and earth cracks.

In marked contrast to river sediments, the alluvial deposits were emplaced by ephemeral stream and sheet floods. Floods are usually produced by intense precipitation-runoff events on high-gradient, highly dissected and sparsely vegetated uplands or valley sideslopes, such as those that flank the Española Valley. Resultant flash-flood discharge in this setting is usually characterized by very high suspended sediment loads, and most of the transported material is ultimately deposited as fan-shaped bodies of alluvium on the river-valley border. Long periods of time may separate major flood events, and water tables are characteristically deep in valley-border areas (usually >30 feet). Therefore, surficial deposits emplaced by this process are characteristically unsaturated and include thick fine-grained (silty-clayey) beds. Deposits formed in this manner commonly preserve their high void ratios and low dry bulk densities.

The geologic and hydrologic processes involved in deposition of ephemeral-stream and sheet-flood sediments have been widely studied in semiarid and arid regions of the western United States. Pertinent published research on depositional processes includes reports by Bull (1964), Hawley and Wilson (1965), Schumm (1977), Gile and others (1981), Love (1983), and Pierson and Costa (1984). Geotechnical and environmental aspects of young alluvial-fan and arroyo-valley deposits are also discussed in detail by Bull (1964, 1972) and many later workers, including Lambert and others (1982), and Clary and others (1984).

There are five aspects of the geology of the area surrounding El Llano that needed to be considered in some detail. First, the general nature of subsidence depressions and earth cracks in the El Llano area must be described. Second, the composition and thicknesses of the deposits underlying the area were determined (do weak or soluble rocks underlie El Llano?). Third, the nature of deformation of the deposits was determined (are the rocks broken by faults?). Fourth, the timing of deposition and deformation was determined (when were the sediments deposited or when did faulting movement last occur?). Fifth, the present level and movement of ground water was determined.

6.1 Subsidence Depressions and Earth Cracks

The primary cause for declaring an emergency in the El Llano area was the sudden appearance of a large subsidence pit and several linear cracks in one neighborhood. The possible threat posed by these features to public works and private homes led to accelerated study by the New Mexico Bureau of Mines and Mineral Resources. Subsequent to the initial examination, several other subsidence pits and many earth cracks were found in the area. Damage to structures is described separately (Appendix VIII).

Subsidence pits range in size from approximately 15 to 150 feet in diameter; depths range from 1 to 5 feet. The large pit behind Mr. Moya's residence included a subsided volume of material at the surface of approximately 4,000 cubic feet. Other pits range from 10 to 150 cubic feet of surface displacement. In general, the pits are circular, although at least two are elongate. One elongate depression is oriented north-south and another is oriented to the northwest. Most of the pits appear to be aligned in a general north-south direction.

All of the subsidence depressions are associated with areas where water has accumulated at or near the surface, and the presence of the depressions has allowed more water to accumulate. For example, the depression affecting the Vigil garage has accumulated runoff from the road, the driveway, and the roof. Most of the depressions in El Llano have septic tanks and/or leach fields associated with them (Fig. 0-1). East of NM-291, small depressions are associated with present or abandoned drainages.

Several cracks were encountered at or near the surface that are not associated with subsidence depressions. Backhoe trenches were dug across several of the earth cracks. The cracks are oriented in various directions. Most are open or partially filled with sand and clay that has fallen from the walls above. Some of the cracks extend only 6-7 feet below the ground surface, although others extend beyond 12 feet. Some cracks split into two or more smaller cracks at depth. No cracks were noticed in cores taken from boreholes in the area. Most cracks either do not extend to the surface or are obscured at the surface by soil processes or human disturbance. The general description of these cracks is practically identical to cracks described by Bull (1972).

Reports of holes in irrigated fields that "swallowed" irrigation water prompted trenching some of the features known as sòtanòs. A description of the findings at one of these trenchs is discussed in Section 10.6.3.

The sòtanòs were reported at widespread localities in the area and seem to be related to desiccation of a near-surface clay layer. The desiccation produces shrinking of the expansive minerals that compose the clay fraction of the soil (see X-ray data, Appendix XIX). Surface water from irrigation apparently enters the network of cracks and flows down through more permeable layers at depth. This process seems to continue until the clay minerals become saturated, at which point they expand. Upon expansion, the cracks tend to close and, depending upon the volume of irrigation water being applied, this may "shut off" the entry of water to the deeper soils. The above description of the sòtanò phenomenon has not been witnessed by the investigators in the El Llano area, but this process is well documented in other parts of New Mexico and the southwest where similar clay-rich, expansive soils occur (Maker and others, 1974; Soil Conservation Service, 1975).

6.2 Composition and Thicknesses of Deposits

The 102 drill holes in the El Llano area penetrated up to 110 feet of sand, silt, clayey-sand, and gravelly-sand alluvial deposits very similar to sediments carried by modern arroyos east of El Llano. The deposits commonly are loose to medium dense, and they are not cemented together to form rock. Away from places where water has soaked into the ground due to human activity (e.g., leaky water lines or irrigated fields), the deposits are nearly dry from the surface down to the total depth of the drill hole or to near the water table which is at a level of about 5,600 ft above sea level (the level of the Rio Grande to the west, Appendix XI). The deposits slope to the west and are thinner both toward the river and toward the hills to the east. The deposits are probably near their maximum thickness along the north-south portion of NM-291. These deposits were laid down by small streams eroding materials from the bluffs to the east and transporting the sediments down gradient toward the Rio Grande to the west. Each small stream built its own fan-shaped deposit and all the fans overlapped each other. This produced a continuous slope from east to west.

The deposit underneath the alluvium at El Llano consists of rounded gravel and sand and is at least 10-20 feet thick. Unlike the pebbles in the alluvium above, the gravel is made up of pebbles and cobbles of rocks found upstream along the Rio Grande such as the black lavas and quartzites from the Rio Grande gorge. The gravel is about the same elevation as the present Rio Grande and slopes from north to south with about the same gradient. Therefore, the gravel and sand unit represents the former course of the Rio Grande and is here designated the river-gravel unit (Qrg on geologic maps and cross sections). The river has shifted to the west side of the valley and the arroyos from the east have deposited alluvial fans over the older river beds.

Although the drill rigs used in this study were unable to drill through the coarse Rio Grande deposits, domestic water wells drilled in the area have successfully penetrated the river-gravel unit (well logs from files of the State Engineer). Sandstones and mudstones very similar to the Santa Fe Group rocks seen in the bluffs and ridges east of Española Valley High School are encountered in the deeper wells. These ancient basin-fill deposits are tilted to the north-northwest, so their range in composition and thickness can be seen as one goes from the Santa Cruz River north along the ridge past the water tanks and northeast along the ridges east of San Juan Pueblo. These exposures show that the Santa Fe Group is at least several hundred feet thick and may be much thicker. Other geologists have measured nearly 5,000 feet of similar sedimentary rocks exposed around Española (e.g., Galusha and Blick, 1971; Baltz, 1978). The seismic reflection line (Appendix VII) suggests that these deposits are at least 2,700 feet thick beneath El Llano.

These rocks consist predominantly of sandstone and mudstone, with some layers of cemented gravel (conglomerate) and volcanic ash (commonly white, gray, or green layers a few feet thick). No thick beds of limestone or gypsum, capable of dissolving to form caverns, are known to exist at depth, and there is no known expression of collapse features within the Santa Fe Group due to solution subsidence. The sandstones commonly are partially cemented with calcium carbonate and silica, but some loose sand also occurs. The mudstones are somewhat compacted because they were buried by a few thousand feet of rocks that have since been eroded. The consolidation of these rocks makes them slightly harder to erode and more brittle, which allows faults to form more readily.

Beneath the sediments of the Santa Fe Group is a very thick sequence of older bedrock units. The uppermost layers are more consolidated sedimentary and volcanic rocks at least 575 feet thick. These rocks are harder, and they are not soluble. Below these rocks, at least in part of the Española Basin, are rocks that formed when the last sea was in the region (marine rocks; Black, 1984). These rocks are thought to be primarily insoluble sandstones and mudstones. Where present, these rocks are up to 6,000 feet thick. Below these marine rocks, in part of the Española Basin, are more sandstones and mudstones, but included in these rocks are some limestones and gypsum that would be capable of dissolving to form caverns. However, these rocks are so deep that even if caverns had formed and collapsed, the cavities would have filled with rock debris from above long before a subsidence feature could have reached the surface.

Below the limestone and gypsum are more sandstones and limestones, which are up to 3,000 feet thick. The limestones would also be capable of producing caverns, but similar limitations would prevent zones of collapse from being propagated to the surface. The base of all the sedimentary sequence rests on hard crystalline rocks (granites, metamorphic rocks) now exposed in the Sangre de Cristo Mountains to the east and the Rio Grande gorge to the north. These hard rocks are not subject to dissolution to form cavities.

Other unconsolidated deposits do not directly underlie El Llano, but are exposed on nearby hills and may be used to indicate ages for recent geological events at El Llano. These deposits consist of boulder gravels capping the hills east of El Llano and Rio Grande gravels and alluvium forming hills east of San Juan Pueblo. These gravels and similar gravels in other parts of the Española valley have been studied by Manley (1978), Kelley (1979), Harrington and Aldrich (1984), and Dethier and Demsey (1984).

The boulder gravels cap the ridges east of Española and are up to 20 feet thick. At least two levels of similar sediments rest on terraces along the Santa Cruz River. Most of the gravel is less than 1 foot in diameter, but boulders exceeding 3 feet are present. The composition of the rocks is primarily hard crystalline rocks from the Sangre de Cristo Mountains.

East of San Juan Pueblo are hills where gravel has been quarried in the past. Exposures show a terrace deposit of ancient Rio Grande gravel, 15 to 20 feet thick, resting on sandstone of the Santa Fe Group. The gravel is essentially horizontal although the sandstone dips a few degrees to the northwest (Fig. A-1; Appendix X). Overlying the gravel are essentially horizontal beds of alluvium up to 60 feet thick. The uppermost beds of alluvium are coarser than the rest. With the exception of the uppermost beds, the exposures are analogous to the river-gravel unit that lies beneath El Llano.

This summary of the composition and thickness of deposits underlying El Llano suggests that ground failure due to soluble rocks is unlikely. The weakest rocks appear to be the unconsolidated alluvium in the uppermost 100 feet. While mudstones may be weak and provide zones where slippage and compaction can occur, there must be a slope or gradient for movement to happen. Limestones and gypsum exist at great depths in some parts of the Española Basin. Only where deformation has uplifted the soluble rocks closer to the surface could cavern formation and collapse become a possible mechanism for subsidence at the surface.

6.3 Deformation

Forces and heat released from within the earth can deform rocks and cause earthquakes and volcanoes. The magnitude of these forces is evident from the position of the Española Valley between a volcanic mountain range to the west and the uplifted Sangre de Cristo Mountains to the east.

Within the El Llano area, exposed rocks exhibit two types of deformation: tilting and faulting. As previously mentioned, the rocks east of El Llano are tilted to the north-northwest a few degrees (originally they were deposited nearly flat). Therefore, in the past, the area to the south must have been uplifted or the area to the north must have sagged or both. Because the modern alluvium is not tilted and rivers are not affected by tilting, the process is not continuing at present.

In the seismic reflection profile (Appendix VII), the upper part of the bedrock appears to be tilted to the west (except where the beds are bent in an arch and a sag; see seismic interpretation). The apparent tilt may be due to the orientation of the profile compared to the orientation of the sloping beds. Unless the seismic profile was oriented at right angles to the slope of the northwestward tilted beds, there would appear to be some amount of dip to the west or east shown in the profile.

Faults cutting the Santa Fe Group are exposed in the hills east of Española and are interpreted in the seismic profile. Only two of the faults may be traced northwestward along the exposures of bedrock east of Española (see Geologic Map, Appendix V). The western fault trends northwest through the hill west of the Española landfill. The fault disturbs a zone only a few feet wide and appears to be offset 10-20 feet (down to the southwest). The fault east of the landfill trends 20 degrees to the northwest and dips 65-85 degrees to the southwest with stratigraphic separation of beds down to the southwest. Stratigraphic separation is about 60 feet across both faults, with the west side down. The eastern fault zone ranges up to 20 feet wide and consists of many smaller faults. The faults commonly are coated with clay or are cemented with calcium carbonate. No recent ruptures along the fault have broken the cemented zone. Due to this cementation, the fault is less easily eroded than the surrounding beds so the zone sticks up along a series of knobs. The low eroded areas between the knobs along the fault have been partially filled with alluvium, which is not offset by the fault. Also, the fault is buried by ancient terrace gravels north of the Santa Cruz River. The terraces are not offset by the fault. Neither of these faults could be traced north of bedrock exposures north of the Española landfill.

Although faults generally are not straight, line projections of the trend of these two faults, at an elevation of 5,800 feet, cross the El Llano area (see geologic map) and generally correspond with faults interpreted on the seismic line. However, the sense of movement on the eastern fault is interpreted seismically to be down to the east, opposite the direction seen to the south. Seismically, the western fault is interpreted to be larger than the eastern fault. Other faults to the east are interpreted seismically but do not correspond with surface features.

Two fault zones cut the Santa Fe Group bedrock east of the Española Municipal Airport. The more prominent of the two zones trends 41 degrees northwest and dips from 73 degrees northeast to vertical. Offset is about 10-30 feet. Locally the zone consists of two parallel faults. Adjacent to and within the fault zone the beds dip to the northeast, giving the overall structure the geometry of a faulted monocline. This fault is buried locally by alluvium and does not offset it. The fault does not project toward the damaged structures.

The second fault zone trends north 38 degrees east and also has the geometry of a faulted monocline with a faulted syncline in the down block. The fault zone pinches out to the northeast and northwest. The eastern fault dips 59 to 86 degrees to the southeast. The western fault dips 51 degrees to the southeast. Beds between the two faults dip up to 59 degrees to the southeast. Although the overlying conglomeratic beds have been eroded to expose the central portions of the fault zone, the conglomeratic units northeast and southwest of the fault zone are not disturbed. It appears that the fault has not been active since the conglomeratic units were deposited and consolidated.

6.4 Timing of Geologic Events

Two aspects of the geologic history of the El Llano area are critical for interpreting causes of cracking and subsidence. First, the age of the alluvial deposits beneath El Llano determines the amount of time allowable for development of cracks and depressions. Second, the age of last movement along the faults determines whether they are still active.

Five charcoal samples were submitted for radiocarbon dating. One was found to contain insufficient amounts of carbon to give a date. The date obtained from a charcoal sample taken at a depth of 7 feet (Trench ESBH-5, Appendix II), shows that the uppermost alluvium is less than 2,300 years old. None of the trenches excavated across the zones where faults were interpreted seismically showed any faults in the upper 12 feet. The lack of faults and the lack of scarps cutting the ground surface indicate that faulting has not occurred during the past 2,300 years.

The alluvium above the buried river-gravel unit is approximately 110 feet thick (see Appendix I). In general, the ancestral Rio Grande is thought to have been a much larger stream during the last ice age, about 15,000-20,000 years ago. If this interpretation is correct, the alluvium deposited by tributary arroyo systems has built up during the past 15,000 years. Investigations to date have not demonstrated that the cracks and subsidence cut downward through the entire section of alluvium or that the interpreted faults cut upward into the alluvium. In exposures of alluvium near the traces of the two faults, the alluvium is not cut by the faults. Therefore, the faults have not moved during the past several thousand years.

To the south, the faults are buried by terrace gravels of the Santa Cruz River. These terraces are interpreted to be no younger than about 70,000 years old. Therefore, the faults in that area have not moved in at least 70,000 years. However, the faults definitely cut the Santa Fe Group below. Fossils found east of El Llano are forms that lived between about 10 and 14.5 million years ago (Tedford, 1981). Therefore, the faults cutting these deposits are younger than about 10 million years. Much of the faulting related to development of the northern Española Basin apparently took place between 3 and 7 million years ago (Manley, 1984).

The soil cracks in the El Llano area cut deposits that are generally less than 4,000 years old. Some cracks extend from the surface to a depth of only 5 or 6 feet. These cracks are considerably younger than 2,300 years old and have not propagated upward from below. Some cracks have been known to disrupt houses in the El Llano area for at least the past 40 years (N. Voight, oral comm. 1985). Some cracks do not appear to cut the upper 2 - 3 feet of deposits, so these cracks may be older than 200-300 years (however, cracks at the surface may also be "healed" by expansive soil pressures).

Subsidence depressions and elongate systems of cracks have been known to occur in the El Llano area since at least 1963 (Dr. Yelvington, oral comm. 1985; Dr. V. C. Kelley, oral comm. to John Hawley, 1978). Depressions along stream courses east of El Llano are apparent on the 1935 aerial photographs, before most soil conservation measures were built. The small size and shallow depth of most depressions adjacent to houses are difficult to detect on aerial photographs. It is unlikely, however, that the depressions were there when the houses were first built. Some of the houses have been jacked up repeatedly in response to continued subsidence. At least two homeowners moved their septic tanks when subsidence depressions formed around the tanks adjacent to the homes. In one case, a second subsidence pit developed around the tank at the new location. All of these depressions formed before November 1984. Other subsidence features and cracked structures have developed in response to leaks in water lines since March 1985 (R. Cook, oral comm. 1985; F. Bustos, oral comm. 1985). At least one portion of NM-291 (Airport Road) has settled repeatedly due to ponding of water upstream from the road (Dr. Yelvington, oral comm. 1985).

6.5 Ground-water Conditions

Ground-water conditions in the El Llano area are of special concern in this study because the shallow, water-bearing deposits (aquifers) constitute a very important reservoir of high-quality ground water. This resource is widely utilized for both community and domestic systems and must be protected. Depths to the top of the zone of saturation (water table) range from slightly less than 30 ft to more than 100 ft. Studies by R. L. Borton (1974) of ground-water conditions in the southeastern part of Rio Arriba County (Truchas-Española-Velarde area) show that "ground-water movement is westward toward the Rio Grande from the principal area of recharge near the (Sangre de Cristo) mountains." Near El Llano, Borton's (1974) water-table map shows that shallow ground water has a flow component to the southwest, which is towards the local ground-water discharge area in the lower part of Española Valley (near San Ildefonso). More recent work on regional ground-water flow in north-central New Mexico (Coons and Kelly, 1984, fig. 2) confirms Borton's interpretation of general flow conditions in southeastern Rio Arriba County.

East of the Rio Grande and Santa Cruz river valleys the principal aquifer is the Tesuque Formation of the Santa Fe Group basin fill. The other major aquifer, according to Borton (1974, p. 353), is "the alluvium of major stream channels" and includes the buried river-gravel unit (Qrg) of El Llano area. The top of the saturated zone (water table) occurs in basal fine sand, silt, and clay beds of the overlying alluvial deposits (alluvium of this report). However, test drilling shows that saturated, permeable beds in the basal alluvium are very thin and discontinuous. During the course of this study, direct observations of ground-water conditions were only made on the river-gravel unit and overlying alluvial deposits. No monitoring wells penetrated the Sante Fe Group.

The general distribution of aquifers and water-table configuration near El Llano is illustrated on Figures 6-1 and 6-2, which provide map and cross-section views of an area centering in sections 25 and 26, Township 21 north, Range 8 east. Control points for use in preparing these illustrations include our 11 test holes drilled below the water table. These holes have been cased and developed as temporary observation wells for water-level and water-quality monitoring. Other primary control points are domestic water wells in the area that have been drilled and logged by local commercial drillers. Records for these wells were obtained from files of the office of the State Engineer in

Santa Fe and from local residents and one driller. In several cases, direct measurement (with steel tape) of water levels is possible in these wells. However, well-pump construction usually does not permit access for measurement. Water-level control points established by Borton (1974) were also used in this study.

The direction of shallow ground-water flow shown on Figure 6-1 agrees with the general east to west (mountain to valley) and northeast to southwest (down the Rio Grande Valley) water-table gradients previously determined by Borton (1974) and Coons and Kelley (1984). Ground-water elevations near El Llano are definitely higher than the water table in the area adjacent to the Rio Grande floodplain south of Ranchitos; and they are lower than the levels measured by Borton (1974) in wells on San Juan Pueblo lands to the north and east.

However, examination of water-table contours and individual water-level measurements (Fig. 6-1 and 6-2, see also Appendix X) indicates that the top of the saturated (or ground-water) zone is not a smooth surface with uniform west to southwest gradient. Instead, the surface is almost level in most of the area, and there are slight local depressions and mounds.

North and east of Española Municipal Airport and near the High School (about 1 mile southeast of El Llano) there is a marked increase in the water-table slope relative to areas to the west (100 ft/mi versus less than 10 ft/mi; Fig. 6-1). Wells to the east appear to be developed in the Santa Fe Group-Tesuque Formation; and steeper water-table gradients reflect relatively low hydraulic conductivities of partly consolidated, fine, sandy

EXPLANATION

PROJECT DRILL HOLE WITH MEASURED WATER-LEVEL ALTITUDE

● COMPLETED IN Qrg AQUIFER — 5617

● P COMPLETED IN PERCHED ZONE — 5639

WELL WITH WATER-LEVEL ALTITUDE

○ COMPLETED IN Qrg AQUIFER — 5621 WATER-LEVEL MEASURED

○ S POSSIBLY COMPLETED IN SANTA FE AQUIFER — 5621

○ WATER LEVEL REPORTED — 5615

WELL WITH WATER-LEVEL ALTITUDE, UNVERIFIED LOCATION

× COMPLETED IN Qrg AQUIFER — 5610-15

WELL WITH WATER-LEVEL ALTITUDE

□ COMPLETED IN SANTA FE AQUIFER — 5602 WATER LEVEL MEASURED

□ WATER LEVEL REPORTED — 5644

□ G WELL ALSO PENETRATED Qrg AQUIFER — 5616

WATER-LEVEL CONTOUR IN FEET ABOVE MEAN SEA LEVEL

5620 — WELLS COMPLETED IN Qrg AQUIFER

5640 — WELLS COMPLETED IN SANTA FE AQUIFER

SUBCROP OF Qrg AND SANTA FE AQUIFERS (Appendix V)

W—E LINE OF HYDROLOGIC CROSS SECTION (Figure 6-2, Appendix XI)

A—A′ LINE OF GEOLOGIC CROSS SECTION (Appendix X)

0 — 1 MILE

0 — 2000 — 4000 FEET

CONTOUR INTERVAL 20 FEET

N

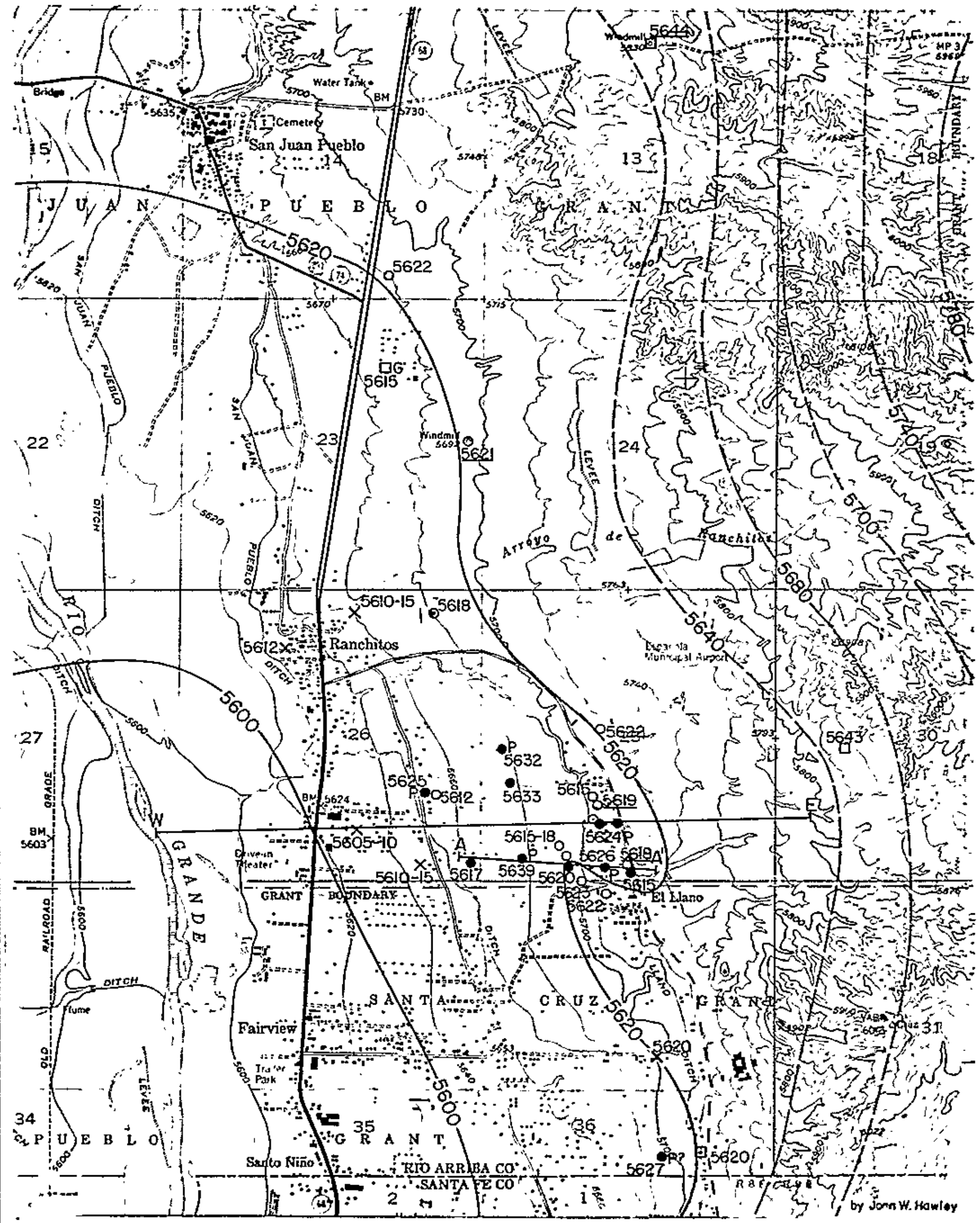


Figure 6-1. Water-table configuration in the El Llano area.

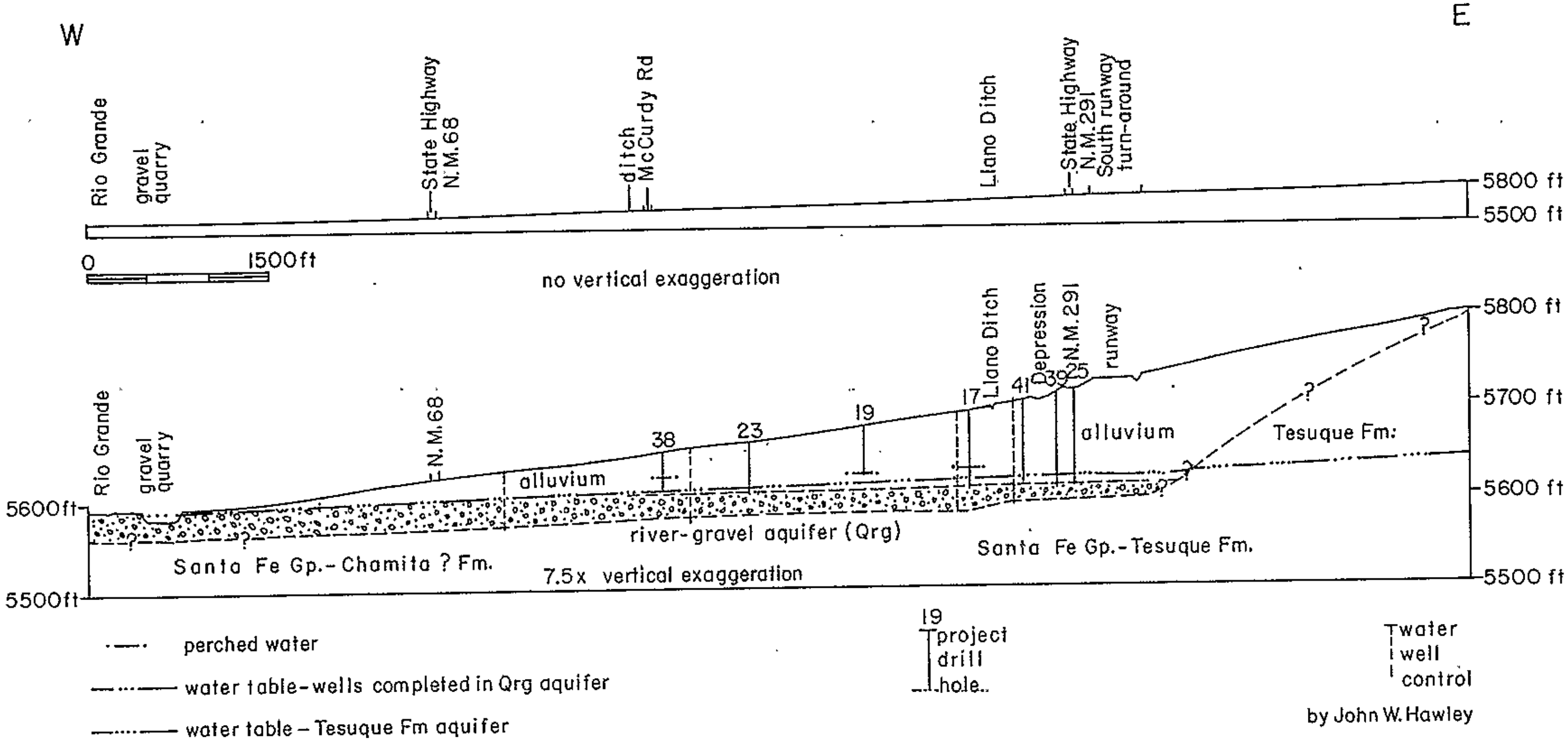


Figure 6-2. West-East hydrologic cross section through the El Llano area.

to silty aquifer materials. Work by Hearne (1980) on the Tesuque aquifer system in the nearby Pojoaque River basin indicates that conductivities are in the 0.5 to 2 feet per day range. All domestic wells in the EL Llano community area, and much of the valley to the west, appear to be completed in the buried river-gravel unit (Qrg). Hydraulic conductivities of this clean gravel and sand unit should be significantly higher (Davis and DeWiest, 1966, Tables 6.1, 6.2) than conductivities in the Tesuque Formation, even though specific field measurements have not been made in the Española Valley. The very low water-table gradients (commonly less than 5 ft/mi) shown in the valley area of Figure 6-1 therefore reflect a shallow aquifer system that can transmit water at linear velocities many times as fast as water-bearing units in the Tesuque Formation. At the above-noted hydraulic gradients (Fig. 6-1) and conductivities, linear velocities for ground-water flow in Tesuque Formation should range from 0.1 to 0.2 ft/day. Velocities in the river-gravel unit could be at least 10 times greater.

Localized pumping effects of the community and domestic wells, recharge from surface-water sources, and well-construction factors also affect the water levels measured during this study. Therefore, the water-table configuration shown in Figures 6-1 and 6-2 only approximates the true surface of the saturated zone. Pumping drawdown effects are definitely expected in an area with many domestic wells. Wells also tap different levels of the valley-fill aquifer system and have differing pressure heads. Local effects of fine-grained confining beds and perching layers should be expected even in areas where unconfined conditions are prevalent. Some of the El Llano area appears to be in a recharge zone and heads (static water levels) are expected to be higher in shallower wells. Local recharge to the river-gravel aquifer includes seepage from natural drainageways crossing the area, infiltration of water from irrigation canals and field spreading sites, and seepage from other sources related to intensive urban or suburban land use. Another probable source of recharge to the river-gravel unit is upward leakage from the underlying Santa Fe (Tesuque) aquifer; but verification of this recharge component was beyond the scope of the El Llano geotechnical investigation.

Considerable care was taken during this study to prevent contamination of the river-gravel aquifer unit, the major source of ground water in the area. Where monitoring wells penetrated this unit, bentonite (clay) plugs were emplaced around the casings to seal off ground water in the basal layers of overlying "alluvium". Most monitoring holes were only drilled into saturated zones near the base of the "alluvium" and did not penetrate the "river-gravel" unit. At least one monitoring well may have been completed in a perched zone of saturation above the general level of water table (drill hole ESPDH-19).

Work on water quality conditions also was done in cooperation with the Ground Water Hazardous Waste Bureau of the State Environmental Improvement Division (EID). Principal cooperators are D. Earp, P. Longmire, and D. McQuillan. A supplemental report on ground-water quality in the El Llano area has been prepared for the Civil Emergency Preparedness Division (OMA) by Douglas Earp (1985; Appendix XXII). Nitrate contamination of ground-water is usually related to human activity. Septic tank leach fields and fertilization practices in agriculture are common major sources; but animal wastes and plant materials can also provide nitrates to the ground-water system. Nitrate contamination is already a recognized problem in many parts of the State, including a number of sites in the Rio Grande Valley (Thompson and McQuillan, 1984). The EID is currently studying the ground-water nitrate problem in the Ranchitos and Santo Niño area of Española Valley.

This phase of the study was recommended after noting high moisture contents at depth in alluvial deposits cored near the El Llano community well and in an area where waste-water effluent may be contributing to ground-water recharge. Water samples from the present community well were analyzed by the State Environmental Improvement Division between 1977 and 1982. Reported ground-water quality is generally excellent, with the exception that the nitrate level of 8.39 mg/l (reported as N) measured in 1982 approaches the upper recommended limit for a community water-supply system (10 mg/l). Moreover, R. L. Borton (1974, p. 354) of the State Engineer Office had already noted that "ground water from the alluvium or Tesuque Formation (Santa Fe Group) commonly has a high calcium-magnesium hardness and concentrations of iron or nitrate which exceed Public Health Service standards for domestic use are not uncommon in local areas." Thus, there was definitely cause for concern about sources of nitrate and other types of ground-water contamination in the El Llano area.

As of 28 June, 1985, nitrate concentrations exceeding 10 mg/l had been noted in two domestic wells in the El Llano community. Elevated concentrations of manganese (0.2 mg/l or higher), which are another pollution indicator, were also noted in one domestic well and four monitoring wells in the area (Earp, 1985; Appendix XXII).

7.0 WORKING HYPOTHESES

A number of hypotheses were considered that might explain the observed subsidence phenomena in the El Llano area. Each was evaluated using field research, existing literature, and personal interviews. Brief discussion of each hypothesis that was considered follows; the technique used to evaluate the hypothesis is considered, and the sections of this report containing more detailed information are noted.

7.1 Vehicular Vibrations

Initial hypotheses centered on natural and human-induced vibrations that may have contributed in some manner to settlement. Natural vibrations from earthquakes required research into the earthquake history of northern New Mexico and the regional earthquake history of the southwestern U.S. (Sec. 10.6). Man-made vibrations caused by vehicular traffic necessitated research into known threshold levels of damage due to heavy equipment and traffic (Sec. 10.1). In addition, two ground-vibration monitors were installed in condemned houses with the approval of the owners (Moya and Valdez).

7.2 Geophysical Exploration

Vibrations due to geophysical exploration, especially seismic surveys, are sometimes the cause of structural damage. Shell Western Exploration and Production, Inc. conducted geophysical surveys south of El Llano in November of 1984. A summary of their work is discussed in Section 10.2. A report submitted to NMBM&MR is included as Appendix XV.

7.3 Ground-water Fluctuations

Due to known relationships between ground-water (or other fluid) fluctuations, ground subsidence, and building distress in some parts of the southwestern U.S., the ground-water levels in the El Llano vicinity were mapped. This was done by gathering ground-water level data from state agencies, literature searches, personal interviews with local drillers, and by the installation of 11 ground-water monitoring wells (Sec. 10.3).

7.4 Effects of Offsite Hydrologic Phenomena

Effects of offsite hydrologic phenomena were suggested as a cause of possible ground-water fluctuations in the El Llano area. In particular, gravel pit operations west of El Llano near the Rio Grande River were cited as a mechanism whereby the ground water beneath El Llano could have been adversely affected. These offsite hydrologic phenomena are evaluated in Section 10.4.

7.5 Effects of Highways and Flood-Control Dams

The presence of NM-291 (Airport Road) and flood-control dams east of El Llano were suggested as structures that may retard surface runoff, leading to increased moisture in the upper soils. Evaluation of this hypothesis required both drilling and aerial photo interpretation (Sec. 10.5).

7.6 Earth Deformation, Earthquakes, and Related Phenomena

Deep-seated movements of the earth's crust (tectonic movements) stress and break rocks, cause earthquakes, sag or up-arch areas of land, and cause related disruption of the ground surface. In the El Llano area, three hypotheses for forming cracks and subsidence pits from deep-seated forces may be formulated. First, known deformation of the area northwest of Española (Reilinger and others, 1979) may be causing bending and ground rupture in El Llano (Sec. 10.6.1). Second, movements along a fault or several faults beneath the area may cause the cracks and subsidence features (Sec. 10.6.2). Third, shaking by earthquakes nearby may cause the ground to crack and subside by rearranging loosely packed deposits (Sec. 10.6.3).

7.7 Precipitation

Although some structures and utilities have been cracked for many years, as evidenced by earlier attempts at repair, there were reports of increased subsidence and cracking in the fall of 1984. One possible explanation for the increased level of apparent subsidence was short-duration, high-intensity rainfall, which may have occurred in or near El Llano before November 1984. To evaluate this hypothesis, daily weather records for the past 90 years were obtained and evaluated (Sec. 10.7).

7.8 Karst

Selected areas of New Mexico are underlain by soluble rocks such as dolomite, gypsum, and limestone. Dissolution of these rocks can produce large subsidence pits known as karst. Because the depression immediately west of the Moya residence is somewhat similar to karst topography, it became necessary to evaluate the "deep" subsurface geology and lithology. To do this, geophysical surveys were conducted (Appendix VII), deep drill holes (up to 124 feet) were drilled (Section 10.8), and geologic mapping was conducted (Appendix V).

7.9 Mining Activities

Settlement above abandoned mine workings is a common cause of ground subsidence in some parts of New Mexico. To document any early mines in El Llano and vicinity, literature searches and aerial photo analyses were conducted (Sec. 10.9).

Two types of mining activities could be considered hypothetically as causes of cracks and subsidence in the El Llano area. The first type of mining, which has caused cracking and subsidence in other areas, includes inadequately reinforced tunnels and drifts in shallow underground mines. Cave-ins of old mines can make the surface of the ground subside and form both concentric cracks around pits and long linear cracks above old mine workings.

The second type of mining activity, which conceivably could affect the El Llano area, is the removal of building materials adjacent to the affected area. In this case, gravel quarry workers are removing gravel up to 20 feet deep from the Rio Grande floodplain 1.2 miles west of the El Llano area. Hypothetically, the removal of gravel stresses the surrounding ground by generating vibrations during operations and by altering ground-water flow. Horizontal stress in soils can form in response to removal of adjacent material support. Cracks form and soil slumps laterally to partially fill the adjacent hole. Vibrations associated with the removal of material could help create new cracks around the hole. The alteration of ground-water flow is considered separately in Secs. 7.3 and 10.3.

7.10 Expansive Soils

Expansive soils typically contain appreciable amounts of certain clay minerals that expand when wetted. These soils are suspected to be present locally in the El Llano area. To evaluate the presence of expansive soils, X-ray diffraction analyses were conducted on numerous shallow soil samples (Appendix XIX). The consequences of expansive soils are evaluated in Sec. 10.10.

7.11 Areal Subsidence as a Possible Cause of Cracks

Cracks can be observed both at the surface and in excavated trenches. They appear as tension cracks and seem to be associated with the El Llano acequia. However, little was known initially about the areal distribution of these cracks and their relationship to subsidence. To evaluate the cause and significance of soil cracks, several trenches were excavated, sampled, and logged (Appendix II). In addition, major soil cracks were delineated on the geologic map (Appendix V), and selected samples were age dated (Appendix IX). The significance of the soil cracks is discussed in Sections 6.0 and 10.11.

7.12 Organic Matter at Depth as a Possible Cause of Cracks

The ground surface can subside because buried organic matter such as peat may compact or oxidize. Stephens and others (1984) document the processes that reduce the volume of peat and cause ground subsidence. If similar peat deposits existed under El Llano, perhaps associated with the former floodplain of the Rio Grande, compaction of the peat could cause subsidence.

7.13 Subsidence Along a Buried Bluff Line of the Ancestral Rio Grande

When the Rio Grande flowed on the east side of the valley and deposited the gravel now buried beneath El Llano, the river must have eroded the margins of the valley and may have cut a steep bluff on its east edge. Such a bluff line would be similar to the bluffs west of the river at present. When the river moved to the west, the alluvial fans accumulated on the floodplain and may have buried the old bluff line. Different amounts of settling of the alluvium on either side of the bluff line could cause cracking of the ground surface along a general north-south trend.

7.14 Collapsible Soil

Collapsible soils reduce in volume appreciably when wetted. The subsidence features and utility damage noted in the El Llano area is consistent with damage associated with collapsible soils. To evaluate the presence of collapsible soils, undisturbed and disturbed samples were obtained from carefully drilled holes. Selected holes were fitted with monitoring equipment to detect settlement. These holes were monitored on a regular basis for up to seven months (Appendix VI). A suite of laboratory tests was devised to test for collapsible potential. The results of laboratory tests are included in Appendices III and XIX. A detailed description of the laboratory tests and their results is presented in Section 9.0. The characteristics of collapsible soil are described in detail in Section 11.0

8.0 FIELD ACTIVITIES

The field activities completed for this study are plotted on the activity location maps (Appendix XII). They generally consist of drilling, monitoring, geophysical surveying, and sampling.

Weekly logs of field (and office) activites were kept. They document numerous day-by-day events that would otherwise become lost or forgotten in a project of this magnitude (Appendix XXIII).

For each field activity that required ground disturbance (geophysical surveys, drilling, and trenching) verbal permission was obtained from the landowner or the landowner's close relative. Written permission was obtained from Mr. Richard Cook for use of his land for the geotechnical ground stabilization studies. All disturbed sites were restored as much as possible to their original condition, or left in place with the permission of the property owner, in place to allow future monitoring. All sites are checked regularly to assure our activities caused no detrimental effects and none have been found. Two backhoe trenches that were excavated in close proximity to houses (ESBH-1 and ESBH-9) were later partially re-excavated and sealed (with bentonite), then refilled and compacted. The surface depressions formed at the geotechnical ground stabilization study areas were sealed with bentonite, backfilled and graded.

9.0 LABORATORY TESTING

Soil samples taken from the project site were tested in the laboratory for their Atterberg Limits, grain-size distribution, moisture content, specific gravity, dry and wet density, consolidation, and clay mineralogy. In addition, selected specimens were studied with a scanning electron microscope.

9.1 Atterberg Limits

Atterberg Limits are the liquid and plastic limits of the fine sand and smaller size fraction of the soil. The liquid limit is the water content of the soil at which it behaves like a viscous fluid. It is determined by placing a paste of the soil sample in an Atterberg Limit device which shakes the sample by raising and dropping a standard container a standard distance. The paste is smoothed out and is divided with an ASTM standardized grooving tool. Once the Atterberg Limit device is started the operator counts the number of drops it takes to close a 1/2 inch-long groove in the soil. The procedure is repeated several times at different soil water contents to obtain a range of counts from 10 to 40. After each test, part of the sample is weighed at its liquid limit, dried in an oven, and weighed again to determine the water content of the soil. A plot of the water content in percent versus the number of drops on a log scale generally produces a straight line. The liquid limit of the soil is the water content corresponding to 25 drops on the plot.

The plastic limit is the water content below which the soil no longer behaves as a plastic material. It is found by taking 15 grams of moist cohesive soil and rolling it on a glass plate with the palm of the hand until it is a 1/8 inch diameter thread. Once the thread shows signs of crumbling it is at its plastic limit. The specimen is weighed, dried in the oven, and weighed again to obtain its water content, which is the plastic limit value in percent. This procedure is repeated three times to obtain an average.

Many of the soil samples tested for Atterberg Limits had no liquid limit and were nonplastic. These soils generally were classified as slightly silty to poorly graded sands (SP-SM and SP). However, other more plastic soils tested exhibited a range of liquid limits between 15-82 and a range of plastic limits between 0-47. The average liquid limit and plastic limit of all these plastic soils was 31.6 and 16.5, respectively. The range of plasticity index of these soils was between 0-37 with an average of 24.2. Due to the low plasticity index many of these soils were classified as low plasticity clays and silts (CL-ML). A few samples displayed such high liquid limits that they had to be classified as high plasticity clays and silts (CH-MH).

Soils west of the El Llano acequia are, for the most part, considered non-collapsible because they have been wetted by irrigation water for hundreds of years and are thus believed to be collapsed. Their average liquid limit was 34.0, the plastic limit was 20.7, and the plasticity index 27.8. In contrast, soils east of the acequia had significantly lower liquid limits, plastic limits and plasticity index averages (31.2, 15.6, and 23.4, respectively). This suggests that the collapsible soils east of the acequia generally have less high plasticity silt and clay and/or more low plasticity silt and clay than do soils west of the acequia. Based on grain-size distribution data (see Section 9.2) it was found that the collapsible soils have much less silt and clay than do noncollapsible soils which is consistent with the above Atterberg Limit data.

9.2 Grain-size Distribution

The particle-size analysis requires a set of seven to 10 sieves ranging from the No. 4 size (0.187 inches) to the No. 200 size (0.0029 inches). The sieve sizes are chosen depending on the visual grain-size estimation. However, ASTM requires the following sieves for soils finer than the No. 10 size: Nos. 20, 40, 60, 140, and 200. The recommended procedure for this test is as follows:

1) weigh each sieve to 0.1 gram;
2) weigh the soil sample of approximately 500 grams to 0.1 gram accuracy. If the soil has many particles coarser than the No. 4 seive then a larger sample should be used;
3) after the soil is disaggregated using either the dry or the wet preparation method described above, pour the soil into the nest of sieves;
4) place the sieves into a Roto-tap machine for 10 minutes;
5) weigh each sieve and the pan with their retained soil fraction to 0.1 gram accuracy;
6) subtract the weights obtained in step 1 from those of step 5 to obtain the weight of the soil retained on each sieve and plot them on a grain-size distribution chart;
7) use the soil in the pan for the following hydrometer analysis.

Most of the soil samples tested are classified as poorly graded silty sand (SM). Slightly silty poorly graded sands (SP-SM), poorly graded clayey sands (SC), and poorly graded sands with little or no fines (SP) were the second, third, and fourth most common grain-size distributions respectively. In minor abundance were well-graded sands and gravels (SW, GW) and low and high plasticity silts and clays (ML, MH, CL, CH). Many of the silty sands have interbeds of clay and gravel as shown on the east-west cross section through El Llano (see Appendix XII).

The noncollapsible soils west of the El Llano acequia generally have a greater percentage of fines (finer than the number 200 sieve) than do the collapsible soils east of the acequia. Also, the collapsible soils have a greater percentage of gravel and fine-to-medium sand than do the noncollapsible soils.

9.3 Pipette Analyses

Pipette analyses determine the percentage of silts and clays finer than the No. 200 sieve based on the rate of settling of small particles through water (Stoke's Law). The following procedure was followed:

1) about 50 grams of sample (finer than 200 mesh) was mixed with 500 ml of distilled water;
2) a deflocculating agent (usually 2 drops of 10% sodium hydroxide) was added to the mixture;
3) the fluid was mixed in a blender for 10 minutes;
4) the mixed sample was put in a liter cylinder and

subsequently filled to exactly 1000 ml with distilled water;

5) the top of the cylinder was covered and the cylinder turned upside-down while the contents were shook back-and-forth for 1 minute;

6) a 20 ml pipette was inserted to a depth of 20 cm and after 20 sec. 20 ml of fluid was withdrawn and put in a preweighed 50 ml beaker. The pipette was washed with 20 ml of distilled water that was put in the beaker;

7) withdrawal of 20 ml aliquots ws repeated depending on temperature, time, depth and Stoke's Law until samples of clay less than 2 microns in diameter were taken (commonly after 7 hrs and 4 min. at 24° C

8) the beakers with samples were dried and weighed, the weight of dispersant was subtracted, and the total weight of size fractions of silt and clay were calculated.

Many of the soils examined for grains smaller than the No. 200 sieve had a greater percentage of coarse to fine silt (0.0625-0.002 mm) than clay (0.002-0.00006 mm). This was especially true for the collapsible soils east of the acequia where the average percentage of coarse to fine silt and clay was 16.0% and 3.1%, respectively. No pipette analyses were performed on soils west of the acequia. It is believed, based on field classification and description, that these soils have a much greater percentage of clay due to their more distal position on the alluvial-fan surface.

9.4 Moisture Content

This is a simple test that involves weighing the soil sample, drying it in an oven at 110°C for 24 hours, and weighing it again. The difference in weight before and after drying is the weight of the water in the soil. It can be expressed as a percentage when the weight of the water is divided by the dry weight of the soil.

Moisture content is a good detector of pre-collapsed or post-collapsed conditions in areas susceptible to subsidence from collapsing soils. Soils from drillholes drilled east of the acequia around structures that had experienced differential settlement have an average moisture content of 16.1% to a depth of 50 feet. In contrast, soils from drillholes in potentially collapsible areas where no subsidence or damage had occurred yet had an average moisture content of 8.0% to a depth of 50 feet. A similar increase in moisture content also occurred in the geotechnical ground stabilization study areas 1, 3, and 4 when soil collapse, cracking, and subsidence occured due to water injection. Clearly, the uncollapsed soils east of the acequia are moisture deficient.

9.5 Specific Gravity

This is the ratio of the weight in air of a given volume of soil at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature. First a pycnometer is calibrated by weighing it with and without water and recording the water temperature in degrees Celsius (T). A 25-gram oven-dried soil sample is placed in the pycnometer with distilled water. After putting the bottle stopper on the top of the pycnometer the trapped air is removed by gently boiling the solution for 10 minutes and connecting the device to an aspirator. The pycnometer is then weighed with its contents, and the temperature of the distilled water is taken. The specific gravity of the soil is calculated using the equation:

$$Wo/\{Wo+(Wa-Wb)\}$$

where, Wo = the weight of soil,

Wa = the weight of the pycnometer filled with water at a measured temperature, and

Wb = the weight of the pycnometer filled with water and soil at the measured temperature.

If the temperature is above or below 20°C a correction factor is multiplied by the calculated specific gravity value.

Only a few specific gravity tests were performed in conjunction with the consolidation tests. Values ranged from 2.57 to 2.60 with an average value of 2.58 for the soil grains.

9.6 Dry and Wet Density

The dry density of a soil is the mass or weight of an oven dried sample (110°C) divided by its volume. The wet density is similar except the soil sample is weighed at its natural moisture state. Therefore, wet densities of soils are greater than dry densities due to the added weight of the moisture content. Both are important tests on undisturbed samples as collapsible soils commonly have low densities.

There are several direct and indirect methods of determining dry and wet density. One method is to take a 100 gram clump of soil, weigh it, coat it with paraffin, weigh it again, and immerse it in a beaker of water to find its volume. The weight and volume of the clump can then be calculated and the density can be obtained by dividing the weight by the volume. Many density calculations are made during a consolidation test where a soil mass is forced into a ring of known volume and weight. Once the ring plus the soil is weighed its density can be determined. In addition, wet density can be calculated by knowing the weight and volume of soil in the sample tubes. This is probably the fastest method and gives accurate values.

Density is another indicator of soil collapse because soils will increase in density due to consolidation from the addition of water and/or load. The average dry density of soils taken from drillholes in previously collapsed areas such as west of the acequia and around the Moya's subsidence pit was 98.5 pcf. In contrast, collapsible soils east of the acequia that have not yet subsided only averaged 91.3 pcf. Collapsed soils west of the acequia have dry densities ranging between 82-117 pcf while uncollapsed soils east of the acequia ranged between 72-110 pcf. The range of dry density for collapsible soils in El Llano, based on laboratory data, falls between 75-95 pcf.

9.7 Standard and Modified Consolidation Tests

When a cohesive (e.g. clay-bearing) soil is loaded it compresses because its grains deform while air and water are compressed and finally squeezed out of the voids. As the pore fluid is squeezed out the soil grains rearrange themselves into a denser configuration resulting in decreased volume.

The consolidation test determines the amount of volume reduction of a soil when it is loaded. To do this, a consolidometer is used with a device for holding the undisturbed sample. Porous stones are placed on the top and bottom of the sample to allow drainage of water from the sample during the test. Both the load on the soil and its amount of deformation are monitored over a variable period of time depending on the type of soil being tested. Typically, two weeks is sufficient to obtain data on soils that undergo slow primary consolidation. During this time the load is increased incrementally, then decreased in the same sequence to observe the "rebound" of the sample.

Presentation of the data collected includes a plot of the percent consolidation or vertical strain, which is determined from the deformation readings, versus the effective consolidation stress, which is calculated from the load readings divided by the surface area of the sample. Another way of displaying the data is to plot the soil void ratio versus the effective consolidation stress. By examining this curve the stress history of the clay can be determined.

The modified consolidation test is used specifically for testing collapsing soils. First, the overburden pressure of the undisturbed sample is calculated by multiplying its density, acceleration due to gravity, and depth from the surface. The sample is loaded on the consolidometer for 24 hours to simulate overburden pressure and to obtain a time versus deformation curve. Then the sample is saturated with distilled water and loaded with the same overburden pressure for another 24 hours.

This test simulates the natural consolidation of the soil at depth and at its natural moisture content. The test also shows the effect of water on the consolidation of the sample when it is saturated with distilled water.

The double consolidation test also is useful in examining the consolidation characteristics of collapsible soils. During this test two consolidometers, with identical soil samples, are loaded incrementally to 8 tons per square foot (tsf). One sample is flooded with water at the beginning of the test while the other remains at its natural moisture content. The results are plotted as void ratio or percent consolidation versus log stress. The differences in consolidation characteristics between the saturated and unsaturated soil samples are then recorded.

Modified and double consolidation tests were run on 17 soil samples. Each sample was incrementally loaded to stresses between 0.25-2 tsf (500-2000 psf) and then saturated for 24 hours. Then the samples were incrementally loaded further to stresses between 5-15 tsf (10,000-30,000 psf). The total percent consolidation of each sample shown in Table 9-1 represents the decrease in sample height after each consolidation test.

Based on the consolidation test data listed in Table 9-1 it can be concluded that soil samples taken from east of the El Llano acequia are, in general, collapsible if they have a moisture content below 10%, are silty or clayey sands to sandy silts (SM or SC to ML) and consolidate more than 10%. The more poorly sorted, slightly silty sands (SP-SM) with similar moisture contents from the same area (east of the acequia), consolidate

Table 9-1: CONSOLIDATION TEST DATA

Drill Hole No.	Depth (ft)	Moisture Content %	USCS Soil Description	Location*	Total Cons. %
GGSSS - 1	9-11	7.27	SM	E. of acequia	24.9
GGSSS - 2	3	10.96	SM	E. of acequia	3.8
GGSSS - 3	19-21	5.19	SM	E. of acequia	10
GGSSS - 4	9-11	6.99	SC	E. of acequia	18
GGSSS - 5	9-11	5.64	SM	E. of acequia	12.2
GGSSS - 12	2-4	10.72	SM	W. of acequia	25.9
GGSSI - 1	9-11	6.3	SM	E. of acequia	11
GGSSI - 2	9-11	2.2	SP-SM	E. of acequia	6.5
ESPDH - 5	9-11	4.1	SM	E. of acequia	11
ESPDH - 5	19-21	2.7	SP-SM	E. of acequia	14
ESPDH - 7	10-12	8.8	SM	E. of acequia	20
ESPDH - 9	5-7	5.2	SM	E. of acequia	22
ESPDH - 9	14-16	2.4	SP-SM	E. of acequia	4.5
ESPDH - 10	14-16	3.8	SM	E. of acequia	5
ESPDH - 11	5-7	21.2	ML	E. of acequia	7
ESPDH - 12	11.5-14	2.9	SM	E. of acequia	5
ESPDH - 14	14-16	33.6	ML	E. of acequia	7.5
ESPDH - 16	9-11	11.4	SM	E. of acequia	11
ESPDH - 17	14-16	7.9	SM	W. of acequia	5.5
ESPDH - 17	29-31	23.1	ML	W. of acequia	8.5

*Referenced acequia is El Llano acequia that generally trends N-S through the study area and roughly divides soils of higher collapse potential (east of acequia) from soils of lower collapse potential (west of acequia) less than 10% and are therefore considered as non-collapsible and more geologically stable soils. Other soil samples taken from drill holes near damaged houses generally had high moisture contents (greater than 10%), and consolidated less than 10% when tested. These soils are regarded as having been already collapsed due to man-caused wetting.

A limited number of tests were run on samples west of the acequia but in general samples had less than 10% total consolidation and were considered largely non-collapsible due to the fact that they had already collapsed due to the irrigation which has taken place for hundreds of years. However, local areas may still retain some collapse potential.

9.8 Direct Shear Strength Test

This test determines the consolidated undrained shear strength of a cohesionless soil by (a) placing a sample of known density, volume, and mass in the shear device mold, (b) applying a predetermined normal stress, and (c) applying a shear force until the sample fails. Because the resistance to shear of a cohesionless soil is derived from the grain friction and the interlocking of the grains, varying the relative density and water saturation should change the point of shear failure or the shear strength of the soil. Dense soils usually have a higher shear strength than loose soils.

If a saturated soil shears quicker than its pore water can flow out, the normal stresses are transmitted into the water that has no shear resistance. Therefore, a loose saturated soil that contracts during shear can lose its strength and liquefy. Silty sands can be extremely vulnerable to liquefaction caused by seismic shear waves or strong vibratory ground motion.

For the first two minutes of the direct shear test the vertical and horizontal strain and shear stress dials are monitored every 15 seconds; then they are monitored every minute until the sample fails. The calculated shear strength, T, is given by the equation:

$$T = \sigma \tan \Theta$$

where σ is the normal stress and Θ is the angle of internal friction, or the resultant angle between the normal and shear forces at failure.

The data are plotted as stress-strain curves consisting of a shear/normal stress ratio and normal displacement versus shear displacement. In addition, normal stress versus shear stress are plotted to obtain a failure envelope for each sample. Therefore, an angle of the Mohr failure envelope (Θ) can be determined for the relative densities and water saturations of each sample.

9.9 Clay Mineralogy

Identifying expandable clay minerals through X-ray diffraction helps in predicting the shrink-swell potential of a cohesive soil. There are several methods of preparing clays for X-ray diffraction identification each of which has advantages and limitations. The method used in this study was the pipette-on-glass-slide method. With this method a pipette or eyedropper is used to place a suspension of clay particles onto a glass slide. The slide is allowed to dry overnight and is then ready to be used for the test.

The X-ray diffractometer is run at certain angles and speeds over the glass slide depending on the clay mineralogy and the nature of information needed. Generally, for montmorillinite, illite, and kaolinite clays the angle spread is from 2 to 38 degrees at 2 degrees per minute.

Additional clay mineral identification is done by treating the glass slide overnight with ethylene glycol in a desiccator. Smectite clays will expand and absorb the glycol between layers, thus changing their basal spacings. Mixed-layer clays are more easily identified with glycol treatment due to the expanding smectite clays in the clay mineral assemblage. By comparing the glycol run with the first run, the smectite and mixed-layer clay peaks can be identified by their shifts in position.

A third stage of identification, to help differentiate other clay minerals, is a glass-slide heat treatment. Heating the clay on a glass slide drives off the water in the crystal lattices. The duration and temperature of heat treatment varies depending upon what is identified. In all X-ray diffraction runs the clay minerals are identified by the 2θ angle and the intensity of their corresponding peaks using standardized tables.

Twenty-four soil samples were tested for clay mineralogy (Appendix XIX). Based on 100% of the clay-sized fraction (less than 0.002 mm) the average of all samples tested consisted of 46% smectite, 26% illite, 19% kaolinite, and 9% mixed-layer illite-smectite. Nonclay minerals in the less-than-0.002 mm (clay size) fraction are, on the average, quartz, calcite, and feldspar in decreasing order of abundance. It should be noted that one sample consisted entirely of smectite and was most likely a volcanic ash or bentonitic layer.

The abundance of smectite, an expansive clay, may reveal an important clue in understanding the collapse mechanism in collapsible soils. Clay aggregates, which consist of many individual clay platelets, bond the sand and silt grains together. As the soil becomes wetted the smectite clays expand. The soil structure actually increases in volume initially until the clay aggregates are dispersed and can no longer support the sand and silt grains. As the shear force between the grains increases (from increased saturation) the sand and silt grains slide past one another into vacant void spaces (Burland, 1965). This process seems to be consistent with the observed large volume reduction in the silty to clayey collapsible sands in the El Llano area.

9.10 Soil Structure Analyses with the Scanning Electron Microscope

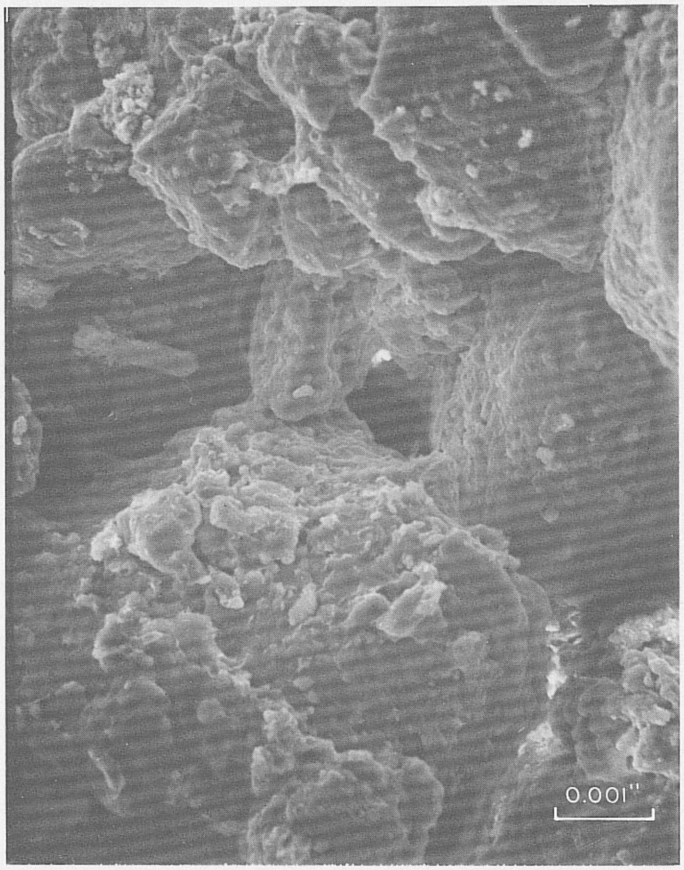
To examine the clay aggregates and relationships between the sand and silt grains in collapsing soils, a scanning electron microscope (SEM) was used to magnify the field of view up to 5,000 times. It is important to observe the structure of clays before, during, and after collapse of the soil structure to ascertain the role of clay in the collapse mechanism.

Scanning electron microscopy was performed in conjunction with staff and equipment from the Metallurgical Engineering Department of the New Mexico Institute of Mining and Technology. The instrument used was a Hitachi Model HHS-2R scanning electron microscope interfacing with a Tracor Northern Model 5400 Energy Dispersive System X-ray Analyzer.

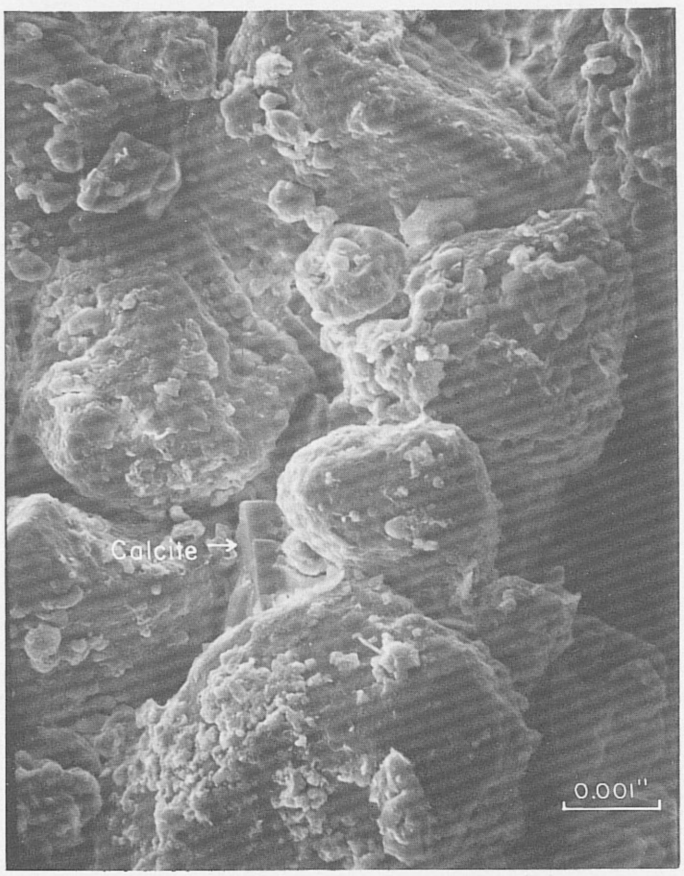
Sample preparation consisted of air-drying undisturbed chunks of soil (generally silty sands) from depths up to 20 ft below ground surface. Once dry, samples were carefully trimmed to approximately 1x1x1 cm dimensions. The upper surfaces of the sample were then cleaned thoroughly using adhesive tape and compressed air to remove any loose material that might obscure the SEM image. Once adhered to a conductive sample mount, the sample edges were coated with a conductive paint and spatter-coated with a gold-palladium alloy to remove any accumulated surface charge from the sample.

Samples were then examined using the SEM, with special attention given to grain-grain relationships and intergranular material. Where feasible, areas of interest were photographed, and a semiquantitative analysis was performed using the EDS system.

Examination indicated that soils from unirrigated areas east of the El Llano acequia (Photograph 12) tended to be more open



PHOTOGRAPH 11—Scanning electron photomicrograph of uncollapsed soil sample at well number GGSSS–1 **east** of El Llano acequia. Sample is from 10 feet below surface. Note open structure with larger quartz grains loosely bound with finer grained (silt and clay) material along grain-to-grain contacts.



PHOTOGRAPH 12—Scanning electron photomicrograph of collapsed soil sample at well number GGSSS–12 **west** of El Llano acequia. Sample is from 3 feet below surface. Note closely packed soil structure and secondary crystallization (calcite) in center of photograph. Large grains are quartz.

and porous with structurally large void spaces and clay bridges between sand grains. In contrast, samples from irrigated areas west of the acequia (Photograph 11), tended to exhibit less porosity, a denser packing arrangement of sand and silt grains, and an absence of clearly defined clay bridges. Although there were some variations from these trends, in general, samples observed conformed well to the above tendencies.

10.0 EVALUATION OF WORKING HYPOTHESES

The 14 working hypotheses presented in Sec. 7.0 were evaluated utilizing field, laboratory, and literature-based data. The data show conclusively that some of the hypotheses cannot explain the observed subsidence. However, some hypotheses required additional data or analyses of data already gathered. The following is an evaluation of each of the working hypotheses introduced in Section 7.0. For each hypothesis, the data gathered are discussed and tentative conclusions are drawn.

10.1 Vehicular Vibrations

To document the effect of vehicular vibrations on utilities and structures, literature searches and ground-vibration monitoring were conducted. NM-291 (Airport Road) serves as the main access for Española Municipal Airport, Española High School, local residences between the Taos Highway and Santa Cruz, and loaded dump trucks or other heavy equipment serving the construction industry in the area. The road is used heavily in the morning and the early afternoon when loaded school buses traverse the area.

Vibration monitors were deployed in two vacated houses to detect the effect of vehicular traffic. The first was set up in the living room of the Moya residence on December 17, 1984. It operated at its lowest level of sensitivity (0.02 in/sec) until February 21, 1985. The second monitor was set up in the Valdez residence on January 10, 1985. It also was set at its lowest level of sensitivity and operated until February 21, 1985, when it was removed because of increased levels of human activity in the house.

The tape recordings of the vibration monitor were sent in for analyses on February 26, 1985 (Appendix IV). The interpreter (Dallas Instruments) indicated that the number and magnitude of recorded events were extremely small. The strongest events recorded were those made by the machine as it cycled every third night at 12:00 p.m. Other events correspond to activity in the house and appear to be triggered by human footsteps.

Preliminary data indicate that vibrations from vehicular traffic along Airport Road are not related to the subsidence damage to utilities and structures in the El Llano area. Measured levels of vibration are well below published threshold levels for damage (Ames and others, 1976).

10.2 Geophysical Exploration

In November 1984, Shell Western Exploration and Production, Inc. (SWEPI) ran a seismic line in the Española Basin near El Llano. Becaues the timing of their tests roughly coincided with reports of increased cracking, NMBM&MR personnel requested a technical meeting with SWEPI to discuss implications of the seismic survey. The meeting was held at the offices of Military Affairs, Civil Emergency Preparedness Division, on February 11, 1984. At the meeting, representatives of SWEPI displayed the geophysical data they had acquired and reviewed the procedures they routinely take to prevent damage. They noted that, as of February 11, they had not been contacted by any private landowners concerning damage they may have caused inadvertently. Because all concerned governmental agencies and landowners had the phone numbers of SWEPI personnel to report any claims, and all payment checks to landowners had been cashed, they felt no unresolved problems existed.

SWEPI presented technical data indicating that their exploration activities did not affect the community utilities or structures. At the request of the NMBM&MR, they prepared a report describing their operations near El Llano (Appendix XV). The report describes their interaction with the community before and after their exploration activities, gives an overview of their field methods, discusses the safety procedures they routinely follow, and makes conclusions about their work. The Bureau and its consultants evaluated the report and no inconsistencies were discovered. Furthermore, the seismic signals generated by SWEPI were too small to be detected by instruments monitored by Los Alamos National Laboratory.

10.3 Ground-water Fluctuations

No abnormal ground-water fluctuations have been reported in the area by hydrologists of the State Engineer Office or the U.S. Geological Survey. Water levels observed in project monitoring wells since February, 1985 conform to water-table conditions predicted by existing records (Borton, 1974). However, it is not possible to definitely determine whether or not abnormal fluctuations have occurred in the recent past because a continuous water-level recorder has not been in operation. It is recommended that a continuous water-level recorder be installed in an unused water well in the area for future observations.

10.4 Effects of Offsite Hydrologic Phenomena

Consultation with hydrologists and geologists of the State Engineer Office and Los Alamos National Laboratory, and field investigation by NMBM&MR geologists in the Española Basin have not uncovered any evidence that offsite activities such as gravel removal on the Rio Grande floodplain could have caused subsidence in the El Llano area. The gravel pit operations are in the Fairview area 1.2 miles west of and about 100 feet lower than the nearest El Llano subsidence features. No one living or working in the area between El Llano and the Rio Grande floodplain has reported any unusual hydrologic (or geologic) phenomena; and no unusual discharges of water and sediment have been reported in gravel pit operations.

10.5 Effects of Highways and Flood Control Dams

Drainage impoundments such as bar ditches along roads or flood control structures across drainageways in the El Llano area, particularly upslope from active subsidence features, are of special concern in this study. Such impoundments (whether constructed with intent or created accidentally) definitely trap water from natural precipitation-runoff events and could promote deep infiltration of soil water. Dr. Yelvington (oral comm., 1985) reported subsidence problems along NM-291 that were apparently due to ponding of water adjacent to the road before culverts were installed. However, test drilling in two areas of impeded surface drainage east of El Llano Road on San Juan Pueblo lands did not reveal any significant increase in soil moisture at depth. Nevertheless it is strongly recommended that drainage conditions along El Llano Road and other streets be improved and that ponding of surface runoff be prevented in any area where subsidence constitutes a potential hazard.

10.6 Earth Deformation, Earthquakes, and Related Phenomena

Hypotheses relating cracks and subsidence in the area to deep-seated forces include 1) cracks due to bending of rocks along a hinge zone at depth, 2) cracks and subsidence along one or more faults cutting across the area, and 3) settling ground due to shaking from nearby earthquakes (10.6.3).

10.6.1 Cracks Due to Rock Bending

Given the first hypothesis, the ground surface could conceivably crack and some local areas could rise or sink as rocks were bent at depth. Problems with this hypothesis include 1) the rate of such earth deformation is relatively slow--on the order of 1/100 to 1/10 of an inch per year (Reilinger and others, 1979), 2) the weakness of the soil to withstand forces that would tend to pull it apart from below (lack of tensile strength), and 3) the structure of the rocks beneath El Llano as interpreted from seismic profiles and other geologic evidence.

Given the rate of deformation mentioned above (which is fast from a geologic perspective, but not fast for ground subsidence), stress would have to accumulate and be released episodically either in the surface deposits or in the rocks immediately beneath the surface deposits in order to form the cracks and subsidence pits. There is no known mechanism for storing tensile stress in relatively loose surficial deposits. If the rocks below the surficial deposits were stressed slowly to the point of breaking, the overlying loose deposits would probably adjust by grain-to-grain movements without any surface disruption. Only if the breaks in the underlying rocks suddenly formed wide cracks could the overlying deposits move downward to fill the consequent spaces. Finally, the seismic profiles do not show appreciable stressing of rocks at shallow depths. Although there are small upward and downward folds interpreted from the seismic reflection profile, rocks in the Española Basin beneath El Llano appear to be bent downward to the west, with possibly increasing compressive stresses at depth. Rocks exposed in the bluffs east of El Llano dip a few degrees to the north-northwest and do not show any evidence of being bent under modern stresses.

10.6.2 Cracks Due to Faulting

The second hypothesis, which is related to faults, may be considered as three similar hypotheses: 1) one or more active faults cut the surface, forming the cracks and pits; 2) inactive faults do not cut the surface, but their presence below the surface affects the soil, causing cracks and subsidence; and 3) older, inactive faults that are less erodable because of cementation form buried, topographically high features that affect the soil settling around them.

A recently active fault would break the ground surface, moving one side up or horizontally past the other side of the fault. Generally, recent fault breaks disrupt linear or slightly arcuate zones rather than wide areas. Subsidence depressions along faults generally are elongate and are bounded by linear scarps. No linear topographic scarps crossing the El Llano area have been recognized and no young fault scarps were mapped in the area by Machette and Personius (1984). Furthermore, no faults cutting the upper 12 feet of soil were encountered in trenches excavated across the area. As previously described, the numerous cracks cutting the deposits in El Llano do not exhibit features of a fault zone. None of the cracks, except those bounding subsidence depressions, show any evidence of vertical or horizontal movement. The cracks have numerous horizontal orientations, generally are vertical, and extend over an area more than 200 feet wide for at least 3 miles on the east side of the Española Valley. Some of the cracks do not extend more than 7 feet below the surface, while others extend deeper than 12 feet. Some remain open, but most are filled with loose sand or clay which has fallen or washed into the cracks from above. In short, the cracks and depressions do not exhibit features of recent faults.

A second possible indication that no active fault exists is the paucity of minor earthquakes detected near El Llano. The Los Alamos seismic network has operated since 1973, and only two minor quakes were detected within 3 miles of El Llano. Their local Richter magnitudes were only 0.1 and 0.8 and both occurred west of the Rio Grande in 1980 (D. Cash, written comm. 1985; Wechsler and others, 1981). While the network has not operated long enough to define all areas of earthquake activity in northern New Mexico, many zones with active faults may be detected using the linear locations of small earthquakes (Cash and Wolff, 1984).

Evidence implying inactive faults in the area include 1) northwestward projection of faults exposed in the bluffs east of Santa Cruz and 2) interpretations of both seismic reflection and refraction profiles in El Llano. One major fault exposed east of the city landfill trends northwest and dips 65-85° to the southwest. Separation is down to the west. The fault zone is up to 20 feet wide and commonly is well cemented with calcium carbonate. No recent breakage (brecciation) has taken place in the fault zone. The fault is overlain by and does not offset terrace gravel of the Santa Cruz River and slope alluvium of drainages from the bluffs to the east. A second, subparallel fault trends northwest through the city landfill. It disturbs a much narrower zone, at most only a few feet wide. Stratigraphic separation across both faults appears to be about 60 feet, down to the southwest. Other smaller faults were found in fresh exposures, but could not be traced. None of the faults could be traced beyond the bedrock exposures north of the landfill. Nonetheless, where the faults are projected straight northwestward from the exposures, they do cross the El Llano area and points farther north. Ordinarily, such projections of straight lines are not warranted geologically over distances of more than a few hundred feet. However, the projected faults do correspond closely with interpreted faults on the seismic reflection line, although the interpreted sense of movement for the eastern fault is down to the east. Moreover, anomalies noted on the two seismic refraction lines west of NM-291 may correspond to the eastern projected fault. It must be noted that these coincidences are based on interpretations and extrapolations and not on direct observations. Two major questions, based on these interpretations, are how deeply buried are the faults and what connection is there between possible buried faults and the cracks and subsidence depressions in El Llano.

The interpreted faults were not found in trenches excavated across their interpreted traces so they do not extend within 12 feet of the surface. The reflection seismic line does not show the upper 100 feet clearly, so the fault is interpreted based on reflections below that depth. The anomalies on refraction line 2 begin between 50 and 100 feet below the surface while anomalies on refraction line 4 extend to the surface. Deep drill holes intersecting gravel at depths between 90-120 feet show that the gravel is not consistently offset on either side of the interpreted faults. Therefore, the geophysical anomalies are not the traces of faults in alluvium above the gravel layer.

If the eastern fault is beneath the gravel and is as well cemented as its exposure near the city landfill, it may be a buried, topographically high zone that resisted erosion. Differential settlement of alluvium around buried hills following ground-water withdrawal is responsible for cracks in the Phoenix area (Pêwè and Larson, 1982). Even if the Rio Grande beveled the fault when it deposited the gravel that is presently buried by 90-100 ft of more recent alluvium, some differential settlement across the fault could have occurred. Propagation of cracks through approximately 20 feet of gravel into the overlying alluvium would require a substantial amount of differential settlement. The logs of wells in the vicinity of the Valdez residence suggest differential settlement may have taken place. If the gravel layer encountered near the base of the wells was continuous across the area, it presently is about 10 feet closer to the surface near the Valdez house. However, the gravel could be at different levels because the river moved back and forth across the area (see cross-section in Appendix X).

The relationship between interpreted faults and the generation of cracks and subsidence depressions needs to be considered. As described previously, the exposed major faults have associated subsidiary fault zones with nearly parallel orientations. The fault zones are generally narrow, commonly less than 20 feet wide, and the cracks are closed and commonly sealed with either clay or calcium carbonate. In contrast, the cracks in the alluvium in the El Llano area have diverse orientations over a wide zone and are open or loosely filled with sand and clay. The subsidence depressions are aligned in a manner similar to the alignment of the community along NM-291. Within the community, the depressions are scattered east and west of the road and are far from the projected faults in the northern part of El Llano. Neither the cracks nor depressions resemble those associated with known faults in other localities.

If a fault had ruptured the alluvium in the past, cracks generated by the fault would remain as conduits for excessive moisture to move downward. The open cracks would be a barrier for movement of capillary moisture (moisture which moves between touching sand grains).

10.6.3 Cracks Due to Nearby Earthquakes

Shaking of the ground by earthquakes nearby is a possible cause of cracks and subsidence, but only if the ground is already weak or under stress. Two other requirements are that the earthquake be strong enough to cause significant ground shaking and that structures be relatively weak. Stover and others (1983) list earthquakes between 1849-1980 large enough to be felt by humans. Quakes too small to be felt are not apt to cause sudden damage to soil or structures. Nine local quakes have been large enough to be felt in the Española Valley since 1969 (Table A-1; Appendix XIII). Larger quakes have occurred elsewhere in New Mexico and may have been felt in the Española Valley (Northrop, 1976; Sanford and others, 1972; Sanford and others, 1981). For example, the Cerrillos earthquake of 1918 shook Española with an estimated Modified Mercalli intensity of IV-V (Olsen, 1979). The largest of the local quakes is classified V on the Modified Mercalli Scale (Appendix XIII), which is below the threshold of damage to all but extremely poorly constructed structures. It appears unlikely that the cracks and subsidence pits are due to earthquakes during the period on record. Because most of the subsidence pits and damage have appeared during the past 25 years, they could not have been caused directly by earthquakes. Conceivably, cracks could be caused or extended by prehistoric quakes, but only if the ground was already weak or under stress.

Possible evidence for prehistoric earthquakes includes some soft-sediment-deformation structures in two young deposits. These structures, however, also can be formed without earthquake shaking so the evidence is equivocal. The first examples, called flame structures (see trench log ESBH-10 in Appendix II), were exposed at a depth of 3 feet in a trench near the Yelvington residence. "Flame structures show curved, pointed tongues of mud projecting upward into an overlying sand layer. Because of unequal loading and liquefaction, the mud layer has moved up in the form of tongues into the overlying sand layer....overloading or unequal loading is adjusted by mainly vertical movements leading to the sinking of the sand layer in the form of lobes..." (Reineck and Singh, 1980, p. 85). Earthquake shaking can lead to liquefaction of mud layers and cause settling of the overlying sand.

The second example of soft-sediment deformation is exposed in a large artificial arroyo cut northeast of the municipal water tank northeast of Española Valley High School. The young sediments are in an eolian dune with primary depositional laminations sloping up to 48 degrees to the northeast (Fig. 10-1). These laminations are cut by slump structures and small faults dipping up to 44 degrees to the northeast. Most slump structures in the exposures, however, are due to collapse of insect and rodent burrows. Some structures appear to be the result of animal footprints. While earthquakes could have triggered the slumping and faulting, the steep angle of laminations show that the deposit rested at an unstable angle beforehand so that any event could have caused the movement.

In summary, no evidence has been found indicating that young active faults and earthquakes in El Llano have caused cracking and subsidence. Geophysical interpretations and geological extrapolation suggest the presence of two buried faults beneath El Llano, but the extent of influence of these faults on the overlying alluvial deposits is equivocal. The zone of soil cracks and subsidence is more extensive and does not run strictly parallel to these faults. Ground shaking from nearby earthquakes

Figure 10-1. Sketch of small faults (heavy lines) cutting windblown deposits northeast of Espanola Valley High School. Bedding is shown by fine lines. Both faults and bedding dip away from view. Blobs are insect burrows (krotovina) and deformed bedding left of center appears to be an animal track.

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in historic time does not appear to be a likely cause for the cracks, and it is not correlated with the formation of subsidence pits.

10.7 Precipitation

The precipitation data discussed in this section were compiled from the New Mexico Climatological Data 1850-1975 (Gabin and Lesperance, 1977) and Climatological Data, New Mexico (National Oceanic and Atmospheric Administration, 1951-1980). The collecting station was located in Española at an elevation of 5,643 feet (36°01' latitude, 106°03' longitude). Recent (1984-1985) Española precipitation data were supplied by Philip Barck. The present collecting station is located in Espanola at 5,643 feet (36°00' latitude, 106°05' longitude). The mean monthly precipitation for Española, based on compilations made between 1895-1985, is listed in Appendix XVIII (Fig. A-1). In addition, the precipitation data are plotted on Figures A-2 and A-3 in Appendix XVIII. The normal monthly precipitation pattern shows a gradual increase from January to June, a sharp increase during July and August, and a gradual decrease from September through December. Figure A-3 (Appendix XVIII) shows the 1984 monthly precipitation. The wettest month during 1984 was October when 2.93 inches of precipitation were recorded. On three days during that month, the amount of precipitation was greater than 0.5 inches. Wetter-than-normal conditions also occurred during March and April, 1985, when spring storms resulted in 2.17 and 2.71 inches, respectively, of rainfall. Storms of this intensity very likely produce substantial runoff, and ponding of water in preexisting ground depressions, leading to accelerated subsidence of the underconsolidated soils.

In El Llano the increase in human habitation and concomitant increase in structures (Fig. 5-1) has, in places, significantly disrupted previous drainage patterns (arroyos). The greater accumulation of water may have contributed to the subsidence features (ground depressions) adjacent to some structures. Therefore, during the unusually intense October 1984 storms, excessive runoff may have ponded in these local depressions, infiltrated to underconsolidated subsurface soils, and accelerated the compaction and consolidation of these soils.

10.8 Karst

No evidence for local solution subsidence features has been found during geologic and geophysical field investigations or from consultation with geologists, hydrologists, or geophysicists working in the region. Soluble rocks do not occur within thousands of feet of the land surface in the El Llano area, and solution-subsidence depressions or void fillings have never been noted in the basin or valley fill (i.e., Santa Fe Group and overlying river and arroyo deposits).

10.9 Mining Activities

Two hypothetical effects of mining activities could cause cracks in the ground surface and subsidence. The first is collapse of mine tunnels. This hypothesis can be ruled out because no mining has occurred beneath the El Llano area.

The second hypothesis is that cracks and subsidence in the

El Llano area are due to removal of gravel near the Rio Grande. Several problems arise concerning this hypothesis. First, removal of gravel is small (20 feet deep at most) and localized. Second, in order for gravel removal to cause cracks and subsidence in El Llano, tensile stresses (forces tending to pull materials apart) would have to be exerted over a distance of 7,000 feet through relatively loose soil and gravel (Fig. 10-2). The soil and gravel are not strong enough to transmit tensile stresses over such a long distance to form cracks in the El Llano area. Tensional cracks generated by gravel removal should form between gravel clasts (pebbles and cobbles) immediately adjacent to the gravel pits if at all (depending on how steep the walls of the pits are and a number of factors concerning the physical properties of the gravel deposits). Formation of the cracks and subsidence pits in El Llano appears to be physically impossible by this proposed mechanism.

A slightly different version of the second hypothesis would be that the soil between El Llano and the Rio Grande was moving toward the quarries and the river as a giant earth slide (Fig. 10-3). The cracks and subsidence pits would then be considered features where the slide was breaking away from a more stable headwall. Removing gravel would be similar to removing the toe of the slide, causing further movement to the west. The problems with this hypothesis include 1) the extremely low slope over which the slide would have to move, 2) the apparent lack of a suitable slide surface along which slippage could occur, 3) the lack of offset (down to the west) on the cracks in El Llano, and 4) the lack of other landform features, which should be found

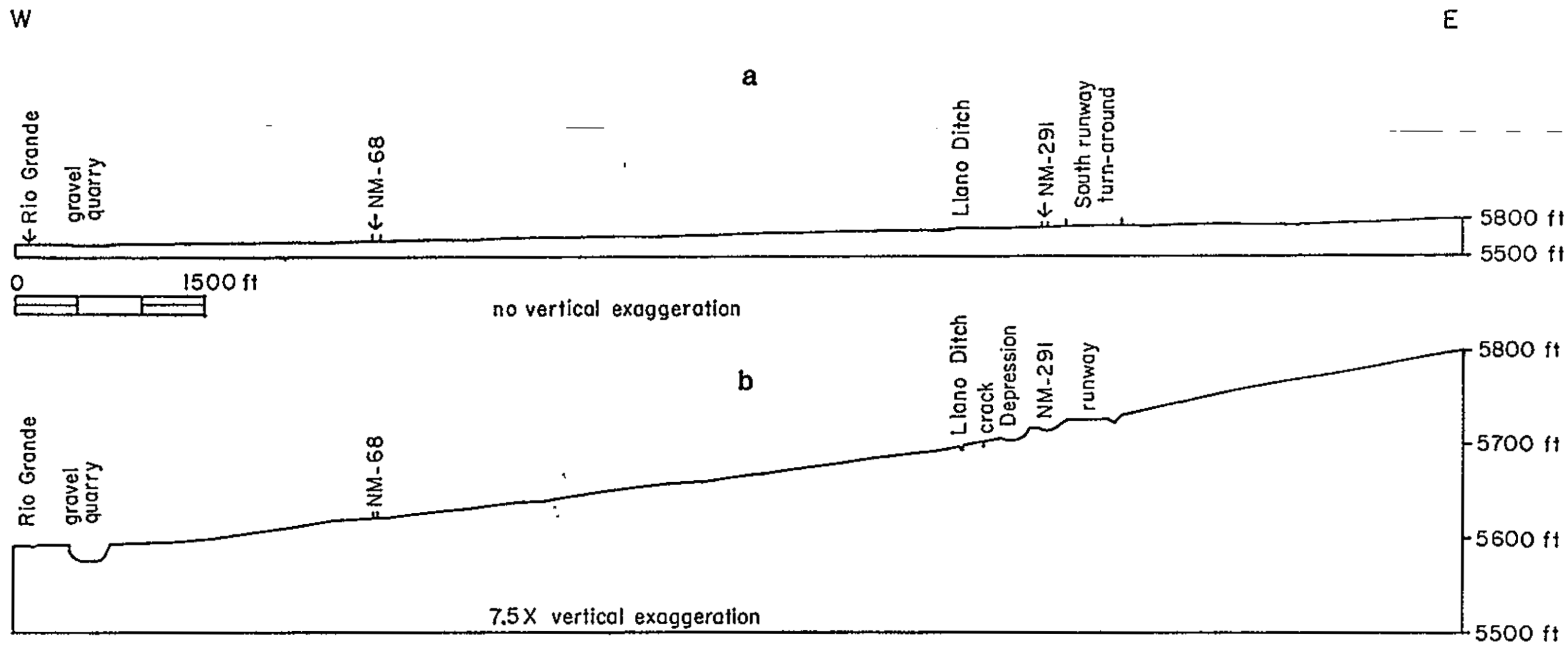

Figure 10-2. Topographic profile across the El Llano area from east of the airport to the Rio Grande. Gravel quarry projected into line of profile. (a) profile with no vertical exaggeration. Note extremely gentile slope. (b) Same profile with 7.5 times vertical exaggeration.

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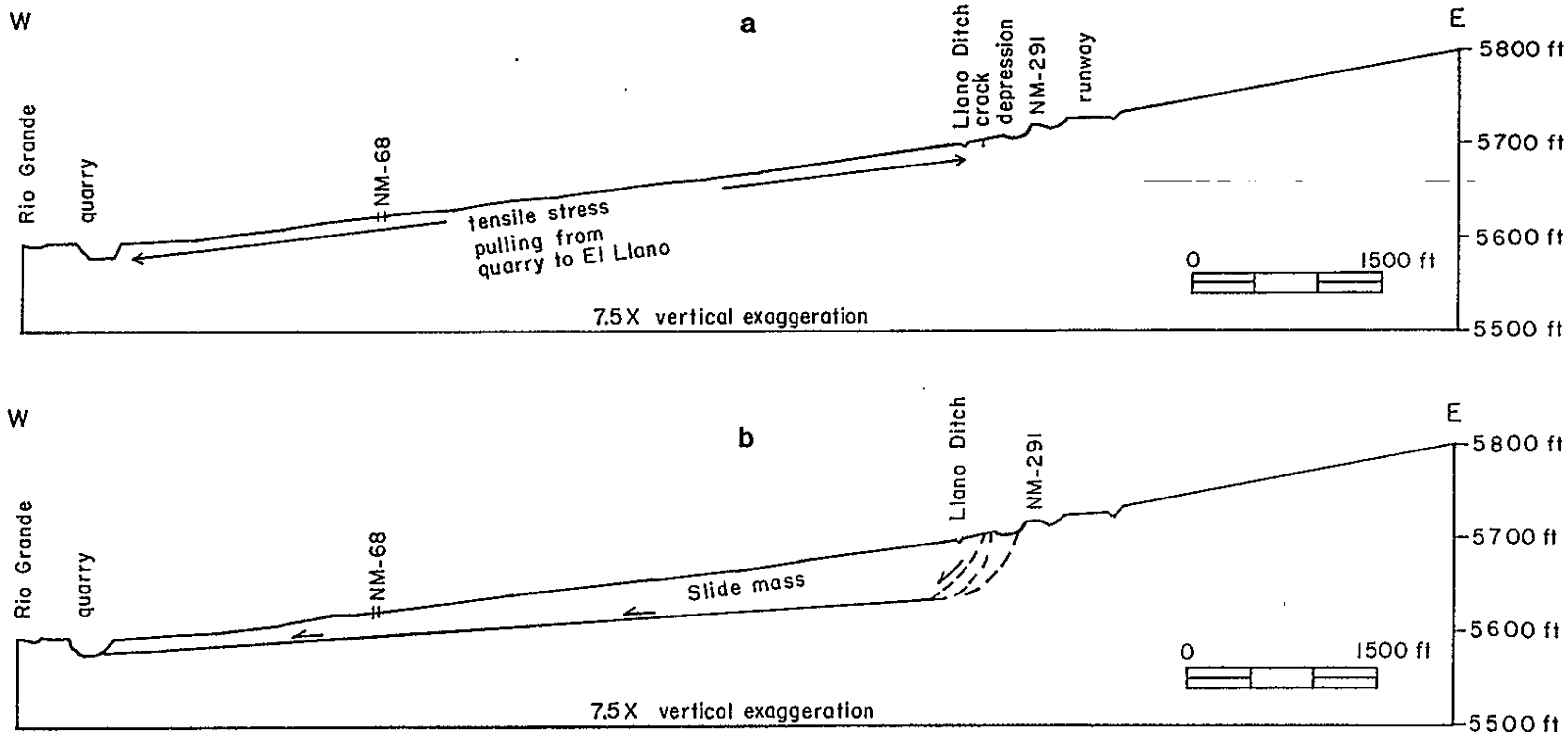

Figure 10-3. Illustrations of hypothetical stresses related to gravel removal. (a) Tensile stress pull-apart forces) transmitted between quarry and El Llano. (b) Landslide moving from El Llano to quarry.

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from the toe to the top of the slide if the whole area had moved to the west. Each of these points could be discussed in detail, but the conclusion is that large-scale landsliding brought on by local removal of gravel is not physically possible in this case.

10.10 Expansive Soil

Some soils commonly expand when wetted and have been the cause of a number of structural failures in New Mexico as well as other parts of the southwest. The expansion upon wetting is due to the presence of expandible clay minerals that make up a portion of the soil. To assess the impact of expansive soils, X-ray diffraction, and scanning electron microscopy (SEM) were conducted on selected soil specimens obtained from drilling and trenching activities. The data show that, while expansive soils are present (Appendix XIX and Section 9.10), their abundance and grain-to-grain relationship would seem to preclude them as a cause of structural damage. Generally, high contents of expandible minerals (smectite-mixed layer illites) are required to produce the type of observed damage in El Llano. The SEM photographs (Photographs 11 and 12) show large void spaces in soil samples obtained from east of El Llano acequia, generally the area of reported damage. The expansion of clay minerals would be expected to partially or largely fill these voids and thereby cause no noticeable overall expansion of a soil column.

In conclusion, expansive minerals are present in El Llano soil samples, but they are not abundant enough to cause structural distress. In addition, the results of experiments at the geotechnical ground stabilization areas are not consistent with soil expansion theory.

10.11 Areal Subsidence as a Possible Cause of Cracks

During the course of the investigation, ground cracks were noted in several areas. Some of these cracks are closely related to subsidence features while others show no obvious relationship. Large cracks are depicted on the geologic map (Appendix V) and others are depicted on trench logs (Appendix II) and detailed topographic survey maps (Appendix XVII). The purpose of this section is to discuss the significance of what appears to be areal subsidence.

Circular cracks around the Moya subsidence pit are obviously related to local settlement. They appear as vertical cracks near the surface. Their depth is not known, but they may extend at least to the depth of increased moisture, which is approximately 55 feet.

An earthcrack on the Yelvington property trends approximately northeast for a distance of 125 feet. The log of a trench across this crack (trench ESBH-10) shows a nearly vertical crack in layers of moist silty sand and clay. The crack is less than 1 inch wide and filled with clayey material. Portions of the crack show evidence of fine-grained material being actively transported. Also noted in the trench were worm castings at a depth of about 1 foot and a "nest" at 9-15 inches below the surface (Appendix II). The filled cracks and other subsurface relationships indicate that the crack is largely inactive beyond approximately 1 foot below the surface. However, in dryer times of the year the crack may open to greater depths. A geophysical refraction line across this crack does not show any offset at depth (Appendix VII).

A 2-inch-wide crack north of the Vigil residence trends approximately northeast, subparallel, and adjacent to the abandoned acequia. It can be probed to a depth of about six feet. It appears to be relatively young because no infilling material can be noted (this crack was not excavated).

Other cracks were noted in excavated trenches near the Moya residence. Most appear to be older cracks now filled with sediment. A number of cracks contain organic material and insect remains. Others are closely associated with animal burrows (krotovina).

A trench was excavated at the extreme west end of the Valdez property to examine the nature of a crack or hole that reportedly took large volumes of water when irrigated. The owner apparently attempted to fill the feature with sand but couldn't "plug" it. Upon excavation a thick clay interval was found to overlie clean sand. No active or otherwise open cracks were noted although it appeared that some cracks were present in the overlying clay layer. It appears that the irrigation water flowed into an extensive network of desiccated cracks in the clay layer. At 8 feet depth the water soaked into a clean, well-sorted sand (SP) layer, which continued to the 11.5 foot depth of the trench (see Appendices II and XII).

In summary, most of the cracks appear to be tensional with less than one inch separation. Some, such as the ones west of the Moya residence, are related to local areas of soil collapse. Still others are related to desiccation of near-surface clay layers.

There is little evidence to suggest that the cracks caused areal subsidence. They are produced by a number of causes rather than by a single cause. Some of the tension cracks may be caused by stresses that arise due to extensive irrigation west of the El Llano acequia in contrast to the general lack of irrigation, except in localized areas, east of the acequia. Most of the observed cracks in El Llano and vicinity appear to be a result, rather than the cause, of areal subsidence.

10.12 Organic Matter at Depth as a Cause of Subsidence

The hypothesis that compaction or oxidation of organic matter buried beneath El Llano causes subsidence and cracking may be discounted because none of the drill holes encountered extensive layers of organic matter.

10.13 Subsidence Along a Buried Bluffline of the Ancestral Rio Grande

If subsidence and cracking were caused by different amounts of compaction on either side of a buried bluffline, the bluffline would have to pass through El Llano. Neither the seismic refraction or reflection lines nor the drill holes indicate that the bluffline passes near the cracks. A layer of Rio Grande gravel was encountered in all deep drill holes in the El Llano area; therefore, the bluffline, if present, must be farther east.

10.14 Collapsible Soils

Collapsible soils are really extensive in New Mexico and have been reported previously in northern New Mexico (Lovelace and others, 1982). There have been a number of structures condemned, voluntarily abandoned, or extensively damaged by collapsing soils in close proximity to those now condemned. Among these are the San Juan Bingo Hall, a New Mexico State Highway building (Alcalde), the Española Valley High School, and houses in El Llano and on Indian lands to the north. Many laboratory data gathered are consistent with collapsible soils (Section 11.0). The distribution and size of earthcracks is very similar to earthcracks found in other areas of collapsing soils in New Mexico. In addition, geophysical profiles showing near-surface low-velocity zones and geologic deposits that are young and poorly consolidated also support this hypothesis. The documented contrast in collapse potential of near-surface soils in close proximity highlights the potential for differential subsidence.

Collapsible soils typically weaken and reduce in volume subsequent to wetting. If kept dry or near their natural moisture content, the soils maintain their structural integrity and can support not only their own weight but the added weight of surface structures. It appears that only selected localities have become wetted significantly and subsequently have settled. A reasonable approach to mitigating the problem would be to greatly reduce the water infiltration rate in the area (Section 12.0).

In conclusion, the geologic, geophysical, and laboratory testing to date heavily support the hypothesis that surface subsidence causing utility line distress and damage to surface-based structures is caused by collapsing soils.

The following section describes in greater detail the nature of collapsible soils. Numerous characteristics of these problem soils, many of which are present in the El Llano area, are cited.

11.0 COLLAPSIBLE SOILS

Collapsible soils generally consist of loose, low density, dry, fine- to medium-grained material that compacts appreciably when wetted. They have been studied in California, the midwestern United States, South Africa, and Russia, but have been recognized also in New Mexico. Collapsible soils exist in the Rio Grande Valley from El Paso, Texas, to southern Colorado. They most likely originated as debris flow and eolian deposits. In addition, colluvial and residual soils weathering from silicic igneous rocks along the rift valley margins also may be collapsible. The recent structural damage to houses, utilities, highways, and other structures in New Mexico, possibly due to collapsing soils, has prompted a number of geotechnical investigations. Based on these studies and previous research, the geologic and engineering properties of collapsible soils will be outlined. Also, using field and laboratory tests, methods to recognize and predict the location of collapsible soils will be described. Present soil stabilization and treatment procedures also are outlined.

11.1 Geologic Properties of Collapsible Soils

The collapsible soils of the Rio Grande Valley are mostly low-gradient alluvial-fan mud and debris flow deposits. Each deposit dries significantly before the overlying layer is deposited and thus the original layer is buried by subsequent flows without being wetted or consolidated under its own weight. When water percolates through this collapsible layer, rearrangement of the soil grains occurs, producing a denser compacted layer. This, combined with the relatively small applied load of a structure, often results in differential settlement.

11.1.1 Mud and Debris Flows

Mudflows have been described by Blackwelder (1928), as "a thick film of muddy slime viscously rolling over a gently rolling plain." Debris flows are similar but coarser grained. They consist of a gravelly to sandy mass containing enough silt and clay to make them slippery when wet. Mud and debris flows can spread out several miles on an alluvial-fan surface carrying large boulders and filling in pre-existing arroyos. Therefore, they tend to overlap and bury stream sand and gravel deposits. With subsequent incision of new stream channels the loose, dry, clayey, and collapsible deposits occur as interfluvial areas beneath knolls and ridges between the present-day arroyos. If present in arroyos, the sediments are usually wetted by intermittent stream flow, compacted, and thus they are no longer susceptible to collapse. However, those same deposits in the interfluvial areas remain dry, uncompacted, and vulnerable to collapse.

It is the textural characteristics of these deposits that identifies them as collapsible soils. Large intergranular voids result from sand, silt, clay, and water settling into a low-density packing arrangement with the grains being held in place by the clay bonds after the material has dried. The clay bonds preserve the void space that otherwise would be squeezed out if the clay was not present. Collapsible soil deposits in the San

Joaquin Valley, California, contain approximately 12% clay. (Bull, 1964).

Significant volumes of bubble cavities that formed when air is trapped during and after deposition also create a very loose open-structured collapsible soil. Other voids may be produced by buried desiccation cracks and decomposing vegetation within the flow.

11.1.2 Other Types of Collapsible Soils in the Rio Grande Valley

Some residual granitic soils near the base of the Manzano, Sandia, and Sangre de Cristo Mountains also have been observed to compact when wetted. Chemical weathering produces thin clay films around quartz and feldspar grains giving the soil a relatively high dry strength. The collapsible structure results from the leaching out of the soluble and colloidal matter from these well-drained soils, which creates an unstable grain arrangement (Brink and Kantey, 1961). The short, intense, summer cloud bursts and abundant water from the spring snowmelt in New Mexico's mountains contribute to the leaching and eventual collapse of these residual granitic soils.

Wind-deposited soils of the midwestern United States have been known to display a collapsible structure when loaded or saturated. There are abundant deposits of dry, loose eolian (wind-deposited) sands and silts in New Mexico, especially along the Rio Grande. These sediments are usually well sorted, very permeable, and porous. As water percolates through the soil the chemically unstable minerals are weathered to clay. This results in a loose intergranular packing of sand grains bridged by clay aggregates. When additional wetting occurs the clay aggregates disperse and no longer support the sand grains. The latter then move into vacant spaces producing a denser packing arrangement. Calcitic and dolomitic minerals acting as cementing agents also can support the sand-grain structure until they are dissolved from the soil and reprecipitated at depth (Lobdell, 1981).

11.1.3 General Distribution of Collapsible Soils

Collapsible soils are likely to be found from the proximal to distal parts of alluvial fans where mud and debris flows have covered the fan surface. Patches of collapsible soil are found in undulating alluvial-fan topography near the tops of the knolls and seldom in the hollows or near arroyos. Generally, they are not found in the Rio Grande floodplain because the river has reworked the soil and destroyed the characteristic loose, dry, collapsible soil structure. Also, drainage of the soil mass is important because areas with a high water table will have soil that has already been compacted by wetting. Conversely, well-drained areas with very deep water tables are prime areas for collapsible soils.

11.1.4 Factors Affecting Formation of Collapsible Soils

Factors influencing the physical and chemical properties and distribution of collapsible soils on an alluvial fan are: 1) ratio of water to solids at the time of deposition; 2) time duration between successive mud and debris flows; 3) local variations in topography; 4) thickness of mud and debris flow deposits; and 5) the amount of vegetation at the time of, and subsequent to, deposition. Landscape position is significant because it affects runoff and infiltration. Runoff from higher areas markedly increases the depth of wetting in soils in topographic lows thus rendering them non collapsible. Conversely, such runoff decreases moisture in the soils upslope and on topographic highs producing moisture-deficient collapsible soils.

Microrelief can also greatly affect moisture infiltration. In small depressions the depth of moisture infiltration is much greater than in soils lacking these surface features. Consequently, the depth of wetting to precompact the soil can vary significantly within just a few feet laterally (Gile and others, 1981).

The amount of soil development on the alluvial-fan surface depends on the frequency of mud and debris flows. A high frequency of mud and debris flows (every few hundred years) inhibits soil development and prevents the soil from consolidating under its own weight. This rapid burial preserves delicate textural features and increases the possibility of soil collapse when later wetting or loading occurs. In contrast, a low frequency of mud and debris flow deposition (every several thousand years) gives the soil a chance to precompact under its own weight, which inhibits the formation of a collapsible structure.

11.2 Engineering Properties of Collapsible Soils

11.2.1 Field Tests

Evaluation of collapsible soils is complicated by the difficulty of assessing marginal sites and by the rapid rate of settlement occurring when a source of water such as a broken or leaky underground conduit develops. In addition, these soils are site-specific--the soil type, surrounding geology, climate, vegetation, topography, and the nature of wetting and loading are all so variable that few working models for collapsible soils can be formed.

Thorough geotechnical investigations should include hollowstem auger drillholes with undisturbed sampling, split-spoon sampling, standard penetration tests, high quality samples, and careful laboratory testing. Trenches should be excavated, logged, and sampled. There are a number of "quick and easy" tests for recognizing collapsible soils in the field at the surface, in trenches, or at depth from split-spoon samples. The "sausage" test involves obtaining a hand-sized block of soil, trimming each piece, breaking it into two pieces, and trimming each piece so they are of equal volume. One specimen is wetted and molded in the hands to form a damp ball. If the volume of the damp ball is smaller than the undisturbed piece then collapse may be suspected (Jennings and Knight, 1975).

A simplified soil dispersion can be done either in the laboratory or the field. This procedure requires dropping a 2-gram soil clump, at its natural moisture content, into a beaker with 125 ml of distilled water and recording the time it takes the soil to disperse. Collapsible soils commonly disperse in approximately 25-30 seconds (Sultan, 1971).

11.2.2 Laboratory Tests

Most workers use grain-size analyses, dry density, moisture content, Atterberg Limits (liquid and plastic limits), specific gravity, standard and modified consolidation, clay mineralogy, soil structure analysis, and direct shear strength tests to identify and characterize collapsing soils. Because no single test truly identifies these soils, a combination of all the data generated from the above methods is used for the evaluation. Table 11-1 lists the average estimated values and characteristics for collapsible soils in northern New Mexico. Not all collapsible soils have soil parameters within these limits.

An example of combining test data to identify collapsible soils is by using liquid limit and dry density values as shown in Fig. 11-1. Soils plotting above their specific limiting density (the density at which their consistency is near its weakest condition when saturated) are collapsible and those plotting below their specific limiting density are noncollapsible. This is illustrated in case I (Fig. 11-1) where the void space in the soil is greater than the amount sufficient to hold the liquid limit moisture content. Thus, saturation of this soil results in a minimum of consistency, which enhances the collapse of the soil structure. In contrast, if the void space is less than the amount sufficient to hold the liquid limit moisture content as in case III (Fig. 11-1), the soil will always be in the plastic state and will have greater restraint against particle shifting even when saturated (Gibbs and Bara, 1967). Soils for Case II are either collapsible or noncollapsible, depending the specific gravity of the soil grains.

Table 11-1: Average estimated values of laboratory test data for collapsible soils in Espãnola area, New Mexico.

Grain-size distribution	poorly to well-graded sands to silty-clayey sands
Geologic age	<4000 years
Dry density	75-95 pounds per cubic foot
Porosity	30-45%
Void ratio	0.5-1.0
Moisture content	4-10%
Percent saturation	<60%
Atterberg Limits (liquid & plastic)	0-40/0-20
Specific grvity (soil grains)	2.50-2.65
Clay mineralogy	smectite, illite, mixed-layer illite-smectite, kaolinite
Total consolidation	>5%
Soil structure	Clay aggregates bridging sand and silt grains; loose structure
Blow counts (N-value)	<18
P-wave velocity	<1000 fps (approx.)

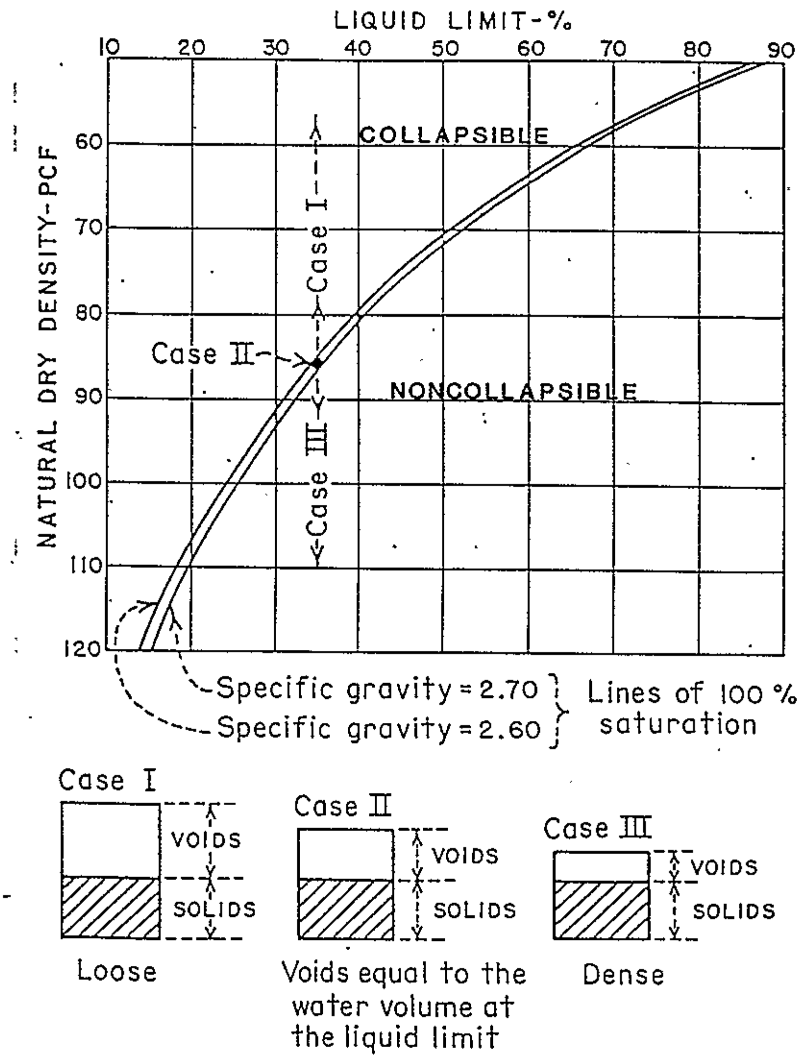

Figure 11-1. Criteria for evaluating collapse potential (modified from Gibbs and Bara, 1967).

11.2.3 The Collapse Mechanism

11.2.3.1 Cohesive soil

Cohesive foundation soils that are suspected to be collapsible should be as wet as possible when loaded to prevent the development of a "new" dry strength that may result in collapse later. Most cohesive soils used as base and subbase for foundations and highways are compacted to a moisture content and density greater than their optimum moisture content (OMC).

Soils compacted below their OMC usually aren't sufficiently saturated to disperse the flocculated clay aggregates that form bulky peds grouped in a loose "cardhouse" structure around sand and silt grains (Fig. 11-2). Wetting the soil above their OMC induces collapse because the clay aggregates are dispersed, causing loss of all of their dry strength. Essentially, the clay aggregates act as grains themselves binding the larger silt and sand grains together. When moisture is less than the OMC the flocculated clay aggregates have a high shear strength that resists distortion during compaction and results in large air-filled interpedal channels (Barden and Sides, 1969). When wetted further or upon application of a load the clay peds lose all of their dry strength, which results in a shear failure between the larger sand and silt grains and the clay aggregates. The larger grains, now with no intergranular support, slide past one another deforming the weakened clay peds. The sand and silt grains move into vacant space producing a large volume reduction.

11.2.3.2 Partially saturated cohesionless soils

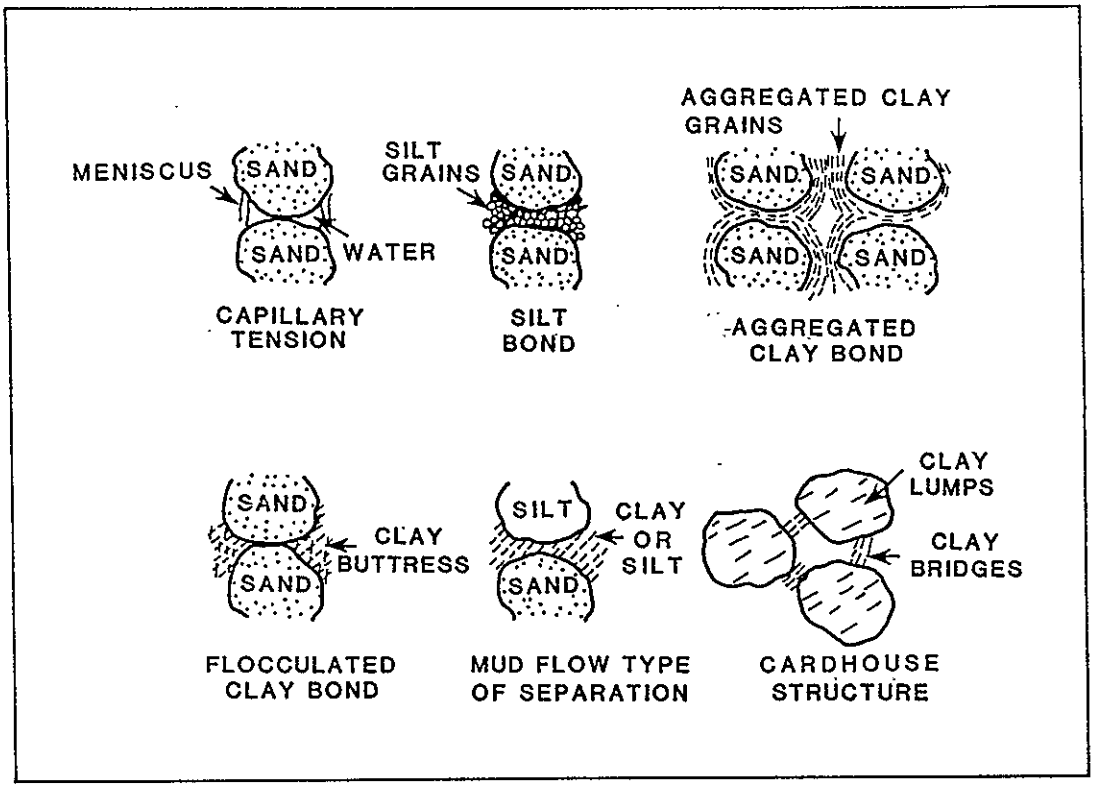

Figure 11-2. Typical collapsible soil structures (adapted from Barden, 1971).

There are three main causes of grain contact instability in cohesionless soils that can lead to collapse: 1) an increase in the shear force (T) from increased saturation without a corresponding increase in the normal force (P) between the grains from the overburden load; 2) a decrease in P without a corresponding decrease in T (the normal force could be decreased either by the dissipation of any initial capillary stress or by an increase in pore pressure); and 3) a decrease in the angle of friction between the grains following saturation (Burland, 1965). These forces are illustrated in Figure 11-3.

Any single grain within a soil mass is exposed to a normal force and a shear force. The displacement of a grain either by translation or rotation can occur as a result of a slip at the grain-to-grain contact points. For a grain to be in equilibrium at every contact point the ratio T/P must be less than or equal to the angle of internal friction. Therefore, when saturation occurs (increasing the shear force but not the normal force of the grains) the T/P ratio overcomes the angle of friction between the grains, resulting in grain slippage or shear failure.

It should be noted that wetting a partially saturated soil under a load need not lead invariably to collapse. The soil will eventually come to equilibrium with its overburden pressure as a result of seasonal wetting and drying cycles. A structure could be erected on the soil under wet conditions so that settlement occurs as each load increment is applied. Here rapid settlement due to subsequent loading is unlikely.

11.2.4 Stabilization and Treatment of Collapsible Soils

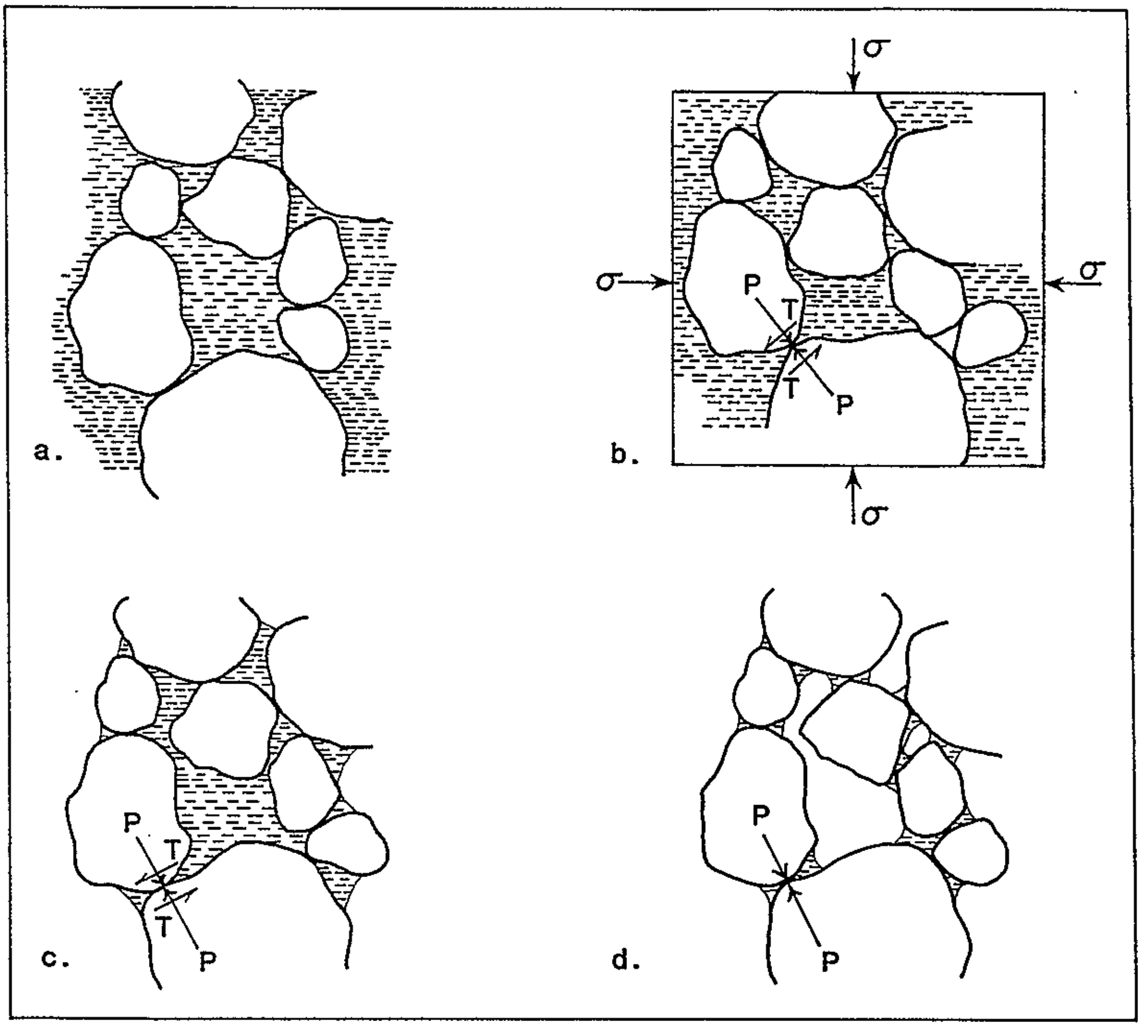

Figure 11-3. Intergranular normal (P) and shear (T) forces in saturated and partially saturated soils (from Burland, 1965).

11.2.4.1 Compaction and flooding

As discussed earlier, many contractors precompact the base of a foundation or highway to achieve an optimum moisture content and density. To insure that no further collapse occurs the soils are wetted slightly more than their optimum moisture content (OMC). Stabilization methods for collapsible soils beneath Interstate 25 near Algodones, New Mexico, included 1) deep plowing or ripping, wetting the soils above their OMC, and compacting with a vibratory roller; 2) induced hydrocompaction followed by vibratory roller compaction; 3) vibrofloatation; and 4) dynamic densification using the impact of a free-falling weight (Lovelace and others, 1982).

Near the Indus River in India, where irrigation canals were cracking and settling, another method for stabilizing collapsible soils, involved saturating the soils before construction. This was accomplished by designing soakage channels beside the future canal that produced soil compaction under the canal liner. Permeable sand filter layers were installed in each channel to facilitate the saturation and compaction process (Haq, 1976).

Similarly, in the San Joaquin Valley, California, the San Luis Canal has undergone settlement from collapsing soils since its construction in the late 1950's. Bara (1972) found that subsoil movement continued long after the wetting operations ceased because of the low vertical permeability of the fine-grained soils. It was then concluded that structures should not be built for 3-6 months after wetting operations had been completed. Wetting the soils was done by drilling water injection wells and packing them with gravel.

Methods of ponding and sprinkling water on collapsing soils of mudflow origin were used near Interstate 70 in western Colorado to induce settlement (Shelton and others, 1975). They concluded that loading of the soil should take place as soon as possible after wetting because additional settlement can occur long after the area has been prewetted and later loaded. If the soil has a chance to dry after wetting, without being loaded, it can attain a new dry strength. A second wetting, with or without loading, could produce appreciable additional collapse.

To make sure collapsible soils can withstand the stresses equal to or greater than the final structure load, even while they are wetted, contractors may dump surcharge fill over the construction site and leave it for several months before building. In Romania, where 11% of the surface area is covered with collapsible loess soils, hydraulic structures such as underground conduits and pumps are located at a distance (2-3 times the thickness of the collapsible soil layer) away from the irrigation canals. Waterproof pipes are used to prevent wetting the surrounding soils (Thorton and Arulanaden, 1975).

11.2.4.2 Landscaping considerations

Often the primary cause of settlement beneath structures is from excessive watering. Designing a landscape that is compatible with the southwest climate (one which requires little watering), often protects against differential settlement due to collapsing soils. Any grass or trees should be at least 15 feet away from the structural foundation.

Site drainage protection to carry runoff away and above-grade plumbing usually eliminate potential soil wetting and ponding that may cause settlement. Of course, provisions must be made to prevent freezing of water lines. Roof runoff should be conveyed away from the house by overhanging eaves. A 1/2 to 1 foot layer of gravel underlain by a plastic moisture barrier should be placed around the structure's perimeter. Alternatively, in excessively wet areas, French drains around the house can be used to carry the runoff away and prevent ponding. Finally, structures should be built approximately 1/2 to 1 foot higher than the surrounding natural soils and landscape to facilitate runoff away from the structure.

11.2.4.3 Foundation design and excavation

If the zone of collapsible soils is shallow they can be excavated and replaced with more competent "engineered fill". Unfortunately, collapsible soils are often deeper than 10 feet, which makes excavation uneconomical. In this case foundations should be designed so they can withstand some settlement without sustaining structural damage. If the suspect soils exist at a considerable depth, piles can be driven to a depth below the collapsible layer to give the structure adequate bearing capacity. Sometimes this demands expensive foundation underpinning to depths up to 125 feet as was the case with the Montessa Detention Facility in Albuquerque, New Mexico (Woodward-Clevenger and Associates, Inc., 1973). Driving piles not only stabilizes the foundation but also precollapses and densifies the surrounding soils to improve subsurface conditions.

Many foundations built upon collapsible soils are designed for "permissible" settlement. This is done by using continuous strip footings in a grid system (Fig. 11-4) rather than using conventional isolated footings for a foundation. The foundation grid system is composed of reaction beams formed by placing footing and load balancing beams in the longitudinal direction. This BRAB-type foundation, which was used at GGSS-Area 4, utilizes this concept. The load balancing beams are reinforced to make the system rigid and to minimize vertical displacement (Clemence and Finbarr, 1981). This type of foundation also allows the foundation to be releveled if differential settlement occurs.

Proper design of the stem walls, the joints in the exterior walls, and the partitions of the structure also protect against damage from settlement. There should be positive separation between the slab and the stem walls by using expansion joint material. Sultan (1969) found that the most severe foundation failures from collapsing soil in Tucson, Arizona, occurred in houses constructed with unreinforced concrete blocks and adobe. Houses constructed with common brick suffered the least damage. Damage consisted of the corner-down type, upward heaving near the middle of the walls, slight rotation of the stem walls, horizontal translation outward, and a slight rotation of the corners about a vertical axis.

The damaged houses in the Tucson area were constructed in the early spring after heavy rain had saturated the ground. The load of the houses on the saturated soil caused collapse. Because of the additional load transmitted by the sloping roof,

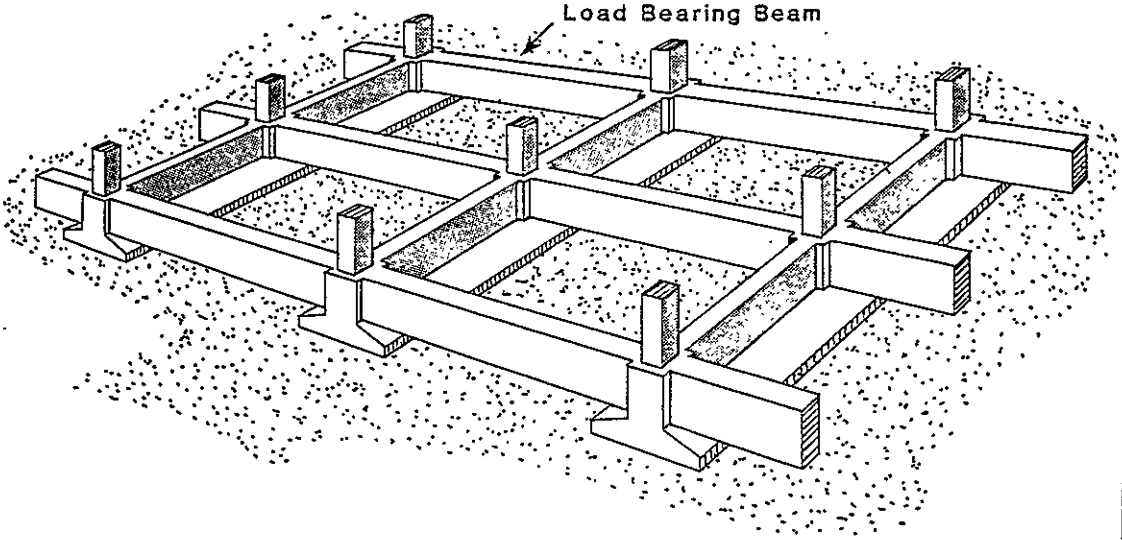

Figure 11-4. Continuous footing. (Clemence and Finbarr, 1981)

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the stresses at the corner of a house are greater than along the rest of the longitudinal footings. As a result, the corners are expected to settle more than the rest of the house. In the summer, with little rain and high temperatures (up to 100°F), the foundation soils shrink. Soils near the house corners, receiving less moisture from roof runoff than the soils along the sides of the houses, should then be expected to shrink more, thus producing the corner-down type of damage. When the soil is wetted by rainfall or watering it swells more under the middle of the footing than under the corner due to the smaller load along the sides of the house. It is clear that houses built without structural continuity in the footings or reinforcement in the footings and stem walls are prime targets for differential settlement from collapsing soils.

11.2.4.4 Chemical treatment and grouting

The primary purpose of treating collapsible soils chemically is to increase their bond strength and to diminish the clay dispersive power of water, which may percolate through the soil. This is sometimes done by treating the soils with chemicals that flocculate the clays between the sand and silt grains (such as $Ca(OH)_2$, $CaSO_4$, $FeSO_4$, or $AlSO_4$). Grouting with high slump Portland cement also stabilizes the clay binder in the soils and cements the larger grains together effectively. A 1:3 ratio of lime to water mixture could be injected into drillholes around the future foundation to the depth of the collapsible zone. As the lime reacts with the silicic and colloidal silicic acids in the soils, a calcarous-siliceous binder forms between the sand

and silt grains. This strengthens the intergranular bonds and decreases their tendency to collapse abruptly.

A second grouting technique with a low slump grout mixture is designed to densify surrounding soils as a result of injecting the mixture under pressure. This technique, although widely used in the western U.S., has not been proven highly effective when used in collapsible soils.

11.2.4.5 Thermal treatment

The Russians have used two thermal methods for a long time to stabilize collapsible soils. The first method involves blowing pressurized hot air into the soil through heat-proof pipes and drillholes. The second method, which is preferred in construction work, involves burying fuel in the collapsible soils. Fuel combustion takes place in a sealed drillholes equipped for control of temperature and chemical composition. The heat transfer into the collapsible zone increases soil cohesion, the compressive and shear strength, and arrests the differential settlement under applied load and increased moisture conditions. The combustion process usually changes the soil color from a natural pale yellow to various shades of brick red (Litvinov, 1960).

11.3 Discussion

In identifying, testing, and treating collapsing soils one cannot overlook their geologic origin, engineering properties (grain size, density, moisture content, etc.), and the role of clay and soil structure in the collapse mechanism. There are several common misconceptions about collapsible soils, that need clarification. One misconception is that these soils only consist of sands and silts with some clay-forming bridges between the grains. Although this is true for eolian and loess soils, it is not an exclusive condition. Many colluvial soils also exhibit collapse potential as do most loose fills, regardless of clay content or soil type. In addition, many dry clays also collapse at high applied pressures (Burland, 1965).

Another misconception is that all soils of low density (<95 pcf) are considered collapsible. Again, although this statement might apply to some loose eolian and mudflow deposits, it is not correct for all soils. The clay content and type will influence both the dry density and, most importantly, the natural water content and degree of saturation, which are not even considered in this false generalization.

Finally, even a thorough study of the geologic origin of the sediments in a specific area is not sufficient enough to identify collapsible soils. Although collapsible soils are commonly associated with loess, eolian sands, and mud and debris flow deposits, they also are known to be present in residual, colluvial, and other alluvial soils.

The above misconceptions, as well as the amount of damage collapsing soils have caused to engineered structures clearly demonstrate the need to use overall, precise, multidisciplinary methods in identifying and treating these soils. A combination of geologic and soil mapping and field and laboratory testing using the methods described in this report is required for a thorough evaluation of collapsing soils. Data generated from testing might be used to form an overall "collapse index" for soils in the area studied.

12.0 GEOTECHNICAL GROUND STABILIZATION STUDY (GGSS)

The GGSS was done to demonstrate the direct relationship between ground wetting and subsidence, to test a possible stabilization technique (induced hydrocompaction), and to examine the performance of contrasting concrete-foundation designs. The implications of this study for retarding soil-collapse damage to structures in developed areas are significant.

The first part of the GGSS involved injecting water into the subsurface soils at three areas: two areas (GGSS-Area 1 and 3) were located east of El Llano acequia where subsurface soils have not been wetted significantly and where highly collapsible soils were suspected based on field observations and laboratory testing. The third area (GGSS-Area 2) was located west of the acequia, where the ground has been irrigated for a long time. It was suspected that soils there had already collapsed substantially because of continual wetting by irrigation water over the past 300 years (Appendix XII). Therefore, this area was used as a control.

Table 12-1 illustrates the results of the experiments. The main difference between areas 1 and 3 was the depth of the water-injection wells. At area 1 the injection well was 30 ft deep, with two shallow (10-ft-deep) wells close by; at area 3 the injection well was 10 ft deep. Water injected into the deeper well at area 1 consolidated the deep soils rather than the shallower near-surface soils; therefore, subsidence did not occur initially. However, after water was injected into the shallow, 10-ft-deep wells, subsidence did occur at area 1. It took 42

TABLE 12-1. Water injection and settlement data for the GGSS-Areas.

GGSS Area	Max. depth of injection wells(s) (ft)	No. days to induce settle-ment	Water required to induce settle-ment (gal)	Amount of surface subsidence (ft)	Total water injected (gal)	Duration of experiment (days)
1	30	42	21,294	0.5	42,996	63
2	30	NA	NA	None	24,567	84
3	10	7	~7,000	2.2	16,880	16
4	10	13	19,881	1.4	107,691	28

days to induce settlement at area 1. This shows that the entire alluvial soil section (approximately 30 ft thick) is collapsible.

At GGSS-Area 3 subsidence occurred within 7 days (Photograph 7) even though considerably less water was injected there than was injected at area 1 (Table 12-1). The near-surface soils (up to 15 ft deep) absorbed most of the water, which led to rapid soil collapse. Monitoring data indicate the entire alluvial soil section (approximately 30 ft thick) was eventually wetted. This area most accurately represents the situation found around a house where a point-source of water leakage occurs at fairly shallow depths (less than 15 ft). The volume of water (~7,000 gal) required to induce surface subsidence at area 3 is approximately equal to the amount of water used by a family of four in one month. Subsidence features observed by investigators elsewhere in the El Llano area have reportedly formed equally fast.

At GGSS-Area 2 subsidence did not occur even though the subsurface monitoring indicated that the volume of soil wetted was consistent with the volume wetted at areas 1, 3, and 4 (Fig. 12-1). The experiment at area 2 was continued for 84 days, at which time it was apparent that collapse would not occur. As noted above, the soils at area 2 have been wetted for a long time, and soil collapse in these irrigated lands between the two acequias appears to have ceased, although some potential for subsidence may still exist.

The second part of the GGSS could affect the state building code in areas where collapsible soils are present. It was

PHOTOGRAPH 7—Geotechnical ground stabilization study area 3 (GGSS–3) showing surface settlement and ground cracks (view to the south).

PHOTOGRAPH 8—Geotechnical ground stabilization study area 4 (GGSS–4) before collapse occurred (view to the west).

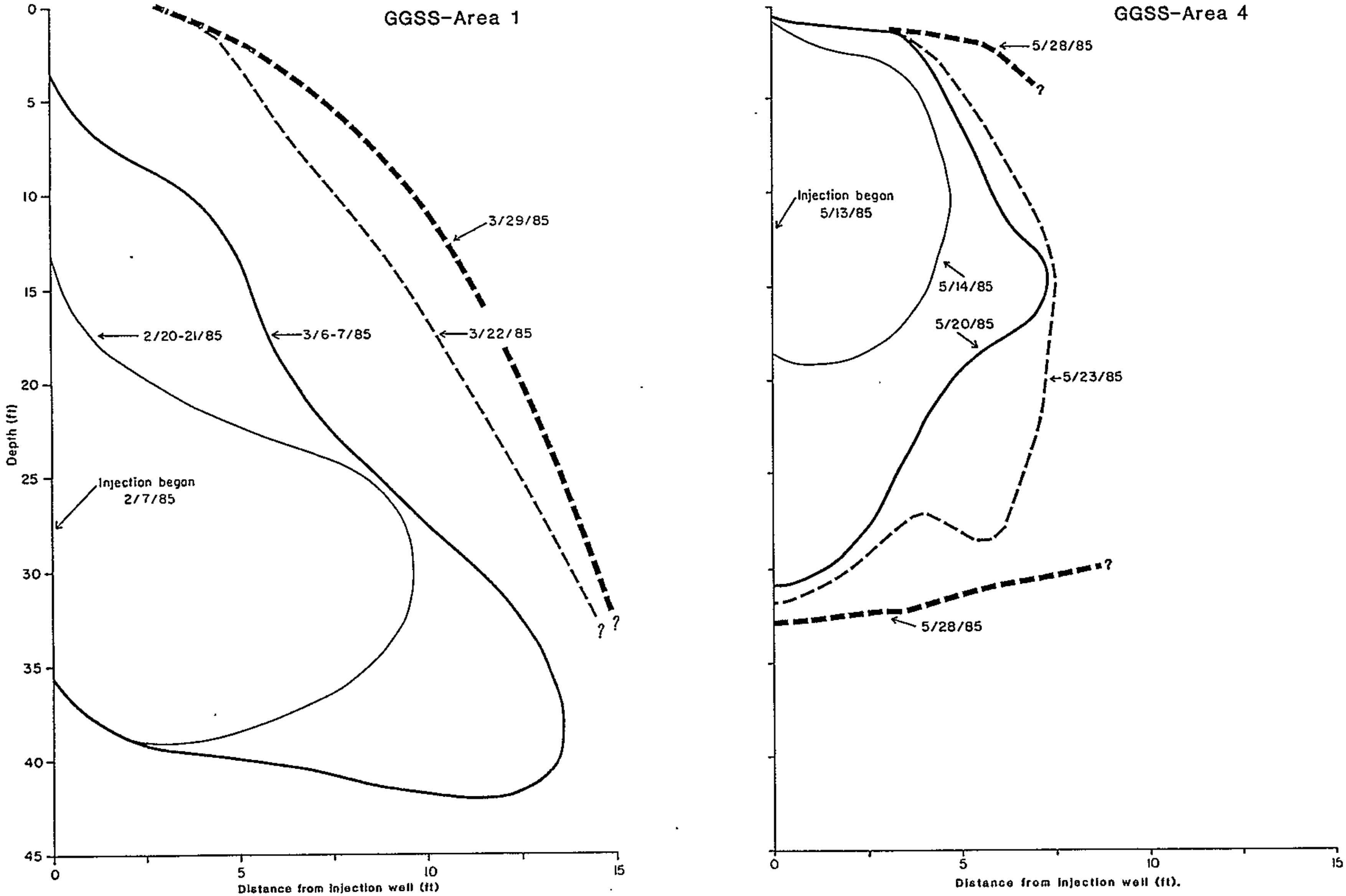

Figure 12-1. Changes of moisture front position with time at GGSS-Areas 1 & 4. Positions extrapolated from drill hole log information, moisture samples, and down-hole nuclear probe data.

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conducted at GGSS-Area 4 with two contrasting concrete foundations (photograph 8, Fig. 12-2). The two foundations (approximately 10 ft x 15 ft x 4 inches) were constructed side-by-side approximately 50 ft from areas 1 and 3 in similar-type soils. One foundation was constructed with footings and rebar support common to foundations in the El Llano area. The other foundation was constructed as a BRAB foundation, with more extensive footings and an interlocking rebar "cage" that adds greatly to the strength of the foundation. This type of foundation was devised by the Building Research Advisory Board (BRAB) for use on soils that expand when wetted. However, the foundation appears to function equally well when used with structures built on collapsible soils. Both foundations were weighted with sand bags to simulate the weight of a building. The 15 monitoring wells placed around the foundations made it possible to trace the underground water seepage and to measure the amount, the timing, and the location of the settlement.

A significant advantage of the BRAB foundation-type design is that it remains intact subsequent to any differential settlement of soils. In contrast to conventional foundations, its strength allows it to be releveled if differential settlement should occur. Any structure on the BRAB foundation remains essentially undisturbed. Conventional foundations in the El Llano area commonly fracture when subjected to the stresses that arise from differential settlement.

The foundations began to subside uniformly within 13 days, after 19,881 gal of water had been injected into the five water-injection wells which were 10-ft deep (Photograph 9). Injection

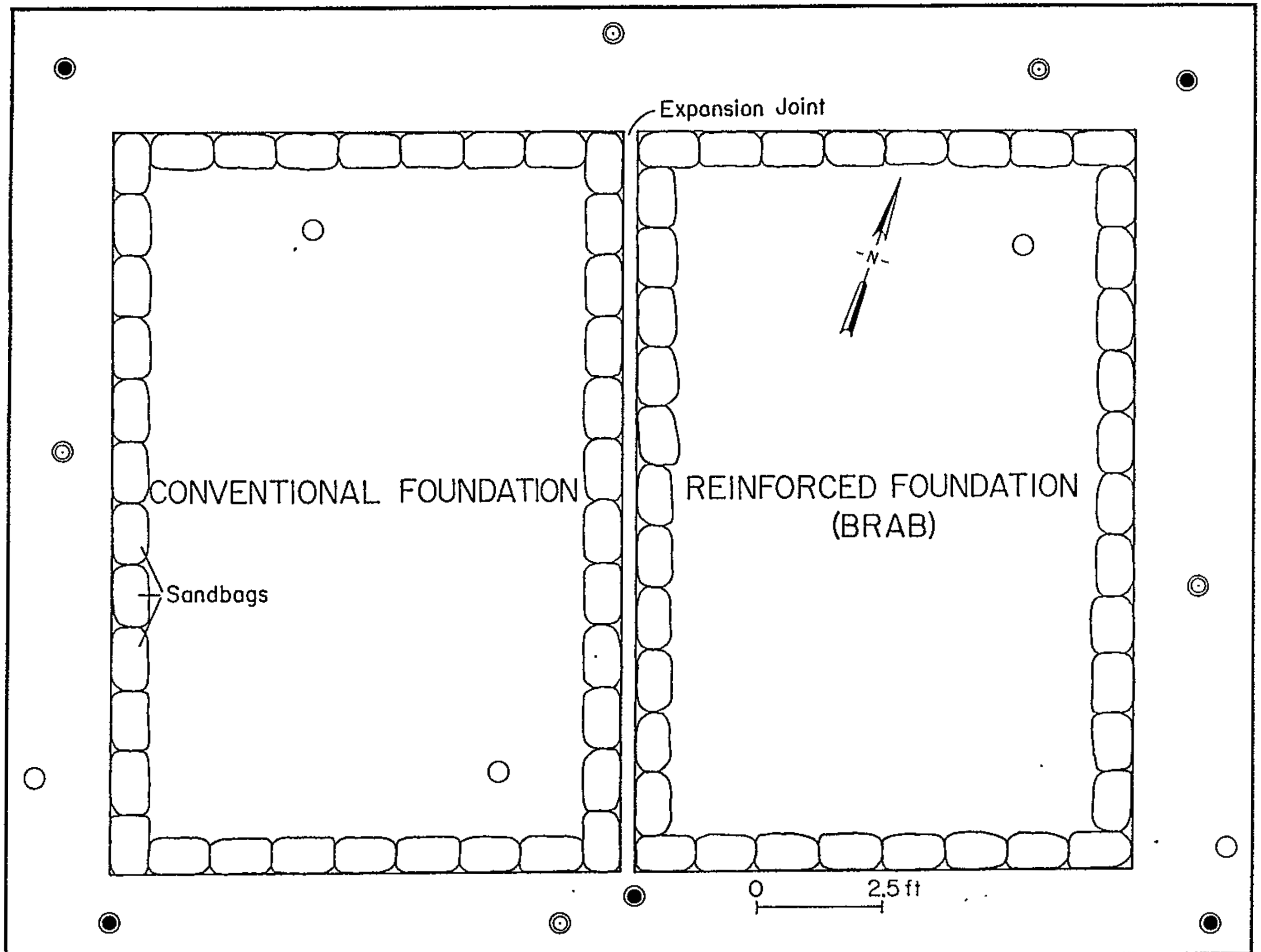

Figure 12-2. Map of GGSS-Area 4 (concrete foundations) showing well locations.

Monitoring well symbols:

○ water level and injection

◎ moisture and density

● settlement

PHOTOGRAPH 9—Geotechnical ground stabilization study area 4 (GGSS–4) showing incipient surface subsidence and ground cracks on May 29, 1985 (view to the west).

PHOTOGRAPH 10—Geotechnical ground stabilization study area 4 showing near-to-maximum surface settlement and ground cracks on June 10, 1985 (view to the west).

of water was continued until surface and subsurface monitoring confirmed that collapse had largely ceased (Photograph 10). A total of 107,691 gallons of water was injected during the experiment.

The foundations were carefully monitored during the 28-day-long experiment. It was determined that 1.4 ft of surface settlement had been induced. The rate of settlement was initially about 3 inches per day (average). After seventeen days settlement was less than one-half inch per day. More importantly, the foundations settled evenly; no measurable differential settlement was detected and neither foundation exhibited any cracks (Appendix XX, Photograph 10).

The even settlement of both foundations did not allow us to assess their relative strengths during the experiment. However, their relative strengths were assessed during removal. The conventional foundation cracked extensively as it was removed with a large front-end loader. In contrast, the BRAB foundation was removed intact and incurred no cracking. It was then placed on edge and allowed to free-fall (four times) through an arc of ten feet and still did not crack. The tremendous stresses imparted to the BRAB foundation during these tests demonstrate its advantage over conventional foundation design in areas where foundations may become stressed due to collapsing soils.

To the authors' knowledge this is the first time that induced hydrocompaction had been used to successfully settle a foundation. The success of this experiment implies that induced hydrocompaction may be a viable technique to stabilize soils beneath existing full-scale structures. The GGSS experiments demonstrate that induced hydrocompaction is also an effective technique to stabilize relatively shallow (<30 ft) collapsible soils. It is reasonable for building code officials to recommend (perhaps require) this relatively inexpensive procedure as a pre-treatment of collapsible soils.

13.0 PREVENTIVE AND MITIGATIVE MEASURES-EL LLANO AND VICINITY

The above discussions strongly suggest that inadequate foundation preparation before construction and moisture increases in foundation materials subsequent to construction are major causes of the utility and structural distress in El Llano and vicinity. In areas yet to be developed, relatively inexpensive and routine measures can be implemented to minimize damage. In contrast, in areas that have already been developed, the damage is much more difficult to mitigate. Associated with these difficulties are increased costs.

The following discussion is therefore divided into two parts. In the first part preventive measures that can be implemented in undeveloped areas are discussed. The second part discusses mitigative measures that can be employed in areas already developed.

13.1 Preventive Measures in Undeveloped Areas

There are large areas in the El Llano vicinity that are certain to be developed in the near future. These areas range in size from single family dwellings to housing tracts. Other development, such as additional utilities, roads, businesses, and schools, should also be anticipated.

In site exploration for these developments, careful attention should be given to testing for collapse potential. Selected techniques that proved useful in this study included drilling, sampling, laboratory testing, seismic refraction, geologic mapping, and aerial photograph analyses. In areas found to have collapse potential, sites should be given maximum compactive effort to depths determined from drilling, testing, and geophysical study. To densify foundation materials before construction, a number of techniques may be utilized depending loading constraints and cost factors. Among those commonly used are surcharging, overexcavation and backfill, induced hydrocompaction, dynamic compaction and vibroflotation. Special consideration should be given to maintenance of water and sewer lines and to establishing positive surface drainage away from structures. In addition to these measures, the recommendations below for developed areas can be implemented subsequent to construction.

13.2 Mitigative Measures in Developed Areas

Generally, it is considerably more difficult and expensive to mitigate or repair already damaged areas. In the El Llano area, repairs are even more complex due to the structurally weak adobe-type construction that is common.

Mitigative measures can be divided into two types. One type seeks to restore a damaged structure to its original condition and the other seeks to stabilize foundation soils at depth so that no further damage will occur.

"Stabilization" of collapsible soil by preventing infiltration of moisture is not a difficult task but one which must be assured permanently. In many cases, damage can be halted by removing the prime ingredient required for settlement--water. The direct relationship between moisture and settlement has been established through the procedures and techniques described in this report. Removal or retardation of moisture influx seems to be the easiest goal to achieve. Associated with the drier soils will be an increase in bearing strength. The following describes relatively inexpensive techniques that should be applied to all existing and planned structures in collapse-prone areas.

1) Positive drainage.

Surface contours adjacent to structures should be established to enhance surface runoff. Any depressions should be filled to prevent standing water. The depression west of the Moya residence and other depressions that exist should be backfilled to the original ground contour. All depressions associated with the older acequia, referred to in Appendix XVI, should be filled.

2) Maintenance of water lines.

Water lines in the El Llano area are not in good condition. The metal pipes are, in places, known to be or suspected to be leaking. Consideration should be given to replacing water lines with flexible (plastic-type) pipe. The pipes leading to and from the community water tank should be excavated, inspected, and replaced if found to be leaky.

3) Rain gutters.

Eaves that allow roof runoff to drip onto foundation materials should be modified. Most houses do not have rain gutters or gutters in good repair. Rain gutters should be installed and the water should be collected at downspouts and directed away from foundations. The gutters and downspouts should be inspected closely at least annually for damage from ice and wind.

4) Landscaping.

Desert landscaping should be encouraged and lawn watering should be discouraged. Drill hole data indicate a much greater than normal depth of wetting at houses with "well maintained" lawns.

5) Surface drainage.

Culverts and cement-lined ditches should be installed to minimize sheetwash following rainfall or snowmelt. They should be cleaned and repaired regularly to assure that they function as designed. The ditches should enhance drainage toward the existing acequias.

6) Septic tanks.

Septic tank use should be discontinued in favor of a centralized system connected to the Española sewage system. All pipes used in the system should be high strength and connections should be welded to prevent leaks. The pipes should be checked regularly for leaks or other signs of stress.

Induced hydrocompaction, or the controlled introduction of moisture into foundation soils, was discussed in Section 12.0. This has now been shown to be a viable technique for controlled settling of small structures uniformly such as the 20 by 15 ft foundation used in the GGSS experiments. The technique of controlled and induced hydrocompaction of collapsible soils may also be a viable technique for full-scale structures, but more research is required before its efficacy can be fully assessed.

It may also have applicability in undeveloped areas as an inexpensive pre-treatment technique of collapsible soils.

14.0 PRELIMINARY APPLICATION OF AVAILABLE DATA TO CIVIL ENGINEERING NEEDS

The potential for collapsible soils exists in many parts of New Mexico where similar geologic settings occur. Some areas have already sustained damage similar to that in El Llano, and other areas are very likely to sustain damage in the future.

An important aspect of this study is the possible application of procedures, techniques, and data developed here for use in other areas. As discussed in Section 11.0, a standard procedure for studying collapsible soils is not possible due to differences in geologic history from place to place, which result in changes in gradation, density, soil structure, and collapse potential. The effort put forth for this study has provided an approach to studying New Mexico's soil collapse potential. The techniques being developed to stabilize these soils are applicable to many other areas.

15.0 RECOMMENDATIONS FOR FURTHER WORK

As discussed in Section 1.0, this is not a site-specific study. To fully evaluate collapse potential at individual houses will require many additional drill holes and more laboratory testing. This site-specific work should be done by private consultants. Our area-wide study of collapsible soils was aimed at gathering widely spaced data. Fortunately, it was possible to gather some information at damaged houses. It is hoped that these data will aid the homeowner or his/her agent in fully developing the necessary site-specific repair recommendations.

Additional research is required for developing techniques to predict collapse potential. The standard geotechnical exploratory methods do not work well in predicting soil collapse. Additional work is also required to determine whether induced hydrocompaction will be an effective technique for settling full-scale structures.

Some states (not New Mexico) require an engineering geologic report before site development. The report (for example, California Division of Mines and Geology, 1975) must detail the exploratory methods used and discuss the bearing of geologic factors upon the intended land use. The reports must consider the minimum requirements of Chapter 70 of the Uniform Building Code (ICBO, 1982). If such studies had been completed in the El Llano area, the collapse potential would have been identified much earlier. A state-wide requirement of engineering geologic before site development would require legislative action. A significant advantage, were this to be done, is that statewide data could be compiled centrally by state agencies concerned about effects of soil on engineered structures.

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EL LLANO AND VICINITY GEOTECHNICAL STUDY

FINAL REPORT

VOLUME II

Prepared for:

Office of Military Affairs
Civil Emergency
Preparedness Division
P.O. Box 4277
Santa Fe, NM 87501

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New Mexico Bureau of Mines and Mineral Resources
Socorro, NM 87801

28 June 1985

APPENDIX I

Final Boring Logs

BORING: ESPDH-1
DATE DRILLED: 12-17-84
EQUIPMENT USED: CME 55
LOCATION: NE¼SE¼SW¼sec.25T21NR8E
ELEVATION: 5713'
TOTAL DEPTH: 68

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5710.5	2.5	5	12	--	19	NP	D	SM		Silty Sand 4/73/23
5708	5	5	10	--	NV	NP	D	SM		Silty Sand 1/82/17
5705.5	7.5	12	15	--	20	NP	D	SM		Silty Sand 2/67/31
5703	10	5	22	--	19	NP	D	SM		Silty Sand 0/62/38
5702.5	10.5	5	39	--	69	34	D	MH		Sandy Silt 0/34/66
5700.5	12.5	7	31	--	32	12	D	SC		Clayey Sand 0/55/45
5698	15	6	26	--	45	20	D	CL		Sandy Clay 0/44/56
5695.5	17.5	7	23	--	28	6	D	ML		Sandy Silt 0/40/60
5693	20	8	16	--	22	NP	D	SM		Silty Sand 22/49/29
5690.5	22.5	6	17	--	45	20	D	SC		Clayey Sand 0/60/40
5688	25	12	10	--	NV	NP	D	SM		Silty Sand 1/82/17
5685.5	27.5	15	13	--	26	6	D	SM-SC		Silty Clayey Sand 0/76/24
5683	30	7	15	--	20	NP	D	SM		Silty Sand 0/68/32
5680.5	32.5	17	7	--	NV	NP	D	SP-SM		Sl. Silty Sand 2/89/9
5678	35	12	10	--	NV	NP	D	SP-SM		Sl. Silty Sand 1/89/10
5675.5	37.5	12	24	--	NV	NP	D	SM		Silty Sand 0/65/35
5675	38	12	14	--	19	NP	D	SM		Silty Sand 0/75/25
5673	40	11	10	--	NV	NP	D	SP-SM		Sl. Silty Sand 0/89/11
5670.5	42.5	16	10	--	NV	NP	D	SM		Silty Sand 6/74/20
5668	45	12	10	--	NV	NP	D	SM		Silty Sand 10/75/15
5665.5	47.5	21	13	--	NV	NP	D	SM		Silty Sand 0/74/26
5663	50	19	24	--	33	13	D	CL		Sandy Clay 0/46/54
5658	55	15	11	--	NV	NP	D	SM		Silty Sand 1/73/26
5655.5	57.5	12	6	--	22	NP	D	SM		Silty Sand 0/69/31
5653	60	15	9	--	35	13	D	SC		Clayey Sand 3/52/45
5650	63	31	9	--	NV	NP	D	SM		Silty Sand 0/69/31
5648	65	22	4	--	NV	NP	D	SM		Silty Sand 0/82/18
5645.5	67.5	21	5	--	NV	NP	D	SP-SM		Sl. Silty Sand 0/90/10

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:
Approximately 100 feet west of Moya Residence in Subsidence Pit

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-2
DATE DRILLED: 12-18-84
EQUIPMENT USED: CME 55
LOCATION: NE¼SE¼SW¼sec.25, T21N R8E
ELEVATION: 5716'
TOTAL DEPTH: 71'

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

Elevation (ft)	Depth (ft)	"N" Value Std. Pen. Test	Moisture (% of dry wt.)	Laboratory Data: Dry Density (lbs./cu. ft.)	Laboratory Data: Liquid Limit	Laboratory Data: Plasticity Limit	Sample Type U=Undisturbed D=Disturbed	USCS Symbol	Geologic Symbol	Soil Description	Gravel/Sand/Fines (%)
5713.5	2.5	6	8	--	28	NP	D	SM		Silty Sand	0/52/48
5711	5	5	7	--	25	4	D	SM		Silty Sand	0/50/50
5708.5	7.5	5	4	--	NV	NP	D	SM		Silty Sand	0/75/25
5706	10	5	7	--	29	8	D	SC		Clayey Sand	0/54/46
5703.5	12.5	7	4	--	17	NP	D	SM		Silty Sand	0/76/24
5701	15	9	6	--	NV	NP	D	SM		Silty Sand	0/66/34
5698.5	17.5	12	7	--	27	10	D	SC		Clayey Sand	0/66/34
5696	20	12	8	--	26	NP	D	ML		Sandy Silt	1/34/65
5693.5	22.5	13	14	--	54	26	D	CH		Sandy Clay	0/31/69
5693	23	13		--			D	SM*		Silty Sand*	
5691	25	8	6	--	24	NP	D	SM		Silty Sand	0/61/39
5688.5	27.5	10	3	--	NV	NP	D	SM		Silty Sand	1/80/19
5686	30	12	3	--	NV	NP	D	SM		Silty Sand	0/77/23
5683.5	32.5	12	6	--	24	NP	D	SM		Silty Sand	5/48/47
5681	35	14	6	--	31	10	D	SC		Clayey Sand	0/66/34
5678.5	37.5	17	3	--	NV	NP	D	SM		Silty Sand	0/77/23
5676	40	13	1	--	NV	NP	D	SP-SM		Sl. Silty Sand	0/93/7
5673.5	42.5	30	2	--	NV	NP	D	SP-SM		Sl. Silty Sand	26/64/10
5671	45	18	5	--	NV	NP	D	SM		Silty Sand	0/71/29
5668.5	47.5	22	2	--	NV	NP	D	SP-SM		Sl. Silty Sand	1/93/6
5666	50	45	2	--	NV	NP	D	SM		Silty Sand	29/58/13
5663.5	52.5	17	8	--	30	10	D	CL		Sandy Clay	0/47/53
5661	55	15	16	--	55	26	D	CL		Sandy Clay	0/31/69
5658.5	57.5	20	4	--	17	NP	D	SM		Silty Sand	0/74/26
5655.5	60.5	29		--			D	SP		Sand	7/92/1
5653.5	62.5	17		--			D	CL*		Silty Clay*	
5651	65	20		--			D	SP		Sand	0/97/3
5646	70	22		--			D	SP-SM*		Sl. Silty Sand*	

NOTES:
Approximately 20 feet east of Trujillo residence.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH - 3
DATE DRILLED: 12-19-84
EQUIPMENT USED: CME 55
LOCATION: SE¼SE¼SW¼Sec.25, T21N R8E
ELEVATION: 5715'
TOTAL DEPTH: 51'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
			LABORATORY DATA								
5712.5	2.5	23	20	--			D	ML*		Sandy Silt*	
5710	5	7	8	--	22	NP	D	SM		Silty Sand	0/66/34
5707.5	7.5	6	8	--	21	NP	D	SM		Silty Sand	0/57/43
5705	10	5	5	--			D	SP		Sand	2/98/0
5702.5	12.5	11	5	--			D	SP		Sand	0/100/0
5700	15	26	3	--			D	SP-SM*		Sl. Silty Sand*	0/92/8
5697.5	17.5	18	6	--			D	SP		Sand	0/95/5
5695	20	14	17	--	53	23	D	MH		Sandy Silt	
5692.5	22.5	15	10	--	24	NP	D	SM		Silty Sand	0/69/31
5690	25	14		--			D	SP-SM*		Sl. Silty Sand*	0/88/12
5687.5	27.5	15		--			D	SP		Sand	0/96/4
5685	30	21		--			D	SM*		Silty Sand*	0/65/35
5682.5	32.5	24		--			D	SM*		Silty Sand*	1/87/12
5680	35	23		--			D	SM*		Silty Sand*	0/56/44
5677.5	37.5	25		--			D	SP		Sand	0/98/2
5675	40	35		--			D	SP-SM*		Sl. Silty Sand*	0/89/11
5670	45	25		--			D	SP		Sand	0/96/4
5665	50	30		--			D	SM*		Silty Sand*	0/65/35

NOTES:

Approximately 45 feet north of F. Valdez residence.

* = field classification
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

BORING: ESPDH-4
DATE DRILLED: 12-20-84
EQUIPMENT USED: CME 55
LOCATION: SE¼SE¼SW¼sec.25 T21N R8E
ELEVATION: 5718'
TOTAL DEPTH: 67.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5713	5-7	--					U	SP*		Sand*
5710	8-10	--	7	101	NV	NP	U	SM		Silty Sand 2/77/21
5704	14	9	12	--	26	6	D	SM-SC		Silty Clayey Sand 0/71/29
5699	19-21	--	9	100	NV	NP	U	SM		Silty Sand 0/73/27
5694	24-26	--					U	SP*		Sand*
5689	29-31	--	7	99	NV	NP	U	SM		Silty Sand 0/84/16
5684	34-36	--	17	96	28	11	U	CL		Sandy Clay 0/43/57
5679	39-41	--	8	109	NV	NP	U	SM		Silty Sand 0/84/16
5674	44-46	--	8	100	NV	NP	U	SM		Silty Sand 0/85/15
5669	49-51	--	9	95	NV	NP	U	SM		Silty Sand 0/81/19
5664	54-56	--	10	102	NV	NP	U	SM		Silty Sand 2/71/27
5659	59-61	--	5	107	NV	NP	U	SP-SM		Sl. Silty Sand 14/79/7
5654	64-66	--					U	SM*		Silty Sand*
5652	66	41	7	--	15	NP	D	SP-SM*		Sl. Silty Sand* 7/85/8

NOTES: Approximately 20 feet west of El Llano community water tank.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-5
DATE DRILLED: 12/21/84
EQUIPMENT USED: CME 55
LOCATION: NE¼SE¼SW¼sec.25 T.21N. R8E
ELEVATION: 5717'
TOTAL DEPTH: 41'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Grave/Sand/Fines (%)
5715	2-4	--					U	SP*		Sand*	
5709	6-8	--	5	97	NV	NP	U	SP-SM		Sl. Silty Sand	1/88/11
5706	9-11	--	4	85	NV	NP	U	SM		Silty Sand	1/80/19
5703	14-16	--	11	83	38	14	U	CL		Sandy Clay	1/28/71
5698	19-21	--	3	84	NV	NP	U	SP-SM		Sl. Silty Sand	1/88/11
5693	24-26	--	12	82	39	16	U	CL		Sandy Clay	0/31/69
5688	29-31	--			23	NP	U	ML		Sandy Silt	1/47/52
5683	34-36	--	3	100	NV	NP	U	SM		Silty Sand	1/81/18
5678	39-41	--	3	126	NV	NP	U	SM		Silty Sand	0/73/27

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: Approximately 30 feet east of Trujillo residence.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH - 6
DATE DRILLED: 12-26-85
EQUIPMENT USED: CME 55
LOCATION: NW¼SE¼SW¼sec.25.T21N R8E
ELEVATION: 5703'
TOTAL DEPTH: 45'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
			LABORATORY DATA							
5702	1-3	--	10	88	31	11	U	CL		Sandy Clay 0/42/58
5698	5-7	--					U	SP*		Sand*
5695	8-10	--	5	101	NV	NP	U	SM		Silty Sand 7/78/15
5689	14-16	--	10	94	NV	NP	U	SM		Very Silty Sand 0/68/32
5684	19-21	--					U	CL*		Sandy Clay*
5679	24-26	--	5	104	NV	NP	U	SM		Silty Sand 0/85/15
5669	34-36	--	23	96	64	33	U	CH		Clay 0/38/62
5664	39-41	--	5	111	NV	NP	U	SM		Silty Sand 0/86/14
5659	44	26	6	--			D	SP-SC*		Sl. Clayey Sand* 0/91/9

NOTES:
Southwest of Espinosa residence, 75 feet east of acequia.

* = field classification
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-7
DATE DRILLED: 12-26-84
EQUIPMENT USED: CME 55
LOCATION: NE¼SE¼SW¼sec.25 T21N R8E
ELEVATION: 5707'
TOTAL DEPTH: 50'

Elevation (ft)	Depth (ft)	"N" Value Std. Pen. Test	Moisture (% of dry wt.)	Dry Density (lbs./cu.ft.)	Liquid Limit	Plasticity Limit	Sample Type U=Undisturbed D=Disturbed	USCS Symbol	Geologic Symbol	Soil Description	Gravel/Sand/Fines (%)
5705	2-4	-	6	100	NV	NP	U	SM		Silty Sand	0/80/20
5702	5-7	-					U	SM*		Silty Sand*	
5697	10-12	-	9	74	NV	NP	U	SM		Silty Sand	2/71/27
5694	15-17	-					U	SP*		Sand*	
5686	21-23	-	4	106	NV	NP	U	SP-SM		Sl. Silty Sand	1/89/10
5683	24	20	3	--	NV	NP	D	SW		Gravelly Sand	26/70/4
5678	29-31	-	3	103	NV	NP	U	SM		Silty Sand	2/78/20
5673	34-36	-	7	98	21	NP	U	SM		Silty Sand	0/54/46
5668	39-41	-	4	91	NV	NP	U	SM		Silty Sand	0/83/17
5663	44-46	-	4	97	NV	NP	U	SM		Silty Sand	0/76/24
5658	49	17	4	--	18	NP	D	SM		Silty Sand	0/77/23

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

Approximately twenty feet west of Voight House.
Organic layer at 26.5 feet submitted for age date.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-8
DATE DRILLED: 12-26-84
EQUIPMENT USED: CME 55
LOCATION: SE¼SE¼SW¼sec.25 T21N R8E
ELEVATION: 5712'
TOTAL DEPTH: 50'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
				LABORATORY DATA						
5710	2-4	--	16	78	61	30	U	MH		Clayey Silt 0/23/87
5707	5-7	--	22	92	75	40	U	MH		Silt 0/30/70
5702	10	23	1	--			D	SP-SM*		Sl. Silty Sand* 21/72/7
5698	14-16	--					U	SM*		Silty Sand*
5693	19	30	1	--			D	SW		Gravelly Sand 22/74/4
5688	24-26	--	6	96	24	3	U	SM		Very silty sand 0/62/38
5683	29-31	--	6	95	26	NP	U	SM		Very silty sand 0/62/38
5678	34-36	--	9	95	29	9	U	ML		Very sandy silt 0/46/54
5673	39-41	--	4	99	NV	NP	U	SM		Silty Sand 1/81/18
5668	44	28	1	--			D	SP-SM*		Sl. Silty Sand* 2/87/11
5663	49	50	17	--			D	SP-SM*		Sl. Silty Sand* 12/80/8

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:
In Gutierrez field approximately two hundred feet west of Middle Road.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-9
DATE DRILLED: 12-26-84
EQUIPMENT USED: CME 55
LOCATION: SE¼SE¼SW¼Sec.25, T21N R8E
ELEVATION: 5713'
TOTAL DEPTH: 125.5'

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5711	2-4	--	5	86	21	NP	U	SM		Silty Sand	3/65/32
5708	5-7	--	5	85	NV	NP	U	SM		Silty Sand	3/75/22
5699	14-16	--	2	95	NV	NP	U	SP-SM		Sl. Silty Sand	0/94/6
5694	19-21	--					U	SM*		Silty Sand*	
5689	24-26	--	5	101	NV	NP	U	SM		Silty Sand	0/72/28
5684	29-31	--	2	93	NV	NP	U	SP-SM		Sl. Silty Sand	0/93/7
5679	34-36	--	3	107	NV	NP	U	SM		Silty Sand	1/83/16
5674	39	--	1	--			D	SP		Sand	4/92/4
5669	44	28	2	--			D	SP-SM*		Sl. Silty Sand*	0/91/9
5664	49	22	2	--			D	SP-SM*		Sl. Silty Sand*	6/87/7
5659	54	21	2	--			D	SP-SM*		Sl. Silty Sand*	1/89/10
5654	59	24	3	--			D	SP-SM*		Sl. Silty Sand*	6/87/7
5649	64	33	4	--			D	SP-SM*		Sl. Silty Sand*	0/91/9
5644	69	22	7	--	19	NP	D	SM		Silty Sand	0/68/32
5643.5	69.5	22	20	--	44	17	D	SC		Clayey Sand	0/55/45
5639	74	26	5	--	19	NP	D	SM		Silty Sand	1/85/14
5634	79	24	17	--	25	7	D	SM-SC		Silty Clayey Sand	0/59/41
5629	84	13	15	--	24	8	D	SC		Clayey Sand	7/77/16
5624	89	25	12	--	18	NP	D	SM		Silty Sand	0/73/27
5618.5	94.5	49	7	--			D	SW		Gravelly Sand	33/62/5
5609.5	103.5	28	25	--	48	21	D	SC		Clayey Sand	0/57/43
5599	114	50	2	--			D	GW*		Gravel*	
5589	124	REF	5	--			D	SM*		Silty Sand*	0/87/13

NOTES: Approximately 50 feet south of F. Valdez residence.
Water monitoring well installed, but subsequently destroyed.

* = field classification
REF = refusal
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-10
DATE DRILLED: 12-28-84
EQUIPMENT USED: CME 55
LOCATION: SE¼SE¼SW¼sec.25 T21N R8E
ELEVATION: 5716'
TOTAL DEPTH: 40'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5714	2-4	--	9	82	26	5	U	ML		Very sandy silt	0/42/58
5709	5-7	--	13	87	28	8	U	CL		Silty clay	0/37/63
5707	9	9	1	--			D	SP-SM*		Sl. Silty Sand*	0/91/9
5702	14-16	--	4	86	NV	NP	U	SM		Silty Sand	0/80/20
5697	19	30	1	--			D	SP		Sand	3/92/5
5692	24-26	--	4	96	NV	NP	U	SM		Silty Sand	0/77/23
5687	29-30	--	6	88	25	NP	U	SM		Very silty sand	0/60/40
5686	30	41	--	--	--	--	D	--		No recovery	
5682	34	29	6	--	24	5	D	SM		Silty Sand	0/77/23
5677	39	43	1	--			D	SP-SM*		Sl. Silty Sand*	12/79/9

NOTES:

Approximately fifteen feet east of Felipe Valdez residence.

* = field classification
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

BORING: ESPDH-11
DATE DRILLED: 12-28-84
EQUIPMENT USED: CME 55
LOCATION: SE¼SE¼SW¼Sec.25, T21N R8E
ELEVATION: 5722'
TOTAL DEPTH: 84'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
			LABORATORY DATA								
5720	2-4	--	18	92	26	7	U	SM-SC		Silty Clayey Sand	0/64/36
5717	5-7	--	21	95	22	NP	U	ML		Sandy Silt	0/41/59
5713	9-11	--	9	101	21	NP	U	ML		Sandy Silt	0/48/52
5708	14-16	--	7	88	NV	NP	U	SM		Silty Sand	0/79/21
5703	19-21	--	8	105	22	NP	U	SM		Silty Sand	8/62/30
5698	24-26	--					U	SM*		Silty Sand*	
5693	29-31	--	3	112	28	NP	U	ML		Sandy Silt	0/27/73
5688	34-36	--	3	112	69	41	U	CH		Sandy Clay	0/31/69
5683	39-41	--	28	89	NV	NP	U	SP		Sand	2/95/3
5681	41	17	5	---			D	SM*		Silty Sand*	0/83/17
5678	44-46	--	9	98	NV	NP	U	SM		Silty Sand	0/86/14
5673	49-51	--					U	SM*		Silty Sand*	
5668	54-56	--	7	107	NV	NP	U	SM		Silty Sand	1/80/19
5663	59-61	--	3	104	NV	NP	U	SP-SM		Sl. Silty Sand	2/89/9
5661	61	16	4	---			D	SP-SM*		Sl. Silty Sand*	0/91/9
5657	65-67	--	6	107	NV	NP	U	SM		Silty Sand	6/77/17
5655	67	37	1	--			D	SP		Sand	16/82/2
5652	70	22	12	--			D	SP-SM*		Sl. Silty Sand*	0/90/10
5643	79	32	8	--			D	SM*		Silty Sand*	0/85/15

NOTES:

Approximately 20 feet east of Manzanares residence.
Settlement monitor installed.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-12
DATE DRILLED: 1-2-85
EQUIPMENT USED: CME 55
LOCATION: SE¼NE¼SW¼sec.25 T21N R8E
ELEVATION: 5711'
TOTAL DEPTH: 34'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5709.5	1.5-4	--	2	99	NV	NP	U	SP		Sand	1/94/5
5704.5	6.5-9	--						CL*		Silty Clay*	
5699.5	11.5-14	--	3	104	NV	NP	U	SM		Silty Sand	0/64/36
5694.5	16.5-19	--	12	89	61	32	U	CH		Sandy Clay	0/22/78
5689.5	21.5-24	--					U	ML*		Sandy Silt*	
5684.5	26.5-29	--	1	117	NV	NP	U	SP-SM		Sl. Silty Sand	28/65/7
5679.5	31.5-34	--	3	106	NV	NP	U	SM		Silty Sand	1/74/25

NOTES:
Approximately 20 ft. southwest of Lopez residence.

* = field classification
NV= no value
NP= non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-13
DATE DRILLED: 1-3-85
EQUIPMENT USED: CME 55
LOCATION: SE¼NE¼SW¼sec.25, T21N R8E
ELEVATION: 5710'
TOTAL DEPTH: 62.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5708	2-4	--					U	CL*		Sandy Clay*	
5705	5-7	--	41	82	62	30	U	MH		Sandy Silt	0/11/89
5701	9-11	--			NV	NP	U	ML		Sandy Silt	0/42/58
5696	14-16	--	28	91	37	14	U	CL		Sandy Clay	0/18/82
5691	19-21	--	7	110	NV	NP	U	SM		Silty Sand	0/82/18
5686	24	8	31	--			D	SP*		Sand*	
5681	29-31	--					U	SP*		Sand*	
5676	34-36	--					U	MH*		Clayey Silt*	
5671	39-41	--	25	96	30	NP	U	ML		Sandy Silt	0/33/67
5666	49-51	--	9	107	NV	NP	U	SM		Silty Sand	0/86/14
5661	59-61	--	4	108	NV	NP	U	SP		Sand	5/91/4
5659	61	15	5	--			D	SW		Gravelly Sand	32/66/2

NOTES:

Approximately 15 ft south of Lopez residence.

* = field classification
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-14
DATE DRILLED: 1-3-85
EQUIPMENT USED: CME 55
LOCATION: NE¼NE¼SW¼sec.25, T21N R8E
ELEVATION: 5711'
TOTAL DEPTH: 51'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5709	2-4	--	17	82	28	NP	U	ML		Sandy Silt	0/46/54
5706	5-7	--					U	SM*		Silty Sand*	
5702	9-11	--	4	105	NV	NP	U	SP		Sand	0/96/4
5697	14-16	--	34	80	NV	NP	U	ML		Sandy Silt	0/32/68
5692	19-21	--					U	SP*		Sand*	
5687	24-26	--	6	106	NV	NP	U	SP-SM		Sl. Silty Sand	0/93/7
5682	29	10	25	--			D	SC*		Clayey Sand*	
5677	34-36	--	28	92	41	15	U	CL		Sandy Clay	0/34/66
5672	39-41	--					U	SC*		Clayey Sand*	
5667	44-46	--	12	80	42	18	U	CL		Sandy Clay	0/10/90
5662	49-51	--	3	108	NV	NP	U	SP-SM		Sl. Silty Sand	1/94/5

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

Approximately 10 ft north of C. Trujillo residence. Settlement monitor well emplaced, but subsequently destroyed by vandalism.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-15
DATE DRILLED: 1-3-85
EQUIPMENT USED: CME 55
LOCATION: SE¼NE¼SW¼sec.25 T21N R8E
ELEVATION: 5713'
TOTAL DEPTH: 41'

ELEVATION (ft)	DEPTH (ft)	STD. PEN. TEST "N" VALUE	LABORATORY DATA: MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5711	2-4	--	5	101	NV	NP	U	SP-SM		Slightly silty sand	2/88/10
5708	5-7	--					U	SM*		Silty Sand*	
5704	9-11	--	8	100	NV	NP	U	SM		Silty Sand	0/66/34
5699	14-16	--	15	95	31	10	U	CL		Very sandy clay	0/40/60
5694	19-21	--					U	CL*		Sandy Clay*	
5689	24-26	--	10	87	28	5	U	ML		Very sandy silt	0/43/57
5684	29-30	--	4	95	NV	NP	U	SM		Silty Sand	2/83/17
5679	34-35	--	3	98	NV	NP	U	SM		Silty Sand	0/85/15
5674	39-41	--	2	104	NV	NP	U	SP-SM		Slightly Silty Sand	2/90/8
5672	41	37	1	--			D	SP		Sand	8/87/5

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: Approximately 240 feet east of Espinosa residence in Espinosa field.

Settlement monument installed

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-16
DATE DRILLED: 1-4-85
EQUIPMENT USED: CME 55
LOCATION: SE¼SE¼SW¼sec.25 T21N R8E
ELEVATION: 5713'
TOTAL DEPTH: 55.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5711	2-4	--	31	89	74	37	U	MH		Sandy Silt	0/41/59
5708	5-7	--					U	ML*		Sandy Silt*	
5704	9-11	--	11	81	NV	NP	U	SM		Silty Sand	0/53/47
5699	14-16	--	3	108	NV	NP	U	SP-SM		Sl. Silty Sand	2/92/6
5694	19	7	8	--			D	SC*		Clayey Sand*	0/86/14
5689	24-26	--	8	101	NV	NP	U	SM		Silty Sand	0/72/28
5684	29-31	--	9	99	42	19	U	SC		Clayey Sand	0/72/28
5679	34	8	12	--			D	SC*		Clayey Sand*	0/81/19
5674	44-46	--	4	107	NV	NP	U	SP-SM		Sl. Silty Sand	5/88/7
5669	54	34	9	--			D	SC*		Clayey Sand*	0/83/17

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

Approximately 10 ft north of Quintana garage.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-17
DATE DRILLED: 1-4-85
EQUIPMENT USED: CME 55
LOCATION: SW¼SE¼SW¼sec.25, T21N R8E
ELEVATION: 5698'
TOTAL DEPTH: 100'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5696	2-4	--	6	99	NV	NP	U	SM		Silty Sand	1/79/20
5694	4-6	--					U	CL*		Silty Clay*	
5689	9-11	--	3	102	NV	NP	U	SM		Silty Sand	0/83/17
5684	14-16	--	8	89	NV	NP	U	SM		Silty Sand	0/80/20
5679	19-21	--	23	92	21	NP	U	ML		Sandy Silt	0/33/67
5674	24-26	--					U	SP-SM*		Sl. Silty Sand*	
5669	29-31	--	23	92	17	NP	U	ML		Sandy Silt	0/44/56
5659	39-41	--	12	112	27	6	U	SM-SC		Silty Clayey Sand	1/65/34
5649	49-51	--	19	97	NV	NP	U	SM		Silty Sand	0/54/46
5639	59-61	--					U	SM*		Silty Sand*	
5629	69-71	--	18	109	NV	NP	U	SM		Silty Sand	0/71/29
5619	79	17	19	--			D	SP-SM*		Sl. Silty Sand*	2/87/11
5609	89	28	25	--			D	SC*		Clayey Sand*	0/66/34
5598	100	REF	11	--			D	GW		Sandy Gravel	63/34/3

NOTES:
Approximately 200 ft west of El Llano acequia on southern margin of Gutierrez field. Water monitoring well installed.

* = field classification
REF = refusal
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-18
DATE DRILLED: 1-7-85
EQUIPMENT USED: CME 55
LOCATION: SE¼SE¼SW¼Sec.25 T21N R8E
ELEVATION: 5723'
TOTAL DEPTH: 30.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5721	2-4	--	9	87	31	12	U	SC		Clayey Sand	1/57/42
5718	5-7	--					U	SP-SM*		Sl. Silty Sand*	
5714	9	15	12	--			D	SC*		Clayey Sand*	0/58/42
5709	14-16	--	9	94	NV	NP	U	SM		Silty Sand	0/71/29
5704	19	12	7	--			D	SC*		Clayey Sand*	0/84/16
5699	24-26	--	8	95	NV	NP	U	SM		Silty Sand	0/80/20
5694	29	11	13	--			D	SM*		Silty Sand*	0/70/30

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:
50 ft east of Manzanares residence near fence. Settlement monitor well installed.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-19
DATE DRILLED: 1-7-85
EQUIPMENT USED: CME 55
LOCATION: SE¼SW¼SW¼sec.25 T21N R8E
ELEVATION: 5682'
TOTAL DEPTH: 55'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5680.5	1.5-4	--	14	112	27	7	U	SC		Clayey Sand	0/63/37
5674.5	7.5-10	--					U	SM*		Silty Sand*	
5669.5	12.5-15	--	3	104	NV	NP	U	SM		Silty Sand	0/78/22
5664.5	17.5-20	--	5	112	18	NP	U	SM		Silty Sand	0/80/20
5659.5	22.5-25	--					U	SM*		Silty Sand	
5654.5	27.5-30	--	5	98	NV	NP	U	SM		Silty Sand	0/80/20
5649.5	32.5-35	--	5	113	NV	NP	U	SM		Silty Sand	0/80/20
5644.5	37.5-40	--					U	SP-SM*		Sl. Silty Sand*	
5639.5	42.5-45	--	7	107	NV	NP	U	SP-SM		Sl. Silty Sand	0/88/12
5635	47	--		--			D	SP-SM*		Sl. Silty Sand*	
5634.5	47.5-50	--	17	115	NV	NP	U	SM		Silty Sand	0/86/14
5629.5	52.5-55	--	14	124	NV	NP	U	SP-SM		Sl. Silty Sand	2/87/11
5627	55	--	13	--			D	SP-SM*		Sl. Silty Sand*	15/75/10

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: In Gutierrez land north of A. Valdez residence. Water monitoring well installed. Water level at 5619 ft elevation as of 3-6-85.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-20
DATE DRILLED: 1-7-85
EQUIPMENT USED: CME 55
LOCATION: SE¼SE¼SW¼sec.25 T21N R8E
ELEVATION: 5713'
TOTAL DEPTH: 51'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U: Undisturbed D: Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5711	2-4	--	21	108	NV	NP	U	SM		Silty Sand	0/70/30
5708	5-7	--	12	98	NV	NP	U	SM		Silty Sand	0/73/27
5704	9-11	--					U	CH*		Sl. Sandy Clay*	
5699	14-16	--	8	102	NV	NP	U	SP-SM		Sl. Silty Sand	1/90/9
5694	19-21	--					U	SP*		Sand*	
5689	24	6	9	--			D	SM*		Silty Sand*	0/81/19
5679	34-36	--	7	108	NV	NP	U	SM		Silty Sand	0/87/13
5664	49-51	--	4	109	NV	NP	U	SP-SM		Sl. Silty Sand	1/91/8

LABORATORY DATA

NOTES: Approximately 10 ft east of Vigil residence, in front lawn. Settlement monitoring well installed.

* = field classification
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-21
DATE DRILLED: 1-8-85
EQUIPMENT USED: CME-55
LOCATION: SE¼SW¼SW¼Sec.25 T21N R8E
ELEVATION: 5680'
TOTAL DEPTH: 50'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5679	1	11	14	--	29	9	D	SC		Clayey Sand	0/68/32
5675	5	16	10	--	36	12	D	SM		Silty Sand	0/62/38
5672	8	21	2	--	18	NP	D	SM		Silty Sand	15/72/13
5666	14	20	15	--			D	SM*		Silty Sand*	0/55/45
5665.5	14.5	20		--			D	CL*		Sandy Clay*	
5665	15-17.5	-					U	SM*		Silty Sand*	
5657.5	22.5-25	-	3	107	NV	NP	U	SM		Silty Sand	0/82/18
5652.5	27.5-30	-	7	109	18	NP	U	SM		Silty Sand	0/70/30
5650	30-32.5	-					U	SM*		Silty Sand*	
5642.5	37.5-40	-	6	109	NV	NP	U	SM		Silty Sand	0/86/14
5636	44-45	-	14	102	NV	NP	U	SM		Silty Sand	2/77/21
5633	47	-	24	--	18	NP	D	SM		Silty Sand	2/85/13
5632.5	47.5-50	-	5	125	NV	NP	U	SM		Silty Sand	0/87/13

NOTES:

Approximately 30 feet south of A. Valdez residence.

*= field classification
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-22
DATE DRILLED: 1-8-85
EQUIPMENT USED: CME 55
LOCATION: NE¼SE¼SW¼Sec.25 T21N R8E
ELEVATION: 5715'
TOTAL DEPTH: 31'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5713	2-4	--	8	90	NV	NP	U	SM		Silty Sand	0/68/32
5710	5-7	--					U	ML*		Sandy Silt*	
5706	9-11	--	4	94	NV	NP	U	SM		Silty Sand	0/79/21
5701	14-16	--					U	SP-SM*		Sl. Silty Sand*	
5696	19-21	--	11	90	32	13	U	SC		Clayey Sand	0/55/45
5691	24	16	11	--			D	SM*		Silty Sand*	0/54/46
5686	29-31	--	6	89	NV	NP	U	SM		Silty Sand	0/61/39

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

West of A. Trujillo residence, approximately 10 feet from back door. Settlement monument installed.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH - 23
DATE DRILLED: 1-8-85
EQUIPMENT USED: CME-55
LOCATION: SE¼SE¼SE¼Sec.25, T21N R8E
ELEVATION: 5666'
TOTAL DEPTH: 66'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U-Undisturbed D-Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5665	1	7	26	--	41	13	D	SC		Clayey Sand	0/80/20
5661	5	11	9	--	29	6	D	SM		Silty Sand	0/72/28
5658	8	17	3	--			D	SP-SM*		Sl. Silty Sand*	0/92/8
5652	14	14		--			D	SP*		Sand*	
5651.5	14.5	14	10	--	22	NP	D	SM		Silty Sand	0/63/37
5651	15-17.5	--					U	SP-SM*		Sl. Silty Sand*	
5643.5	22.5-25	--					U	SP-SM*		Sl. Silty Sand*	
5641	25-27	--	3	103	NV	NP	U	SP-SM		Sl. Silty Sand	0/91/9
5633.5	32.5-35	--	23	104	18	NP	U	SM		Silty Sand	0/80/20
5631	35	--	24	--	24	NP	D	SM		Silty Sand	0/60/40
5626	40	8	39	--	54	11	D	SC		Clayey Sand	0/78/22
5616	50	8	33	--	56	32	D	SC		Clayey Sand	0/69/31
5606	60	REF	8	--			D	SM*		Silty Sand*	14/61/25
5600	65	50	3	--			D	GW*		Sandy Gravel*	

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: Approximately 1000 ft west of A. Valdez residence, on western end of Valdez property. Water monitoring well installed.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-24
DATE DRILLED: 1-8-85
EQUIPMENT USED: CME 55
LOCATION: NE¼SE¼SW¼sec.25 T21N R8E
ELEVATION: 5710'
TOTAL DEPTH: 50.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5708	2-4	--	10	82	28	7	U	ML		Sandy Silt	0/34/66
5705	5-7	--					U	ML*		Sandy Silt*	
5701	9-11	--	18	72	58	28	U	CL		Silty Clay	0/32/68
5696	14-16	--	3	99	NV	NP	U	SP-SM		Sl. Silty Sand	0/94/6
5691	19-21	--					U	SP-SM*		Sl. Silty Sand*	
5686	24-26	--	2	103	NV	NP	U	SM		Silty Sand	3/83/14
5684	26	27	1	--			D	SP*		Sand*	
5676	34-36	--	4	95	NV	NP	U	SM		Silty Sand	0/76/24
5661	49	37	--	--	--	--	D	--	--	No Recovery	

NOTES:
On upper flats west of depression in Moya's field.
Settlement monument installed.

* = field classification

NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-25
DATE DRILLED: 1-9-85
EQUIPMENT USED: CME 55
LOCATION: SW¼SW¼SE¼sec.25 T21N R8E
ELEVATION: 5724'
TOTAL DEPTH: 123'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	LABORATORY DATA DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5723	1	13	14	--			D	SM*		Silty Sand*	
5719	5	11	4	--			D	SM*		Silty Sand*	
5716	8	41	1	--			D	SP*		Sand*	
5710	14	35	2	--			D	SP-SM*		Sl. Silty Sand*	
5709	15-17	--	3	117	NV	NP	U	SP-SM		Sl. Silty Sand	12/77/11
5707	17	--	1	--			D	SM*		Silty Sand*	
5704	20-22.5						U	SM*		Silty Sand*	
5701.5	22.5	--	1	--			D	SM*		Silty Sand*	
5699	25-27.5	--	4	102	20	NP	U	SM		Silty Sand	2/76/22
5696.5	27.5		3	--			D	SP*		Sand*	
5694	30-32.5	--	4	96	NV	NP	U	SM		Silty Sand	0/77/23
5691.5	32.5	--	1	--			D	SM*		Silty Sand*	
5689	35-37.5	--					U	SM*		Silty Sand*	
5686.5	37.5	--	1	--			D	SM*		Silty Sand*	
5684	40-42.5	--	3	114	NV	NP	U	SM		Silty Sand	5/78/17
5681.5	42.5	--	1	--			D	SM*		Silty Sand*	
5679	45-47.5	--	7	105	NV	NP	U	SM		Silty Sand	0/77/23
5676.5	47.5	--	4	--			D	SP-SM*		Sl. Silty Sand*	
5674	50-52.5	--					U	SM*		Silty Sand*	
5671.5	52.5	--	4	--			D	SP-SM*		Sl. Silty Sand*	
5664	60-62.5	--	3	115	NV	NP	U	SM		Silty Sand	0/76/24
5661.5	62.5	--	3	--			D	SM*		Silty Sand*	
5659	65-67	--	2	115	NV	NP	U	SM		Silty Sand	0/81/19
5656.5	67.5	--	2	--			D	SM*		Silty Sand*	
5644	80	38	10	--			D	SM*		Silty Sand*	
5634	90	55	2	--			D	SP*		Sand*	
5624	100	36	12	--			D	SP*		Sand*	
5614	110	28	15	--			D	SP-SM*		Sl. Silty Sand*	

NOTES: Page 1 of 2
Approximately 40 feet west of highway on extreme east end of Felipe Valdez's land. Water monitoring well installed.
Water level at 5615 ft. elevation as of 3-5-85.

NV=no value
NP=non-plastic

* = field classification

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-25
DATE DRILLED: 1-9-85
EQUIPMENT USED: CME 55
LOCATION: SW¼SW¼SE¼sec.25 T21 N R8E
ELEVATION: 5724'
TOTAL DEPTH: 123'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5604	120	REF	19	--			D	GW*		Sandy Gravel*
5601	123	REF		--			D			No Recovery

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: Page 2 of 2

* = field classification
REF = refusal
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-26
DATE DRILLED: 1-9-85
EQUIPMENT USED: CME 55
LOCATION: SE¼SE¼SW¼Sec.25 T21N R8E
ELEVATION: 5714'
TOTAL DEPTH: 30.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5712	2-4	-	9	95	20	NP	U	SM		Silty Sand 0/71/29
5709	5-7	-					U	ML*		Sandy Silt*
5705	9-11	-	8	93	32	11	U	ML		Sandy Silt 0/47/53
5700	14-16	-					U	SM*		Silty Sand*
5795	19-21	-	5	96	19	NP	U	SM		Silty Sand 6/64/30
5790	24-26	-	2	103	NV	NP	U	SP-SM		Sl. Silty Sand 1/93/6
5785	29	40	1	--			D	SM*		Silty Sand*

NOTES:

Approximately 50 feet east of A. Vigil residence, in front of mobile home.

* = field classification
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-27
DATE DRILLED: 1-10-85
EQUIPMENT USED: CME 55
LOCATION: NE¼SE¼SW¼Sec.25 T21N R8E
ELEVATION: 5711'
TOTAL DEPTH: 50'

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5710	1-2.5	--	6	90	22	NP	U	SM		Silty Sand	0/78/22
5709	2-4.5	--	2	94	NV	NP	U	SM		Silty Sand	0/80/20
5706	5-7.5	--					U	SM*		Silty Sand*	
5701	10	--	8	--			D	ML*		Silt*	
5700.5	10.5-12	--	20	88	NV	NP	U	SP-SM		Sl. Silty Sand	2/88/10
5695	16-18.5	--					U	SM*		Silty Sand*	
5692.5	18.5	--	9	--			D	SM*		Silty Sand*	
5691	20	--	10	--			D	SM*		Silty Sand*	
5690.5	20.5-23	--	13	109	20	NP	U	SM		Silty Sand	0/64/36
5688	23	--	1	--			D	SP-SM*		Sl. Silty Sand*	
5685.5	25.5-28	--	20	98	33	11	U	CL		Sandy Clay	0/42/58
5683	28	--	9	--			D	SM*		Silty Sand*	
5681	30-31.5	--					U	SM*		Silty Sand*	
5679.5	31.5	--	6	--			D	SM*		Silty Sand*	
5675.5	35.5	--	11	--			D	SC*		Clayey Sand*	
5675	36-38.5	--	5	102	NV	NP	U	SM		Silty Sand	0/81/19
5672.5	38.5	--	1	--			D	SP-SM*		Sl. Silty Sand*	
5671	40-42.5	--	3	110	NV	NP	U	SM		Silty Sand	2/82/16
5668.5	42.5	--	3	--			D	SM*		Silty Sand*	
5666	45	--	3	--			D	SM*		Silty Sand*	
5665.5	45.5-48	--	3	106	NV	NP	U	SM		Silty Sand	0/81/19
5663	48	--	4	--			D	SM*		Silty Sand*	

NOTES:

Approximately 30 feet north of A. Vigil residence.
Sondex casing installed to 42' depth.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH - 28
DATE DRILLED: 1-9-85
EQUIPMENT USED: CME 55
LOCATION: NW¼NE¼SW¼ sec.25 T21N R8E
ELEVATION: 5702'
TOTAL DEPTH: 50.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5700	2-4	--	4	103	NV	NP	U	SP-SM		Sl. Silty Sand	0/91/9
5697	5-7	--	2	101	NV	NP	U	SP-SM		Sl. Silty Sand	0/94/6
5693	9-11	--					U	SP*		Sand*	
5688	14-16	--	11	87	NV	NP	U	SM		Silty Sand	0/65/35
5683	19-21	--					U	SP*		Sand*	
5678	24-26	--	3	106	NV	NP	U	SP-SM		Sl. Silty Sand	0/92/8
5673	29	17	23	--			D	MH*		Clayey Silt*	
5668	34	13	28	--			D	CH*		Sandy Clay*	
5663	39	11	8	--			D	SP-SM*		Sl. Silty Sand*	
5658	44-46	--	20	93	37	16	U	CL		Silty Clay	0/16/84
5653	49	20	29	--			D	CH*		Clay*	

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:
Adjacent to driveway at El Llano Beauty Salon.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-29
DATE DRILLED: 1-11-85
EQUIPMENT USED: CME 55
LOCATION: NE¼SE¼SW¼Sec.25 T21N R8E
ELEVATION: 5714'
TOTAL DEPTH: 55'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5713	1-2.5	--	14	94	22	NP	U	SM		Silty Sand 0/50/50
5709	5-7.5	--					U	SM*		Silty Sand*
5704	10	--	17	--			D	SM*		Silty Sand*
5703	11-13.5	--	12	100	23	NP	U	SM		Silty Sand 0/70/30
5699	15-17.5	--					U	CL*		Sandy Clay*
5694	20	--	19	--			D	CL*		Sandy Clay*
5693.5	20.5-23	--	17	105	29	9	U	SM		Silty Sand 0/59/41
5689	25-27.5	--					U	SP-SM*		Sl. Silty Sand*
5684	30-32.5	--	15	108	19	NP	U	SM		Silty Sand 0/65/35
5679	35	--	13	--			D	SM*		Silty Sand*
5678.5	35.5-38	--	13	111	NV	NP	U	SM		Silty Sand 2/67/31
5674	40-42.5	--					U	SM*		Silty Sand*
5669	45-47.5	--	11	106	NV	NP	U	SM		Silty Sand 0/88/12
5666.5	47.5	--	4	--			D	SP*		Sand*
5664	50	--	24	--			D	CL*		Sandy Clay*
5663	51-53.5	--	11	110	NV	NP	U	SM		Silty Sand 3/71/26

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

In field west of Moya residence on north side of subsidence pit.
Installed Sondex casing to 47 feet.

* = field classification.

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-30
DATE DRILLED: 1-10-85
EQUIPMENT USED: CME 55.
LOCATION: NE¼SE¼SW¼sec.25 T21N R8E
ELEVATION: 5718'.
TOTAL DEPTH: 40.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5716	2-4	--	4	92	NV	NP	U	SM		Silty Sand	0/77/23
5713	5-7	--					U	SM*		Silty Sand*	
5709	9-11	--	19	84	57	29	U	CL		Sandy Clay	0/42/58
5704	14-16	--	6	89	24	NP	U	SM		Silty Sand	0/51/49
5699	19-21	--					U	SW*		Gravelly Sand*	
5694	24	22	2	--			D	SM*		Silty Sand*	
5689	29-31	--	14	83	40	17	U	CL		Silty Clay	0/25/75
5684	34-36	--	3	103	17	NP	U	SM		Silty Sand	0/82/18
5679	39	78	1	--			D	SW*		Gravelly Sand*	

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: In field between Middle road and highway, approximately 25 feet from Middle Road

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-31
DATE DRILLED: 1-14-85
EQUIPMENT USED: CME 55
LOCATION: SE¼SE¼SW¼sec.25 T21N R8E
ELEVATION: 5714'
TOTAL DEPTH: 110'

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5713	1-2.5	--	21	84	55	27	U	CL		Silty Clay	0/20/80
5709	5-7.5	--					U	SM*		Silty Sand*	
5704	10-12.5	--	5	103	NV	NP	U	SM		Silty Sand	0/79/21
5699	15-17.5	--	2	113	NV	NP	U	SP-SM		Sl. Silty Sand	9/83/8
5694	20-22.5	--	17	105	44	22	U	CL		Silty Clay	0/33/67
5689	25-27.5						U	SM*		Silty Sand*	
5684	30-32.5	--	5	107	NV	NP	U	SM		Silty Sand	1/85/14
5681	33	--	4	--			D	SM*		Silty Sand*	0/86/14
5675	39-41	--	6	103	NV	NP	U	SM		Silty Sand	0/87/13
5665	49-51	--	5	105	NV	NP	U	SP-SM		Sl. Silty Sand	6/86/8
5655	59	21	--	--	--	--	D	--	--	No recovery	
5645	69	36	6	--			D	SP-SM*		Sl. Silty Sand*	0/89/11
5635	79	29	24	--	32	12	D	SC		Clayey Sand	0/71/29
5625	89	32	18	--			D	SM*		Silty Sand*	0/81/19
5615	99	24	17	--	20	NP	D	SM		Silty Sand	0/69/31
5605	109	REF	24	--			D	CL*		Sandy Clay*	
5604.5	109-.5	REF	15	--			D	SW		Gravelly Sand	45/49/6

NOTES: Approximately 7 feet from Felipe Valdez front porch on west side of residence. Installed water monitoring well with Sondex casing to 65 feet. Water level at 5627 ft. elevation as of 3-6-85.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-32
DATE DRILLED: 1-10-85
EQUIPMENT USED: CME 55
LOCATION: SE¼SE¼SW¼sec.25 T21N R8E
ELEVATION: 5716'
TOTAL DEPTH: 36'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5714	2-4	--	6	83	28	4	U	ML		Sandy Silt	0/46/54
5711	5-7	--					U	SP*		Sand*	
5707	9-11	--	5	86	24	NP	U	SM		Silty Sand	0/72/28
5702	14-16	--	3	98	NV	NP	U	SM		Silty Sand	2/82/16
5697	19-21	--					U	ML*		Sandy Silt*	
5692	24-26	--	4	93	17	NP	U	SM		Silty Sand	0/75/25
5687	29	19	5	--			D	SP-SM*		Sl. Silty Sand*	
5682	34-36	--	5	92	NV	NP	U	SM		Silty Sand	0/68/32

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:
In northwest corner of Gutierrez field approximately 30 feet east of Middle Road. Sondex casing installed.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-33
DATE DRILLED: 1-14-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼SE¼sec.26 T21N R8E
ELEVATION: 5656'
TOTAL DEPTH: 35.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5654	2-4	--	11	79	37	10	U	ML		Sandy Silt	0/19/81
5651	5-7	--	15	80	40	12	U	ML		Sandy Silt	0/34/66
5647	9-11	--					U	SM*		Silty Sand*	
5642	14-16	--	5	91	NV	NP	U	SM		Silty Sand	0/79/21
5637	19-21	--	4	98	NV	NP	U	SP-SM		Sl. Silty Sand	0/90/10
5632	24-26	--					U	SP-SC*		Sl. Clayey Sand*	
5627	29-31	--	7	110	NV	NP	U	SP-SM		Sl. Silty Sand	0/91/9
5622	34	6	29	--			D	SP*		Sand*	

NOTES: Approximately 30 feet south of Calle Gallegos in field between Gallegos residence and McCurdy road.

* = field classification
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-34
DATE DRILLED: 1-11-84
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1 T20N R8E
ELEVATION: 5723'
TOTAL DEPTH: 51'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5721	2-4	--	18	92	29	10	U	SC		Clayey Sand	0/60/40
5718	5-7	--					U	SP-SC*		Sl. Clayey Sand*	
5714	9-11	--	17	88	NV	NP	U	SM		Silty Sand	0/57/43
5709	14-16	--	8	94	19	NP	U	SM		Silty Sand	4/73/23
5704	19-21	--					U	SP-SM*		Sl. Silty Sand*	
5699	24	9	14	--			D	SC*		Clayey Sand*	
5694	29-31	--	9	101	17	NP	U	SM		Silty Sand	0/77/23
5684	39-41	--	20	94	31	11	U	CL		Sandy Clay	0/38/62
5674	49-51	--	--	--	--	--	U	--		No Recovery	

NOTES:
In field south of Yelvington residence, approximately 80 feet west of highway. Sondex casing installed.

* = field classification
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-35
DATE DRILLED: 1-15-85
EQUIPMENT USED: CME-55
LOCATION: NE¼SE¼SW¼Sec.25 T21N R8E
ELEVATION: 5721'
TOTAL DEPTH: 49.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5719	2-4	--	4	94	23	NP	U	SM		Silty Sand	0/83/17
5717	4-6	--	3	105	NV	NP	U	SM		Silty Sand	0/87/13
5713	8-10	--					U	SM*		Silty Sand*	
5708	13-15	--	15	75	40	15	U	CL		Clay	0/12/88
5703	18-19	--	--	--	--	--	U	--	--	No Recovery	
5702	19	38	1	--			D	SP-SM*		Sl. Silty Sand*	
5697	24	19	10	--			D	CL*		Silty Clay*	
5693	28-30	--	5	96	20	NV	U	SM		Silty Sand	0/72/28
5688	33-35	--					U	SP-SM*		Sl. Silty Sand*	
5683	38-40	--	9	86	31	7	U	ML		Sandy Silt	0/37/63
5678	43-44.5	--	4	98	24	NP	U	SM		Silty Sand	4/72/24
5673	48	REF	4	--			D	SP-SM*		Sl. Silty Sand*	

NOTES:

Approximately 60 feet east of highway at junction with Middle Road.

* = field classification
REF = refusal
NV = no value
NP = non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-36
DATE DRILLED: 1-15-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NW¼SW¼Sec.25 T21N R8E
ELEVATION: 5680'
TOTAL DEPTH: 50.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5678	2-4	--	3	95	NV	NP	U	SM		Silty Sand	0/85/15
5675	5-7	--					U	SP*		Sand*	
5671	9-11	--	5	92	20	NP	U	SM		Silty Sand	0/75/25
5666	14-16	--					U	ML*		Sandy Silt*	
5661	19-21	--	13	94	27	NP	U	SM		Silty Sand	0/63/37
5656	24-26	--	15	99	28	NP	U	SM		Silty Sand	0/63/37
5651	29	7	33	--			D	CH*		Clay*	
5646	34-36	--	28	93	NV	NP	U	SM		Silty Sand	0/70/30
5641	39	26	17	--			D	CH*		Clay*	
5636	44	23	12	--			D	SM*		Silty Sand*	
5631	49	13	16	--			D	SM*		Silty Sand*	

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

Approximately 75 feet east of Gallegos salvage yard.
Water monitoring well with Sondex casing installed.
Water level at 5631 ft. elevation as of 3-6-85.

NV=no value
NP=non-plastic

* = field classification

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-37
DATE DRILLED: 1-15-85
EQUIPMENT USED: CME-55
LOCATION: NE¼SE¼SW¼sec.25 T21N R8E
ELEVATION: 5721'
TOTAL DEPTH: 29.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	LABORATORY DATA DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5719	2-4	--	4	102	18	NP	U	SM		Silty Sand	0/74/26
5717	4-6	--	5	91	NV	NP	U	SM		Silty Sand	1/74/25
5715	6	13	10	--			D	SM*		Silty Sand*	
5713	8	12	3	--			D	SM*		Silty Sand*	
5708	13-15	--					U	SM*		Silty Sand*	
5703	18-20	--	6	93	NV	NP	U	SM		Silty Sand	0/72/28
5698	23	17	1	--			D	SP-SM*		Sl. Silty Sand*	
5693	28	13	4	--			D	SP*		Sand*	

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: Approximately 60 feet east of highway across from Trujillo residence.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-38
DATE DRILLED: 3-27-85
EQUIPMENT USED: CME-55
LOCATION: SW¼NE¼SE¼sec.26 T21N R8E
ELEVATION: 5654'
TOTAL DEPTH: 45.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5652	2-4	--	18	95	77	45	U	CH		Silty Clay	0/39/61
5649	5-7	--	27	86	78	43	U	SC		Clayey Sand	0/52/48
5645	9-11	--					U	SP*		Sand*	
5640	14-16	--	6	107	NV	NP	U	SP-SM		Sl. Silty Sand	0/90/10
5635	19-21	--	36				U	CH*		Clay*	
5630	24-26	--	19	103	21	NP	U	SM		Silty Sand	0/83/17
5625	29	10	35	--			D	SP-SM*		Sl. Silty Sand*	
5620	34	28	32	--			D	CH*		Clay*	
5615	39	9	28	--			D	CH*		Clay*	
5610	44	15	23	--			D	SC*		Clayey Sand*	

NOTES:
On Alarid property approximately 100 feet east of McCurdy road.
Water monitoring well installed.
Water level at 5626 ft. elevation as of 3-6-85.

* = field classification
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-39
DATE DRILLED: 1-15-85
EQUIPMENT USED: CME-55
LOCATION: NE¼SE¼SW¼sec.25 T21N R8E
ELEVATION: 5718'
TOTAL DEPTH: 103'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
			LABORATORY DATA								
5716	2-4	--	4	90	NV	NP	U	SM		Silty Sand	0/78/22
5714	4-6	--	6	92	23	NP	U	SM		Silty Sand	0/60/40
5710	8-10	--					U	SM*		Silty Sand*	
5705	13-15	--	14	74	46	19	U	ML		Silt	0/14/86
5700	18-20	--					U	SM*		Silty Sand*	
5695	23-25	--	10	86	37	14	U	CL		Sandy Clay	0/48/52
5690	28-30	--	12	78	35	13	U	CL		Silty Clay	0/21/79
5685	33	47	1	--			D	SM*		Silty Sand*	
5680	38	14	5	--			D	SM*		Silty Sand*	
5675	43	32	1	--			D	SP-SM*		Sl. Silty Sand*	
5670	48	23	2	--			D	SM*		Silty Sand*	
5660	58	29	8	--			D	SM*		Silty Sand*	
5650	68	50	1	--			D	SP-SM*		Sl. Silty Sand*	
5638	80	45	14	--			D	SP*		Sand*	
5628	90	26	12	--			D	SP*		Sand*	
5618	100	1		--			D	SP*		Sand*	

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

Approximately 40 feet east of Moya residence. Water monitoring well with Sondex casing installed.

Water level at 5621 ft. elevation as of 3-7-85.

*= field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-40
DATE DRILLED: 1-16-85
EQUIPMENT USED: CME-55
LOCATION: SW¼NW¼SW¼sec.25 T21N R8E
ELEVATION: 5682'
TOTAL DEPTH: 51.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5680	2-4	--	6	95	NV	NP	U	SM		Silty Sand	0/77/23
5677	5-7	--	25	103	48	28	U	CL		Sandy Clay	5/44/51
5673	9-11	--					U	CL*		Sandy Clay*	
5668	14-16	--	10	99	24	NP	U	SM		Silty Sand	0/74/26
5663	19-21	--					U	SP*		Sand*	
5658	24-26	--	34	88	82	47	U	CH		Clay	0/15/85
5653	29-31	--	32	92	61	30	U	CH		Clay	0/2/98
5648	34	15	18	--			D	CH*		Clay*	
5643	39	15	26	--			D	CH*		Clay*	
5638	44	19	7	--			D	CH*		Clay*	
5633	49	17	18	--			D	SC*		Clayey Sand*	
5631.5	50.5	15	23	--			D	SP*		Sand*	

NOTES:
On Bellas Drive, approximately 40 feet south of Martinez residence. Water monitoring well installed. Water level at 5633 ft. elevation as of 2-21-85.

*= field classification
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-41
DATE DRILLED: 1-17-85
EQUIPMENT USED: CME 55
LOCATION: NE¼SE¼SW¼sec.25, T21N R8E
ELEVATION 5710'
TOTAL DEPTH: 110'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5708	2-4	--					U	SM*		Silty Sand*
5702	8-10	--					U	SP-SM*		Sl. Silty Sand*
5692	18-20	--					U	CL*		Sandy Clay*
5690	20	--	17	--			D	CL*		Sandy Clay*
5682	28-30	--					U	SM*		Silty Sand*
5672	38-40	--					U	SM*		Silty Sand*
5662	48	18	3	--			D	SM*		Silty Sand*
5652	58	28	3	--			D	SM*		Silty Sand*
5642	68	55	4	--			D	SM*		Silty Sand*
5632	78	50	11	--			D	SP-SM*		Sl. Silty Sand*
5622	88	20	19	--			D	SM*		Silty Sand *
5612	98	27	16	--			D	CL*		Silty Clay*
5602	108	REF		--			D	GW*		Sandy Gravel*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: Approximately 300 ft west of Moya residence. Settlement and water monitoring well installed.

* = field classification
REF = refusal
NV= no value
NP= non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-42
DATE DRILLED: 1-17-85
EQUIPMENT USED: CME-55
LOCATION: NE¼SE¼NE¼sec.23 T21N R8E
ELEVATION: 5686'
TOTAL DEPTH: 65.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5684	2-4	--	7	101	NV	NP	U	SM		Silty Sand	1/87/12
5681	5-7	--					U	SP*		Sand*	
5677	9-11	--	3	96	NV	NP	U	SP-SM		Sl. Silty Sand	1/93/6
5672	14-16	--					U	SP-SM*		Sl. Silty Sand*	
5667	19-21	--	5	98	NV	NP	U	SM		Silty Sand	0/78/22
5662	24-26	--	3	106	NV	NP	U	SP-SM		Sl. Silty Sand	0/90/10
5657	29	29	14				D	CL*		Sandy Clay*	
5652	34-36	--	4	103	NV	NP	U	SM		Silty Sand	0/85/15
5647	39-41	--					U	SM*		Silty Sand*	
5642	44-46	--	8	96	21	NP	U	SM		Silty Sand	0/68/32
5637	49	37	20				D	CH*		Sl. Sandy Clay*	
5627	59	25	26				D	CH*		Clay*	
5622	64	REF	25				D	SP*		Sand*	

NOTES:
Approximately 500 feet east of San Juan Bingo parlor.

* = field classification
REF = ref
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-43
DATE DRILLED: 1-18-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼SE¼ Sec. 36 T21N R8E
ELEVATION: 5744'
TOTAL DEPTH: 41'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5742	2-4	--	9	92	NV	NP	U	SM		Silty Sand	1/73/26
5740	4-6	--	5	91	16	NP	U	SM		Silty Sand	0/75/25
5736	8-10	--					U	SP-SM*		Sl. Silty Sand*	
5731	13-15	--	7	98	NV	NP	U	SM		Silty Sand	0/83/17
5726	18-20	--	4	103	NV	NP	U	SP-SM		Sl. Silty Sand	0/89/11
5721	23-25	--					U	SM*		Silty Sand*	
5716	28-30	--	9	95	17	NP	U	SM		Silty Sand	0/79/21
5711	33-35	--	6	99	NV	NP	U	SM		Silty Sand	0/80/20
5706	38-40	--					U	SM*		Silty Sand*	
5704	40	41	6	--			D	SM*		Silty Sand*	
5703	41	41	2	--			D	SP*		Sand*	

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: Approximately 150 feet north of Espanola High School, adjacent to school driveway.

*= field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-44
DATE DRILLED: 1-18-85
EQUIPMENT USED: CME-55
LOCATION: SW¼SE¼SE¼ Sec. 36 T21N R8E
ELEVATION: 5725'
TOTAL DEPTH: 43.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5723	2-4	--	8	80	26	8	U	SC		Clayey Sand	0/58/42
5721	4	--	--	--	--	--	U			No Recovery	
5718	7	30	7	--			D	SM*		Silty Sand*	
5713	12	20	1	--			D	SW*		Gravelly Sand*	
5708	17-19	--	4	92	NV	NP	U	SM		Silty Sand	14/67/19
5703	22-24	--					U	SM*		Silty Sand*	
5698	27-29	--	6	99	16	NP	U	SM		Silty Sand	0/78/22
5693	32	21	4	--			D	SM*		Silty Sand*	
5688	37	15	8	--			D	SM*		Silty Sand*	
5683	42	7	6	--			D	SM*		Silty Sand*	

NOTES: Approximately 20 feet north of Spiers residence south of Espanola High School

*= field classification
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: ESPDH-45
DATE DRILLED: 3-7-85
EQUIPMENT USED: CME 55
LOCATION: SW¼SW¼SE¼sec.36, T21N R8E
ELEVATION: 5700'
TOTAL DEPTH: 100'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
				LABORATORY DATA						
5696	4	9	4	--			D	SP-SM*		Sl. Silty Sand*
5686	14	16	4	--			D	SM*		Silty Sand*
5676	24	14	6	--			D	SP*		Sand*
5666	34	14	13	--			D	SM*		Silty Sand*
5656	44	14	8	--			D	SP*		Sand*
5646	54	19	7	--			D	SW*		Gravelly Sand*
5636	64	19	14	--			D	SP-SM*		Sl. Silty Sand*
5626	74	10	17	--			D	SM*		Silty Sand*
5616	84	17	22	--			D	SM*		Silty Sand*
5601	99	15	21	--			D	SM*		Silty Sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

Approximately 20 ft from northern margin of Cook's field west of Acequia. Water monitoring well installed.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSI-1
DATE DRILLED: 2-7-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 36.5

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5731	2-4	--					U	SM*		Silty sand*	
5729	4	12	6	--			D	SP		Sand	0/96/4
5724	9-11	--	6		NV	NP	U	SM		Silty sand	0/68/32
5719	14	15	7	--	20	11	D	SP		Sand	1/97/2
5714	19-21	--	6	88			U	SM*		Silty sand*	
5709	24	13	8	--			D	SP-SM*		Sl. silty sand*	0/92/8
5704	29-31	--	8	85			U	SP*		Sand	
5699	34	37	9	--			D	SM*		Silty sand*	0/85/15

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:
GGSS Area 1 injection well.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSI-2
DATE DRILLED: 2-8-85
EQUIPMENT USED: CME-55
LOCATION: SE¼SW¼SE¼sec.36 T21N R8E
ELEVATION: 5695'
TOTAL DEPTH: 35.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	LABORATORY DATA DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION	Gravel/Sand/Fines (%)
5693	2-4	--	3				U	SM*		Silty sand*	
5691	4	11	4	--			D	SC*		Clayey sand*	0/88/12
5686	9-11	--	2	96	NV	NP	U	SP-SM*		Sl. silty sand*	0/94/6
5681	14	23	6	--			D	SW		Gravelly sand	18/79/3
5676	19-21	--	9	88			U	SC*		Clayey sand*	
5671	24	14	10	--			D	SM*		Silty sand*	
5666	29-31	--	7				U	SP-SC*		Sl. Clayey Sand*	
5661	34	28	6	--			D	SW		Gravelly sand	16/81/3

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: GGSS Area 2 injection well.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

BORING: GGSSI-3
DATE DRILLED: 3-8-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1 T20N R8E
ELEVATION: 5734'
TOTAL DEPTH: 10'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U: Undisturbed D: Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5734	0-2	--					U	SM*		Silty sand*
5732	2-4	--					U	SP*		Sand*
5730	4-6	--					U	SW*		Gravelly sand*
5728	6-8	--					U	SM*		Silty sand*
5726	8-10	--					U	SP-SM*		Sl. silty sand*

NOTES: GGSS Area 3 injection well.

* = field classification

NV = no value
NP = non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSI-4
DATE DRILLED: 5-6-85
EQUIPMENT USED: Mobile B61
LOCATION: NW¼NE¼NE¼sec.1 T20N R8E
ELEVATION: 5734.5'
TOTAL DEPTH: 11'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U:Undisturbed D:Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5732.5	2	6		--			D	SM-SC*		Silty clayey sand*
5730.5	4	7		--			D	SM*		Silty sand*
5725.5	9	8		--			D	SP-SM*		Sl. silty sand*

NOTES:
GGSS Area 4 injection well.

* = field classification

NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSI-5
DATE DRILLED: 5-6-85
EQUIPMENT USED: Mobile B61
LOCATION: NW¼NE¼NE¼sec.1 T20N R8E
ELEVATION: 5734.5'
TOTAL DEPTH: 12'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5732.5	2	8		--			D	SM*		Silty sand*
5730.5	4	10		--			D	SW*		Gravelly sand*
5725.5	9	9		--			D	SP*		Sand*

NOTES:

GGSS Area 4 injection well.

* = field classification

NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSI-6
DATE DRILLED: 5-7-85
EQUIPMENT USED: Mobile B61
LOCATION: NW¼NE¼NE¼sec.1 T20N R8E
ELEVATION: 5734.5'
TOTAL DEPTH: 12'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5732.5	2	7		--			D	SM*		Silty sand*
5730.5	4	12		--			D	SP*		Silty sand*
5725.5	9	26		--			D	SP*		Silty sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

GGSS Area 4 injection well.

* = field classification

NV= no value
NP= non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSI-7
DATE DRILLED: 5-7-85
EQUIPMENT USED: Mobile B61
LOCATION: NW¼NE¼NE¼sec.1 T20N R8E
ELEVATION: 5734.5'
TOTAL DEPTH: 12'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5732.5	2	10		--			D	SM*		Silty sand*
5730.5	4	8		--			D	SP-SM*		Sl. silty sand*
5725.5	9	11		--			D	SM*		Silty sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

GGSS Area 4 injection well.

* = field classification

NV=no value

NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSI-8
DATE DRILLED: 5-7-85
EQUIPMENT USED: Mobile B61
LOCATION: NW¼NE¼NE¼sec.1 T20N R8E
ELEVATION: 5734.5'
TOTAL DEPTH: 12'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5732.5	2	12		--	-	-	D	-	-	No recovery
5730.5	4	9		--			D	SM*		Silty sand*
5725.5	9	11		--			D	SM*		Silty sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

GGSS Area 4 injection well.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-1
DATE DRILLED: 2-5-85
EQUIPMENT USED: CME-55
LOCATION: SE¼SE¼SE¼sec.36, T21N R8E
ELEVATION: 5746'
TOTAL DEPTH: 49.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE (U=Undisturbed D=Disturbed)	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5744	2-4	--					U	CL*		Silty clay*
5742	4	4	13	--	19	NP	D	SM		Silty sand 0/55/45
5737	9-11	--	7	82			U	SM*		Silty sand*
5732	14	29	14	--			D	SM*		Silty sand*
5727	19	REF	15	--			D	CH*		Clay*
5722	24	REF	16	--			D	CH*		Clay*
5717	29	50	20	--			D	CH*		Clay*
5712	34	REF	15	--			D	CH*		Clay*
5707	39	REF	9	--			D	GW*		Sandy gravel*
5702	44	REF	15	--			D	CL*		Silty clay*
5697	49	REF	15	--			D	CL*		Silty clay*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:
Between GGSS Area 1 and Cook's Hacienda. Settlement monitoring well installed.

* = field classification
REF = refusal
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

BORING: GGSSS-2
DATE DRILLED: 2-5-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 45.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5731	2-4	--	7	89			U	SM*		Silty sand*
5729	4	8	7	--			D	ML*		Sandy silt*
5724	9-11	--					U	SM*		Silty sand*
5719	14	13	7	--			D	SP*		Sand*
5714	19-21	--	6	92			U	SM*		Silty sand*
5709	24	26	6	--			D	SM*		Silty sand*
5704	29-30	--					U	SM*		Silty sand*
5699	34	35	8	--			D	ML*		Sandy silt*
5694	39	REF	13	--			D	CL*		Sandy clay*
5689	44	REF	15	--			D	CL*		Silty clay*

NOTES:
GGSS Area 1 Sondex well.

* = field classification
REF = refusal

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-3
DATE DRILLED: 2-5-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 45.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5731	2-4	--	7	85			U	SP-SM*		Slightly silty sand*
5729	4	12	11	--			D	ML*		Sandy silt*
5724	9-11	--	8	91			U	SP*		Sand*
5719	14	17	5	--			D	SW*		Sand*
5714	19-21	--	4	96			U	SM*		Silty sand*
5709	24	21	7	--			D	SM*		Silty sand*
5704	29-31	--	10	85			U	ML*		Clayey silt*
5699	34	42	10	--			D	ML*		Sandy silt*
5694	39	REF	16	--			D	CL*		Sandy clay*
5689	44	REF	18	--			D	CH-CL*		Slightly silty clay*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

GGSS Area 1 Sondex well.

* = field classification
REF = refusal

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-4
DATE DRILLED: 2-6-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 44.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5731	2-4	--	7	88			U	SM*		Silty sand*
5729	4	9	13	--			D	SP-SM*		Slightly silty sand*
5724	9-11	--	6	93			U	SP-SM*		Slightly silty sand*
5719	14	16	6	--			D	SW*		Gravelly sand*
5714	19-21	--	6	92			U	SM*		Silty sand*
5704	29-31	--	8	93			U	ML*		Clayey silt*
5699	34	41	10	--			D	SM*		Silty sand*
5694	39	REF	24	--			D	CL*		Silty clay*
5689	44	REF	16	--			D	CL*		Sandy clay*

NOTES:
GGSS Area 1 Sondex well.

* = field classification
REF = refusal
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

BORING: GGSSS-5
DATE DRILLED: 2-6-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 44.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5731	2-4	--	7	86			U	SM*		Silty sand*
5729	4	11	7	--			D	SC*		Clayey sand*
5724	9-11	--	6	104			U	SM*		Silty sand*
5719	14	17	3	--			D	SW*		Sand*
5714	19-21	--					U	ML*		Sandy silt*
5709	24	12	6	--			D	SM*		Silty sand*
5704	29-31	--	7	87			U	SM*		Silty sand*
5699	34	32	11	--			D	ML*		Clayey silt*
5694	39-40	--					U	CL*		Sandy clay*
5693	40	REF	15	--			D	CL*		Sandy clay*
5689	44	ref	17	--			D	CL*		Sandy clay*

NOTES:

GGSS Area 1 Sondex well.

* = field classification
REF = refusal
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-6
DATE DRILLED: 2-6-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼Sec.1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 49.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5731	2-4	--	8	84			U	SP-SM*		Slightly silty sand*
5729	4	8	11	--			D	SC*		Clayey sand*
5724	9-11	--	6	95			U	SP*		Sand*
5719	14	10	7	--			D	SP*		Sand*
5714	19	18	3	--			D	SW*		Gravelly sand*
5713.3	19.7	18	7	--			D	SM*		Silty sand*
5709	24-26	--					U	SM*		Silty sand*
5704	29	8	7	--			D	SM*		Silty sand*
5699	34-36	--	10	83			U	SM*		Silty sand*
5694	39	20	9	--			D	ML*		Sandy silt*
5689	44	REF	14	--			D	CL*		Silty sand*
5684	49	REF	12	--			D	CL*		Sandy clay*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

GGSS Area 1 Sondex well.

* = field classification
REF = refusal
NV = no value
NP = non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-7
DATE DRILLED: 2-6-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 49.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5731	2-4	--	5	89			U	SM*		Silty sand*
5729	4	9	13	--			D	SC*		Clayey sand*
5724	9-11	--					U	SP-SM*		Slightly silty sand*
5719	14	10	7	--			D	SM*		Silty sand*
5714	19-21	--	6	92			U	SM*		Silty sand*
5709	24	20	5	--			D	SM*		Silty sand*
5704	29	11	7	--			D	SP*		Sand*
5699	34-36	--					U	SP-SM*		Slightly silty sand*
5694	39	18	8	--			D	ML*		Sandy silt*
5689	44	REF	18	--			D	CL*		Silty clay*
5684	49	REF	14	--			D	CL*		Sandy clay*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:
GGSS Area 1 Sondex well.

* = field classification
REF = refusal
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-8
DATE DRILLED: 2-7-85
EQUIPMENT USED: CME-55
LOCATION: SE¼SW¼SE¼se.36, T21N R8E
ELEVATION: 5695'
TOTAL DEPTH: 45.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5693	2-4	--					U	SM*		Silty sand*
5691	4	11	4	--			D	SP-SM*		Slightly silty sand*
5686	9-11	--					U	SP-SM*		Slightly silty sand*
5681	14	20	3	---			D	SW*		Gravelly sand*
5676	19-21	--					U	SP*		Sand*
5671	24	16	12	--			D	SM*		Silty sand*
5666	29-31	--					U	SP*		Sand*
5661	34	15	12	--			D	SM*		Silty sand*
5656	39-41	--					U	SP-SC*		Slightly clayey sand*
5651	44	21	6	--			D	SP-SM*		Slightly silty sand*

NOTES:

GGSS Area 2 Sondex well.

* = field classification

NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-9
DATE DRILLED: 2-7-85
EQUIPMENT USED: CME-55
LOCATION: SE¼SW¼SE¼sec.36, T21N R8E
ELEVATION: 5695'
TOTAL DEPTH: 45.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5693	2-4	--					U	SP-SM*		Slightly silty sand*
5691	4	12	4	--			D	SP*		Sand*
5686	9-11	--					U	SP-SM*		Slightly silty sand*
5681	14	25	3	--			D	SP*		Sand*
5676	19-21	--					U	SC*		Clayey sand*
5671	24	16	6	--			D	SP*		Sand*
5666	29-31	--					U	SC*		Clayey sand*
5661	34	18	8	--			D	SP-SC*		Slightly clayey sand*
5656	39-41	--					U	SP-SM*		Slightly silty sand*
5651	44	24	6	--			D	SP*		Sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

GGSS Area 2 Sondex well.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-10
DATE DRILLED: 2-7-85
EQUIPMENT USED: CME-55
LOCATION: SE¼SW¼SE¼sec.36, T21N R8E
ELEVATION: 5695'
TOTAL DEPTH: 45.5'

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U: Undisturbed D: Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5693	2-4	--					U	SP*		Sand*
5691	4	11	6	--			D	SP-SM*		Slightly silty sand*
5686	9-11	--					U	SW*		Sand*
5681	14	27	3	--			D	SP*		Sand*
5676	19-21	--					U	SM*		Silty sand*
5671	24	30	8	--			D	SP-SM*		Slightly silty sand*
5666	29-31	--					U	SC*		Clayey sand*
5661	34	18	8	--			D	SP*		Sand*
5656	39	21	8	--			D	SM*		Silty sand*
5651	44	26	7	--			D	SP*		Sand*

NOTES:

GGSS Area 2 Sondex well.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-11
DATE DRILLED: 2-8-85
EQUIPMENT USED: CME-55
LOCATION: SE¼SW¼SE¼sec.36, T21N R8E
ELEVATION: 5695'
TOTAL DEPTH: 40.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE (U: Undisturbed D: Disturbed)	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5693	2-4	--					U	SM*		Silty sand*
5691	4	15	9	--			D	SM*		Silty sand*
5686	9-11	--					U	SP*		Sand*
5681	14	12	4	--			D	SP*		Sand*
5676	19-21	--					U	SP-SM*		Slightly silty sand*
5671	24	--	4				D	SW*		Sand*
5666	29-31	--					U	SP-SM*		Slightly silty sand*
5661	34	20	7	--			D	SW*		Sand*
5656	39	15	12	--			D	SC*		Clayey sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

GGSS Area 2 Sondex well.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-12
DATE DRILLED: 2-8-85
EQUIPMENT USED: CME-55
LOCATION: SE¼SW¼SE¼sec.36, T21N R8E
ELEVATION: 5695'
TOTAL DEPTH: 45.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5693	2-4	--	11	88			U	SM*		Silty sand*
5691	4	13	8	--			D	SC*		Clayey sand*
5686	9-11	--					U	SP*		Sand*
5681	14	10	4	--			D	SP-SM*		Slightly silty sand*
5676	19-21	--					U	SW*		Sand*
5671	24	21	6	--			D	SP*		Sand*
5666	29-31	--					U	SP-SM*		Slightly silty sand*
5659	34	15	9	--			D	SP*		Sand*
5654	39-41	--					U	SP-SC*		Slightly clayey sand*
5651	44	18	8	--			D	SP*		Sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

GGSS Area 2 Sondex well.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-13
DATE DRILLED: 2-8-85
EQUIPMENT USED: CME-55
LOCATION: SE¼SW¼SE¼sec.36, T21N R8E
ELEVATION: 5695'
TOTAL DEPTH: 45.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE (U=Undisturbed D=Disturbed)	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5693	2-4	--					U	SM*		Silty sand*
5691	4	21	9	--			D	SP-SM*		Slightly silty sand*
5686	9-11	--					U	SM*		Silty sand*
5681	14	16	5	--			D	SP*		Sand*
5676	19-21	--					U	SM*		Silty sand*
5671	24	32	8	--			D	SP*		Sand*
5666	29-31	--					U	CL*		Silty clay*
5661	34	20	10	--			D	SP-SM*		Slightly silty sand*
5656	39	44	14	--			D	SP*		Sand*
5651	44	18	7	--			D	SP*		Sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

GGSS Area 2 Sondex well.

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NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSS3 14
DATE DRILLED: 3-8-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5734'
TOTAL DEPTH: 35.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5730	4	21	3	--			D	SM*		Silty sand*
5725	9	12	5	--			D	SM*		Silty sand*
5720	14	14	6	--			D	SP*		Sand*
5715	19	15	9	--			D	SM*		Silty sand*
5710	24	11	9	--			D	SM*		Silty sand*
5705	29	12	7	--			D	SM*		Silty sand*
5700	34	24	7	--			D	ML*		Sandy silt*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: GGSS Area 3 Sondex well.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-15
DATE DRILLED: 3-8-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5734'
TOTAL DEPTH: 35.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5730	4	18	3	--			D	SP*		Sand*
5725	9	8	6	--			D	SM*		Silty sand*
5720	14	15	6	--			D	SP*		Sand*
5715	19	10	8	--			D	SM*		Silty sand*
5710	24	8	8	--			D	ML*		Sandy silt*
5705	29	8	6	--			D	SM*		Silty sand*
5700	34	22	11	--			D	SM*		Silty sand*

NOTES:
GGSS Area 3 Sondex well.

* = field classification

NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-16
DATE DRILLED: 3-8-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5734'
TOTAL DEPTH: 35.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U: Undisturbed D: Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5730	4	21	3	--			D	SP*		Sand*
5725	9	8	3	--			D	SM*		Silty sand*
5720	14	15	9	--			D	SM*		Silty sand*
5715	19	10	7	--			D	SM*		Silty sand*
5710	24	7	8	--			D	ML*		Sandy silt*
5705	29	11	7	--			D	SM*		Silty sand*
5700	34	18	8	--			D	SM*		Silty sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

GGSS Area 3 Sondex well.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-17
DATE DRILLED: 5-6-85
EQUIPMENT USED: Mobile B61
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5734.5'
TOTAL DEPTH: 34'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5730.5	4-6	--					U	SM*		Silty sand*
5720.5	14-16	--					U	SM*		Silty sand*
5710.5	24-26	--					U	SM*		Silty sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

GGSS Area 4 Sondex well.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-18
DATE DRILLED: 5-6-85
EQUIPMENT USED: Mobile B61
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5734.5'
TOTAL DEPTH: 40.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE: STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5730.5	4-6	--					U	SM*		Silty sand*
5725.5	9	9		--			D	SP*		Sand*
5720.5	14-16	--					U	SP-SM*		Slightly silty sand*
5715.5	19	12		--			D	SM*		Silty sand*
5705.5	29-31	--					U	SC*		Clayey sand*
5695.5	39	19		--			D	CL*		Sandy clay*

NOTES: GGSS Area 4 Sondex well.

* = field classification
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-19
DATE DRILLED: 5-7-85
EQUIPMENT USED: Mobile B61
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5734.5'
TOTAL DEPTH: 40.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5725.5	9	15		--			D	SP*		Sand*
5720.5	14-16	--					U	SP-SM*		Slightly silty sand*
5710.5	24-26	--					U	SP*		Sand*
5705.5	29	27		--			D	SC*		Clayey sand*
5695.5	39	43		--			D	SC*		Clayey sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

GGSS Area 4 Sondex well.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-20
DATE DRILLED: 5-7-85
EQUIPMENT USED: Mobile B61
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5734.5'
TOTAL DEPTH: 40.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5730.5	4-6	--					U	SM*		Silty sand*
5725.5	9	10		--			D	SP*		Sand*
5720.5	14-16	--					U	SP-SM*		Slightly silty sand*
5710.5	24-26	--					U	SM*		Silty sand*
5705.5	29	14		--			D	CL*		Sandy clay*
5695.5	39	24		--			D	CL*		Sandy clay*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:
GGSS Area 4 Sondex well.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSS-21
DATE DRILLED: 5-8-85
EQUIPMENT USED: Mobile B61
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5734.5'
TOTAL DEPTH: 40.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE (U=Undisturbed D=Disturbed)	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5730.5	4-5	--	--	--	--	--	U	--		No recovery
5729.5	5	20		--			D	SM*		Silty sand*
5725.5	9-11	--					U	SM*		Silty sand*
5720.5	14-16	--					U	SP-SM*		Slightly silty sand*
5710.5	24-26	--					U	SM*		Silty sand*
5705.5	29	17		--			D	SM*		Silty sand*
5695.5	39	REF		--			D	SC*		Clayey sand*

NOTES:
GGSS Area 4 Sondex well.

* = field classification
REF = refusal
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSM-1
DATE DRILLED: 2-20-85
EQUIPMENT USED: CME-55
LOCATION: SE¼SW¼SE¼sec.36, T21N R8E
ELEVATION: 5695'
TOTAL DEPTH: 35.5'

Elevation (ft)	Depth (ft)	"N" Value Std. Pen. Test	Moisture (% of dry wt.)	Dry Density (lbs./cu. ft.)	Liquid Limit	Plasticity Limit	Sample Type (U=Undisturbed D=Disturbed)	USCS Symbol	Geologic Symbol	Soil Description Gravel/Sand/Fines (%)
5694	1	10	10	--			D	SM*		Silty sand*
5692.5	2.5	14	5	--			D	SP-SM*		Slightly silty sand*
5691	4	14	4	--			D	SP-SM*		Slightly silty sand*
5689.5	5.5	13	4	--			D	SM*		Silty sand*
5688	7	14	5	--			D	SP*		Sand*
5686.5	8.5	9	6	--			D	SM*		Silty sand*
5685	10	9	18	--			D	SM*		Silty sand*
5683.5	11.5	13	7	--			D	SM*		Silty sand*
5682	13	27	5	--			D	SW*		Sand*
5680.5	14.5	25	7	--			D	SM*		Silty sand*
5679	16	44	4	--			D	SW*		Sand*
5677.5	17.5	11	4	--			D	SM*		Silty sand*
5674.5	20.5	7	12	--			D	SM*		Silty sand*
5673	22	9	10	--			D	SM*		Silty sand*
5671.5	23.5	17	9	--			D	SM*		Silty sand*
5670	25	9	11	--			D	SM*		Silty sand*
5668.5	26.5	11	17	--			D	SC*		Clayey sand*
5667	28	16	13	--			D	SP-SM*		Slightly silty sand*
5665.5	29.5	24	33	--			D	SM*		Silty sand*
5664	31	40	20	--			D	CL*		Sandy clay*
5663.2	31.8	40	5	--			D	SW*		Sand*
5663.5	32.5	31	17	--			D	CL*		Sandy clay*
5661	34	23	8	--			D	SW*		Sand*

NOTES:

GGSS Area 2 moisture well.

* = field classification

NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSM-2
DATE DRILLED: 2-20-85
EQUIPMENT USED: CME-55
LOCATION: SE¼SW¼SE¼sec.36, T21N R8E
ELEVATION: 5695'
TOTAL DEPTH: 35.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu.ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5691	4	16	5	--			D	SM*		Silty sand*
5686	9	11	3	--			D	SP-SM*		Slightly silty sand*
5681	14	14	4	--			D	SP*		Sand*
5676	19	2[illegible]	6	--			D	SP*		Sand*
5671	24	28	4	--			D	SP*		Sand*
5666	29	16	7	--			D	SP-SM*		Slightly silty sand*
5661	34	15	6	--			D	SM*		Silty sand*
5660.7	34.3	15	6	--			D	SM*		Silty sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

GGSS Area 2 moisture well.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSM-3
DATE DRILLED: 2-21-85
EQUIPMENT USED: CME 55
LOCATION: NW¼NE¼NE¼Sec.1, T 20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 40'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U: Undisturbed D: Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5732	1	4	14	--			D	SM*		Silty Sand*
5731.5	2.5	11	8	--			D	SM*		Silty Sand*
5729	4	11	6	--			D	SM*		Silty Sand*
5727.5	5.5	11	7	--			D	SM*		Silty Sand*
5726	7	11	7	--			D	SM*		Silty Sand*
5724.5	8.5	12	7	--			D	SM*		Silty Sand*
5723	10	8	7	--			D	SM*		Silty Sand*
5721.5	11.5	16	6	--			D	SM*		Silty Sand*
5720	13	14	9	--			D	SM*		Silty Sand*
5718.5	14.5	13	4	--			D	SP-SM*		Sl. Silty Sand*
5717	16	11	7	--			D	SM*		Silty Sand*
5715.5	17.5	11	7	--			D	SP-SM*		Sl. Silty Sand*
5714	19	9	6	--			D	SM*		Silty Sand*
5713.5	20.5	15	6	--			D	SM*		Silty Sand*
5711	22	8	7	--			D	SM*		Silty Sand*
5709.5	23.5	3	12	--			D	SM*		Silty Sand*
5708	25	2	20	--			D	SC*		Clayey Sand*
5706.5	26.5	2	22	--			D	SM*		Silty Sand*
5705	28	8	22	--			D	SM*		Silty Sand*
5703.5	29.5	14	20	--			D	SM*		Silty Sand*
5702	31	13	20	--			D	SC*		Clayey Sand*
5700.5	32.5	12	18	--			D	SC*		Clayey Sand*
5699	34	11	21	--			D	SC*		Clayey Sand*
5697.5	35.5	9	21	--			D	SM*		Silty Sand*
5696	37	48	21	--			D	CL*		Sandy Clay*
5694.5	38.5	REF	20	--			D	CH*		Clay*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: GGSS Area 1 Sondex well

* = field classification
REF = refusal
NV= no value
NP= non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSM-4
DATE DRILLED: 2-21-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 35.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U: Undisturbed D: Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5729	4	6	6	--			D	SM*		Silty sand*
5724	9	7	5	--			D	SM*		Silty sand*
5719	14	7	5	--			D	SP*		Sand*
5714	19	11	7	--			D	SP-SM*		Sl. silty sand*
5711.5	21.5	10	7	--			D	SM*		Silty sand*
5709	24	17	6	--			D	SM*		Silty sand*
5706.5	26.5	12	6	--			D	SM*		Silty sand*
5704	29	9	7	--			D	SM*		Silty sand*
6701.5	31.5	27	9	--			D	SC*		Clayey sand*
5699	34	30	11	--			D	CL*		Sandy clay*

NOTES: GGSS Area 1 moisture well.

* = field classification

NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSM-5
DATE DRILLED: 2-21-85
EQUIPMENT USED: CME 55
LOCATION: NW¼NE¼NE¼Sec.1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 33.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5729	4	8	7	--			D	SM*		Silty Sand*
5724	9	11	7	--			D	SM*		Silty Sand*
5719	14	10	6	--			D	SM*		Silty Sand*
5714	19	18	2	--			D	SW*		Gravelly Sand*
5713.8	19.2	18	4	--			D	SP-SM*		Sl. Silty Sand*
5711.5	21.5	1	15	--			D	SM*		Silty Sand*
5710	23	2	18	--			D	SM*		Silty Sand*
5708.5	24.5	1	24	--			D	SM*		Silty Sand*
5707	26	2	23	--			D	SM*		Silty Sand*
5705.5	27.5	1	21	--			D	SM*		Silty Sand*
5704	29	0	23	--			D	SM*		Silty Sand*
5702.5	30.5	7	23	--			D	SM*		Silty Sand*
5701	32	11	24	--			D	SM*		Silty Sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:
GGSS Area 1 moisture well.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSM-6
DATE DRILLED: 2-21-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 35.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5729	4	7	8	--			D	ML*		Sandy silt*
5719	14	15	5	--			D	SM*		Silty sand*
5709	24	7	7	--			D	SM*		Silty sand*
5704	29	9	8	--			D	ML*		Sandy silt*
5699	34	26	8	--			D	SM*		Silty sand*

NOTES:

GGSS Area 1 moisture well.

* = field classification

NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSM-7
DATE DRILLED: 3-6-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1 T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 44.5'

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U:Undisturbed D:Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5731.5	1.5	9	7	--			D	SM*		Silty sand*
5729	4	9	5	--			D	SM*		Silty sand*
5726.5	6.5	7	7	--			D	SM*		Silty sand*
5724	9	10	6	--			D	SM*		Silty sand*
5721.5	11.5	7	7	--			D	SM*		Silty sand*
5719	14	8	5	--			D	SM*		Silty sand*
5716.5	16.5	13	6	--			D	SP*		Sand*
5714	19	22	3	--			D	SW*		Gravelly sand*
5712.5	20.5	9	8	--			D	SM*		Silty sand*
5711	22	7	6	--			D	SM*		Silty sand*
5709.5	23.5	2	11	--			D	SM*		Silty sand*
5708	25	10	14	--			D	SM*		Silty sand*
5706.5	26.5	4	9	--			D	SW*		Gravelly sand*
5705	28	2	14	--			D	SM*		Silty sand*
5700	33	13	22	--			D	SC*		Clayey sand*
5695	38	5	23	--			D	SM*		Silty sand*
5690	43	REF	16	--			D	CL*		Sandy clay*

NOTES:

GGSS Area 1 moisture well.

* = field classification
REF = refusal
NV = no value
NP = non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSM-8
DATE DRILLED: 2-6-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 42.5'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu.ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5731.5	1.5	5	14	--			D	SM*		Silty sand*
5729	4	11	7	--			D	ML*		Sandy silt*
5726.5	6.5	9	7	--			D	SM*		Silty sand*
5724	9	10	6	--			D	SP-SM*		Sl. silty sand*
5721.5	11.5	8	8	--			D	SP*		Sand*
5719	14	13	5	--			D	SP-SM*		Sl. silty sand*
5716.5	16.5	11	5	--			D	SM*		Silty sand*
5714	19	11	6	--			D	SM*		Silty sand*
5712.5	20.5	17	5	--			D	SW*		Sand*
5711	22	15	6	--			D	SP*		Sand*
5709.5	23.5	12	3	--			D	SP*		Sand*
5707	26	15	4	--			D	SP*		Sand*
5704.5	28.5	9	7	--			D	SP*		Sand*
5699	34	2	17	--			D	SM*		Silty sand*
5696.5	35.5	30	14	--			D	SM*		Silty sand*
5694	39	4	16	--			D	SM*		Silty sand*
5691.5	41.5	REF	27	--			D	SM*		Silty sand*

NOTES:
GGSS Area 1 moisture well.

* = field classification
REF = refusal
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSNP-1
DATE DRILLED: 3-6-85
EQUIPMENT USED: CME 55
LOCATION: NW¼NE¼NE¼Sec.1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 29'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
				LABORATORY DATA						
5729	4	11	6	--			D	SM*		Silty Sand*
5724	9	12	5	--			D	SP-SM*		Sl. Silty Sand*
5719	14	5	8	--			D	SM*		Silty Sand*
5714	19	3	14	--			D	SM*		Silty Sand*
5709	24	2	18	--			D	SM*		Silty Sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:
GGSS Area 1 Nuclear Probe well.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSNP-2
DATE DRILLED: 3-6-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼sec.1 T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 29'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5729	4	15	4	--			D	SM*		Silty sand*
5724	9	13	4	--			D	SM*		Silty sand*
5719	14	14	6	--			D	SP*		Sand*
5714	19	17	8	--			D	SP-SM*		Sl. silty sand*
5709	24	6	6	--			D	SM*		Silty sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

GGSS Area 1 Nuclear Probe well.

* = field classification

NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSNP-3
DATE DRILLED: 3-7-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼Sec.1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 29'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5729	4	10	6	--			D	SM*		Silty Sand*
5724	9	11	5	--			D	SM*		Silty Sand*
5719	14	16	5	--			D	SM*		Silty Sand*
5714	19	26	6	--			D	SM*		Silty Sand*
5709	24	33	4	--			D	SM*		Silty Sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: GGSS Area 1 Nuclear Probe well

*= field classification
NV= no value
NP= non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSNP-4
DATE DRILLED: 3-7-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼Sec. 1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 29'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5729	4	4	7	--			D	SP-SM*		sl. silty sand*
5724	9	4	7	--			D	SP-SM*		sl. silty sand*
5719	14	3	19	--			D	SM*		silty sand*
5714	19	6	17	--			D	SC*		clayey sand*
5709	24	5	12	--			D	SC*		clayey sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:
GGSS Area 1 Nuclear Probe well.

*= field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSNP-5
DATE DRILLED: 3-7-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼Sec. 1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 34'

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U: Undisturbed D: Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5729	4	11	5	--			D	SM*		silty sand*
5724	9	7	6	--			D	SM*		silty sand*
5719	14	14	6	--			D	ML*		sandy silt*
5714	19	22	6	--			D	CL*		sandy clay*
5709	24	26	7	--			D	CL*		sandy clay*

NOTES:
GGSS Area 1 Nuclear Probe well.

*= field classification
NV= no value
NP= non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSNP-6
DATE DRILLED: 3-7-85
EQUIPMENT USED: CME-55
LOCATION: NW¼NE¼NE¼ Sec. 1, T20N R8E
ELEVATION: 5733'
TOTAL DEPTH: 34'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LABORATORY DATA: LIQUID LIMIT	LABORATORY DATA: PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5729	4	9		--			D	SM*		silty sand*
5724	9	8	6	--			D	SM*		silty sand*
5719	14	13	6	--			D	ML*		sandy silt*
5714	19	21		--			D	CL*		sandy clay*
5709	24	36	15	--			D	CL*		sandy clay*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:
GGSS Area 1 Nuclear Probe well.

*= field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSNP-10
DATE DRILLED: 3-8-85
EQUIPMENT USED: CME-55
LOCATION: SE¼SW¼SE¼Sec.36, T21N R8E
ELEVATION: 5695'
TOTAL DEPTH: 34'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5691	4	12	3	--			D	SP-SM*		sl. silty sand*
5681	14	15	5	--			D	SP-SM*		sl. silty sand*
5671	24	22	5	--			D	SC*		clayey sand*

NOTES: GGSS Area 2 Nuclear Probe well.

*= field classification
NV=no value
NP=non-plastic

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSNP-11
DATE DRILLED: 3-8-85
EQUIPMENT USED: CME 55
LOCATION: SE¼SW¼SE¼Sec.36, T21N R8E
ELEVATION: 5695'
TOTAL DEPTH: 34'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	LABORATORY DATA: MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE (U=Undisturbed D=Disturbed)	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5691	4	13	3	--			D	SP-SM*		Sl. Silty Sand*
5681	14	18	4	--			D	SM*		Silty Sand*
5671	24	28	5	--			D	SC-SM*		Silty Clayey Sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: GGSS Area 2 Nuclear Probe well.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSNP-12
DATE DRILLED: 3-9-85
EQUIPMENT USED: CME 55
LOCATION: SE¼SW¼SE¼Sec.36, T21N R8E
ELEVATION: 5695'
TOTAL DEPTH: 34'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE	STD. PEN TEST MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5691	4	14	5	--			D	SP-SM*		Sl. Silty Sand*
5681	14	36	8	--			D	SC*		Clayey Sand*
5671	24	49	5	--			D	SC*		Clayey Sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:
GGSS Area 2 Nuclear Probe well

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSNP-13
DATE DRILLED: 3-9-85
EQUIPMENT USED: CME 55
LOCATION: SE¼SW¼SE¼Sec.36, T21N R8E
ELEVATION: 5695'
TOTAL DEPTH: 34'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U-Undisturbed D-Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5691	4	10	4	--			D	SP-SM*		Sl. Silty Sand*
5681	14	46	4	--			D	SM*		Silty Sand*
5671	24	22	8	--			D	SC*		Clayey Sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: GGSS Area 2 Nuclear Probe well.

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSNP-14
DATE DRILLED: 3-9-85
EQUIPMENT USED: CME 55
LOCATION: SE¼SW¼SE¼Sec.36, T21N R8E
ELEVATION: 5695'
TOTAL DEPTH: 34'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U=Undisturbed D=Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5691	4	11	3	--			D	SP*		Sand*
5681	14	32	5	--			D	SM*		Silty Sand*
5671	24	42	6	--			D	SM*		Silty Sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES: GGSS Area 2 Nuclear Probe well

* = field classification
NV=no value
NP=non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

BORING: GGSSNP-15
DATE DRILLED: 3-9-85
EQUIPMENT USED: CME-55
LOCATION: SE¼SW¼SE¼Sec.36, T21N R8E
ELEVATION: 5695'
TOTAL DEPTH: 34'

ELEVATION (ft)	DEPTH (ft)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	LABORATORY DATA: DRY DENSITY (lbs./cu. ft.)	LIQUID LIMIT	PLASTICITY LIMIT	SAMPLE TYPE U: Undisturbed D: Disturbed	USCS SYMBOL	GEOLOGIC SYMBOL	SOIL DESCRIPTION Gravel/Sand/Fines (%)
5691	4	11	4	--			D	SP-SM*		Sl. silty sand*
5681	14	25	4	--			D	SM*		Silty sand*
5671	24	31	5	--			D	SM*		Silty sand*

THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

NOTES:

GGSS Area 2 Nuclear Probe well.

* = field classification

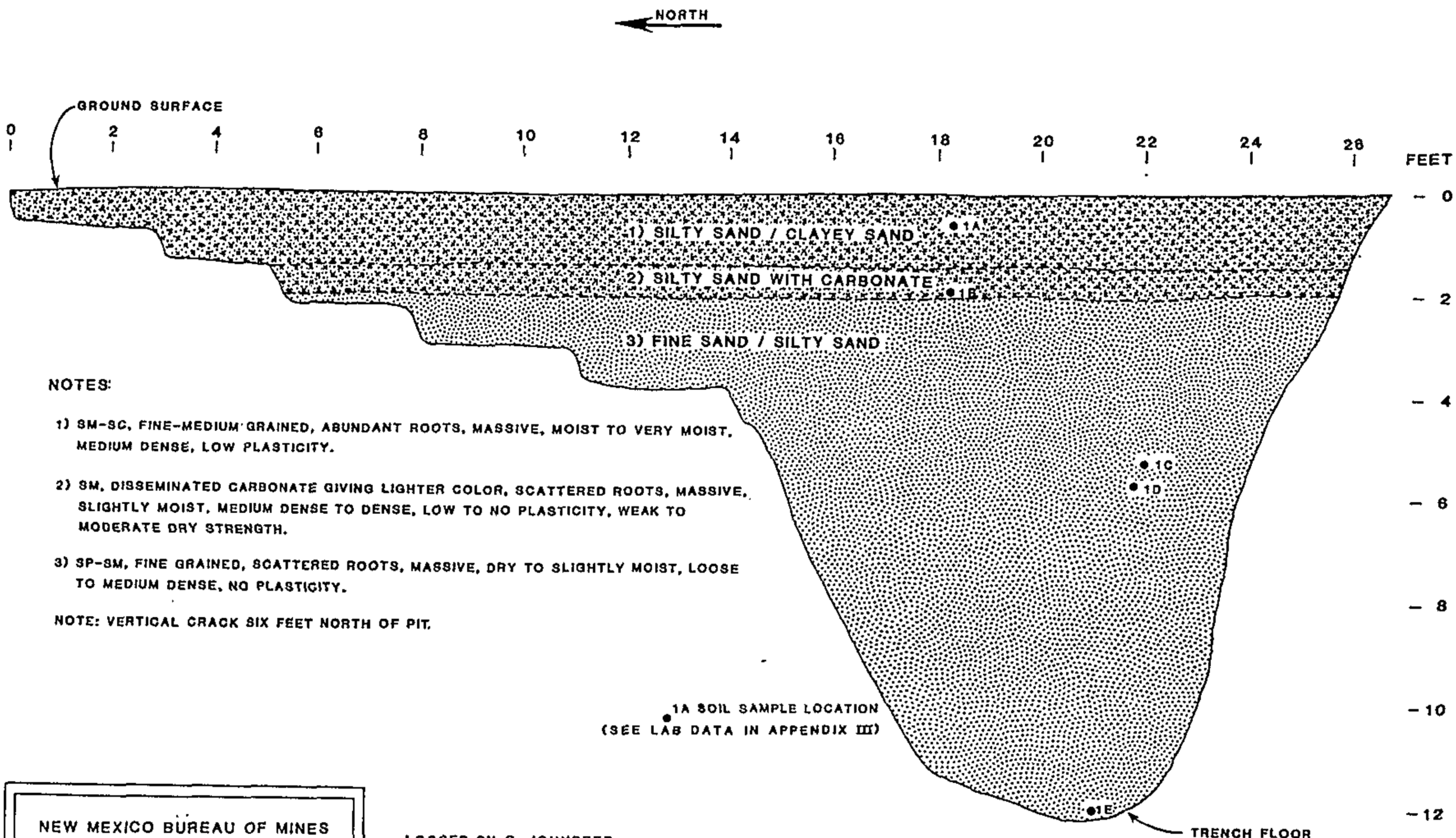
NV= no value
NP= non-plastic

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT

BORING LOG

APPENDIX II

Trench Logs



NOTES:

1) SM-SC, FINE-MEDIUM GRAINED, ABUNDANT ROOTS, MASSIVE, MOIST TO VERY MOIST, MEDIUM DENSE, LOW PLASTICITY.

2) SM, DISSEMINATED CARBONATE GIVING LIGHTER COLOR, SCATTERED ROOTS, MASSIVE, SLIGHTLY MOIST, MEDIUM DENSE TO DENSE, LOW TO NO PLASTICITY, WEAK TO MODERATE DRY STRENGTH.

3) SP-SM, FINE GRAINED, SCATTERED ROOTS, MASSIVE, DRY TO SLIGHTLY MOIST, LOOSE TO MEDIUM DENSE, NO PLASTICITY.

NOTE: VERTICAL CRACK SIX FEET NORTH OF PIT.

NEW MEXICO BUREAU OF MINES
AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT
LOG OF TRENCH ESBH-1
FINAL 28 JUNE 1985

LOGGED BY G. JOHNPEER
12-4-84
SEE ACTIVITY LOCATION MAP FOR TRENCH LOCATION

NOTES:

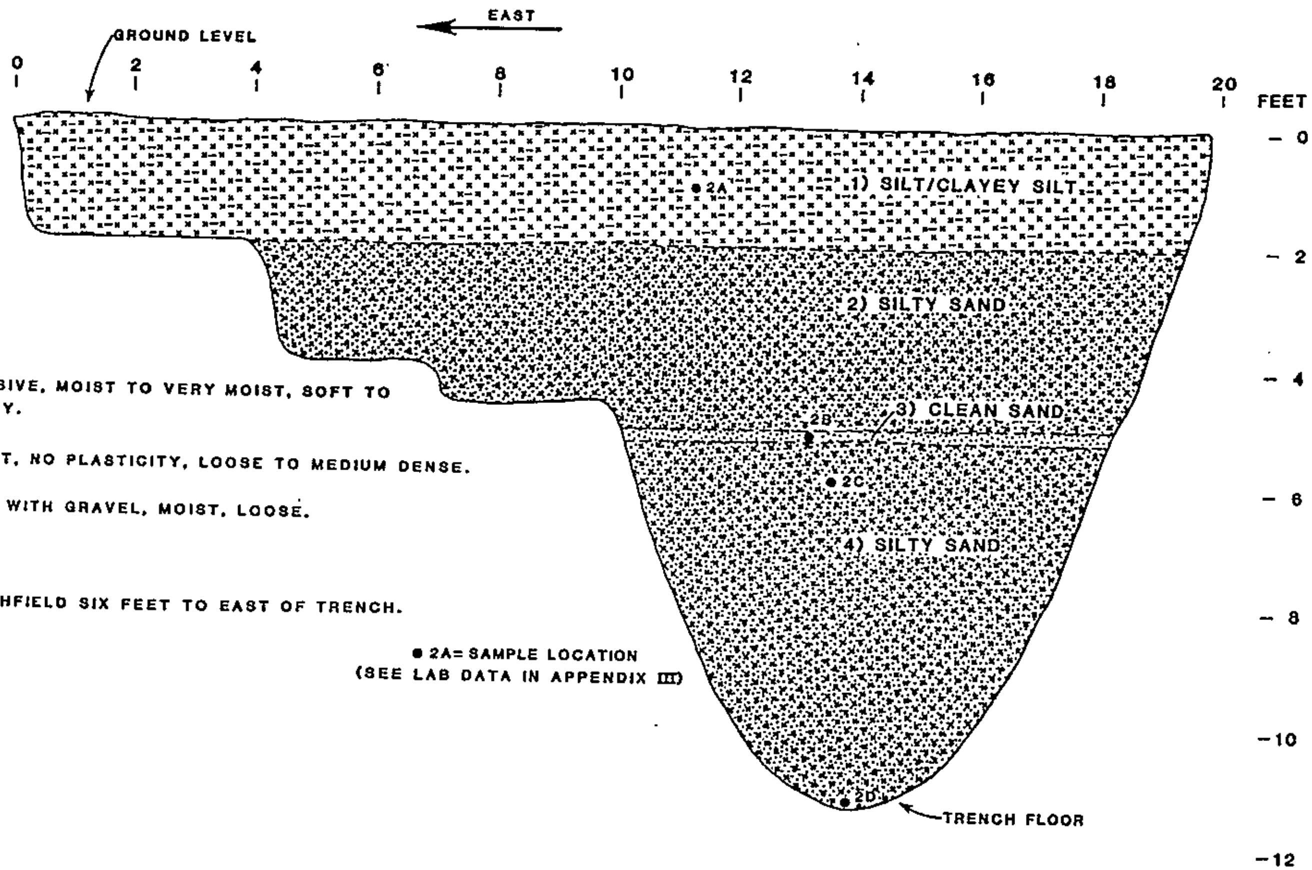
1) ML-CL, SILT TO CLAYEY SILT, MASSIVE, MOIST TO VERY MOIST, SOFT TO FIRM, LOW TO MODERATE PLASTICITY.

2) SM-SP, SILTY SAND, MASSIVE, MOIST, NO PLASTICITY, LOOSE TO MEDIUM DENSE.

3) SP, FINE TO MEDIUM GRAINED SAND WITH GRAVEL, MOIST, LOOSE.

4) SM, SAME AS LAYER 2 ABOVE.

NOTE: GREEN GRASS FROM MOYA LEACHFIELD SIX FEET TO EAST OF TRENCH.

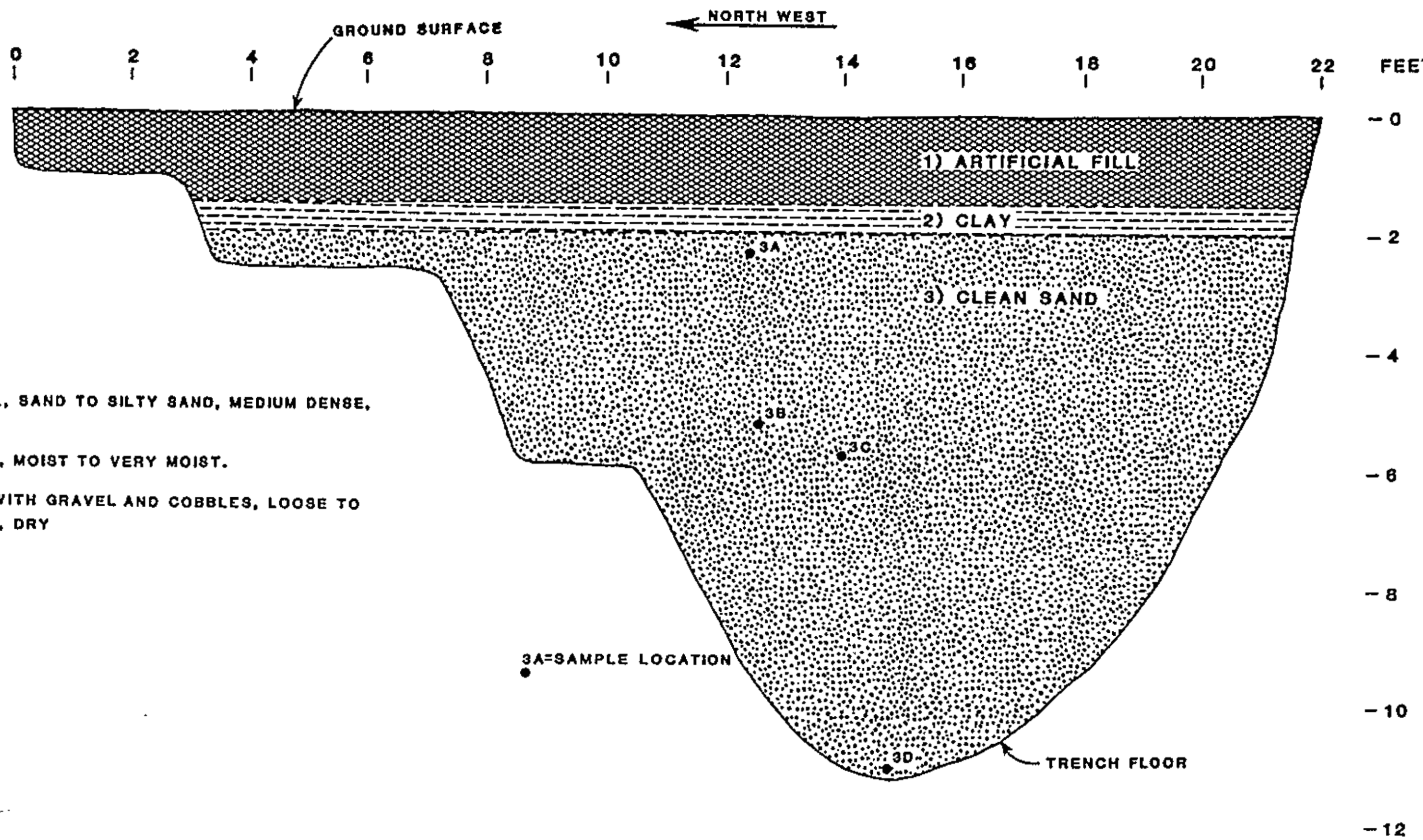


NEW MEXICO BUREAU OF MINES
AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT
LOG OF TRENCH ESBH-2
FINAL 28 JUNE 1985

LOGGED BY: G. JOHNPEER

12-4-84

SEE ACTIVITY LOCATION MAP FOR TRENCH LOCATION



NOTES

1) ARTIFICIAL FILL, SAND TO SILTY SAND, MEDIUM DENSE, VERY MOIST.

2) CL, CLAY, FIRM, MOIST TO VERY MOIST.

3) SW-SP, SAND WITH GRAVEL AND COBBLES, LOOSE TO MEDIUM DENSE, DRY

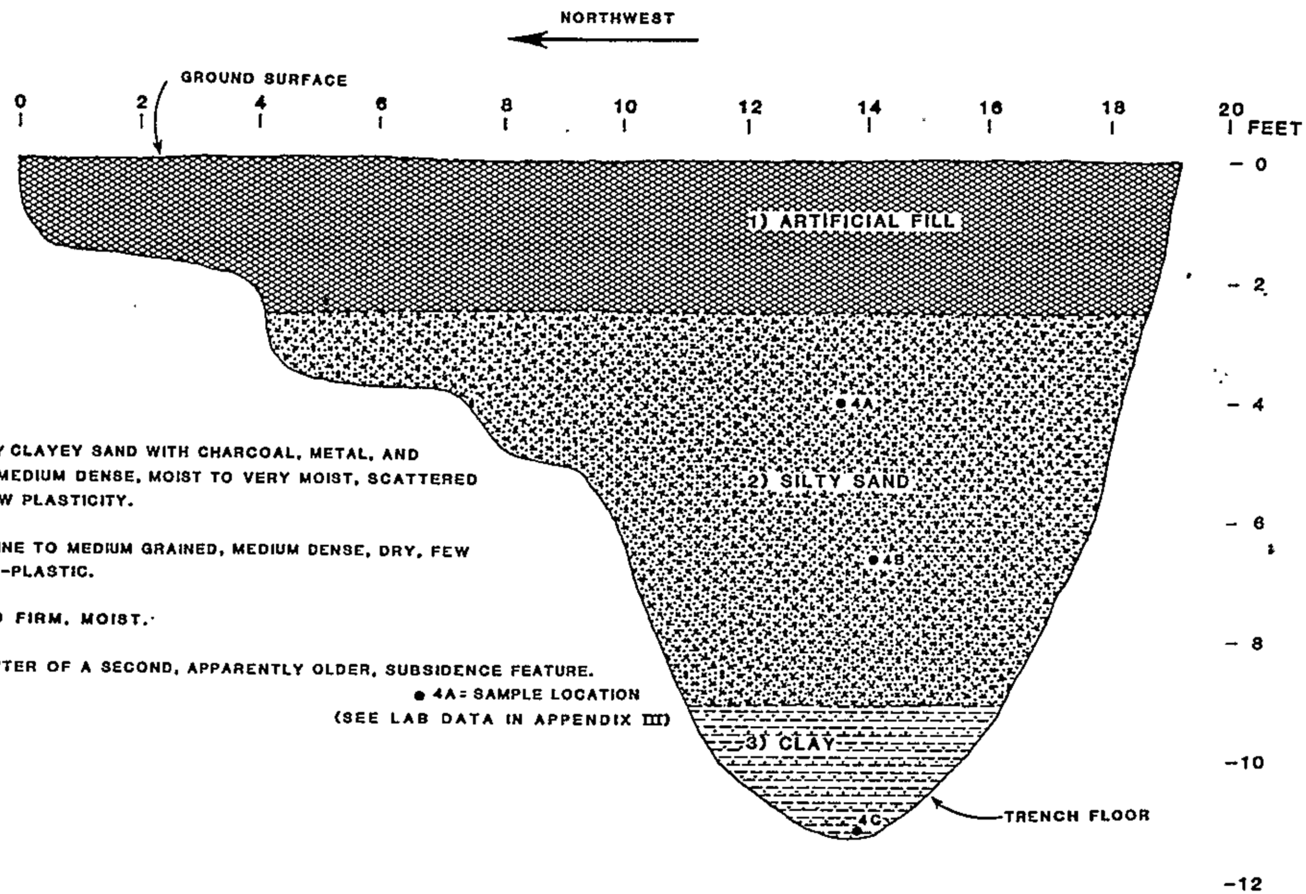
(SEE LAB DATA IN APPENDIX III)

LOGGED BY G. JOHNPEER

12-4-84

SEE ACTIVITY LOCATION MAP FOR TRENCH LOCATION

NEW MEXICO BUREAU OF MINES
AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT
LOG OF TRENCH ESBH-3
FINAL 28 JUNE 1986



NOTES:

1) ARTIFICAL FILL, SILTY CLAYEY SAND WITH CHARCOAL, METAL, AND GLASS FRAGMENTS, MEDIUM DENSE, MOIST TO VERY MOIST, SCATTERED ROOTS, MASSIVE LOW PLASTICITY.

2) SM-SP, SILTY SAND, FINE TO MEDIUM GRAINED, MEDIUM DENSE, DRY, FEW ROOTS, MASSIVE, NON-PLASTIC.

3) CL, CLAY, SOFT TO FIRM, MOIST.

NOTE: TRENCH IS IN CENTER OF A SECOND, APPARENTLY OLDER, SUBSIDENCE FEATURE.

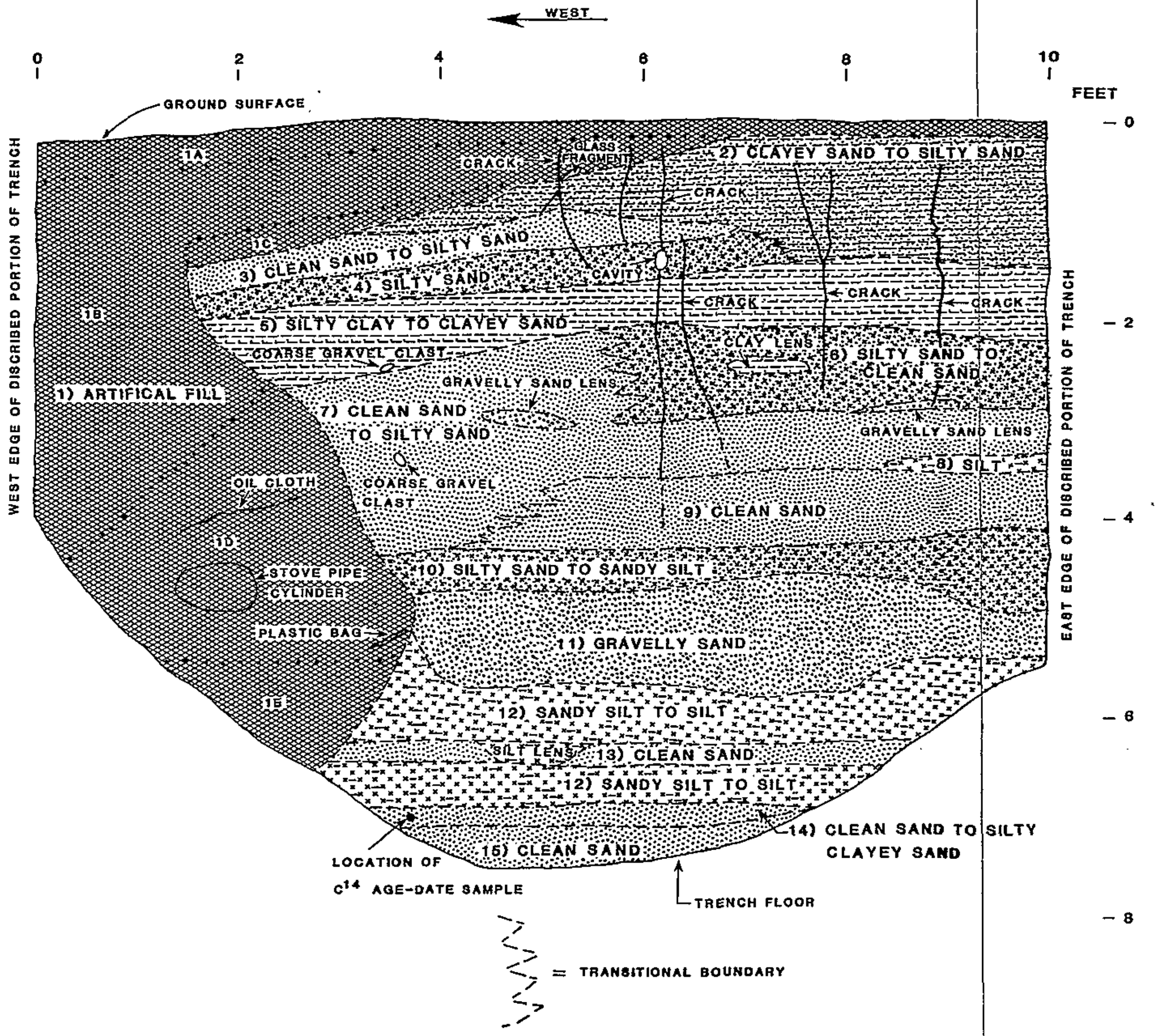
● 4A = SAMPLE LOCATION
(SEE LAB DATA IN APPENDIX III)

NEW MEXICO BUREAU OF MINES
AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT
LOG OF TRENCH ESBH-4
FINAL 28 JUNE 1985

LOGGED BY G. JOHNPEER
12-4-84
SEE ACTIVITY LOCATION MAP FOR TRENCH LOCATION

NOTES:

1) ARTIFICIAL FILL, SLIGHTLY MOIST TO MEDIUM MOIST, LOOSE, SCATTERED CRACKS, SUBDIVIDED AS FOLLOWS:
   - A) SM-ML, SILTY SAND TO SANDY SILT, SURFICIAL DISTURBED LAYER, GLASS FRAGMENTS.
   - B) SM-SC, SILTY TO CLAYEY SAND.
   - C) TRASH WITH GLASS FRAGMENTS.
   - D) TRASH, INCLUDING GLASS FRAGMENTS, CLOTH, STOVE PIPE, AND A PLASTIC BAG CIRCA DECEMBER, 1959.
   - E) SM, SILTY SAND.
2) SC-SM, CLAYEY TO SILTY SAND, SLIGHTLY MOIST, LOOSE, SCATTERED CRACKS.
3) SP-SM, VERY FINE-GRAINED CLEAN TO SILTY SAND, SLIGHTLY MOIST TO MEDIUM MOIST, SCATTERED CRACKS.
4) SM, SILTY SAND, SLIGHTLY MOIST TO MEDIUM MOIST, LOOSE, SCATTERED CRACKS, NOTE SINGLE 3 INCH CAVITY ALONG CRACK.
5) CL-SC, SILTY CLAY TO CLAYEY SAND, VERY MOIST, SCATTERED CRACKS, NOTE SINGLE 1.5 INCH GRAVEL CLAST AT BASE.
6) SM-SP, SILTY TO CLEAN SAND, MEDIUM MOIST, LOOSE, SCATTERED CRACKS, NOTE SINGLE GRAVELLY SAND LENS AT BASE AND SINGLE CLAY LENS.
7) SP-SM, VERY FINE-GRAINED CLEAN TO SILY SILTY SAND, MEDIUM MOIST , LOOSE, SCATTERED CRACKS AND LENSES OF GRAVELLY SAND.NOTE SINGLE 2 INCH GRAVEL CLAST.
8) ML, SILT, MEDIUM MOIST, FIRM, LOW PLASTICITY.
9) SP, VERY FINE-GRAINED CLEAN SAND, MEDIUM MOIST, LOOSE, SCATTERED CRACKS AND LENSES OF GRAVELLY SAND.
10) SM-ML, SILTY SAND TO SANDY SILT, VERY MOIST.
11) SW, GRAVELLY SAND, MEDIUM MOIST, LOOSE.
12) ML, SANDY SILT TO SILT, MEDIUM MOIST, FIRM, LOW PLASTICITY.
13) SP, VERY FINE-GRAINED CLEAN SAND, MEDIUM MOIST, LOOSE, NOTE SINGLE SILT LENS .
14) SP-SM, VERY FINE-GRAINED CLEAN TO SILTY CLAYEY SAND, MEDIUM MOIST, LOOSE, SCATTERED FIRE-CRACKED GRAVEL AND CHARCOAL (CHARCOAL C14 AGE 2330 ± 70 YEARS).
15) SP, VERY FINE-GRAINED CLEAN SAND , MEDIUM MOIST, LOOSE.



NEW MEXICO BUREAU OF MINES
AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT
LOG OF TRENCH ESBH- 5
FINAL 28 JUNE 1985

LOGGED BY: J. HAWLEY
1-24-85
SEE ACTIVITY LOCATION
MAP FOR LOCATION.

NOTES:

1) ARTIFICIAL FILL, MOIST (FROZEN), LOOSE, ABUNDANT ROOTS, SCATTERED PORCELAIN, GLASS, AND METAL FRAGMENTS, SCATTERED CRACKS.

2) SP-SM, SLIGHTLY SILTY SAND, MOIST, LOOSE TO MEDIUM DENSE, POORLY LAMINATED, SCATTERED CRACKS, FINE- TO COARSE-GRAINED GRAVEL AND FINE-GRAINED COBBLES, AND LENSES OF SANDY GRAVEL AND GRAVELLY SAND.

3) SP, CLEAN SAND, MEDUIM MOIST, MEDIUM DENSE, NOTE SINGLE FLATTENED CLAY LENS AND SCATTERED CRACKS.

4) CH, CLAY, MOIST, FIRM, HIGH PLASTICITY, 2 INCHES THICK.

5) SM-ML, SILTY SAND TO SILT, MEDIUM MOIST TO DRY (NOTE MOISTURE BOUNDARY), MEDIUM DENSE SLIGHTLY PLATY AND POORLY LAMINATED SCATTERED FINE-GRAINED GRAVEL, CRACKS, DEFORMED CLAY STRINGERS, NOTE SINGLE LENS OF MOIST SILTY SAND WITH AN UNDULATORY UPPER SURFACE.

6) SP-SM, SLIGHTLY SILTY SAND, MEDIUM MOIST TO DRY (NOTE MOISTURE BOUNDARY), MEDIUM DENSE, FAINTLY LAMINATED, SCATTERED CRACKS AND CLAY STRINGERS.

7) SC, CLAYEY SAND, DRY, MEDIUM DENSE, LAMINATED, SCATTERED CRACKS.

8) SP-SM, SLIGHTLY SILTY SAND, DRY, MEDIUM DENSE, CROSS-LAMINATED, SCATTERED CRACKS.

9) SP, CLEAN SAND, DRY, MEDIUM DENSE, DISCONTINUOUS, SCATTERED CRACKS AND FINE-GRAINED GRAVEL.

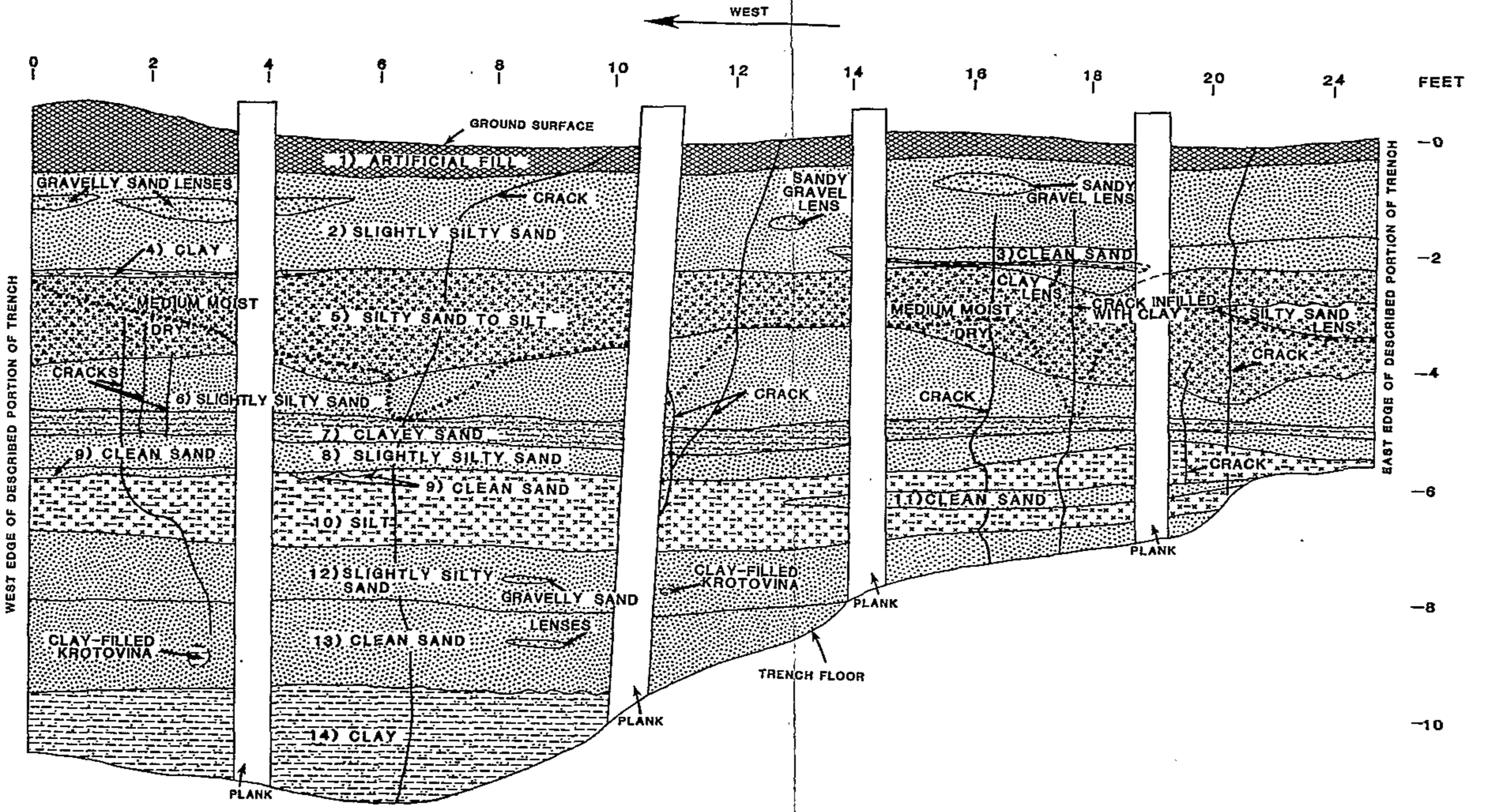
10) ML, SILT, DRY, FIRM, LOW PLASTICITY, WELL-LAMINATED, SCATTERED CRACKS AND 1 INCH THICK INTERBEDS OF CLEAN SAND.

11) SP, CLEAN SAND, DRY, MEDIUM DENSE, SCATTERED CRACKS.

12) SP-SM, SLIGHTLY SILTY SAND, DRY, MEDIUM DENSE, SCATTERED CRACKS, GRAVELLY SAND LENSES, AND CLAY STRINGERS, NOTE SINGLE 3 INCH DIAMETER CLAY-FILLED KROTOVINA.

13) SP, CLEAN SAND, DRY, MEDIUM DENSE, WELL-LAMINATED, ABUNDANT CLAY STRINGERS, SCATTERED CRACKS AND GRAVELLY SAND LENSES, NOTE SINGLE 5 INCH DIAMETER CLAY-FILLED KROTOVINA.

14) CL-ML, CLAY, DRY, FIRM, LOW PLASTICITY, MASSIVE, SCATTERED CRACKS.



LOGGED BY M. HEMINGWAY
1-24,25-85
SEE ACTIVITY LOCATION MAP FOR TRENCH LOCATION

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT
LOG OF TRENCH ESBH- 6
FINAL 28 JUNE 1985

NOTES:

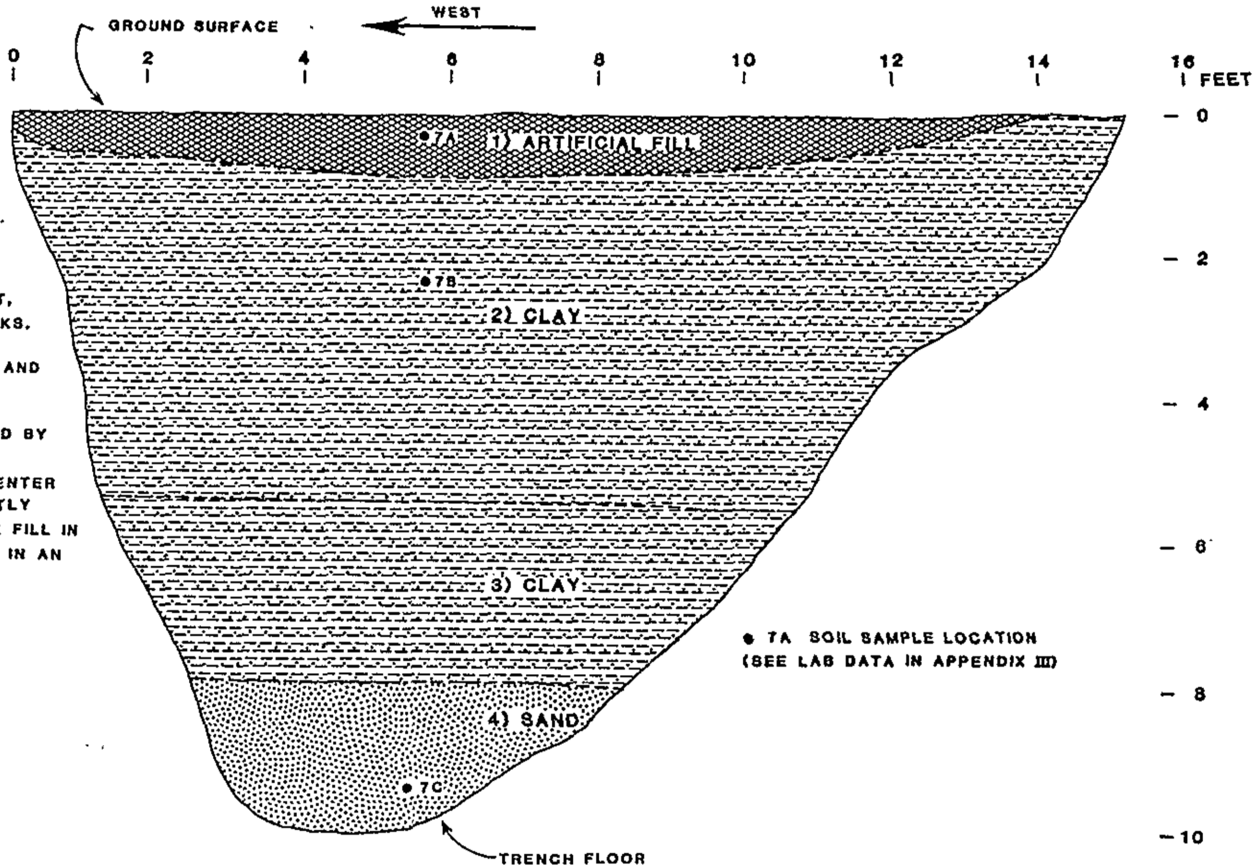
1) ARTIFICIAL FILL, WET TO VERY MOIST, MEDIUM DENSE, SCATTERED METAL FRAGMENTS.

2) CL-CH, CLAY, SATURATED TO VERY MOIST, SOFT, LOW TO MODERATE PLASTICITY, SCATTERED LIVE ROOTS.

3) CL-ML, CLAY TO SILT, MEDIUM TO SLIGHTLY MOIST, FIRM TO HARD, LOW PLASTICITY, ABUNDANT CRACKS.

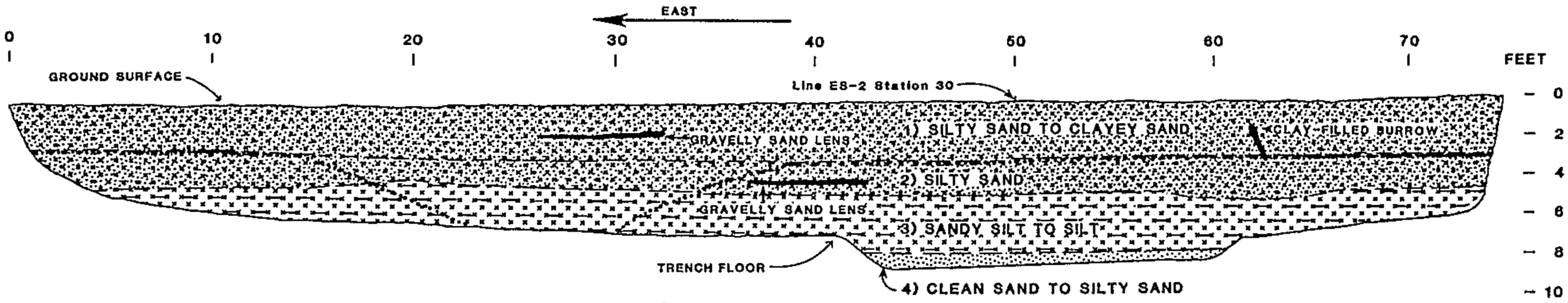
4) SP , CLEAN MEDIUM-GRAINED SAND WITH GRAVEL AND COBBLES, DRY, LOOSE TO MEDIUM DENSE.

NOTE: TRENCH DUG OVER "SOTANO" REPORTED BY F. VALDEZ AT WESTERN END OF HIS PROPERTY. IRRIGATION WATER WOULD ENTER THE SOTANO AND DRAIN OFF, APPARENTLY THROUGH THE CRACKS IN LAYER 3. THE FILL IN LAYER 1 WAS EMPLACED BY F. VALDEZ IN AN ATTEMPT TO PLUG THE SOTANO.



NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT
LOG OF TRENCH ESBH-7
FINAL 28 JUNE 1985

LOGGED BY G. JOHNPEER
1-26-85
SEE ACTIVITY LOCATION MAP FOR TRENCH LOCATION



••••••••••• =MOISTURE BOUNDARY, DISTINGUSHING BETWEEN MOIST TO VERY MOIST ABOVE, AND DRY TO SLIGHTLY MOIST BELOW

NOTES:

1) SM-SC, SILTY SAND TO CLAYEY SAND, MOIST TO VERY MOIST, LOOSE TO MEDIUM DENSE, SCATTERED SILTY CLAY TO SANDY SILT ZONES, GRAVEL, GRAVELLY SAND LENSES. NOTE SINGLE BURROW INFILLED WITH CLAY.

2) SM, SILTY SAND, DRY TO VERY MOIST(NOTE MOISTURE BOUNDARY), LOOSE TO MEDIUM DENSE, POORLY STRATIFIED TO MASSIVE, SCATTERED FINE-GRAINED GRAVEL AND GRAVELLY SAND LENSES.

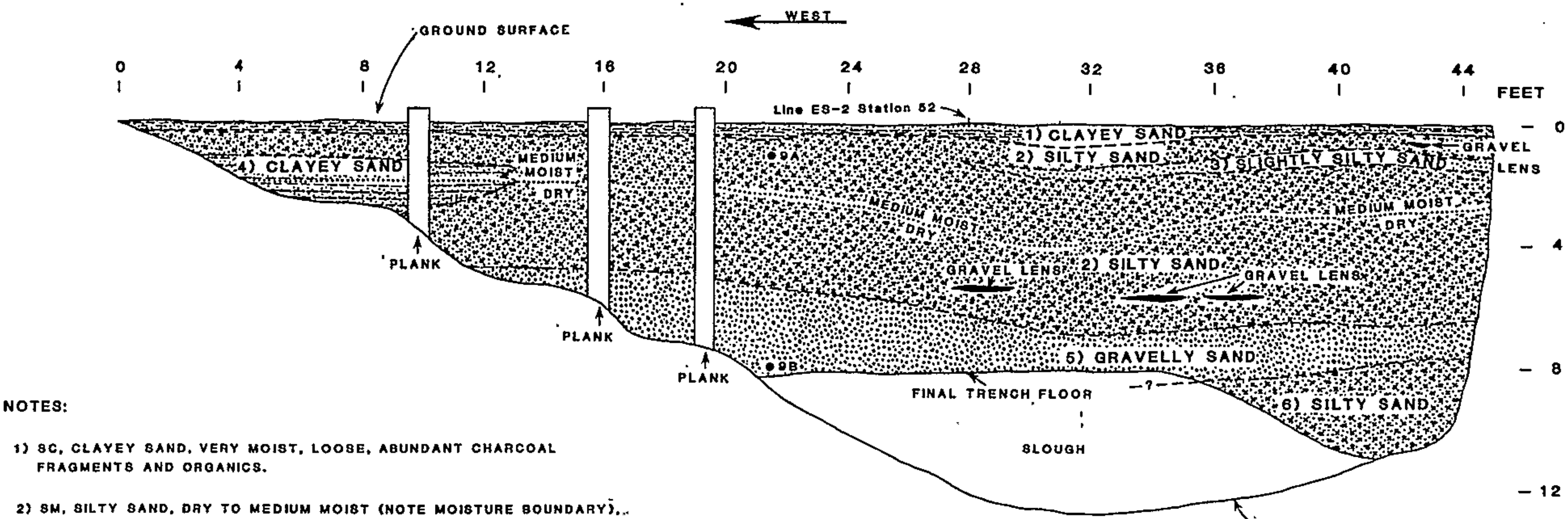
3) ML, VERY FINE-GRAINED SANDY SILT TO SILT, DRY TO VERY MOIST(NOTE MOISTURE BOUNDARY), LOOSE TO MEDIUM DENSE, LOCALLY LAMINATED AND PLATY, SCATTERED SILTY SAND LENSES.

4) SP-SM, FINE-GRAINED CLEAN SAND TO SILTY SAND, DRY TO SLIGHTLY MOIST, LOOSE TO MEDIUM DENSE.

NOTE: TRENCH EXCAVATED OVER TRACE OF GEOPHYSICALLY INTERPRETED FAULT.

LOGGED BY J. HAWLEY
1-25-85
SEE ACTIVITY LOCATION MAP FOR TRENCH LOCATION.

NEW MEXICO BUREAU OF MINES
AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT
LOG OF TRENCH ESBH-8
FINAL 28 JUNE 1985



NOTES:

1) SC, CLAYEY SAND, VERY MOIST, LOOSE, ABUNDANT CHARCOAL FRAGMENTS AND ORGANICS.

2) SM, SILTY SAND, DRY TO MEDIUM MOIST (NOTE MOISTURE BOUNDARY), LOOSE TO MEDIUM DENSE, SCATTERED LENSES OF SANDY GRAVEL.

3) SP-SM, SLIGHTLY SILTY SAND, MEDIUM MOIST, LOOSE.

4) SC-CL, CLAYEY SAND, DRY TO MEDIUM MOIST (NOTE MOISTURE BOUNDARY), MEDIUM DENSE.

5) SW-GW, GRAVELLY SAND, GRAVEL FRACTION FINE-TO MEDIUM-GRAINED, ROUNDED TO SUBROUNDED, DRY, MEDIUM DENSE.

6) SM, SILTY SAND, DRY, MEDIUM DENSE.

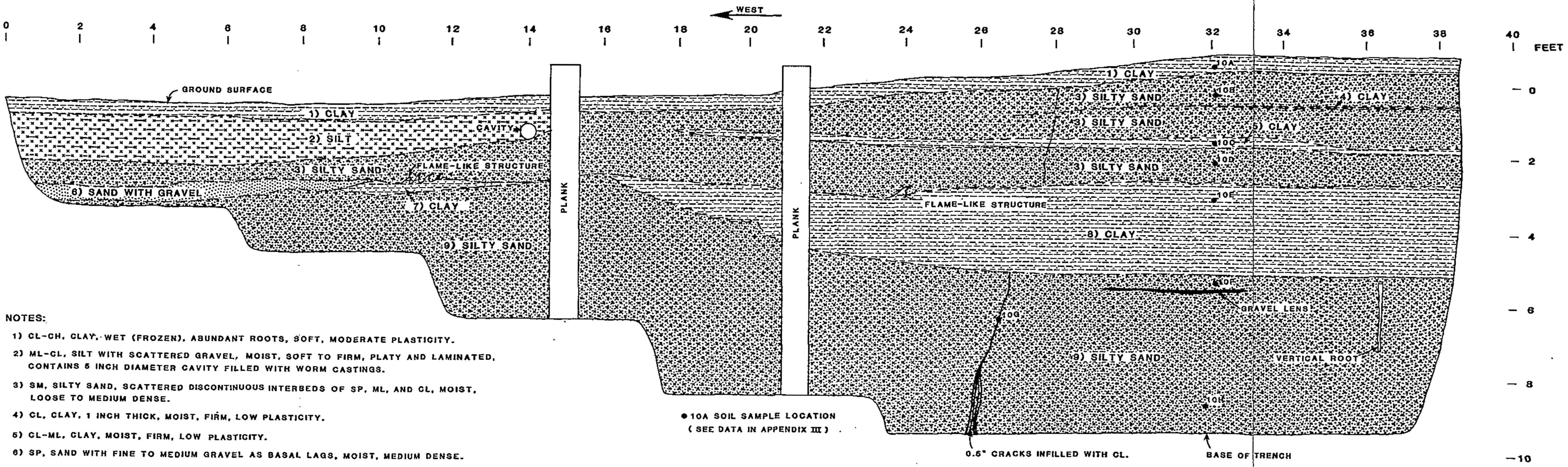
NOTE: DUE TO INSTABILITY OF TRENCH WALLS, TRENCH EAST OF PLANKS WAS LOGGED FROM THE SURFACE. TRENCH EXCAVATED ACROSS TRACE OF GEOPHYSICALLY INTERPRETED FAULT.

● 9B = SOIL SAMPLE LOCATION (SEE LABORATORY DATA IN APPENDIX III)

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT
LOG OF TRENCH ESBH-9
FINAL 28 JUNE 1985

LOGGED BY: G. JOHNPEER, M. HEMINGWAY, AND D. BOBROW
1-30-85

SEE ACTIVITY LOCATION MAP FOR TRENCH LOCATION.



NOTES:

1) CL-CH, CLAY, WET (FROZEN), ABUNDANT ROOTS, SOFT, MODERATE PLASTICITY.
2) ML-CL, SILT WITH SCATTERED GRAVEL, MOIST, SOFT TO FIRM, PLATY AND LAMINATED, CONTAINS 5 INCH DIAMETER CAVITY FILLED WITH WORM CASTINGS.
3) SM, SILTY SAND, SCATTERED DISCONTINUOUS INTERBEDS OF SP, ML, AND CL, MOIST, LOOSE TO MEDIUM DENSE.
4) CL, CLAY, 1 INCH THICK, MOIST, FIRM, LOW PLASTICITY.
5) CL-ML, CLAY, MOIST, FIRM, LOW PLASTICITY.
6) SP, SAND WITH FINE TO MEDIUM GRAVEL AS BASAL LAGS, MOIST, MEDIUM DENSE.
7) CL, CLAY, MOIST, FIRM, LOW PLASTICITY, FLAME-LIKE STRUCTURES ON UPPER SURFACE.
8) CL-ML, CLAY, MOIST, FIRM, LOW PLASTICITY, SCATTERED ZONES OF REDDISH-BROWN MOTTLING, FLAME-LIKE STRUCTURES ON UNDULATORY UPPER SURFACE, PORTIONS OF LOWER SURFACE ALSO UNDULATORY.
9) GM-SC, SILTY SAND, MEDIUM MOIST, MEDIUM DENSE, MASSIVE WITH SCATTERED LENSES OF SP, FINE TO MEDIUM GRAVEL, AND CL, 21 INCH VERTICAL ROOT AT EAST END OF TRENCH.

LOGGED BY G. JOHNPEER, M. HEMINGWAY AND D. LOVE
1-24-85
SEE ACTIVITY LOCATION MAP FOR TRENCH LOCATION

NEW MEXICO BUREAU OF MINES
AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT
LOG OF TRENCH ESBH-10
FINAL 28 JUNE 1985

NOTES:

1) ARTIFICIAL FILL, MOIST(FROZEN), LOOSE, SCATTERED LIVE TREE ROOTS, WOOD, AND FRAGMENTS OF ORGANICS, CHARCOAL, METAL, PORCELAIN, AND GLASS.

2) SM, SILTY SAND, SLIGHTLY MOIST TO DRY(NOTE MOISTURE BOUNDARY), MEDIUM DENSE, ABUNDANT CRACKS AND CLAY-FILLED KROTOVINAS, SCATTERED LENSES OF CLAY, CLAYEY SILT, COARSE-GRAINED SILTY SAND, AND SANDY GRAVEL WITH COBBLES, SCATTERED CLAY STRINGERS, FINE-GRAINED GRAVEL, WOOD FRAGMENTS(POSSIBLY ROOTS), NOTE SINGLE CIRCULAR HOLE INFILLED WITH CLEAN SAND.

3) SP, CLEAN SAND, DRY, MEDIUM DENSE, ABUNDANT FINE LAMINATIONS OF SILT, SCATTERED CRACKS.

4) SM-SP, SILTY SAND, DRY, MEDIUM DENSE, DISCONTINUOUS, SCATTERED 1 TO 2 INCH INTERBEDS OF SLIGHTLY SILTY SAND, SCATTERED CRACKS.

5) SP, CLEAN SAND, DRY, MEDIUM DENSE, DISCONTINUOUS, WELL-LAMINATED, SCATTERED CRACKS.

6) CL-ML, CLAY, DRY, FIRM, LOW PLASTICITY, DISCONTINUOUS.

7) SM, SILTY SAND, DRY, MEDIUM DENSE, MASSIVE, SCATTERED CRACKS AND CLAY-FILLED KROTOVINAS.

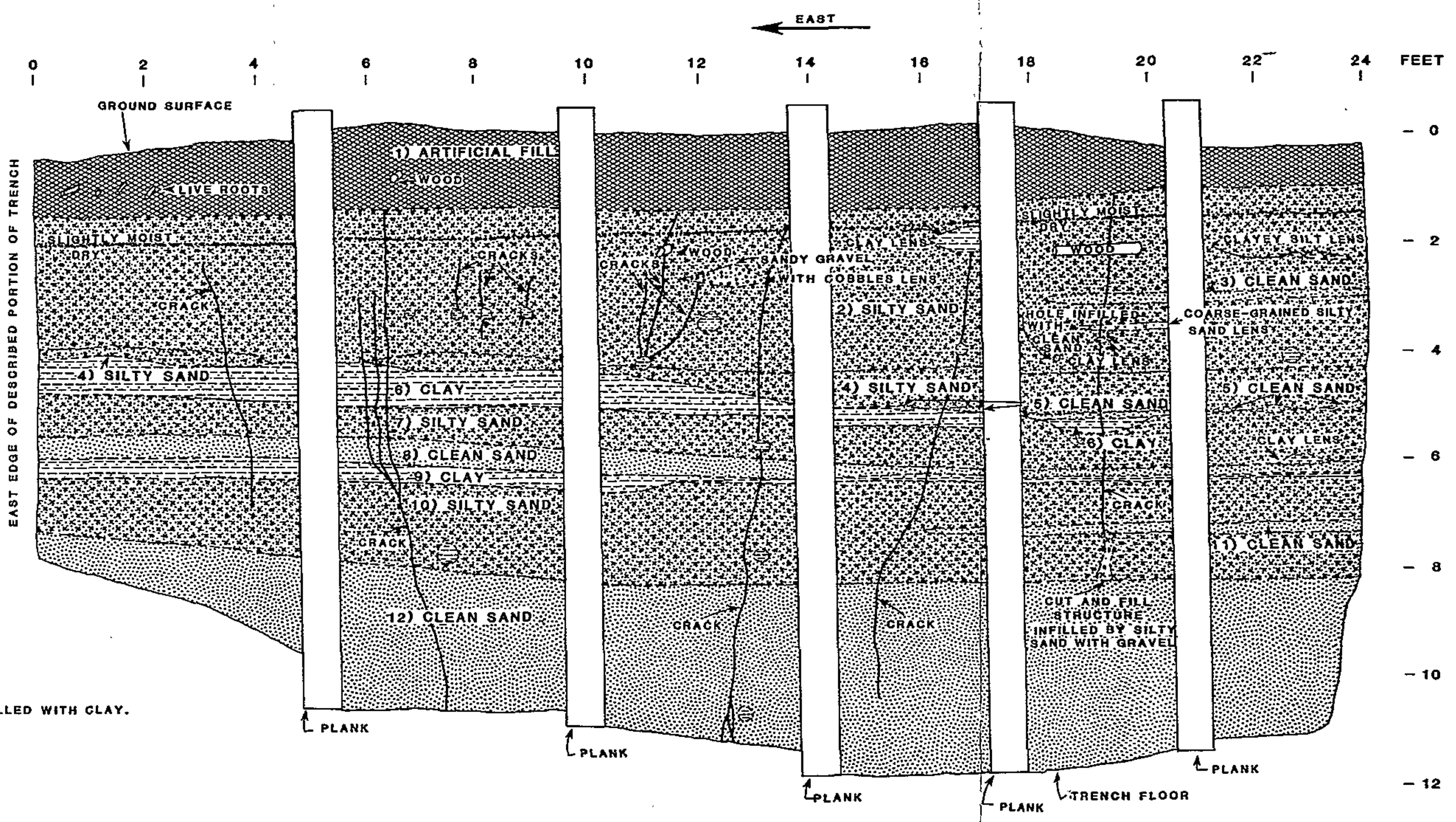
8) SP, CLEAN SAND, DRY, MEDIUM DENSE, SINGLE CLAY LENS ON UPPER SURFACE, SCATTERED CRACKS.

9) CL-ML, CLAY, DRY, FIRM, LOW PLASTICITY, SCATTERED CRACKS.

10) SM-ML, SILTY SAND, DRY, MEDIUM DENSE, MASSIVE, SCATTERED CRACKS AND CLAY-FILLED KROTOVINAS, NOTE SINGLE ELONGATE CUT-AND-FILL STRUCTURE INFILLED BY SILTY SAND WITH GRAVEL.

11) SP, CLEAN SAND, DRY, MEDIUM DENSE, SCATTERED CRACKS.

12) SP, CLEAN SAND, DRY, MEDIUM DENSE, ABUNDANT 1 INCH INTERBEDS OF SILTY SAND, SCATTERED CRACKS, NOTE SINGLE CLAY-FILLED KROTOVINA.



= KROTOVINA, FILLED WITH CLAY.

NEW MEXICO BUREAU OF MINES
AND MINERAL RESOURCES
EL LLANO SUBSIDENCE PROJECT
LOG OF TRENCH ESBH-11
FINAL 28 JUNE 1985

LOGGED BY G. JOHNPEER AND M. HEMINGWAY.
1-31-85
SEE ACTIVITY LOCATION MAP FOR TRENCH LOCATION

APPENDIX III

Laboratory Data Compilation Tables

DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Dry	Moisture Content (%)	Atterberg Limits LL	PI	Sieve Analysis (% Passing) 3/4"	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
ESPDH-1	2.5	F	D	-	-	12	19	NP	100	96	96	96	96	-	91	-	-	66	-	-	23.3	silty sand (SM)
	5	F	D	-	-	10	NP	NP	100	100	100	99	99	-	94	-	-	64	-	-	17.1	silty sand (SM)
	7.5	F	D	-	-	15	20	NP	100	100	100	98	98	-	92	-	-	68	-	-	30.6	silty sand (SM)
	10	F	D	-	-	22	19	NP	100	100	100	100	100	-	97	-	-	78	-	-	37.6	silty sand (SM)
	10.5	F	D	-	-	39	69	34	100	100	100	100	100	-	100	-	-	87	-	-	65.9	sandy silt (MH)
	12.5	F	D	-	-	31	32	12	100	100	100	100	100	-	94	-	-	72	-	-	44.6	clayey sand (SC)
	15	F	D	-	-	26	45	20	100	100	100	100	100	-	95	-	-	81	-	-	56.1	sandy clay (CL)
	17.5	F	D	-	-	23	28	6	100	100	100	100	100	-	97	-	-	89	-	-	59.8	sandy silt (ML)
	20	F	D	-	-	16	22	NP	78	78	78	78	78	-	77	-	-	62	-	-	29.4	silty sand (SM)
	22.5	F	D	-	-	17	45	20	100	100	100	100	99	-	95	-	-	80	-	-	40.4	clayey sand (SC)
	25	F	D	-	-	10	NV	NP	100	100	100	99	99	-	94	-	-	63	-	-	16.8	silty sand (SM)
	27.5	F	D	-	-	13	26	6	100	100	100	100	100	-	91	-	-	54	-	-	24.2	silty-clayey sand (SM-SC)
	30	F	D	-	-	15	20	NP	100	100	100	100	99	-	93	-	-	72	-	-	31.6	silty sand (SM)
	32.5	F	D	-	-	7	NV	NP	100	100	100	98	95	-	70	-	-	34	-	-	9.0	slightly silty sand (SP-SM)
	35	F	D	-	-	10	NV	NP	100	100	100	99	97	-	75	-	-	39	-	-	9.5	slightly silty sand (SP-SM)
	37.5	F	D	-	-	24	NV	NP	100	100	100	100	100	-	99	-	-	90	-	-	34.7	silty sand (SM)
	38	F	D	-	-	14	19	NP	100	100	100	100	99	-	91	-	-	56	-	-	24.7	silty sand (SM)
	40	F	D	-	-	10	NV	NP	100	100	100	100	99	-	73	-	-	40	-	-	10.9	slightly silty sand (SP-SM)
	42.5	F	D	-	-	10	NV	NP	100	100	97	94	91	-	69	-	-	39	-	-	20.3	silty sand (SM)
	45	F	D	-	-	10	NV	NP	100	98	93	90	87	-	62	-	-	27	-	-	15.3	silty sand (SM)
	47.5	F	D	-	-	13	NV	NP	100	100	100	100	99	-	83	-	-	45	-	-	25.5	silty sand (SM)
	50	F	D	-	-	24	33	13	100	100	100	100	99	-	97	-	-	85	-	-	53.6	sandy clay (CL)
	55	F	D	-	-	11	NV	NP	100	100	100	99	99	-	90	-	-	61	-	-	26.1	silty sand (SM)
	57.5	F	D	-	-	6	22	NP	100	100	100	100	100	-	99	-	-	85	-	-	31.1	silty sand (SM)
	60	F	D	-	-	9	35	13	100	100	98	97	97	-	94	-	-	77	-	-	44.6	clayey sand (SC)
	62.5	F	D	-	-	-																sandy clay (CL)*
	63	F	D	-	-	9	NV	NP	100	100	100	100	100	-	96	-	-	66	-	-	30.9	silty sand (SM)
	65	F	D	-	-	4	NV	NP	100	100	100	100	100	-	96	-	-	64	-	-	17.5	silty sand (SM)
	67.5	F	D	-	-	5	NV	NP	100	100	100	100	100	-	81	-	-	36	-	-	10.4	slightly silty sand (SP-SM)
ESPDH-2	2.5	F	D	-	-	8	28	NP	100	100	100	100	100	-	96	-	-	86	-	-	47.5	silty sand (SM)
	5	F	D	-	-	7	25	4	100	100	100	100	100	-	99	-	-	88	-	-	49.6	silty sand (SM)
	7.5	F	D	-	-	4	NV	NP	100	100	100	100	100	-	92	-	-	63	-	-	25.1	silty sand (SM)
	10	F	D	-	-	7	29	8	100	100	100	100	100	-	98	-	-	89	-	-	45.6	clayey sand (SC)
	12.5	F	D	-	-	4	17	NP	100	100	100	100	100	-	92	-	-	67	-	-	23.6	silty sand (SM)
	15	F	D	-	-	6	NV	NP	100	100	100	100	100	-	98	-	-	82	-	-	34.2	silty sand (SM)
	17.5	F	D	-	-	7	27	10	100	100	100	100	100	-	95	-	-	72	-	-	34.1	clayey sand (SC)
	20	F	D	-	-	8	26	NP	100	100	99	99	99	-	97	-	-	93	-	-	64.5	sandy silt (ML)
	22.5	F	D	-	-	14	54	26	100	100	100	100	100	-	100	-	-	92	-	-	68.5	sandy clay (CH)
	23	F	D	-	-	-								-		-	-		-	-		
	25	F	D	-	-	6	24	NP	100	100	100	100	100	-	99	-	-	92	-	-	39.0	silty sand (SM)
	27.5	F	D	-	-	3	NV	NP	100	100	100	99	99	-	92	-	-	62	-	-	19.4	silty sand (SM)
	30	F	D	-	-	3	NV	NP	100	100	100	100	100	-	99	-	-	79	-	-	23.4	silty sand (SM)
	32.5	F	D	-	-	6	24	NP	100	96	96	95	94	-	91	-	-	82	-	-	47.2	silty sand (SM)
	35	F	D	-	-	6	31	10	100	100	100	100	99	-	97	-	-	91	-	-	34.2	clayey sand (SC)
	37.5	F	D	-	-	3	NV	NP	100	100	100	100	100	-	97	-	-	77	-	-	23.0	silty sand (SM)
	40	F	D	-	-	1	NV	NP	100	100	100	100	99	-	72	-	-	28	-	-	7.4	slightly silty sand (SP-SM)
	42.5	F	D	-	-	2	NV	NP	83	83	81	74	68	-	45	-	-	28	-	-	10.2	slightly silty sand (SP-SM)
	45	F	D	-	-	5	NV	NP	100	100	100	100	99	-	92	-	-	72	-	-	28.9	silty sand (SM)
	47.5	F	D	-	-	2	NV	NP	100	100	100	99	96	-	68	-	-	23	-	-	6.0	slightly silty sand (SP-SM)
	50	F	D	-	-	2	NV	NP	86	79	77	71	62	-	46	-	-	32	-	-	13.4	silty sand (SM)
	52.5	F	D	-	-	8	30	10	100	100	100	100	99	-	96	-	-	85	-	-	53.1	sandy clay (CL)
	55	F	D	-	-	16	55	26	100	100	100	100	100	-	99	-	-	92	-	-	69.2	sandy clay (CH)
	57.5	F	D	-	-	4	17	NP	100	100	100	100	99	-	89	-	-	63	-	-	26.1	silty sand (SM)
	60.5	B	D	-	-	-			100	100	100	93	89	77	61	35	-	19	16	6	1.3	sand (SP)
	62.5	B	D	-	-	-																silty clay (CL)*
	65	B	D	-	-	-			100	100	100	100	96	89	75	40	-	25	20	7	2.6	sand (SP)
	70	B	D	-	-	-																slightly silty sand (SP-SM)*

* USCS Soil description is based on field classification of soil sample; not on the limited laboratory data shown here.

DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Density (pcf) Dry	Moisture Content (%)	Atterberg Limits LL	Atterberg Limits PI	Sieve Analysis (% Passing) 3/4"	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
ESPDH-3	2.5	B	D	-	-	20																sandy silt (ML)*
	5	B	D	-	-	8	22	NP	100	100	100	100	100	100	97	89	-	80	70	50	33.6	silty sand (SM)
	7.5	B	D	-	-	8	21	NP	100	100	100	100	100	100	99	94	-	86	79	62	42.6	silty sand (SM)
	10	B	D	-	-	5	NV	NP	100	100	100	98	98	93	40	4	-	3	2	1	0.3	sand (SP)
	12.5	B	D	-	-	5	NV	NP	100	100	100	100	100	97	25	6	-	3	3	1	0.2	sand (SP)
	15	B	D	-	-	3	NV	NP	100	100	100	100	97	89	69	45	-	34	27	16	7.9	slightly silty sand (SP-SM)
	17.5	B	D	-	-	6	NV	NP	100	100	100	100	99	96	91	72	-	55	46	13	4.7	sand (SP)
	20	B	D	-	-	17	53	23	100	100	100	100	100	98	90	79	-	73	69	62	52.7	sandy silt (MH)
	22.5	B	D	-	-	10	24	NP	100	100	100	100	97	85	74	63	-	56	51	41	30.9	silty sand (SM)
	25	B	D	-	-	-			100	100	100	100	100	98	90	69	-	52	41	23	11.6	slightly silty sand (SP-SM)*
	27.5	B	D	-	-	-			100	100	100	100	99	97	93	77	-	62	54	14	4.3	sand (SP)
	30	B	D	-	-	-			100	100	100	100	99	97	94	88	-	81	74	56	34.6	silty sand (SM)*
	32.5	B	D	-	-	-			100	100	100	99	99	97	88	67	-	52	43	22	12.4	silty sand (SM)*
	35	B	D	-	-	-			100	100	100	100	100	94	83	72	-	68	64	56	44.1	silty sand (SM)*
	37.5	B	D	-	-	-			100	100	100	100	98	86	69	40	-	18	16	3	1.5	sand (SP)
	40	B	D	-	-	-			100	100	100	100	96	77	53	34	-	26	22	16	11.4	slightly silty sand (SP-SM)*
	45	B	D	-	-	-			100	100	100	100	99	89	76	48	-	32	24	10	4.2	sand (SP)
	50	B	D	-	-	-			100	100	100	100	99	94	85	71	-	63	58	47	35.4	silty sand (SM)*
ESPDH-4	5-7	B	U			-																sand (SP)*
	8-10	F	U	-	101	7	NV	NP	100	100	99	98	98	-	87	-	-	62	-	-	21.2	silty sand (SM)
	14	B	D	-	-	12	26	6	100	100	100	100	100	97	89	79	-	69	60	42	29.0	silty clayey sand (SM-SC)
	19-21	F	U	-	100	9	NV	NP	100	100	100	100	100	-	98	-	-	72	-	-	26.8	silty sand (SM)
	24-26	B	U			-																sand (SP)*
	29-31	F	U	-	99	7	NV	NP	100	100	100	100	100	-	98	-	-	73	-	-	16.0	silty sand (SM)
	34-36	F	U	-	96	17	28	11	100	100	100	100	100	-	97	-	-	85	-	-	57.4	sandy clay (CL)
	39-41	F	U	-	109	8	NV	NP	100	100	100	100	100	-	90	-	-	49	-	-	16.1	silty sand (SM)
	44-46	F	U	-	100	8	NV	NP	100	100	100	100	100	-	89	-	-	55	-	-	14.5	silty sand (SM)
	49-51	F	U	-	95	9	NV	NP	100	100	100	100	99	-	81	-	-	45	-	-	18.5	silty sand (SM)
	54-56	F	U	-	102	10	NV	NP	100	100	99	98	96	-	79	-	-	60	-	-	27.2	silty sand (SM)
	59-61	F	U	-	107	5	NV	NP	100	95	93	86	77	-	49	-	-	21	-	-	7.1	slightly silty sand (SP-SM)
	64-66	B	U			-																silty sand (SM)*
	66	B	D	-	-	7	15	NP	100	100	100	93	87	71	51	34	-	27	22	13	7.5	slightly silty sand (SP-SM)*
ESPDH-5	2-4	B	U			-																sand (SP)*
	6-8	F	U		97	5	NV	NP	100	100	100	99	98	-	77	-	-	36	-	-	10.8	slightly silty sand (SP-SM)
	9-11	F	U		85	4	NV	NP	-	-	100	99	99	-	97	-	-	79	-	-	19.0	silty sand (SM)
	14-16	F	U		83	11	38	14	100	100	99	99	99	-	98	-	-	93	-	-	71.1	sandy clay (CL)
	19-21	F	U		84	3	NV	NP	-	-	100	99	99	-	84	-	-	45	-	-	11.3	slightly silty sand (SP-SM)
	24-26	F	U		82	12	39	16	100	100	100	100	99	-	98	-	-	94	-	-	69.0	sandy clay (CL)
	29-31	F	U	-	-	-	23	NP	-	100	99	99	99	-	97	-	-	88	-	-	51.8	sandy silt (ML)
	34-36	F	U		100	3	NV	NP	100	100	100	99	98	-	84	-	-	53	-	-	17.5	silty sand (SM)
	39-41	F	U		126	3	NV	NP	100	100	100	100	99	-	75	-	-	45	-	-	27.0	silty sand (SM)
ESPDH-6	1-3	F	U	-	88	10	31	11	100	100	100	100	100	-	97	-	-	82	-	-	57.5	sandy clay (CL)
	5-7	B	U			-																sand (SP)*
	8-10	F	U	-	101	5	NV	NP	100	98	98	93	87	-	44	-	-	22	-	-	14.6	silty sand (SM)
	14-16	F	U	-	94	10	NV	NP	100	100	100	100	100	-	98	-	-	87	-	-	32.3	silty sand (SM)
	19-21	B	U			-																sandy clay (CL)*
	24-26	F	U	-	104	5	NV	NP	100	100	100	100	100	-	90	-	-	54	-	-	14.8	silty sand (SM)
	34-36	F	U	-	96	23	64	33	100	100	100	100	100	-	97	-	-	83	-	-	62.2	clay (CH)
	39-41	F	U	-	111	5	NV	NP	100	100	100	100	100	-	88	-	-	47	-	-	13.8	silty sand (SM)
	44	B	D	-	-	6			100	100	100	100	100	99	88	63	-	47	36	19	8.8	slightly clayey sand (SP-SC)*
ESPDH-7	2-4	F	U		100	6	NV	NP	-	-	-	100	99	-	97	-	-	74	-	-	19.6	silty sand (SM)
	5-7	B	U			-																silty sand (SM)*
	10-12	F	U	-	74	9	NV	NP	-	-	100	98	97	-	91	-	-	65	-	-	27.1	silty sand (SM)
	15-17	B	U			-																sand (SP)*
	21-23	F	U	-	106	4	NV	NP	-	-	100	99	98	-	77	-	-	30	-	-	9.5	slightly silty sand (SP-SM)
	24	B	D	-	-	3	NV	NP	95	85	78	74	65	53	37	20	-	14	11	6	3.8	gravelly sand (SW)
	29-31	F	U	-	103	3	NV	NP	-	100	99	98	98	-	89	-	-	60	-	-	19.1	silty sand (SM)
	34-36	F	U	-	98	7	21	NP	-	-	-	-	100	-	97	-	-	79	-	-	45.7	silty sand (SM)
	39-41	F	U	-	91	4	NV	NP	-	-	-	-	100	-	91	-	-	52	-	-	16.9	silty sand (SM)
	44-46	F	U	-	97	4	NV	NP	-	-	-	-	100	-	95	-	-	67	-	-	23.6	silty sand (SM)
	49	B	D	-	-	4	18	NP	100	100	100	100	100	98	91	74	-	62	53	37	22.8	silty sand (SM)

* USCS Soil description is based on field classification of soil sample; not on the limited laboratory data shown here.

DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Density (pcf) Dry	Moisture Content (%)	Atterberg Limits LL	Atterberg Limits PI	Sieve Analysis (% Passing) 3/4"	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
ESPDH-8	2-4	F	U	-	78	16	61	30	100	100	100	100	100	-	99	-	-	93	-	-	86.6	clayey silt (MH)
	5-7	F	U	-	92	22	75	40	100	100	100	100	100	-	98	-	-	85	-	-	69.8	clayey silt (MH)
	10	B	D	-	-	1	NV	NP	100	100	100	79	76	68	52	34	-	26	20	12	6.8	slightly silty sand (SP-SM)
	14-16	B	U			-																silty sand (SM)*
	19	B	D	-	-	1			100	100	100	78	65	47	33	21	-	14	11	6	3.8	gravelly sand (SW)
	24-26	F	U	-	96	6	24	3	100	100	100	100	100	-	94	-	-	79	-	-	37.9	silty sand (SM)
	29-31	F	U	-	95	6	26	NP	100	100	100	100	100	-	95	-	-	84	-	-	38.1	silty sand (SM)
	34-36	F	U	-	95	9	29	9	100	100	100	100	100	-	95	-	-	80	-	-	54.1	sandy silt (ML)
	39-41	F	U	-	99	4	NV	NP	100	100	100	99	96	-	71	-	-	50	-	-	18.3	silty sand (SM)
	44	B	D	-	-	1	NV	NP	100	100	100	98	95	86	67	45	-	34	28	18	11.2	slightly silty sand (SP-SM)
	49	B	D	-	-	17	NV	NP	100	100	100	88	83	71	57	39	-	30	24	14	8.0	slightly silty sand (SP-SM)
ESPDH-9	2-4	F	U	-	86	5	21	NP	100	98	98	97	97	-	92	-	-	75	-	-	31.9	silty sand (SM)
	5-7	F	U	-	85	5	NV	NP	-	-	100	97	95	-	88	-	-	66	-	-	22.0	silty sand (SM)
	14-16	F	U	-	95	2	NV	NP	-	-	-	-	100	-	96	-	-	54	-	-	6.2	slightly silty sand (SP-SM)
	19-21	B	U			-																slightyly silty sand (SP-SM)*
	24-26	F	U	-	101	5	NV	NP	100	100	100	100	100	-	92	-	-	58	-	-	28.4	silty sand (SM)
	29-31	F	U	-	93	2	NV	NP	-	-	-	100	99	-	84	-	-	35	-	-	7.0	slightly silty sand (SP-SM)
	34-36	F	U	-	107	3	NV	NP	100	100	99	99	99	-	84	-	-	48	-	-	16.2	silty sand (SM)
	39	B	D	-	-	1	NV	NP	100	100	100	96	87	68	46	26	-	17	13	7	4.0	sand (SP)
	44	B	D	-	-	2	NV	NP	100	100	100	100	100	99	91	68	-	51	39	20	8.8	slightly silty sand (SP-SM)
	49	B	D	-	-	2	NV	NP	100	100	100	94	92	86	74	51	-	37	28	15	7.0	slightly silty sand (SP-SM)
	54	B	D	-	-	2	NV	NP	100	100	100	99	98	92	83	63	-	48	38	21	9.7	slightly silty sand (SP-SM)
	59	B	D	-	-	3	NV	NP	100	100	100	94	90	86	75	48	-	34	26	14	6.9	slightly silty sand (SP-SM)
	64	B	D	-	-	4	NV	NP	100	100	100	100	99	91	73	48	-	35	27	16	8.6	slightly silty sand (SP-SM)
	69	B	D	-	-	7	19	NP	100	100	100	100	100	98	92	77	-	67	60	47	32.0	silty sand (SM)
	69.5	B	D	-	-	20	44	17	100	100	100	100	99	94	82	72	-	68	64	56	44.9	clayey sand (SC)
	74	B	D	-	-	5	19	NP	100	100	100	99	98	94	82	58	-	45	36	23	14.2	silty sand (SM)
	79	B	D	-	-	17	25	7	100	100	100	100	100	99	93	83	-	75	68	55	41.0	silty clayey sand (SM-SC)
	84	B	D	-	-	15	24	8	100	100	100	93	90	87	77	59	-	46	38	25	15.7	clayey sand (SC)
	89	B	D	-	-	12	18	NP	100	100	100	100	100	97	86	72	-	62	54	39	26.6	silty sand (SM)
	94.5	B	D	-	-	7	NV	NP	83	72	72	66	57	46	38	27	-	19	15	8	4.7	gravelly sand (SW)
	103.5	B	D	-	-	25	48	21	100	100	100	100	99	98	90	74	-	66	61	51	42.8	clayey sand (SC)
	114	B	D	-	-	2																gravel (GW)*
	124	B	D	-	-	5			100	100	100	100	100	97	79	51	-	38	31	21	13.4	silty sand (SM)*
ESPDH-10	2-4	F	U	-	82	9	26	5	100	100	100	100	100	-	98	-	-	86	-	-	57.7	sandy silt (ML)
	5-7	F	U	-	87	13	28	8	100	100	100	100	98	-	86	-	-	79	-	-	63.3	silty clay (CL)
	9	B	D	-	-	1	NV	NP	100	100	100	100	100	99	94	71	-	51	38	20	8.8	slightly silty sand (SP-SM)
	14-16	F	U	-	86	4	NV	NP	-	-	-	-	100	-	97	-	-	80	-	-	19.7	silty sand (SM)
	19	B	D	-	-	1	NV	NP	100	100	100	97	93	81	67	44	-	29	20	10	4.9	sand (SP)
	24-26	F	U	-	96	4	NV	NP	100	100	100	100	100	-	96	-	-	74	-	-	22.5	silty sand (SM)
	29-30	F	U	-	88	6	25	NP	100	100	100	100	100	-	97	-	-	85	-	-	39.7	silty sand (SM)
	34	B	D	-	-	6	24	5	100	100	100	100	100	100	96	90	-	82	75	58	38.6	silty sand (SM)
	39	B	D	-	-	1	NV	NP	100	100	100	88	85	82	70	50	-	38	30	18	9.0	slightly silty sand (SP-SM)
ESPDH-11	2-4	F	U		92	18	26	7	100	100	100	100	99	-	98	-	-	67	-	-	35.6	silty-clayey sand (SM-SL)
	5-7	F	U	-	95	21	22	NP	-	-	-	-	100	-	98	-	-	95	-	-	58.8	sandy silt (ML)
	9-11	F	U	-	101	9	21	NP	-	-	-	100	99	-	95	-	-	75	-	-	51.9	sandy silt (ML)
	14-16	F	U	-	88	7	NV	NP	-	-	-	-	100	-	99	-	-	77	-	-	20.9	silty sand (SM)
	19-21	F	U	-	105	8	22	NP	96	94	94	92	92	-	90	-	-	76	-	-	30.4	silty sand (SM)
	24-26	B	U			-																silty sand (SM)*
	29-31	F	U	-	112	3	28	NP	-	-	-	-	-	-	100	-	-	97	-	-	73.1	sandy silt (ML)
	34-36	F	U	-	112	3	69	41	-	-	-	-	100	-	98	-	-	89	-	-	68.7	sandy clay (CH)
	39-41	F	U	-	89	28	NV	NP	-	-	100	98	95	-	54	-	-	15	-	-	3.3	sand (SP)
	41	B	D	-	-	5			100	100	100	100	99	94	83	62	-	51	43	29	16.7	silty sand (SM)*
	44-46	F	U	-	98	9	NV	NP	-	-	-	100	94	-	49	-	-	23	-	-	13.5	silty sand (SM)
	49-51	B	U																			
	54-56	F	U	-	107	7	NV	NP	-	-	100	99	99	-	86	-	-	54	-	-	19.2	silty sand (SM)
	59-61	F	U	-	104	3	NV	NP	-	100	99	96	97	-	86	-	-	41	-	-	9.1	slightly silty sand (SP-SM)
	61	B	D	-	-	4	NV	NP	100	100	100	100	99	91	78	55	-	41	32	18	9.0	slightly silty sand (SP-SM)
	65-67	F	U	-	107	6	NV	NP	-	100	96	94	92	-	79	-	-	47	-	-	16.6	silty sand (SM)
	67	B	D	-	-	1	NV	NP	100	95	95	84	75	58	38	18	-	11	7	4	2.0	sand (SP)
	70	B	D	-	-	12	NV	NP	100	100	100	100	99	91	77	55	-	41	32	19	10.3	slightly silty sand (SP-SM)
	79	B	D	-	-	8			100	100	100	100	98	90	74	54	-	43	36	24	15.4	silty sand (SM)*

* USCS Soil description is based on field classification of soil sample; not on the limited laboratory data shown here.

DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Density (pcf) Dry	Moisture Content (%)	Atterberg Limits LL	Atterberg Limits PI	Sieve Analysis (% Passing) 3/4	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
ESPDH-12	1.5-4	F	U	-	99	2	NV	NP	-	-	100	99	99	-	61	-	-	23	-	-	4.3	sand (SP)
	6.5-9	B	U			-																silty clay (CL)*
	11.5-14	F	U	-	104	3	NV	NP	-	-	-	-	100	-	96	-	-	87	-	-	36.4	silty sand (SM)
	16.5-19	F	U	-	89	12	61	32	-	-	-	-	100	-	98	-	-	91	-	-	78.1	sandy clay (CH)
	21.5-24	B	U			-																sandy silt (ML)*
	26.5-29	F	U	-	117	1	NV	NP	97	93	85	72	60	-	30	-	-	15	-	-	6.6	slightly silty sand (SP-SM)
	31.5-34	F	U	-	106	3	NV	NP	-	-	100	99	99	-	95	-	-	72	-	-	25.4	silty sand (SM)
ESPDH-13	2-4	B	U			-																sandy clay (CL)*
	5-7	F	U	-	82	41	62	30	-	-	-	-	100	-	99	-	-	95	-	-	89.4	sandy silt (MH)
	9-11	F	U	-	-	-	NV	NP	-	-	-	-	0	-	-	-	-	-	-	-	57.5	sandy silt (ML)
	14-16	F	U	-	91	28	37	14	-	-	-	-	100	-	98	-	-	93	-	-	82.2	sandy clay (CL)
	19-21	F	U	-	110	7	NV	NP	-	-	-	-	100	-	88	-	-	48	-	-	17.5	silty sand (SM)
	24	B	D	-	-	31																sand (SP)*
	29-31	F	U			-																sand (SP)*
	34-36	B	U			-																clayey silt (MH)*
	39-41	F	U	-	96	25	30	NP	100	100	100	100	100	-	99	-	-	96	-	-	67.3	sandy silt (ML)
	49-51	F	U	-	107	9	NV	NP	-	-	-	-	100	-	89	-	-	45	-	-	13.9	silty sand (SM)
	59-61	F	U	-	108	4	NV	NP	-	100	97	95	87	-	41	-	-	15	-	-	3.7	sand (SP)
	61	B	D	-	-	5			95	81	-	68	63	55	42	22	-	13	9	5	2.4	gravelly sand (SW)
ESPDH-14	2-4	F	U	-	82	17	28	NP	-	-	-	-	100	-	98	-	-	92	-	-	54.0	sandy silt (ML)
	5-7	B	U			-																silty sand (SM)*
	9-11	F	U	-	105	4	NV	NP	-	-	-	-	100	-	85	-	-	27	-	-	4.2	sand (SP)
	14-16	F	U	-	80	34	NV	NP	-	-	-	-	100	-	-	-	-	-	-	-	68.1	sandy silt (ML)
	19-21	B	U			-																sand (SP)*
	24-26	F	U	-	106	6	NV	NP	-	-	-	100	99	-	69	-	-	23	-	-	6.8	slightly silty sand (SP-SM)
	29	B	D	-	-	25																clayey sand (SC)*
	34-36	F	U	-	92	28	41	15	-	-	-	-	100	-	99	-	-	83	-	-	65.8	sandy clay (CL)
	39-41	B	U			-																clayey sand (SC)*
	44-46	F	U	-	80	12	42	18	-	-	-	-	100	-	99	-	-	98	-	-	90.1	sandy clay (CL)
	49-51	F	U	-	108	3	NV	NP	-	-	100	99	98	-	78	-	-	33	-	-	5.2	slightly silty sand (SP-SM)
ESPDH-15	2-3	F	U	-	101	5	NV	NP	100	98	95	88	81	-	50	-	-	26	-	-	10.4	slightly silty sand (SP-SM)
	5-7	B	U			-																silty sand (SM)*
	9-11	F	U	-	100	8	NV	NP	100	100	100	100	100	-	98	-	-	86	-	-	34.3	silty sand (SM)
	14-16	F	U	-	95	15	31	10	100	100	100	100	100	-	95	-	-	88	-	-	60.0	sandy clay (CL)
	19-21	B	U			-																sandy clay (CL)*
	24-26	F	U	-	87	10	28	5	100	100	100	100	100	-	100	-	-	97	-	-	57.1	sandy silt (ML)
	29-30	F	U	-	95	4	NV	NP	100	100	99	98	97	-	91	-	-	57	-	-	16.9	silty sand (SM)
	34-35	F	U	-	98	3	NV	NP	100	100	100	100	100	-	87	-	-	53	-	-	14.9	silty sand (SM)
	39-41	F	U	-	104	2	NV	NP	100	100	100	98	96	-	73	-	-	34	-	-	8.1	slightly silty sand (SP-SM)
	41	B	D	-	-	1	NV	NP	100	100	100	92	84	69	51	29	-	19	14	8	4.5	sand (SP)
ESPDH-16	2-4	F	U	-	89	31	74	37	-	-	-	-	100	-	98	-	-	85	-	-	59.4	sandy silt (MH)
	5-7	B	U			-																sandy silt (ML)*
	9-11	F	U	-	81	11	NV	NP	-	-	-	-	100	-	98	-	-	93	-	-	46.7	silty sand (SM)
	14-16	F	U	-	108	3	NV	NP	-	100	99	98	95	-	60	-	-	24	-	-	6.2	slightly silty sand (SP-SM)
	19	B	D	-	-	8			100	100	100	100	100	96	86	66	-	53	44	27	14.2	clayey sand (SC)*
	24-26	F	U	-	101	8	NV	NP	-	-	-	100	99	-	95	-	-	75	-	-	27.9	silty sand (SM)
	29-31	F	U	-	99	9	42	19	-	-	-	-	100	-	99	-	-	87	-	-	28.0	clayey sand (SC)
	34	B	D	-	-	12			100	100	100	100	99	93	83	71	-	61	51	33	18.9	clayey sand (SC)*
	44-46	F	U	-	107	4	NV	NP	-	100	99	95	93	-	75	-	-	29	-	-	6.9	slightly silty sand (SP-SM)
	54	B	D	-	-	9			100	100	100	100	100	94	76	67	-	48	41	29	17.1	clayey sand (SC)*
ESPDH-17	2-4	F	U	-	99	6	NV	NP	-	-	100	99	99	-	92	-	-	65	-	-	19.6	silty sand (SM)
	4-6	B	U			-																silty clay (CL)*
	9-11	F	U	-	102	3	NV	NP	-	-	-	-	100	-	98	-	-	69	-	-	17.2	silty sand (SM)
	14-16	F	U	-	89	8	NV	NP	-	-	-	-	100	-	89	-	-	56	-	-	20.3	silty sand (SM)
	19-21	F	U	-	92	23	21	NP	-	-	-	100	99	-	98	-	-	92	-	-	67.4	sandy silt (ML)
	24-26	B	U			-																slightly silty sand (SP-SM)*
	29-31	F	U	-	92	23	17	NP	-	-	-	-	100	-	-	-	-	-	-	-	55.5	sandy silt (ML)
	39-41	F	U	-	112	12	27	6	-	100	99	99	99	-	97	-	-	85	-	-	33.6	silty-clayey sand (SM-SC)
	49-51	F	U	-	97	19	NV	NP	-	-	-	100	99	-	91	-	-	78	-	-	45.6	silty sand (SM)
	59-61	B	U			-																silty sand (SM)*
	69-71	F	U	-	109	18	NV	NP	-	-	-	100	99	-	95	-	-	68	-	-	29.4	silty sand (SM)
	79	B	D	-	-	19	NV	NP	100	100	100	98	95	78	55	38	-	30	25	17	11.2	slightly silty sand (SP-SM)
	89	B	D	-	-	25			100	100	100	100	99	91	78	64	-	57	51	43	34.3	clayey sand (SC)*
	100	B	D	-	-	11	NV	NP	80	46	46	37	24	18	14	10	-	8	7	5	3.4	sandy gravel (GW)

* USCS Soil description is based on field classification of soil sample; not on the limited laboratory data shown here.

DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Density (pcf) Dry	Moisture Content (%)	Atterberg Limits LL	Atterberg Limits PI	3/4"	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
									Sieve Analysis (% Passing)													
ESPDH-18	2-4	F	U	–	87	9	31	12	100	100	100	99	98	–	90	–	–	71	–	–	42.0	very clayey sand (SC)
	5-7	B	U			–																
	9	B	D	–	–	12			100	100	100	100	99	91	81	73	–	67	63	53	41.8	clayey sand (SC)*
	14-16	F	U	–	94	9	NV	NP	100	100	100	100	100	–	97	–	–	82	–	–	29.4	silty sand (SM)
	19	B	D	–	–	7			100	100	100	100	100	100	96	80	–	66	55	32	15.5	clayey sand (SC)*
	24-26	F	U	–	95	8	NV	NP	100	100	100	100	100	–	99	–	–	78	–	–	20.1	silty sand (SM)
	29	B	D	–	–	13			100	100	100	100	100	100	89	75	–	65	58	43	30.1	silty sand (SM)*
ESPDH-19	1.5-4	F	U	–	112	14	27	7	100	100	100	100	100	–	96	–	–	69	–	–	36.5	clayey sand (SC)
	7.5-10	B	U			–																silty sand (SM)*
	12.5-15	F	U	–	104	3	NV	NP	–	–	–	100	100	–	96	–	–	64	–	–	21.7	silty sand (SM)
	17.5-20	F	U	–	112	5	18	NP	100	100	100	100	99	–	88	–	–	54	–	–	20.3	silty sand (SM)
	22.5-25	B	U			–																silty sand (SM)*
	27.5-30	F	U	–	98	5	NV	NP	100	100	100	100	100	–	93	–	–	67	–	–	19.8	silty sand (SM)
	32.5-35	F	U	–	113	5	NV	NP	–	–	–	–	100	–	97	–	–	72	–	–	20.1	silty sand (SM)
	37.5-40	B	U			–																slightly silty sand (SP-SM)*
	42.5-45	F	U	–	107	7	NV	NP	100	100	100	100	100	–	94	–	–	42	–	–	11.7	slightly silty sand (SP-SM)
	47.5-50	F	U	–	115	17	NV	NP	–	–	–	100	99	–	78	–	–	44	–	–	14.0	silty sand (SM)
	52.5-55	F	U	–	124	14	NV	NP	100	99	99	98	97	–	71	–	–	35	–	–	11.4	slightly silty sand (SP-SM)
	55	B	D	–	–	13	NV	NP	100	100	100	85	80	69	53	36	–	27	22	15	9.7	slightly silty sand (SP-SM)
ESPDH-20	2-4	F	U	–	108	21	NV	NP	100	100	100	100	99	–	94	–	–	69	–	–	30.1	silty sand (SM)
	5-7	F	U	–	98	12	NV	NP	100	100	100	100	100	–	99	–	–	83	–	–	26.8	silty sand (SM)
	9-11	B	U			–																slightly sandy clay (CH)*
	14-16	F	U	–	102	8	NV	NP	100	100	99	99	98	–	83	–	–	49	–	–	8.7	slightly silty sand (SP-SM)
	19-21	B	U			–																sand (SP)*
	24	B	D	–	–	9			100	100	100	100	100	98	92	79	–	67	56	36	19.1	silty sand (SM)*
	34-36	F	U	–	108	7	NV	NP	100	100	100	100	89	–	83	–	–	42	–	–	13.3	silty sand (SM)
	49-51	F	U	–	109	4	NV	NP	100	100	99	99	98	–	68	–	–	26	–	–	7.7	slightly silty sand (SP-SM)
ESPDH-21	1	B	D	–	–	14	29	9	100	100	100	100	100	98	92	84	–	76	69	52	32.1	clayey sand (SC)
	5	B	D	–	–	10	36	12	100	100	100	100	100	98	90	77	–	70	64	52	38.0	silty sand (SM)
	8	B	D	–	–	2	18	NP	100	100	100	85	83	82	77	61	–	47	37	23	13.3	silty sand (SM)
	14	B	D	–	–	15			100	100	100	100	99	98	93	87	–	83	80	67	45.2	silty sand (SM)
	14.5	F	D	–	–	–																sandy clay (CL)*
	15-17.5	B	U			–																silty sand (SM)*
	22.5-25	F	U	–	107	3	NV	NP	100	100	100	100	100	–	96	–	–	76	57	–	17.9	silty sand (SM)
	27.5-30	F	U	–	109	7	18	NP	100	100	100	100	99	–	94	–	–	72	–	–	29.9	silty sand (SM)
	30-32.5	B	U			–																silty sand (SM)*
	37.5-40	F	U	–	109	6	NV	NP	100	100	100	100	100	–	95	–	–	60	45	–	14.3	silty sand (SM)
	44-45	F	U	–	102	14	NV	NP	100	100	99	98	98	–	85	–	–	47	–	–	21.1	silty sand (SM)
	47	B	D	–	–	24	18	NP	100	100	100	98	98	97	87	64	–	48	38	23	13.1	silty sand (SM)
	47.5-50	F	U	–	125	5	NV	NP	100	100	100	100	99	–	85	–	–	40	34	–	12.5	silty sand (SM)
ESPDH-22	2-4	F	U	–	90	8	NV	NP	100	100	100	100	100	–	96	–	–	74	–	–	32.0	silty sand (SM)
	5-7	B	U			–																sandy silty (ML)
	9-11	F	U	–	94	4	NV	NP	100	100	100	100	100	–	86	–	–	56	–	–	21.2	silty sand (SM)
	14-16	B	U			–																slightly silty sand (SP-SM)*
	19-21	F	U	–	90	11	32	13	100	100	100	100	100	–	96	–	–	84	–	–	45.2	clayey sand (SC)
	24	B	D	–	–	11			100	100	100	100	100	98	91	81	–	75	70	59	46.2	silty sand (SM)*
	29-31	F	U	–	89	6	NV	NP	100	100	100	100	100	–	99	–	–	85	–	–	38.9	silty sand (SM)
ESPDH-23	1	B	D	–	–	26	41	13	100	100	100	100	96	86	70	53	–	44	38	28	19.9	clayey sand (SC)
	5	B	D	–	–	9	29	6	100	100	100	100	100	99	86	69	–	59	51	39	28.0	silty sand (SM)
	8	B	D	–	–	3	NV	NP	100	100	100	100	100	96	83	56	–	39	29	16	8.0	slightly silty sand (SP-SM)
	14	F	D	–	–	–																sand (SP)*
	14.5	B	D	–	–	10	22	NP	100	100	100	100	100	96	90	84	–	79	74	57	37.1	silty sand (SM)
	15-17.5	F	U			–																slightly silty sand (SP-SM)*
	22.5-25	B	U			–																slightly silty sand (SP-SM)*
	25-27	F	U	–	103	3	NV	NP	100	100	100	100	100	–	88	–	–	42	34	–	9.4	slightly silty sand (SP-SM)
	32.5-35	F	U	–	104	23	18	NP	100	100	100	100	100	–	98	–	–	77	–	–	19.5	silty sand (SM)
	33	B	D	–	–	24	24	NP	100	100	100	100	100	100	99	96	–	91	84	64	39.6	silty sand (SM)
	40	B	D	–	–	39	54	11	100	100	100	100	100	95	78	65	–	47	40	30	21.9	clayey sand (SC)
	50	B	D	–	–	33	56	32	100	100	100	100	100	95	81	65	–	56	50	41	31.1	clayey sand (SC)
	60	B	D	–	–	8	NV	NP	100	100	100	86	73	61	53	47	–	42	38	31	24.5	silty sand (SM)
	65	B	D	–	–	3																sandy gravel (GW)*

* USCS Soil description is based on field classification of soil sample; not on the limited laboratory data shown here.

DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Density (pcf) Dry	Moisture Content (%)	Atterberg Limits LL	Atterberg Limits PI	Sieve Analysis (% Passing) 3/4"	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
ESPDH-24	2-4	F	U	-	82	10	28	7	100	100	100	100	100	-	100	-	-	95	-	-	65.9	sandy silt (ML)
	5-7	B	U			-																sandy silt (ML)*
	9-11	F	U	-	72	18	58	28	100	100	100	100	100	-	99	-	-	93	-	-	67.7	silty sand (CL)
	14-16	F	U	-	99	3	NV	NP	100	100	100	100	99	-	83	-	-	27	-	-	5.6	slightly silty sand (SP-SM)
	19-21	B	U			-																
	24-26	F	U	-	103	2	NV	NP	100	98	98	97	96	-	83	-	-	49	-	-	13.7	silty sand (SM)
	26	B	D	-	-	1																sand (SP)
	34-36	F	U	-	95	4	NV	NP	100	100	100	100	99	-	93	-	-	64	-	-	23.7	silty sand (SM)
ESPDH-25	1	B	D	-	-	14																silty sand (SM)*
	5	B	D	-	-	4																silty sand (SM)*
	8	B	D	-	-	1																sand (SP)*
	14	B	D	-	-	2																slightly silty sand (SP-SM)*
	15-17	F	U	-	117	3	NV	NP	97	95	93	88	79	-	48	-	-	22	20	-	10.7	slightly silty sand (SP-SM)
	17	B	D	-	-	1																silty sand (SM)*
	20-22.5	B	U			-																silty sand (SM)*
	22.5	B	D	-	-	1																silty sand (SM)*
	25-27.5	F	U	-	102	4	20	NP	100	100	99	98	96	-	84	-	-	60	-	-	22.2	silty sand (SM)
	27.5	B	D	-	-	3																sand (SP)*
	30-32.5	F	U	-	96	4	NV	NP	100	100	100	100	100	-	96	-	-	80	-	-	22.8	silty sand (SM)
	32.5	B	D	-	-	1																silty sand (SM)*
	35-37.5	B	U			-																silty sand (SM)*
	37.5	B	D	-	-	1																silty sand (SM)*
	40.42.5	F	U	-	114	3	NV	NP	98	97	97	95	92	-	74	-	-	48	-	-	17.4	silty sand (SM)
	42.5	B	D	-	-	1																silty sand (SM)*
	45-47.5	F	U	-	105	7	NV	NP	100	100	100	100	100	-	100	-	-	86	67	-	22.9	silty sand (SM)
	47.5	B	D	-	-	4																slightly silty sand (SP-SM)*
	50-52.5	B	U			-																silty sand (SM)*
	52.5	B	D	-	-	4																slightly silty sand (SP-SM)*
	60-62.5	F	U	-	115	3	NV	NP	100	100	100	100	100	-	97	-	-	61	-	-	23.5	silty sand (SM)
	62.5	B	D	-	-	3																silty sand (SM)*
	65-67	F	U	-	115	2	NV	NP	100	100	100	100	100	-	86	-	-	47	-	-	18.9	silty sand (SM)
	67.5	B	D	-	-	2																silty sand (SM)*
	80	B	D	-	-	10																silty sand (SM)*
	90	B	D	-	-	2																sand (SP)*
	100	B	D	-	-	12																sand (SP)*
	110	B	D	-	-	15																slightly silty sand (SP-SM)*
	120	B	D	-	-	19																sandy gravel (GW)*
ESPDH-26	2-4	F	U	-	95	9	20	NP	100	100	100	100	100	-	96	-	-	78	-	-	29.4	silty sand (SM)
	5-7	B	U			-																sandy silt (ML)*
	9-11	F	U	-	93	8	32	11	100	100	100	100	100	-	97	-	-	87	-	-	53.3	sandy silt (ML)
	14-16	B	U			-																silty sand (SM)*
	19-21	F	U	-	96	5	19	NP	100	98	97	94	92	-	84	-	-	64	-	-	30.3	silty sand (SM)
	24-26	F	U	-	103	2	NV	NP	100	100	100	99	98	-	70	-	-	26	-	-	5.5	slightly silty sand (SP-SM)
	29	B	D	-	-	1																silty sand (SM)* sandy clay (CL)*
ESPDH-27	1-2.0	F	U	-	90	6	22	NP	100	100	100	100	100	-	95	-	-	58	49	-	21.7	silty sand (SM)
	2-4.5	F	U	-	94	2	NV	NP	100	100	100	100	100	-	96	-	-	67	-	-	20.0	silty sand (SM)
	5-7.5	B	U			-																silty sand (SM)*
	10	B	D	-	-	8																silt (ML)*
	10.5-12	F	U	-	88	20	NV	NP	100	99	98	98	98	-	87	-	-	38	27	-	10.3	slightly silty sand (SP-SM)
	16-18.5	B	U			-																silty sand (SM)*
	18.5	B	D	-	-	9																silty sand (SM)*
	20	B	D	-	-	10																silty sand (SM)*
	20.5-23	F	U	-	109	13	20	NP	100	100	100	100	99	-	92	-	-	71	-	-	36.1	silty sand (SM)
	23	B	D	-	-	1																slightly silty sand (SP-SM)*
	25-28	F	U	-	98	20	33	11	100	100	100	100	99	-	95	-	-	86	-	-	58.1	sandy clay (CL)
	28	B	D	-	-	9																silty sand (SM)*
	30-31.5	B	U			-																silty sand (SM)*
	31.5	B	D	-	-	6																silty sand (SM)*
	35.5	B	D	-	-	11																clayey sand (SC)*
	36-38.5	F	U	-	102	5	NV	NP	100	100	100	100	100	-	91	-	-	54	-	-	18.6	silty sand (SM)
	38.5	B	D	-	-	1																slightly silty sand (SP-SM)*
	40-42.5	F	U	-	110	3	NV	NP	100	100	100	98	97	-	79	-	-	45	-	-	16.4	silty sand (SM)
	42.5	B	D	-	-	3																silty sand (SM)*
	45	B	D	-	-	3																silty sand (SM)*
	45.5-48	F	U	-	106	3	NV	NP	100	100	100	100	100	-	93	-	-	52	-	-	18.8	silty sand (SM)
	48	B	D	-	-	4																silty sand (SM)*

* USCS Soil description is based on field classification of soil sample; not on the limited laboratory data shown here.

DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Density (pcf) Dry	Moisture Content (%)	Atterberg Limits LL	Atterberg Limits PI	Sieve Analysis (% Passing) 3/4"	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
ESPDH-28	2-4	F	U	-	103	4	NV	NP	100	100	100	100	99	-	77	-	-	35	-	-	9.3	slightly silty sand (SP-SM)
	5-7	F	U	-	101	2	NV	NP	100	100	100	100	98	-	51	-	-	18	-	-	5.6	slightly silty sand (SP-SM)
	9-11	B	U			-																sand (SP)*
	14-16	F	U	-	87	11	NV	NP	100	100	100	100	100	-	98	-		84	-	-	35.1	silty sand (SM)
	19-21	B	U			-																sand (SP)*
	24-26	F	U	-	106	3	NV	NP	100	100	100	100	99	-	74	-	-	29	-	-	7.8	slightly silty sand (SP-SM)
	29	B	D	-	-	23																clayey silt (MH)*
	34	B	D	-	-	28																sandy clay (CH)*
	39	B	D	-	-	8																slightly silty sand (SP-SM)*
	44-46	F	D	-	93	20	37	16	100	100	100	100	100	-	100	-	-	99	-	-	84.1	silty clay (CL)
	49	B	D	-	-	29																clay (CH)*
ESPDH-29	1-2.5	F	U	-	94	14	22	NP	100	100	100	100	100	-	97	-	-	84	-	-	49.9	silty sand (SM)
	5-7.5	B	U			-																silty sand (SM)*
	10	B	D			17																silty sand (SM)*
	11-13.5	F	U	-	100	12	23	NP	100	100	100	100	99	-	97	-	-	72	-	-	30.1	silty sand (SM)
	15-17.5	B	U			-																sandy clay (CL)*
	20	B	D	-	-	19																sandy clay (CL)*
	20.5-23	F	U	-	105	17	29	9	100	100	100	100	100	-	88	-	-	67	-	-	40.6	silty sand (SM)
	25-27.5	B	U			-																slightly silty sand (SP-SM)*
	30-32.5	F	U	-	108	15	19	NP	100	100	100	100	100	-	97	-	-	75	70	-	34.8	silty sand (SM)
	35	B	D	-	-	13																silty sand (SM)*
	35.5-38	F	U	-	111	13	NV	NP	100	99	98	98	97	-	89	-	-	65	-	-	30.6	silty sand (SM)
	40-42.5	B	U			-																silty sand (SM)*
	45-47.5	F	U	-	106	11	NV	NP	100	100	100	100	100	-	87	-	-	40	35	-	12.3	silty sand (SM)
	47.5	B	D	-	-	4																sand (SP)*
	50	B	D	-	-	24																sandy clay (CL)*
	51-53.5	F	U	-	110	11	NV	NP	100	97	97	97	96	-	94	-	-	80	69	-	26.0	silty sand (SM)
ESPDH-30	2-4	F	U	-	92	4	NV	NP	100	100	100	100	100	-	92	-	-	60	-	-	23.2	silty sand (SM)
	5-7	B	U			-																silty sand (SM)*
	9-11	F	U	-	84	19	57	29	100	100	100	100	100	-	98	-	-	79	-	-	57.9	sandy clay (CL)
	14-16	F	U	-	89	6	24	NP	100	100	100	100	100	-	99	-	-	89	-	-	49.1	silty sand (SM)
	19-21	B	U			-																gravelly sand (SW)*
	24	B	D	-	-	2																silty sand (SM)*
	29-31	F	U	-	83	14	40	17	100	100	100	100	100	-	99	-	-	95	-	-	74.8	silty clay (CL)
	34-36	F	U	-	103	3	17	NP	100	100	100	99	98	-	85	-	-	61	-	-	18.3	silty sand (SM)
	39	B	D	-	-	1																gravelly sand (SW)*
ESPDH-31	1-2.5	F	U	-	84	21	55	27	100	100	100	100	100	-	100	-	-	96	-	-	80.1	silty clay (CL)
	5-7.5	B	U			-																silty sand (SM)*
	10-12.5	F	U	-	103	5	NV	NP	100	100	100	100	100	-	97	-	-	70	-	-	20.9	silty sand (SM)
	15-17.5	F	U	-	113	2	NV	NP	100	97	97	91	86	-	50	-	-	21	-	-	8.3	slightly silty sand (SP-SM)
	20-22.5	F	U	-	105	17	44	22	100	100	100	100	100	-	99	-	-	92	-	-	66.7	silty clay (CL)
	25-27.5	B	U			-																silty sand (SM)*
	30-32.5	F	U	-	107	5	NV	NP	100	100	100	99	98	-	90	-	-	44	-	-	14.1	silty sand (SM)
	33	B	D	-	-	4	NV	NP	100	100	100	100	100	100	95	80	-	64	-	-	13.9	silty sand (SM)
	39-41	F	U	-	103	6	NV	NP	100	100	100	100	99	-	79	-	-	33	-	-	13.1	silty sand (SM)
	49-51	F	U	-	105	5	NV	NP	100	97	95	94	91	-	67	-	-	31	-	-	8.4	slightly silty sand (SP-SM)
	59	B	D	-	-	-																silty sand (SM)*
	69	B	D	-	-	6	NV	NP	100	100	100	100	100	93	71	50	-	39	32	20	10.9	slightly silty sand (SP-SM)
	79	B	D	-	-	24	32	12	100	100	100	100	100	98	90	72	-	59	50	38	29.1	clayey sand (SC)
	89	B	D	-	-	18	NV	NP	100	100	100	100	100	99	95	86	-	74	61	36	18.5	silty sand (SM)
	99	B	D	-	-	17	20	NP	100	100	100	100	98	93	83	70	-	61	55	42	30.6	silty sand (SM)
	109	B	D	-	-	24																sandy clay (CL)*
	109.5	B	D	-	-	15	NV	NP	69	66	66	45	35	29	22	15	-	12	10	8	5.8	gravelly sand (SW)
ESPDH-32	2-4	F	U	-	83	6	28	4	100	100	100	100	100	-	98	-	-	93	-	-	53.6	sandy silt (ML)
	5-7	B	U			-																sand (SP)*
	9-11	F	U	-	86	5	24	NP	100	100	100	100	100	-	94	-	-	62	-	-	27.5	silty sand (SM)
	14-16	F	U	-	98	4	NV	NP	100	100	99	98	97	-	89	-	-	56	-	-	16.0	silty sand (SM)
	19-21	B	U			-																sandy silt (ML)*
	24-26	F	U	-	93	4	17	NP	100	100	100	100	100	-	99	-	-	82	-	-	25.2	silty sand (SM)
	29	B	D	-	-	5																slightly silty sand (SP-SM)*
	34-36	F	U	-	92	5	NV	NP	100	100	100	100	100	-	97	-	-	81	-	-	32.0	silty sand (SM)

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DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Density (pcf) Dry	Moisture Content (%)	Atterberg Limits LL	Atterberg Limits PI	Sieve Analysis (% Passing) 3/4"	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
ESPDH-33	2–4	F	U	–	79	11	37	10	100	100	100	100	100	–	99	–	–	97	–	–	81.2	slightly sandy silt (ML)
	5–7	F	U	–	80	15	40	12	100	100	100	100	100	–	97	–	–	88	–	–	66.2	sandy silt (ML)
	9–11	B	U			–																silty sand (SM)*
	14–16	F	U	–	91	5	NV	NP	100	100	100	100	99	–	90	–	–	51	–	–	21.1	silty sand (SM)
	19–21	F	U	–	98	4	NV	NP	100	100	100	100	100	–	90	–	–	41	–	–	9.9	slightly silty sand (SP-SM)
	24–26	B	U			–																slightly clayey sand (SP-SC)*
	29–31	F	U	–	110	7	NV	NP	100	100	100	100	99	–	70	–	–	27	–	–	9.2	slightly silty sand (SP-SM)
	34	B	D	–	–	29																sand (SP)*
ESPDH-34	2–4	F	U	–	92	18	29	10	100	100	100	100	100	–	98	–	–	83	–	–	40.4	clayey sand (SC)
	5–7	B	U			–																slightly clayey sand (SP-SC)*
	9–11	F	U	–	88	17	NV	NP	100	100	100	100	100	–	97	–	–	88	–	–	42.6	silty sand (SM)
	14–16	F	U	–	94	8	19	NP	100	98	97	96	94	–	84	–	–	69	–	–	23.4	silty sand (SM)
	19–21	B	U			–																slightly silty sand (SP-SM)*
	24	B	D	–	–	14																clayey sand (SC)*
	29–31	F	U	–	101	9	17	NP	100	100	100	100	99	–	93	–	–	59	–	–	22.6	silty sand (SM)
	39–41	F	U	–	94	20	31	11	100	100	100	100	100	–	95	–	–	84	–	–	62.2	sandy clay (CL)
ESPDH-35	2–4	F	U	–	94	4	23	NP	100	100	100	100	100	–	92	–	–	56	–	–	16.6	silty sand (SM)
	4–6	F	U	–	105	3	NV	NP	100	100	100	100	100	–	88	–	–	45	–	–	12.5	silty sand (SM)
	8–10	B	U			–																silty sand (SM)*
	13–15	F	U	–	75	15	40	15	100	100	100	100	100	–	100	–	–	98	–	–	88.2	clay (CL)
	19	B	D	–	–	1																slightly silty sand (SP-SM)*
	24	B	D	–	–	10																silty clay (CL)*
	28–30	F	U	–	96	5	20	NP	100	100	100	100	100	–	97	–	–	79	–	–	28.3	silty sand (SM)
	33–35	B	U			–																slightly silty sand (SP-SM)*
	38–40	F	U	–	86	9	31	7	100	100	100	100	100	–	99	–	–	95	–	–	63.3	sandy silt (ML)
	43–44.5	F	U	–	98	4	24	NP	97	97	96	96	94	–	81	–	–	60	–	–	23.5	silty sand (SM)
	48	B	D	–	–	4																slightly silty sand (SP-SM)*
ESPDH-36	2–4	F	U	–	95	3	NV	NP	100	100	100	100	99	–	85	–	–	42	–	–	15.2	silty sand (SM)
	5–7	B	U			–																sand (SP)*
	9–11	F	U	–	92	5	20	NP	100	100	100	100	100	–	97	–	–	72	–	–	25.1	silty sand (SM)
	14–16	B	U			–																sand silty (ML)
	19–21	F	U	–	94	13	27	NP	100	100	100	100	100	–	91	–	–	78	–	–	36.7	silty sand (SM)
	24–26	F	U	–	99	15	28	NP	100	100	100	100	100	–	88	–	–	60	–	–	37.1	silty sand (SM)
	29	B	D	–	–	33																clay (CH)*
	34–36	F	U	–	93	28	NV	NP	100	100	100	100	100	–	98	–	–	80	–	–	30.3	silty sand (SM)
	39	B	D	–	–	17																clay (CH)*
	44	B	D	–	–	12																silty sand (SM)*
	49	B	D	–	–	16																silty sand (SM)*
ESPDH-37	2–4	F	U	–	102	4	18	NP	100	100	100	100	99	–	87	–	–	62	–	–	25.8	silty sand (SM)
	4–6	F	U	–	91	5	NV	NP	100	100	100	99	98	–	86	–	–	58	–	–	24.8	silty sand (SM)
	6	B	D	–	–	10																silty sand (SM)*
	8	B	D	–	–	3																silty sand (SM)*
	13–15	B	U			–																silty sand (SM)*
	18–20	F	U	–	93	6	NV	NP	100	100	100	100	100	–	100	–	–	87	–	–	27.7	silty sand (SM)
	23	B	D	–	–	1																slightly silty sand (SP-SM)*
	28	B	D	–	–	4																sand (SP)*
ESPDH-38	2–4	F	U	–	95	18	77	45	100	100	100	100	100	–	99	–	–	83	–	–	61.4	silty clay (CH)
	5–7	F	U	–	86	27	78	43	100	100	100	100	100	–	95	–	–	69	–	–	48.0	clayey sand (SC)
	9–11	B	U			–																sand (SP)*
	14–16	F	U	–	107	6	NV	NP	100	100	100	100	100	–	89	–	–	38	–	–	9.7	slightly silty sand (SP-SM)
	19–21	B	U			36																clay (CH)*
	24–26	F	U	–	103	19	21	NP	100	100	100	100	100	–	77	–	–	37	–	–	17.0	silty sand (SM)
	29	B	D	–	–	35																slightly silty sand (SP-SM)*
	34	B	D	–	–	32																clay (CH)*
	39	B	D	–	–	28																clay (CH)*
	44	B	D	–	–	23																clayey sand (SC)*

* USCS Soil description is based on field classification of soil sample; not on the limited laboratory data shown here.

DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Density (pcf) Dry	Moisture Content (%)	Atterberg Limits LL	Atterberg Limits PI	Sieve Analysis (% Passing) 3/4"	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
ESPDH-39	2-4	F	U	-	90	4	NV	NP	100	100	100	100	100	-	99	-	-	77	-	-	21.9	silty sand (SM)
	4-6	F	U	-	92	6	23	NP	100	100	100	100	100	-	98	-	-	87	-	-	40.4	silty sand (SM)
	8-10	B	U			-																silty sand (SM)*
	13-15	F	U	-	74	14	46	19	100	100	100	100	100	-	100	-	-	97	-	-	86.4	silt (ML)
	18-20	B	U			-																silty sand (SM)*
	23-25	F	U	-	86	10	37	14	100	100	100	100	100	-	95	-	-	83	-	-	52.4	sandy clay (CL)
	28-30	F	U	-	78	12	35	13	100	100	100	100	100	-	99	-	-	93	-	-	79.3	silty clay (CL)
	33	B	D	-	-	1																silty sand (SM)*
	38	B	D	-	-	5																silty sand (SM)*
	43	B	D	-	-	1																slightly silty sand (SP-SM)*
	48	B	D	-	-	2																silty sand (SM)*
	58	B	D	-	-	8																silty sand (SM)*
	68	B	D	-	-	1																slightly silty sand (SP-SM)*
	80	B	D	-	-	14																sand (SP)*
	90	B	D	-	-	12																sand (SP)*
	100	B	D			-																sand (SP)*
ESPDH-40	2-4	F	U	-	95	6	NV	NP	100	100	100	100	100	-	94	-	-	57	-	-	22.6	silty sand (SM)
	5-7	F	U	-	103	25	48	28	100	97	97	95	94	-	87	-	-	70	-	-	50.3	sandy clay (CL)
	9-11	B	U			-																sandy clay (CL)*
	14-16	F	U	-	99	10	24	NP	100	100	100	100	100	-	88	-	-	48	-	-	25.9	silty sand (SM)
	19-21	B	U			-																sand (SP)*
	24-26	F	U	-	88	34	82	47	100	100	100	100	100	-	100	-	-	93	-	-	84.8	clay (CH)
	29-31	F	U	-	92	32	61	30	100	100	100	100	100	-	100	-	-	99	-	-	97.8	clay (CH)
	34	B	D	-	-	18																clay (CH)*
	39	B	D	-	-	26																clay (CH)*
	44	B	D	-	-	7																clay (CH)*
	49	B	D	-	-	18																clayey sand (SC)*
	50.5	B	D	-	-	23																sand (SP)*
ESPDH-41	2-4	B	U			-																silty sand (SM)*
	8-10	B	U			-																slightly silty sand (SP-SM)*
	18-20	B	U			-																sandy clay (CL)*
	20	B	D	-	-	17																sandy clay (CL)*
	28-30	B	U			-																silty sand (SM)*
	38-40	B	U			-																silty sand (SM)*
	48	B	D	-	-	3																silty sand (SM)*
	58	B	D	-	-	3																silty sand (SM)*
	68	B	D	-	-	4																silty sand (SM)*
	78	B	D	-	-	11																slightly silty sand (SP-SM)*
	88	B	D	-	-	19																silty sand (SM)*
	98	B	D	-	-	16																silty clay (CL)*
	108	B	D	-	-	-																sandy gravel (GW)*
ESPDH-42	2-4	F	U	-	101	7	NV	NP	100	100	100	99	98	-	82	-	-	39	-	-	12.3	silty sand (SM)
	5-7	B	U			-																sand (SP)*
	9-11	F	U	-	96	3	NV	NP	100	100	99	99	98	-	79	-	-	22	-	-	5.8	slightly silty sand (SP-SM)
	14-16	B	U			-																slightly silty sand (SP-SM)*
	19-21	F	U	-	98	5	NV	NP	100	100	100	100	100	-	98	-	-	79	-	-	21.6	silty sand (SM)
	24-26	F	U	-	106	3	NV	NP	100	100	100	100	100	-	97	-	-	49	-	-	10.0	slightly silty sand (SP-SM)
	29	B	D	-	-	14																sandy clay (CL)*
	34-36	F	U	-	103	4	NV	NP	100	100	100	100	100	-	89	-	-	40	-	-	15.3	silty sand (SM)
	39-41	D	U			-																silty sand (SM)*
	44-46	F	U	-	96	8	21	NP	100	100	100	100	100	-	95	-	-	65	-	-	32.4	silty sand (SM)
	49	B	D	-	-	20																slightly sandy clay (CH)*
	59	B	D	-	-	26																clay (CH)*
	64	B	D	-	-	25																sand (SP)*
ESPDH-43	2-4	F	U	-	92	9	NV	NP	100	100	100	99	99	-	97	-	-	71	-	-	25.9	silty sand (SM)
	4-6	F	U	-	91	5	16	NP	100	100	100	100	100	-	98	-	-	68	-	-	24.8	silty sand (SM)
	8-10	B	U			-																slightly silty sand (SP-SM)*
	13-15	F	U	-	98	7	NV	NP	100	100	100	100	100	-	98	-	-	71	-	-	16.7	silty sand (SM)
	18-20	F	U	-	103	4	NV	NP	100	100	100	100	100	-	99	-	-	50	-	-	10.5	slightly silty sand (SP-SM)
	23-25	B	U			-																silty sand (SM)*
	28-30	F	U	-	95	9	17	NP	100	100	100	100	99	-	96	-	-	64	-	-	21.2	silty sand (SM)
	33-35	F	U	-	99	6	NV	NP	100	100	100	100	99	-	94	-	-	71	-	-	19.9	silty sand (SM)
	38-40	B	U			-																silty sand (SM)*
	40	B	D	-	-	6																silty sand (SM)*
	41	B	D	-	-	2																sand (SP)*

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DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Density (pcf) Dry	Moisture Content (%)	Atterberg Limits LL	Atterberg Limits PI	Sieve Analysis (% Passing) 3/4"	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
ESPLH-44	2-4	F	U	-	80	8	26	8	100	100	100	100	99	-	97	-	-	83	-	-	42.0	clayey sand (SC)
	7	B	D	-	-	7																silty sand (SM)*
	12	B	D	-	-	1																gravelly sand (SW)*
	17-19	F	U	-	92	4	NV	NP	97	95	93	86	79	-	71	-	-	52	-	-	19.1	silty sand (SM)
	22-24	B	U																			silty sand (SM)*
	27-29	F	U	-	99	6	16	NP	100	100	100	100	100	-	98	-	-	78	-	-	22.3	silty sand (SM)
	32	B	D	-	-	4																silty sand (SM)*
	37	B	D	-	-	8																silty sand (SM)*
	42	B	D	-	-	6																silty sand (SM)*
ESPLH-45	4	B	D	-	-	4																slightly silty sand (SP-SM)*
	14	B	D	-	-	4																silty sand (SM)*
	24	B	D	-	-	6																sand (SP)*
	34	B	D	-	-	13																silty sand (SM)*
	44	B	D	-	-	8																sand (SP)*
	54	B	D	-	-	7																gravelly sand (SW)*
	64	B	D	-	-	14																slightly silty sand (SP-SM)*
	74	B	D	-	-	17																silty sand (SM)*
	84	B	D	-	-	22																silty sand (SM)*
	99	B	D	-	-	21																silty sand (SM)*

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DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Density (pcf) Dry	Moisture Content (%)	Atterberg Limits LL	Atterberg Limits PI	Sieve Analysis (% Passing) 3/4"	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
GGSSI-1	2-4	B	U																			silty sand (SM)*
	4	B	D			6			100	100	100	100	97	94	86	19	-	16	14	8	3.9	sand (SP)
	9-11		U		83	6	NV	NP	-	-	-	-	0	-	-	-	-	-	-	-	31.6	silty sand (SM)*
	14	B	D			7	20	11	100	100	100	99	98	95	92	69	-	21	19	4	1.7	sand (SP)
	19-21	B	U	93	88	6																silty sand (SM)*
	24	B	D			8			100	100	100	100	100	99	95	68	-	42	38	16	7.9	slightly silty sand (SP-SM)*
	29-31	B	U	91	85	8																sand (SP)*
	34	B	D			9			100	100	100	100	100	98	84	70	-	61	53	30	14.8	silty sand (SM)*
GGSSI-2	2-4	B	U	95		3																silty sand (SM)*
	4	B	D			4			100	100	100	100	100	100	98	90	-	74	55	24	11.7	clayey sand (SC)*
	9-11		U		96	2	NV	NP	-	-	-	-	100	-	99	-	-	64	-	-	6.3	slightly silty sand (SP-SM)
	14	B	D			6			88	88	87	82	72	56	45	31	-	21	15	7	3.2	gravelly sand (SW)
	19-21	B	U	96	88	9																clayey sand (SC)*
	24	B	D			10																silty sand (SM)*
	29-31	B	U	112		7																
	34	B	D			6			100	100	90	84	76	64	49	30	-	19	13	6	2.6	gravelly sand (SW)
GGSSI-3	0-2	B**	U																			silty sand (SM)*
	2-4	B**	U																			sand (SP)*
	4-6	B**	U																			gravelly sand (SW)*
	6-8	B**	U																			silty sand (SM)*
	8-10	B**	U																			slightly silty sand (SP-SM)
GGSSI-4	2	B	D																			silty clayey sand (SM-SC)*
	4	B	D																			silty sand (SM)*
	9	B	D																			slightly silty sand (SP-SM)*
GGSSI-5	2	B	D																			silty sand (SM)*
	4	B	D																			gravelly sand (SW)*
	9	B	D																			sand (SP)*
GGSSI-6	2	B	D																			silty sand (SM)*
	4	B	D																			sand (SP)*
	9	B	D																			sand (SP)*
GGSSI-7	2	B	D																			silty sand (SM)*
	4	B	D																			slightly silty sand (SP-SM)*
	9	B	D																			silty sand (SM)*
GGSSI-8	4	B	D																			silty sand (SM)*
	9	B	D																			silty sand (SM)*
GGSSM-1	1	B	D			10																silty sand (SM)*
	2.5	B	D			5																slightly silty sand (SP-SM)*
	4	B	D			4																slightly silty sand (SP-SM)*
	5.5	B	D			4																silty sand (SM)*
	7	B	D			5																sand (SP)*
	8.5	B	D			6																silty sand (SM)*
	10	B	D			18																silty sand (SM)*
	11.5	B	D			7																silty sand (SM)*
	13	B	D			5																sand (SW)*
	14.5	B	D			7																silty sand (SM)*
	16	B	D			4																sand (SW)*
	17.5	B	D			4																silty sand (SM)*
	20.5	B	D			12																silty sand (SM)*
	22	B	D			10																silty sand (SM)*
	23.5	B	D			9																silty sand (SM)*
	25	B	D			11																silty sand (SM)*
	26.5	B	D			17																clayey sand (SC)*
	28	B	D			13																slightly silty sand (SP-SM)*
	29.5	B	D			33																silty sand (SM)*
	31	B	D			20																sandy clay (CL)*
	31.8	B	D			5																sand (SW)*
	32.5	B	D			17																sandy clay (CL)*
	34	B	D			8																sand (SW)*
GGSSM-2	4	B	D			5																silty sand (SM)*
	9	B	D			3																slightly silty sand (SP-SM)*
	14	B	D			4																sand (SP)*
	19	B	D			6																sand (SP)*
	24	B	D			4																sand (SP)*
	29	B	D			7																slightly silty sand (SP-SM)*
	34	B	D			6																silty sand (SM)*
	34.3	B	D			6																silty sand (SM)*

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** = Analyzed by Dan Stephens and Assoc.

DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Density (pcf) Dry	Moisture Content (%)	Atterberg Limits LL	Atterberg Limits PI	Sieve Analysis (% Passing) 3/4"	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
GGSSM-3	1	B	D			14																silty sand (SM)*
	2.5	B	D			8																silty sand (SM)*
	4	B	D			6																silty sand (SM)*
	5.5	B	D			7																silty sand (SM)*
	7	B	D			7																silty sand (SM)*
	8.5	B	D			7																silty sand (SM)*
	10	B	D			7																silty sand (SM)*
	11.5	B	D			6																silty sand (SM)*
	13	B	D			9																silty sand (SM)*
	14.5	B	D			4																slightly silty (SP-SM)*
	16	B	D			7																silty sand(SM)*
	17.5	B	D			7																slightly silty sand (SP-SM)*
	19	B	D			6																silty sand (SM)*
	20.5	B	D			6																silty sand (SM)*
	22	B	D			7																silty sand (SM)*
	23.5	B	D			12																silty sand (SM)*
	25	B	D			20																clayey sand (SC)*
	26.5	B	D			22																silty sand (SM)*
	28	B	D			22																silty sand (SM)*
	29.5	B	D			20																silty sand (SM)*
	31	B	D			20																clayey sand (SC)*
	32.5	B	D			18																clayey sand (SC)*
	34	B	D			21																clayey sand (SC)*
	35.5	B	D			21																silty sand (SM)*
	37	B	D			21																sandy clay (CL)*
	38.5	B	D			20																clay (CH)*
GGSSM-4	4	B	D			6																silty sand (SM)*
	9	B	D			5																silty sand (SM)*
	14	B	D			5																sand (SP)*
	19	B	D			7																slightly silty sand (SP-SM)*
	21.5	B	D			7																silty sand (SM)*
	24	B	D			6																silty sand (SM)*
	26.5	B	D			6																silty sand (SM)*
	29	B	D			7																silty sand (SM)*
	31.5	B	D			9																clayey sand (SC)*
	34	B	D			11																sandy clay (CL)*
GGSSM-5	4	B	D			7																silty sand (SM)*
	9	B	D			7																silty sand (SM)*
	14	B	D			6																silty sand (SM)*
	19	B	D			2																gravelly sand (SW)*
	19.2	B	D			4																slightly silty sand (SP-SM)*
	21.5	B	D			15																silty sand (SM)*
	23	B	D			18																silty sand (SM)*
	24.5	B	D			24																silty sand (SM)*
	26	B	D			23																silty sand (SM)*
	27.5	B	D			21																silty sand (SM)*
	29	B	D			23																silty sand (SM)*
	30.5	B	D			23																silty sand (SM)*
	32	B	D			24																silty sand (SM)*
GGSSM-6	4	B	D			8																sandy silt (ML)*
	14	B	D			5																silty sand (SM)*
	24	B	D			7																silty sand (SM)*
	29	B	D			8																sandy silt (ML)*
	34	B	D			8																silty sand (SM)*
GGSSM-7	1.5	B	D			7																silty sand (SM)*
	4	B	D			5																silty sand (SM)*
	6.5	B	D			7																silty sand (SM)*
	9	B	D			6																silty sand (SM)*
	11.5	B	D			7																silty sand (SM)*
	14	B	D			5																silty sand (SM)*
	16.5	B	D			6																sand (SP)*
	19	B	D			3																gravelly sand (SW)*
	20.5	B	D			8																silty sand (SM)*
	22	B	D			6																silty sand (SM)*
	23.5	B	D			11																silty sand (SM)*
	25	B	D			14																silty sand (SM)*
	26.5	B	D			9																gravelly sand (SW)*
	28	B	D			14																silty sand (SM)*
	33	B	D			22																clayey sand (SC)*
	38	B	D			23																silty sand (SM)*
	43	B	D			16																sandy clay (CL)*

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DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Dry	Moisture Content (%)	Atterberg Limits LL	PI	3/4"	1/2"	3/8"	Sieve Analysis (% Passing) No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
GGSSM-4	1.5	B	D			14																silty sand (SM)*
	4	B	D			7																sandy silt (ML)*
	6.5	B	D			7																silty sand (SM)*
	9	B	D			6																slightly silty sand (SP-SM)*
	11.5	B	D			8																sand (SP)*
	14	B	D			5																slightly silty sand (SP-SM)*
	16.5	B	D			5																silty sand (SM)*
	19	B	D			6																silty sand (SM)*
	20.5	B	D			5																sand (SW)*
	22	B	D			6																sand (SP)*
	23.5	B	D			3																sand (SP)*
	26	B	D			4																sand (SP)*
	28.5	B	D			7																sand (SP)*
	34	B	D			17																silty sand (SM)*
	36.5	B	D			14																silty sand (SM)*
	39	B	D			16																silty sand (SM)*
	41.5	B	D			27																silty sand (SM)*
GGSSS-1	2-4	B	U																			silty clay (CL)*
	4	B	D			13																silty sand (SM)*
	9-11	B	U																			silty sand (SM)*
	14	B	D			14																silty sand (SM)*
	19	B	D			15																clay (CH)*
	24	B	D			16																clay (CH)*
	29	B	D			20																clay (CH)*
	34	B	D			15																clay (CH)*
	39	B	D			9																sandy gravel (GW)*
	44	B	D			15																silty clay (CL)*
	49	B	D			15																silty clay (CL)*
GGSSS-2	2-4	B	U	96	89	7																silty sand (SM)*
	4	B	D			7																sandy silt (ML)*
	9-11	B	U																			silty sand (SMP*
	14	B	D			7																sand (SP)*
	19-21	B	U	97	92	6																silty sand (SM)*
	24	B	D			6																silty sand (SM)*
	29-30	B	U																			silty sand (SM)*
	34	B	D			8																sandy silt (ML)*
	39	B	D			13																sandy clay (CL)*
	44	B	D			15																silty clay (CL)*
GGSSS-3	2-4	B	U	91	85	7																slightly silty sand (SP-SM)*
	4	B	D			11																sandy silt (ML)*
	9-11	B	U	99	91	8																sand (SP)*
	14	B	D			5																sand (SW)*
	19-21	B	U	100	96	4																silty sand (SM)*
	24	B	D			7																silty sand (SM)*
	29-31	B	U	93	85	10																clayey silt (ML)*
	34	B	D			10																sandy silt (ML)*
	39	B	D			16																sandy clay (CL)*
	44	B	D			18																slightly silty clay (CH-CL)*
GGSSS-4	2-4	B	U	94	88	7																silty sand (SM)*
	4	B	D			13																slightly silty sand (SP-SM)*
	9-11	B	U	99	93	6																slightly silty sand (SP-SM)*
	14	B	D			6																gravelly sand (SW)*
	19-21	B	U	97	92	6																silty sand (SM)*
	29-31	B	U	100	93	8																clayey silt (ML)*
	34	B	D			10																silty sand (SM)*
	39	B	D			24																silty clay (CL)*
	44	B	D			16																sandy clay (CL)*
GGSSS-5	2-4	B	U	92	86	7																silty sand (SM)*
	4	B	D			7																clayey sand (SC)*
	9-11	B	U																			silty sand (SM)*
	14	B	D			3																sand (SW)*
	19-21	B	U																			sandy silt (ML)*
	24	B	D			6																silty sand (SM)*
	29-31	B	U	93	87	7																silty sand (SM)*
	34	B	D			11																clayey silt (ML)*
	39-40	B	U																			sandy clay (CL)*
	40	B	D			15																sandy clay (CL)*
	44	B	D			17																sandy clay (CL)*

* = USCS Soil description is based on field classification of soil sample; not on the limited laboratory data shown here.

DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Density (pcf) Dry	Moisture Content (%)	Atterberg Limits LL	Atterberg Limits PI	Sieve Analysis (% Passing) 3/4"	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
GGSSS-6	2-4	B	U	91	84	8																slightly silty sand (SP-SM)*
	4	B	D			11																clayey sand (SC)*
	9-11	B	U	101	95	6																sand (SP)*
	14	B	D			7																sand (SP)*
	19	B	D			3																gravelly sand (SW)*
	19.7	B	D			7																silty sand (SM)*
	24-26	B	U																			silty sand (SM)*
	29	B	D			7																silty sand (SM)*
	34-36	B	U	91	83	10																silty sand (SM)*
	39	B	D			9																sandy silt (ML)*
	44	B	D			14																silty clay (CL)*
	49	B	D			12																sandy clay (CL)*
GGSSS-7	2-4	B	U	93	89	5																silty sand (SM)*
	4	B	D			13																clayey sand (SC)*
	9-11	B	U																			slightly silty sand (SP-SM)*
	14	B	D			7																silty sand (SM)*
	19-21	B	U	97	92	6																silty sand (SM)*
	24	B	D			5																silty sand (SM)*
	29	B	D			7																sand (SP)*
	34-36	B	U																			slightly silty sand (SP-SM)*
	39	B	D			8																sandy silt (ML)*
	44	B	D			18																silty clay (CL)*
	49	B	D			14																sandy clay (CL)*
GGSSS-8	2-4	B	U																			silty sand (SM)*
	4	B	D			4																slightly silty sand (SP-SM)*
	9-11	B	U																			slightly silty sand (SP-SM)*
	14	B	D			3																gravelly sand (SW)*
	19-21	B	U																			sand (SP)*
	24	B	D			12																silty sand (SM)*
	29-31	B	U																			sand (SP)*
	34	B	D			12																silty sand (SM)*
	39-41	B	U																			slightly clayey sand (SP-SC)*
	44	B	D			6																slightly silty sand(SP-SM)*
GGSSS-9	2-4	B	U																			slightly silty sand (SP-SM)*
	4	B	D			4																sand (SP)*
	9-11	B	U																			slightly silty sand (SP-SM)*
	14	B	D			3																sand (SP)*
	19-21	B	U																			clayey sand (SC)*
	24	B	D			6																sand (SP)*
	29-31	B	U																			clayey sand (SC)*
	34	B	D			8																slightly clayey sand (SP-SC)*
	39-41	B	U																			slightly silty sand (SP-SM)*
	44	B	D			6																sand (SP)*
GGSSS-10	2-4	B	U																			sand (SP)*
	4	B	D			6																slightly silty sand (SP-SM)*
	9-11	B	U																			sand (SW)*
	14	B	D			3																sand (SP)*
	19-21	B	U																			silty sand (SM)*
	24	B	D			8																slightly silty sand (SP-SM)*
	29-31	B	U																			clayey sand (SC)*
	34	B	D			8																sand (SM)*
	39	B	D			8																silty sand (SM)*
	44	B	D			7																sand (SP)*
GGSSS-11	2-4	B	U																			silty sand (SM)*
	4	B	D			9																silty sand (SM)*
	9-11	B	U																			sand (SP)*
	14	B	D			4																sand (SP)*
	19-21	B	U																			slightly silty sand (SP-SM)*
	24	B	D			4																sand (SW)*
	29-31	B	U																			slightly silty sand (SP-SM)*
	34	B	D			7																sand (SW)*
	39	B	D			12																clayey sand (SC)*

* = USCS Soil description is based on field classification of soil sample; not on the limited laboratory data shown here.

DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Density (pcf) Dry	Moisture Content (%)	Atterberg Limits LL	Atterberg Limits PI	Sieve Analysis (% Passing) 3/4"	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
GGSSS-12	2-4	B	U	[illegible]		11																silty sand (SM)*
	4	B	D			8																clayey sand (SC)*
	9-11	B	U																			sand (SP)*
	14	B	D			4																slightly silty sand (SP-SM)*
	19-21	B	U																			sand (SW)*
	24	B	D			6																sand (SP)*
	29-31	B	U																			slightly silty sand (SP-SM)*
	34	B	D			9																sand (SP)*
	39-41	B	U																			slightly clayey sand (SP-SC)*
	44	B	D			8																sand (SP)*
GGSSS-13	2-4	B	U																			silty sand (SM)*
	4	B	D			9																slightly silty sand (SP-SM)*
	9-11	B	U																			silty sand (SM)*
	14	B	D			5																sand (SP)*
	19-21	B	U																			silty sand (SM)*
	24	B	D			8																sand (SP)*
	29-31	B	U																			silty clay (CL)*
	34	B	D			10																slightly silty sand (SP-SM)*
	39	B	D			14																sand (SP)*
	44	B	D			7																sand (SP)*
GGSSS-14	4	B	D			3																silty sand (SM)*
	9	B	D			5																silty sand (SM)*
	14	B	D			6																sand (SP)*
	19	B	D			9																silty sand (SM)*
	24	B	D			9																silty sand (SM)*
	29	B	D			7																silty sand (SM)*
	34	B	D			7																sandy silt (ML)*
GGSSS-15	4	B	D			3																sand (SP)*
	9	B	D			6																silty sand (SM)*
	14	B	D			6																sand (SP)*
	19	B	D			8																silty sand (SM)*
	24	B	D			8																sandy silt (ML)*
	29	B	D			6																silty sand (SM)*
	34	B	D			11																silty sand (SM)*
GGSSS-16	4	B	D			3																sand (SP)*
	9	B	D			3																silty sand (SM)*
	14	B	D			9																silty sand (SM)*
	19	B	D			7																silty sand (SM)*
	24	B	D			8																sandy silt (ML)*
	29	B	D			7																silty sand (SM)*
	34	B	D			8																silty sand (SM)*
GGSSS-17	4-6	B	U																			silty sand (SM)*
	14-16	B	U																			silty sand (SM)*
	24-26	B	U																			silty sand (SM)*
GGSSS-18	4-6	B	U																			silty sand (SM)*
	9	B	D																			sand (SP)*
	14-16	B	U																			slightly silty sand (SP-SM)*
	19	B	D																			silty sand (SM)*
	29-31	B	U																			clayey sand (SC)*
	39	B	D																			sandy clay (CL)*
GGSSS-19	9	B	D																			sand (SP)*
	14-16	B	U																			slightly silty sand (SP-SM)*
	24-26	B	U																			sand (SP)*
	29	B	D																			clayey sand (SC)*
	39	B	D																			clayey sand (SC)*
GGSSS-20	4-6	B	U																			silty sand (SM)*
	9	B	D																			sand (SP)*
	14-16	B	U																			slightly silty sand (SP-SM)*
	24-26	B	U																			silty sand (SM)*
	29	B	D																			sandy clay (CL)*
	39	B	D																			sandy clay (CL)*
GGSSS-21	5	B	D																			silty sand (SM)*
	9-11	B	U																			silty sand (SM)*
	14-16	B	U																			slightly silty sand (SP-SM)*
	24-26	B	U																			silty sand (SM)*
	29	B	D																			silty sand (SM)*
	39	B	D																			clayey sand (SC)*

* = USCS Soil description is based on field classification of soil sample; not on the limited laboratory data shown here.

DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Dry	Moisture Content (%)	Atterberg Limits LL	PI	Sieve Analysis (% Passing) 3/4"	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
GGSSNP-1	4	B	D			6																silty sand (SM)*
	9	B	D			5																slightly silty sand (SP-SM)*
	14	B	D			8																silty sand (SM)*
	19	B	D			14																silty sand (SM)*
	24	B	D			18																silty sand (SM)*
GGSSNP-2	4	B	D			4																silty sand (SM)*
	9	B	D			4																silty sand (SM)*
	14	B	D			6																sand (SP)*
	19	B	D			8																slightly silty sand (SP-SM)*
	24	B	D			6																silty sand (SM)*
GGSSNP-3	4	B	D			6																silty sand (SM)*
	9	B	D			5																silty sand (SM)*
	14	B	D			5																silty sand (SM)*
	19	B	D			6																silty sand (SM)*
	24	B	D			4																silty sand (SM)*
GGSSNP-4	4	B	D			7																slightly silty sand (SP-SM)*
	9	B	D			7																slightly silty sand (SP-SM)*
	14	B	D			19																silty sand (SM)*
	19	B	D			17																clayey sand (SC)*
	24	B	D			12																clayey sand (SC)*
GGSSNP-5	4	B	D			5																silty sand (SM)*
	9	B	D			6																silty sand (SM)*
	14	B	D			6																sandy silt (MC)*
	19	B	D			6																sandy clay (CL)*
	24	B	D			7																sandy clay (CL)*
GGSSNP-6	4	B	D			-																silty sand (SM)*
	9	B	D			6																silty sand (SM)*
	14	B	D			6																sandy silt (ML)*
	19	B	D			-																sandy clay (CL)*
	24	B	D			15																sandy clay (CL)*
GGSSNP-10	4	B	D			3																slightly silty sand (SP-SM)*
	14	B	D			5																slightly silty sand (SP-SM)*
	24	B	D			5																clayey sand (SC)*
GGSSNP-11	4	B	D			3																slightly silty sand (SP-SM)*
	14	B	D			4																silty sand (SM)*
	24	B	D			5																silty clayey sand (SC-SM)*
GGSSNP-12	4	B	D			5																slightly silty sand (SP-SM)*
	14	B	D			8																clayey sand (SC)*
	24	B	D			5																clayey sand (SC)*
GGSSNP-13	4	B	D			4																slightly silty sand (SP-SM)*
	14	B	D			4																silty sand (SM)*
	24	B	D			8																clayey sand (SC)*
GGSSNP-14	4	B	D			3																sand (SP)*
	14	B	D			5																silty sand (SM)*
	24	B	D			6																silty sand (SM)*
GGSSNP-15	4	B	D			4																slighty silty sand (SP-SM)*
	14	B	D			4																silty sand (SM)*
	24	B	D			5																silty sand (SM)*

* = USCS Soil description is based on field classification of soil sample; not on the limited laboratory data shown here.

DATA COMPILATION TABLES

Test Hole No.	Depth of Sample (ft.)	Tested By B=Bureau F=Fox H=Hwy Dept	Sample Type U=Undisturbed D=Disturbed	Density (pcf) Wet	Density (pcf) Dry	Natural Moisture Content (%)	Atterberg Limits LL	Atterberg Limits PI	Sieve Analysis (% Passing) 3/4"	1/2"	3/8"	No. 4	No. 10	No. 20	No. 40	No. 60	No. 65	No. 80	No. 100	No. 140	No. 200	USCS Soil Description
ESBH-1A	0.5	B	D			8																silty clayey sand (SM-SC)*
1B	1.9	B	D			10																silty sand (SM)*
1C	5	B	D			10																slightly silty sand (SP-SM)*
1D	6	B	D			8																slightly silty sand (SP-SM)*
1E	12	B	D			13																slightly silty sand (SP-SM)*
ESBH-2A	1	B	D			20																silt (ML)*
2B	5	B	D			5																sand (SP)*
2C	6	B	D			13																silty sand (SM)*
2D	11	B	D			26																silty sand (SM)*
ESBH-3A	2.5	B	D			6																gravelly sand (SW)*
3B	5.5	B	D			2																gravelly sand (SW)*
3C	6	B	D			9																gravelly sand (SW)*
3D	11	B	D			19																gravelly sand (SW)*
ESBH-4A	4	B	D			5																silty sand (SM)*
4B	6.5	B	D			9																silty sand (SM)*
4C	11	B	D			24																clay (CL)*
ESBH-7A	0.5	B	D			17																artificial fill*
7B	2.2	B	D			29																clay (CL)*
7C	9.5	B	D			7																sand (SP)*
ESBH-9A	1	B	D			20																silty sand (SM)*
9B	8	B	D			2																gravelly sand (SW)*
ESBH-10A	0.5	B	D			37																clay (CL)*
10B	1	B	D			16																silty sand (SM)*
10C	2.5	B	D			32																clay (CL)*
10D	3	B	D			18																silty sand (SM)*
10E	4	B	D			31																clay (CL)*
10F	6	B	D			13																silty sand (SM)*
10G	7	B	D			13																silty sand (SM)*
10H	8	B	D			30																silty sand (SM)*

* = USCS Soil description is based on field classification of soil sample; not on the limited laboratory data shown here.

APPENDIX IV

Vibration Monitoring Data

Dallas Instruments, Inc.

P. O. BOX 38189 □ DALLAS, TEXAS 75238

DALLAS 214-349-1180
HOUSTON 713-738-1439
U. S. WATS 800-527-7071

April 29, 1985

Mr. George Austin
New Mexico Bureau of Mines
New Mexico Tech
Socorro, NM 87801

Dear Mr. Austin:

We have examined the two seismograph tapes forwarded to our office for evaluation. The first tape labeled MOYA 12/18/84 - 2/21/84 was examined and found to have no events above 0.08 ips peak velocity. The second tape labeled VALDEZ 1-10-85 - 2-21-85, MOYA 2-21-85 - 3-22-85 was also examined. There were several events above 0.20 ips, but these did not appear as normal blast waveforms. Your records indicate this unit was installed inside of a house on flooring. These events appear as door slams or foot stomps. Two or three events might possibly be truck noise, but due to the low signal levels this cannot be confirmed.

On March 28th you questioned the Transducer Extension Cable billing. Our records indicate one cable sent and returned with the instrument and one cable billed on each invoice. Our accounting department had a problem canceling your order so you will receive an invoice and a credit memo for 4-3-85 through 5-28-85. Please excuse our error.

If you need additional information or help please call on our 800 number.

Sincerely,

Bill Wilson

Bill Wilson

BW/asb

Encl: Digital listings
2 tapes

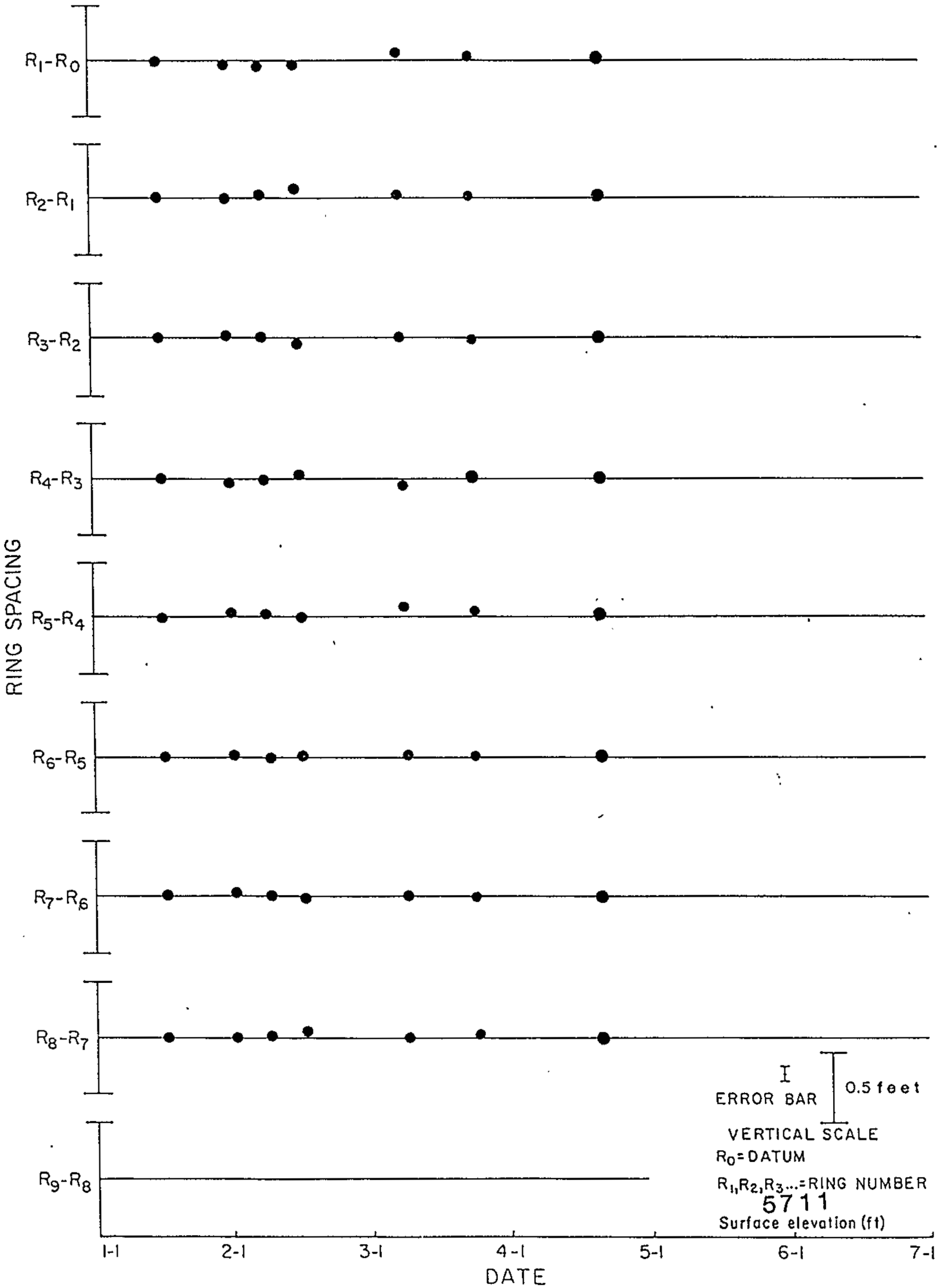
APPENDIX V

Geologic Map

APPENDIX VI

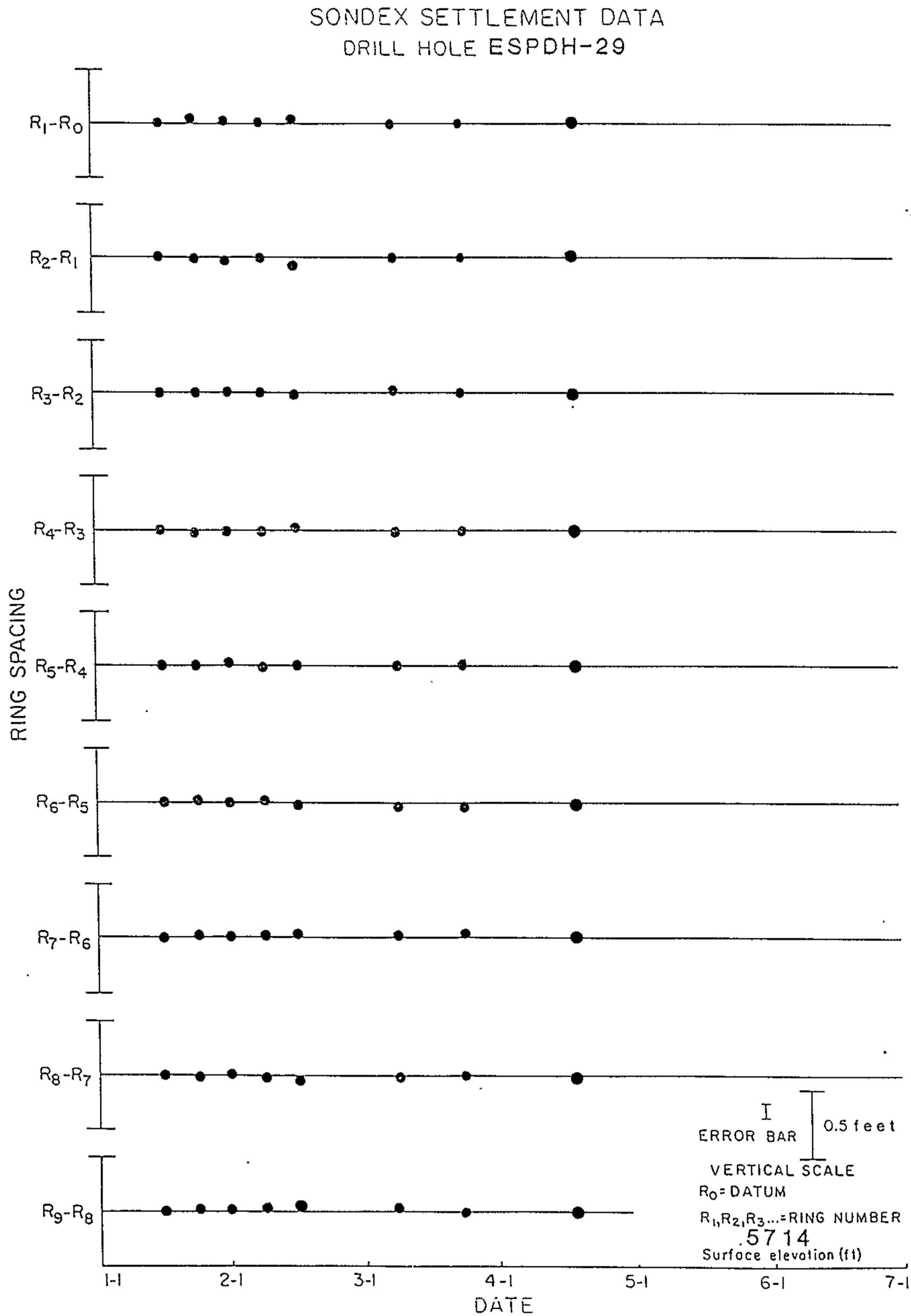
Sondex Settlement Data

SONDEX SETTLEMENT DATA
DRILL HOLE ESPDH-27



New Mexico Bureau of Mines

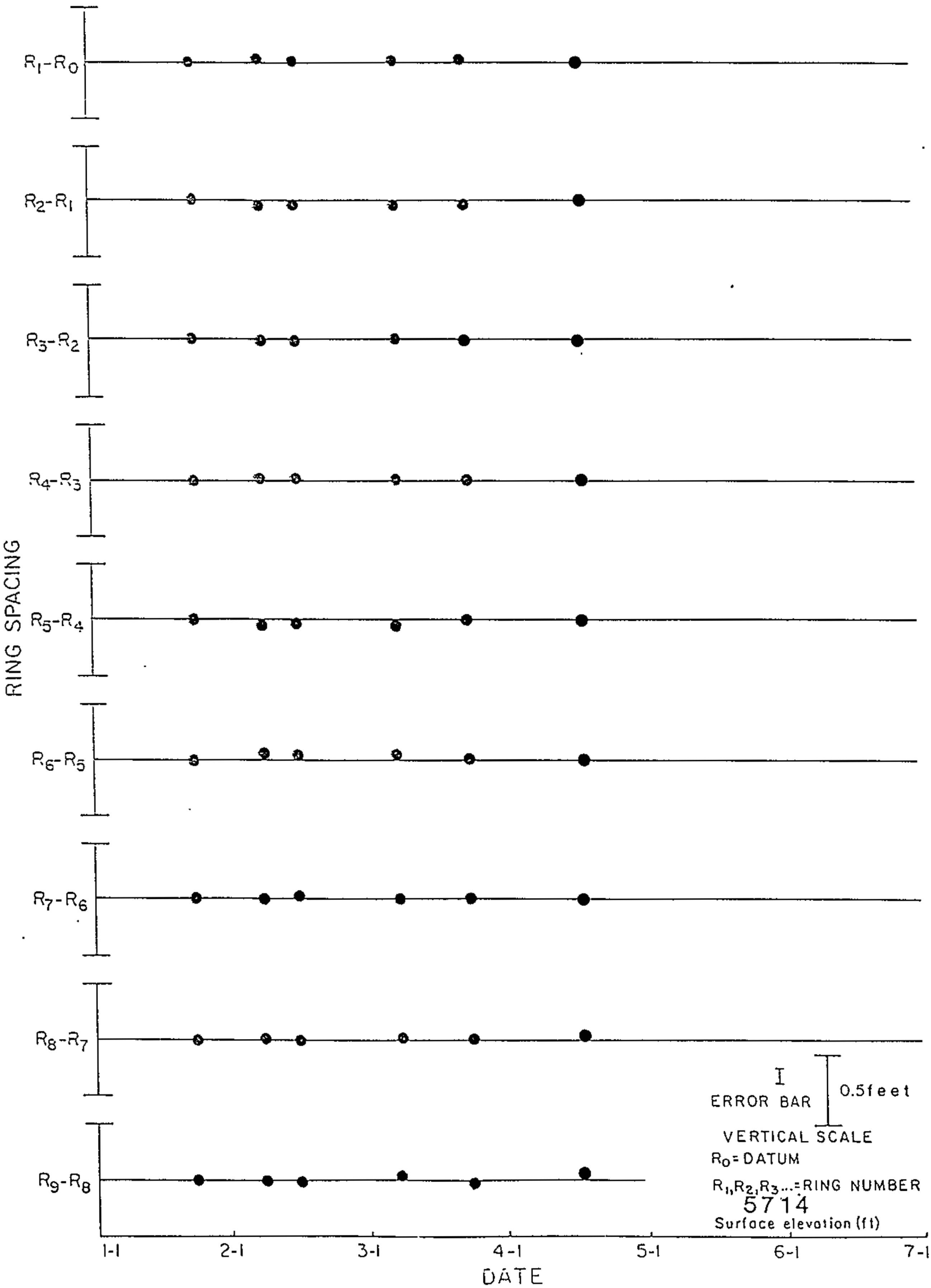
28 JUNE 1985



New Mexico Bureau of Mines

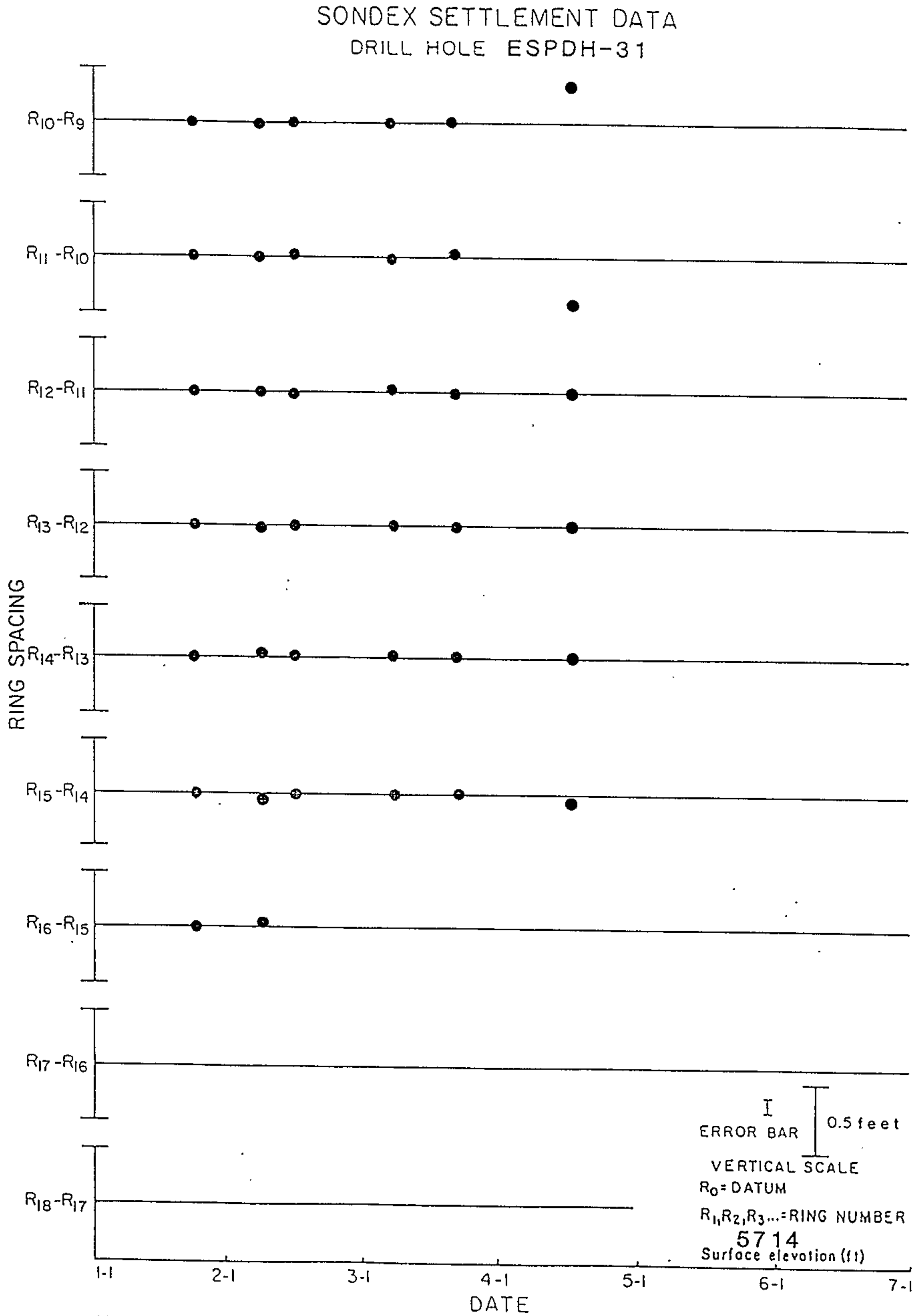
28 JUNE 1985

SONDEX SETTLEMENT DATA
DRILL HOLE ESPDH-31



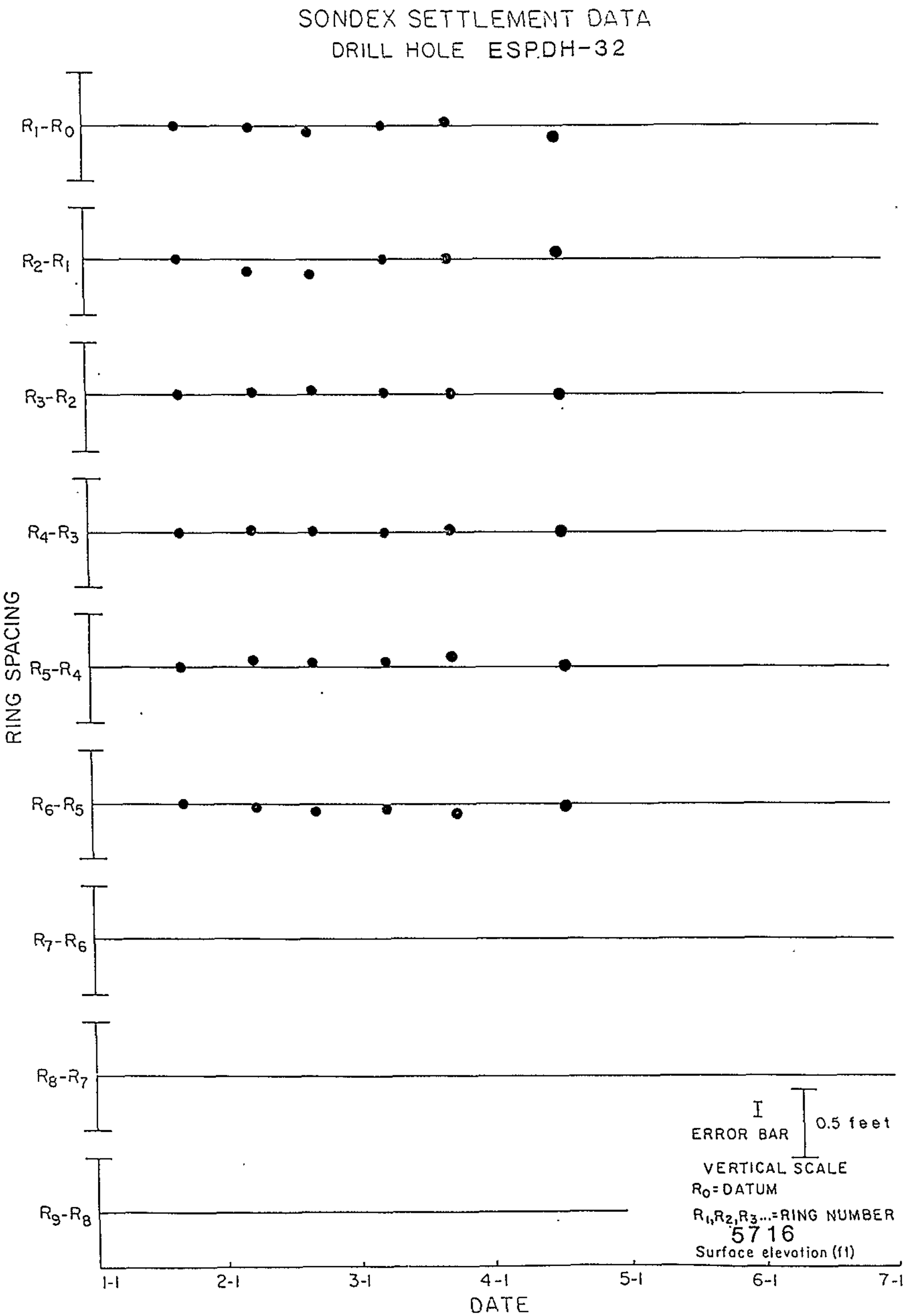
New Mexico Bureau of Mines

28 JUNE 1985



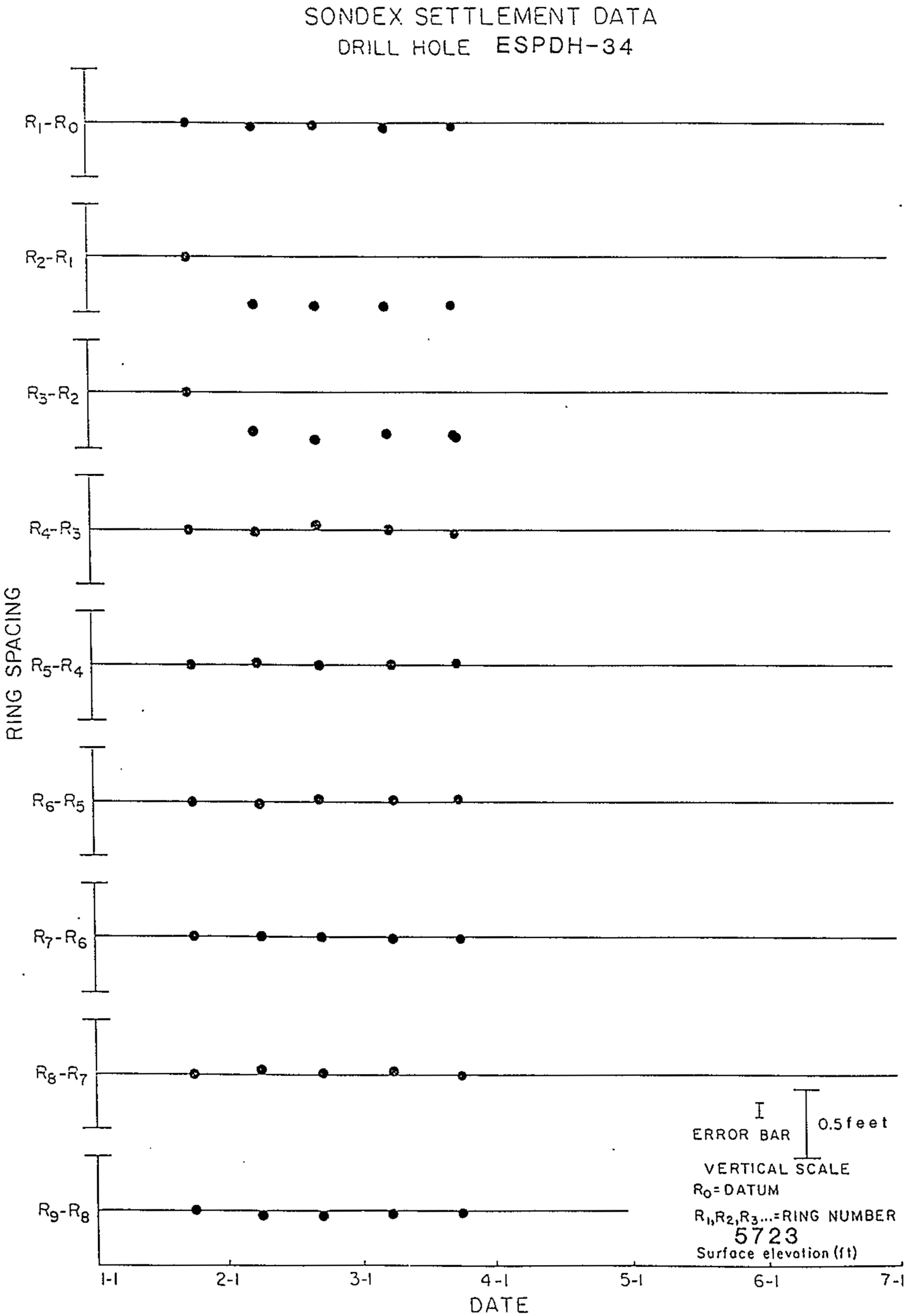
New Mexico Bureau of Mines

28 JUNE 1985



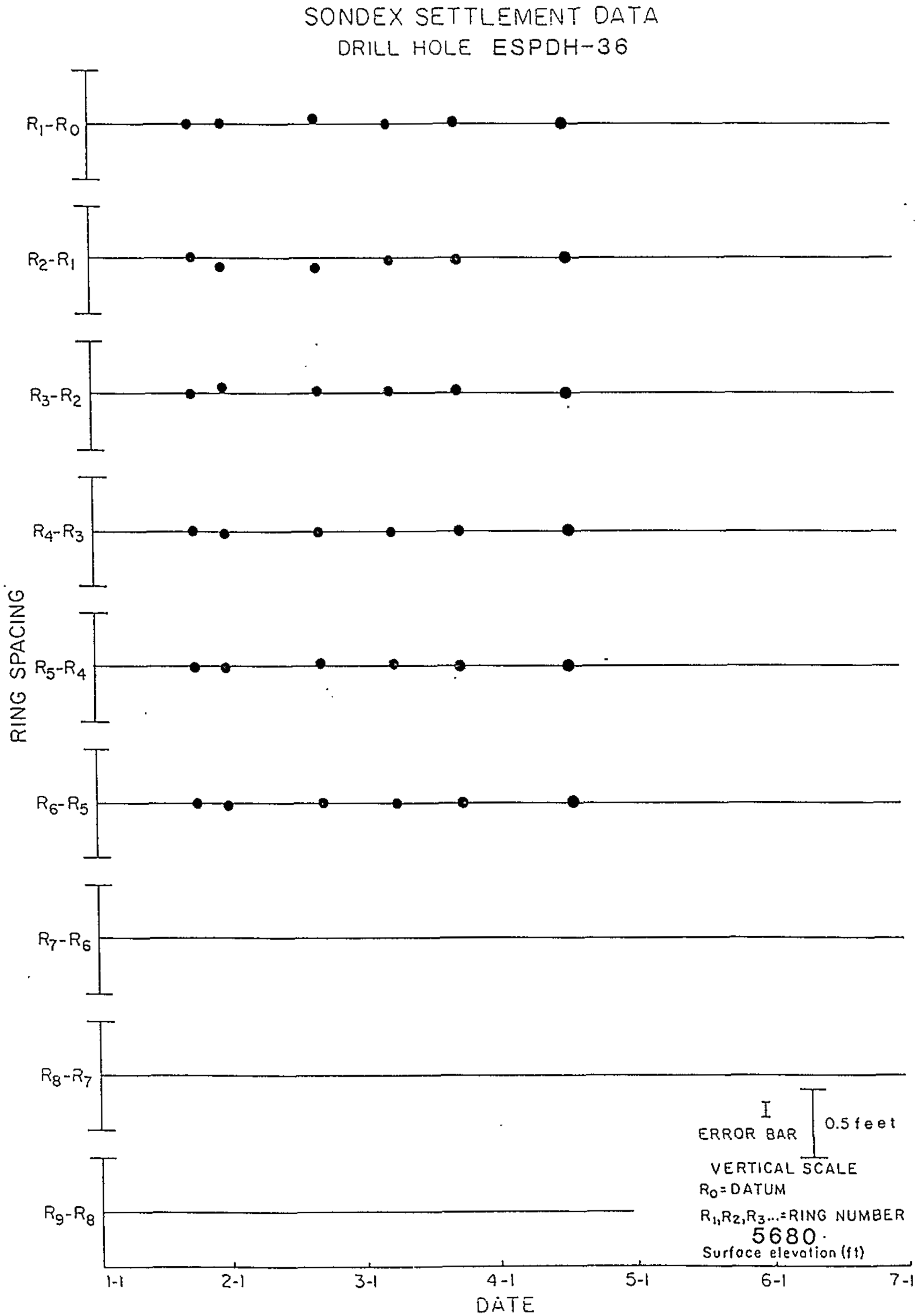
New Mexico Bureau of Mines

28 JUNE 1985



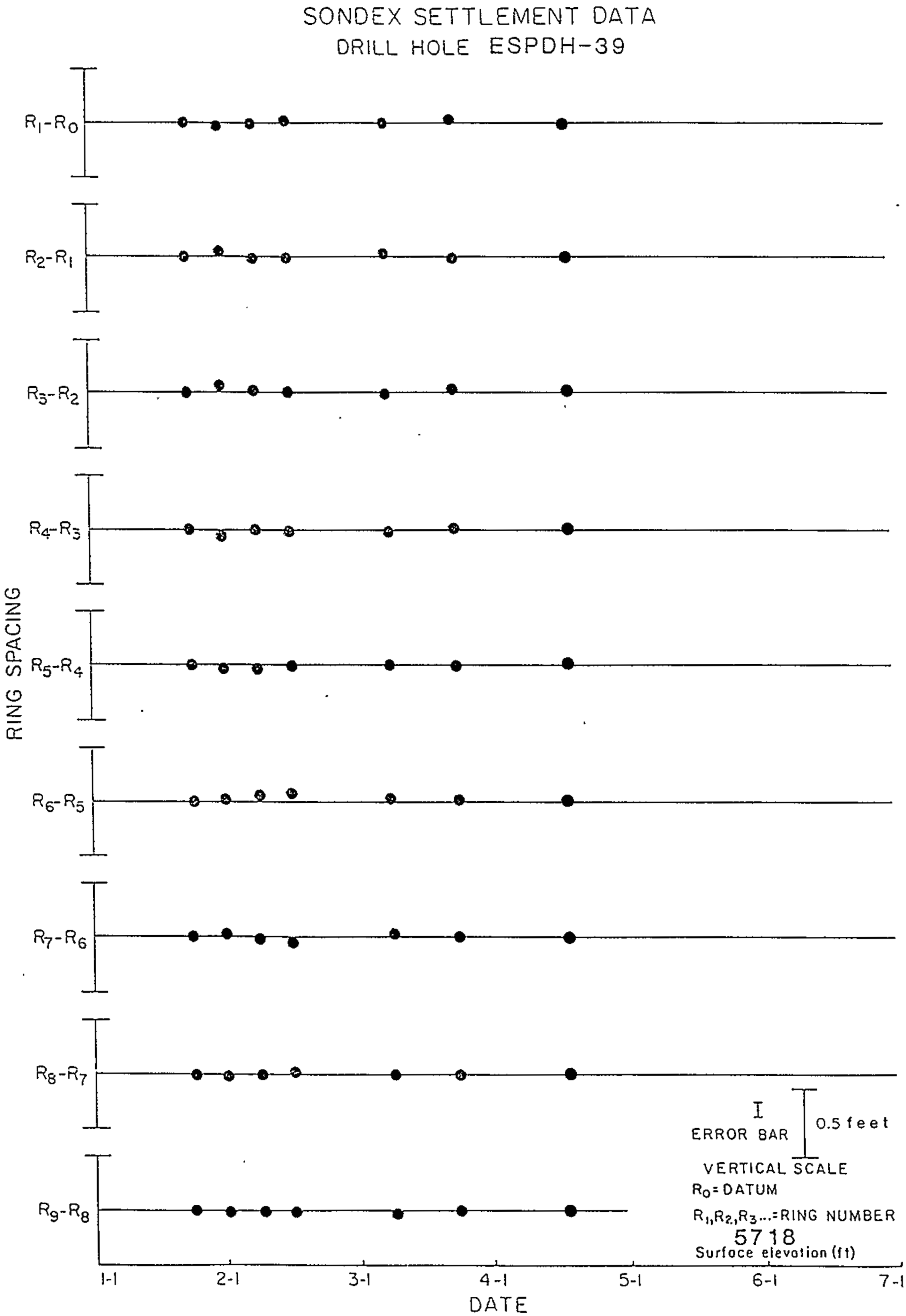
New Mexico Bureau of Mines

28 JUNE 1985



New Mexico Bureau of Mines

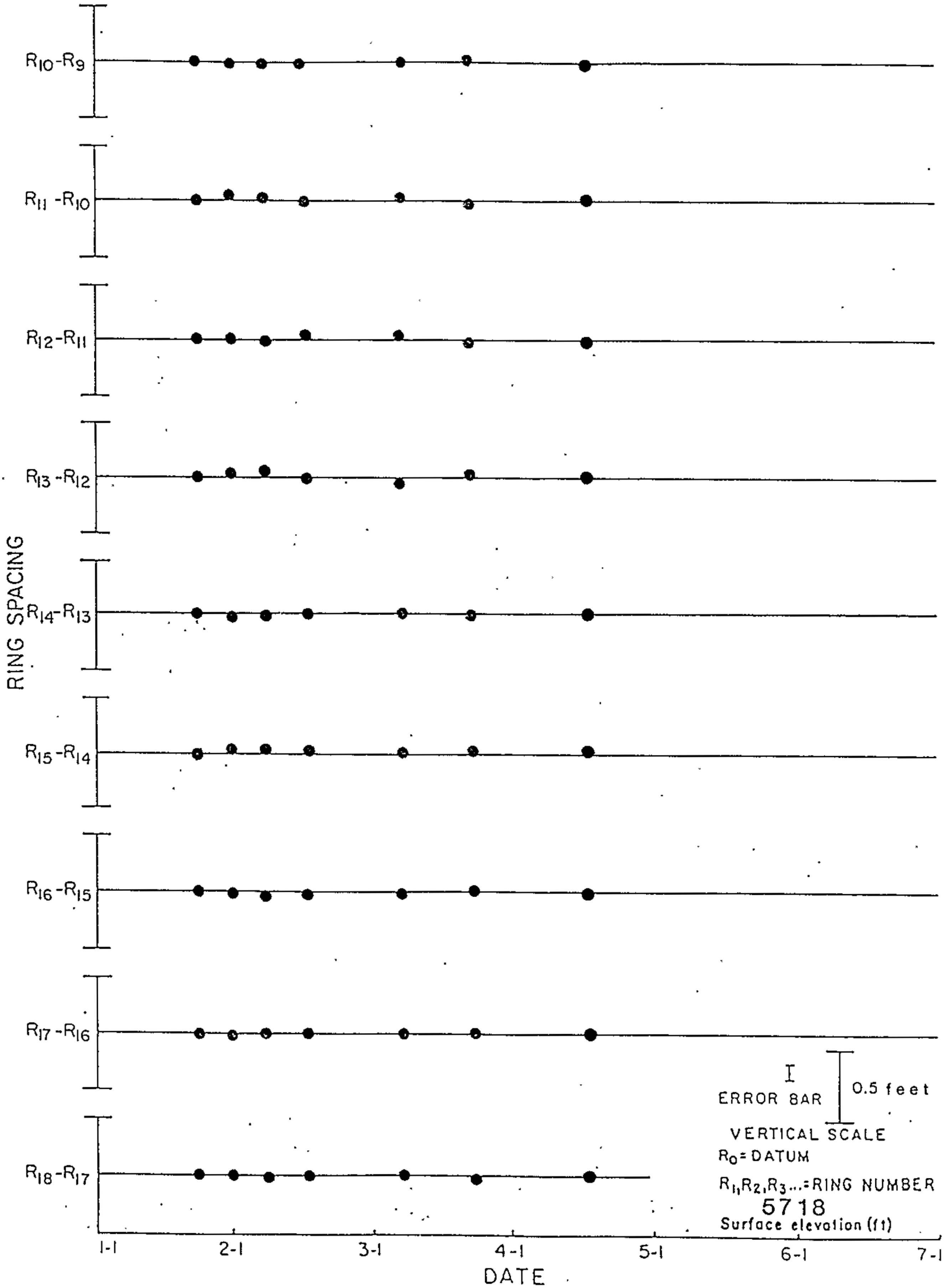
28 JUNE 1985



New Mexico Bureau of Mines

28 JUNE 1985

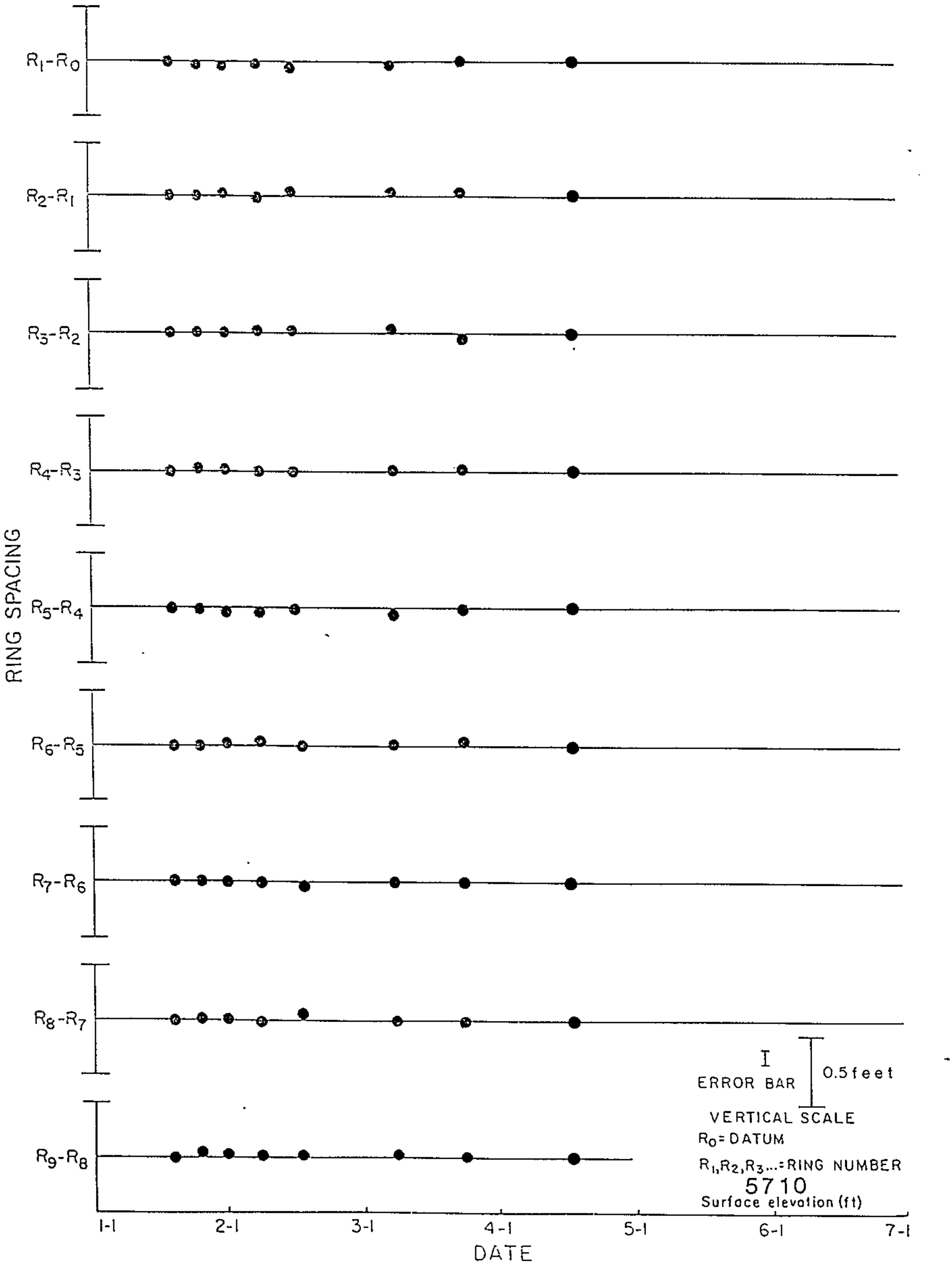
SONDEX SETTLEMENT DATA
DRILL HOLE ESPDH-39



New Mexico Bureau of Mines

28 JUNE 1985

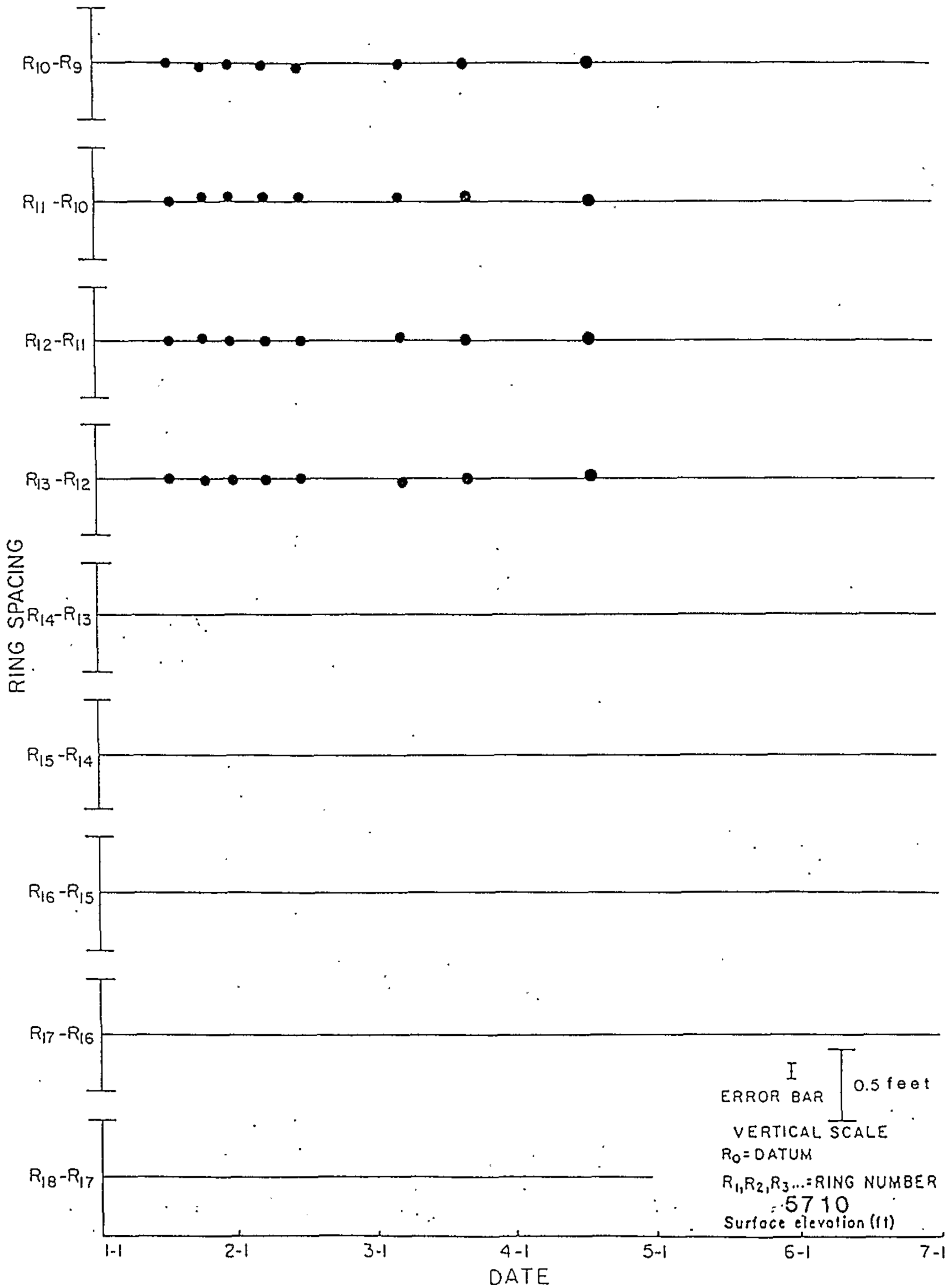
SONDEX SETTLEMENT DATA
DRILL HOLE ESPDH-41



New Mexico Bureau of Mines

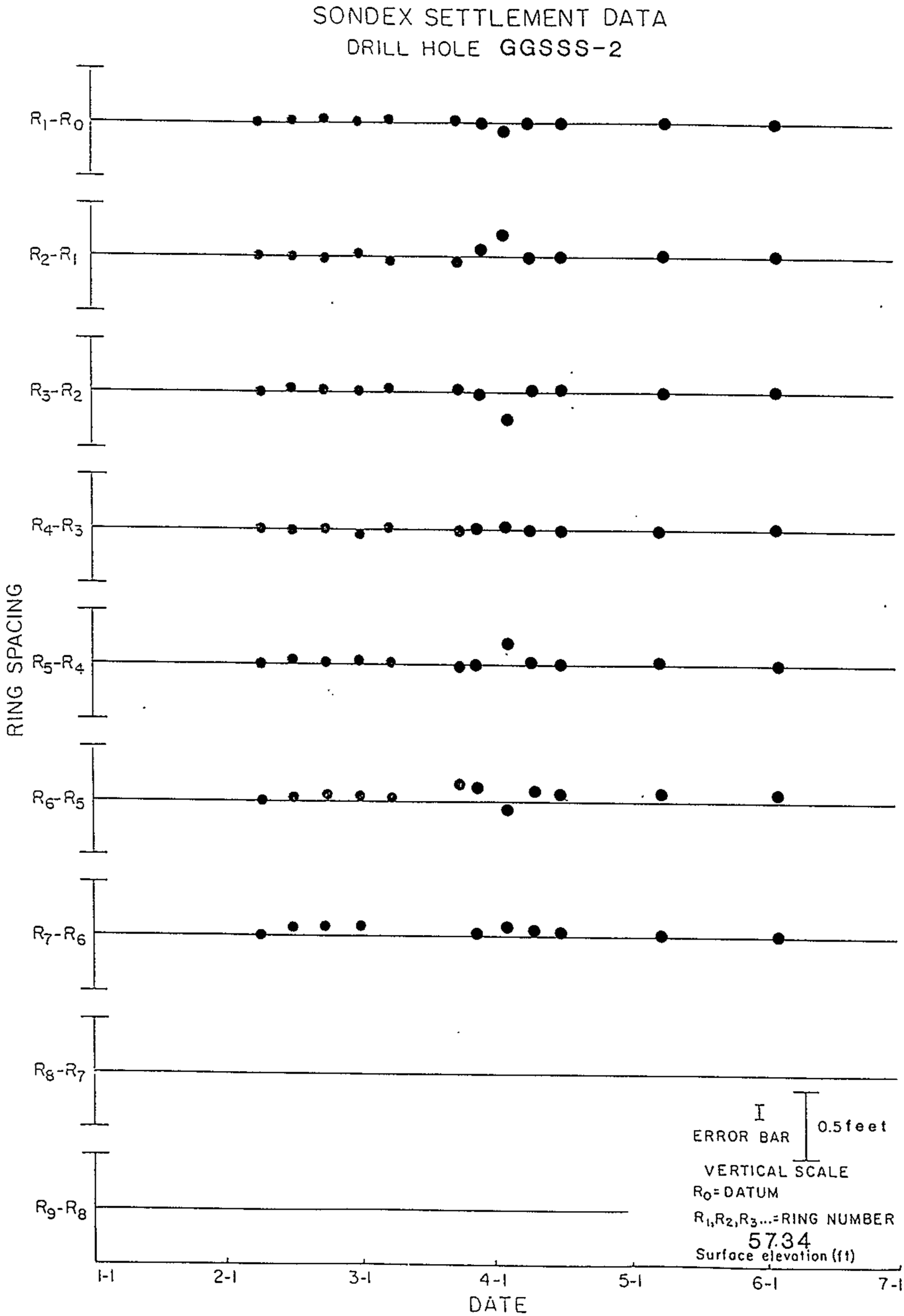
28 JUNE 1985

SONDEX SETTLEMENT DATA
DRILL HOLE ESPDH-41



New Mexico Bureau of Mines

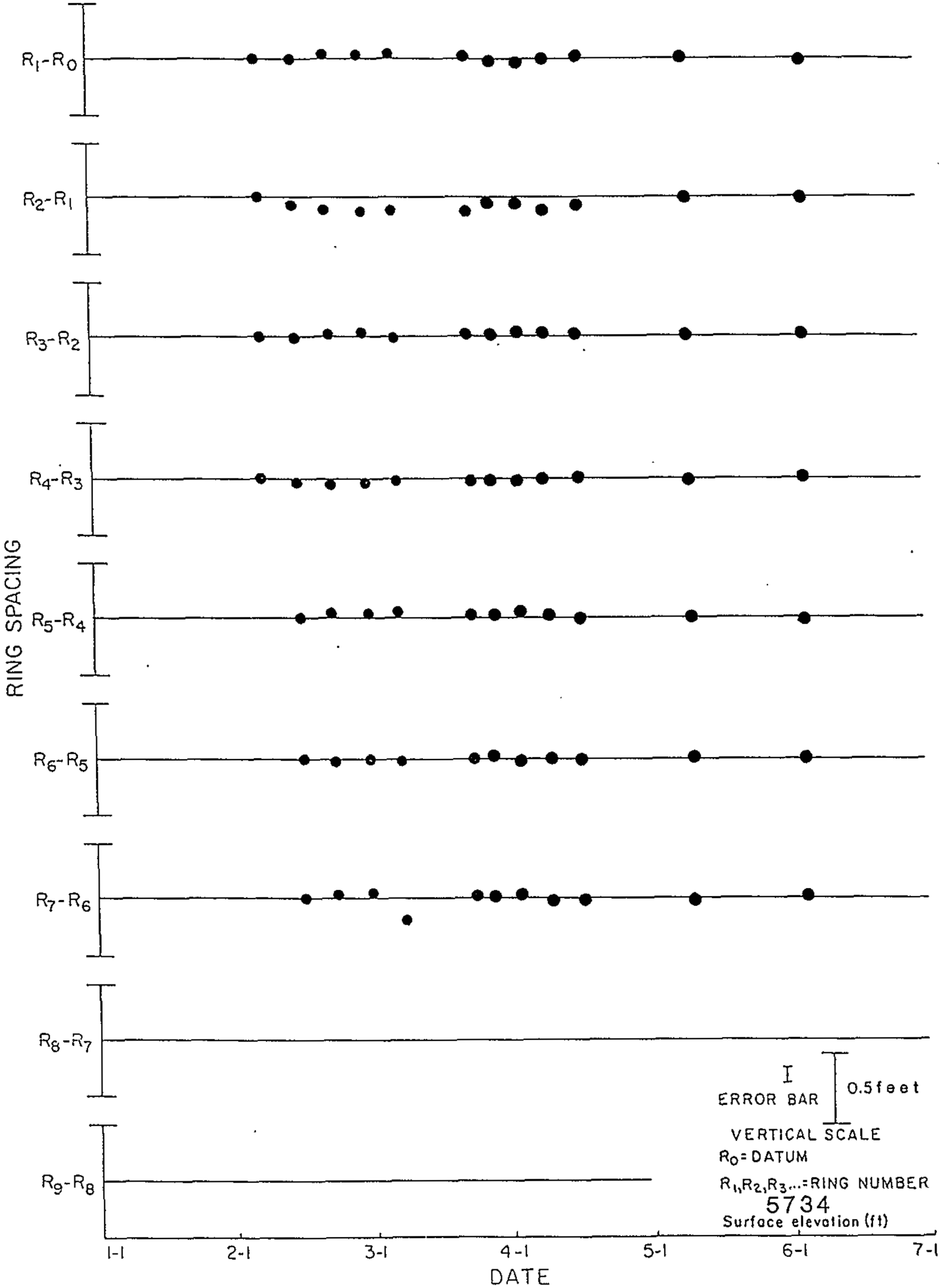
28 JUNE 1985



New Mexico Bureau of Mines

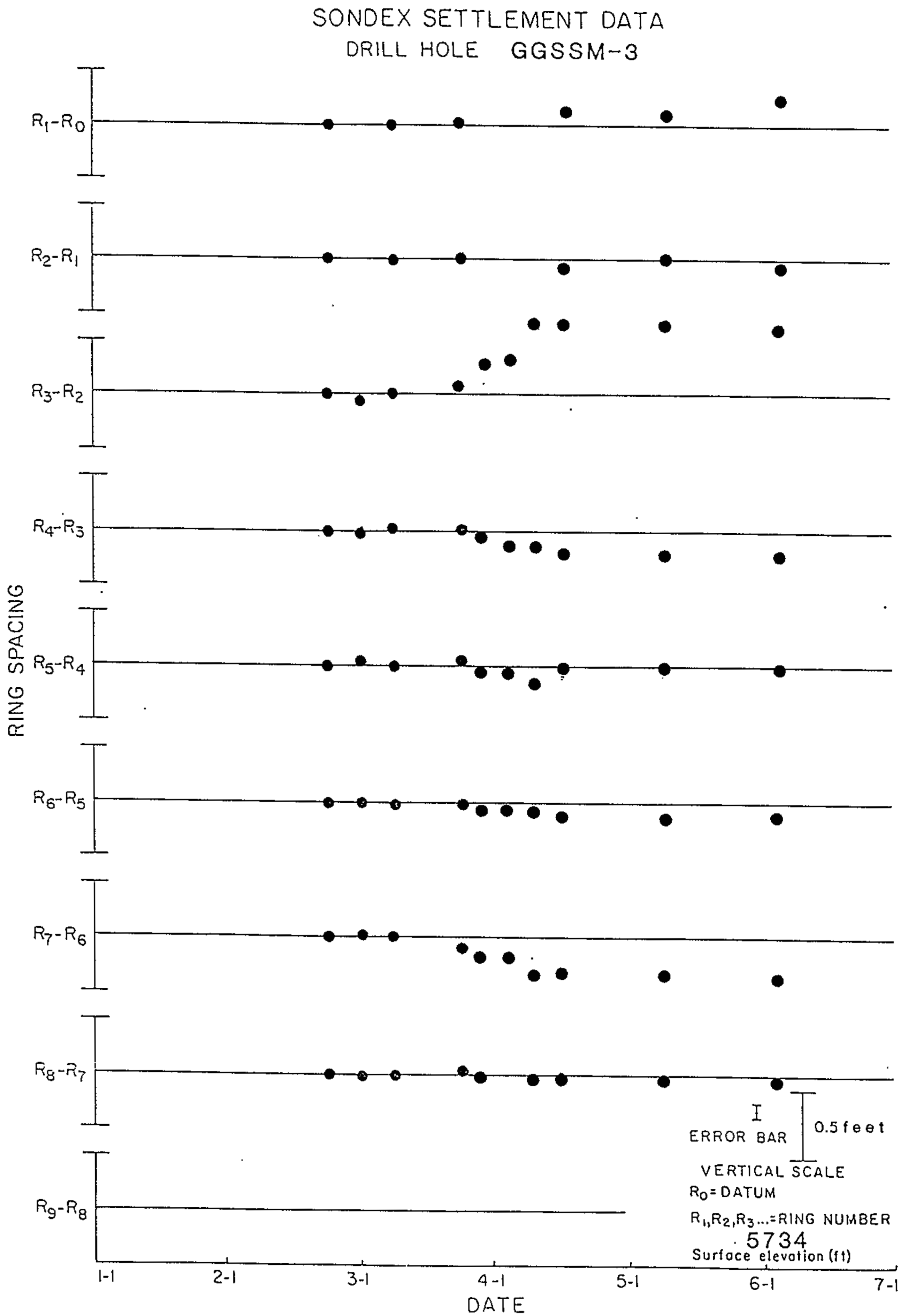
28 JUNE 1985

SONDEX SETTLEMENT DATA
DRILL HOLE GGSSS-3



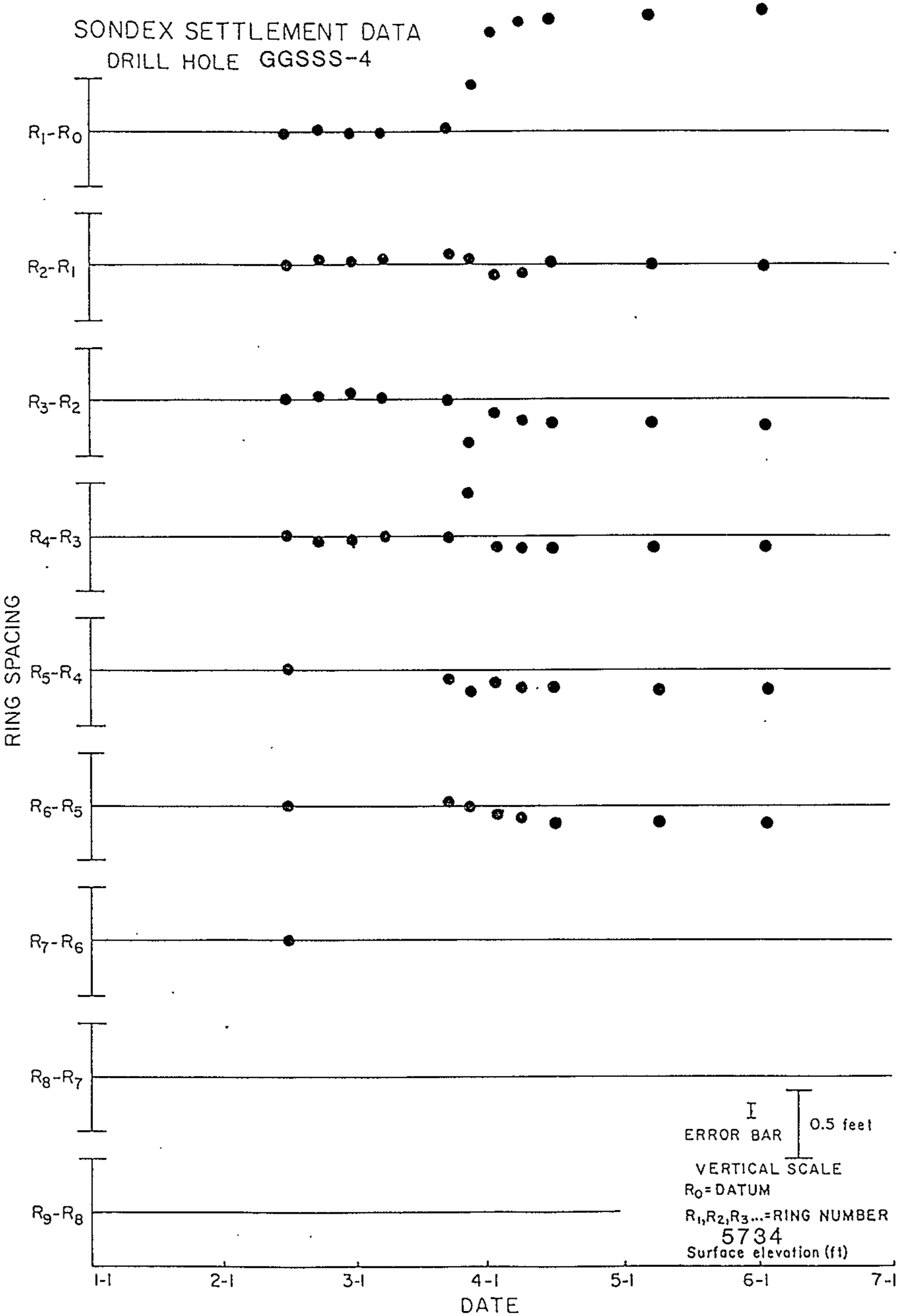
New Mexico Bureau of Mines

28 JUNE 1985



New Mexico Bureau of Mines

28 JUNE 1985



New Mexico Bureau of Mines

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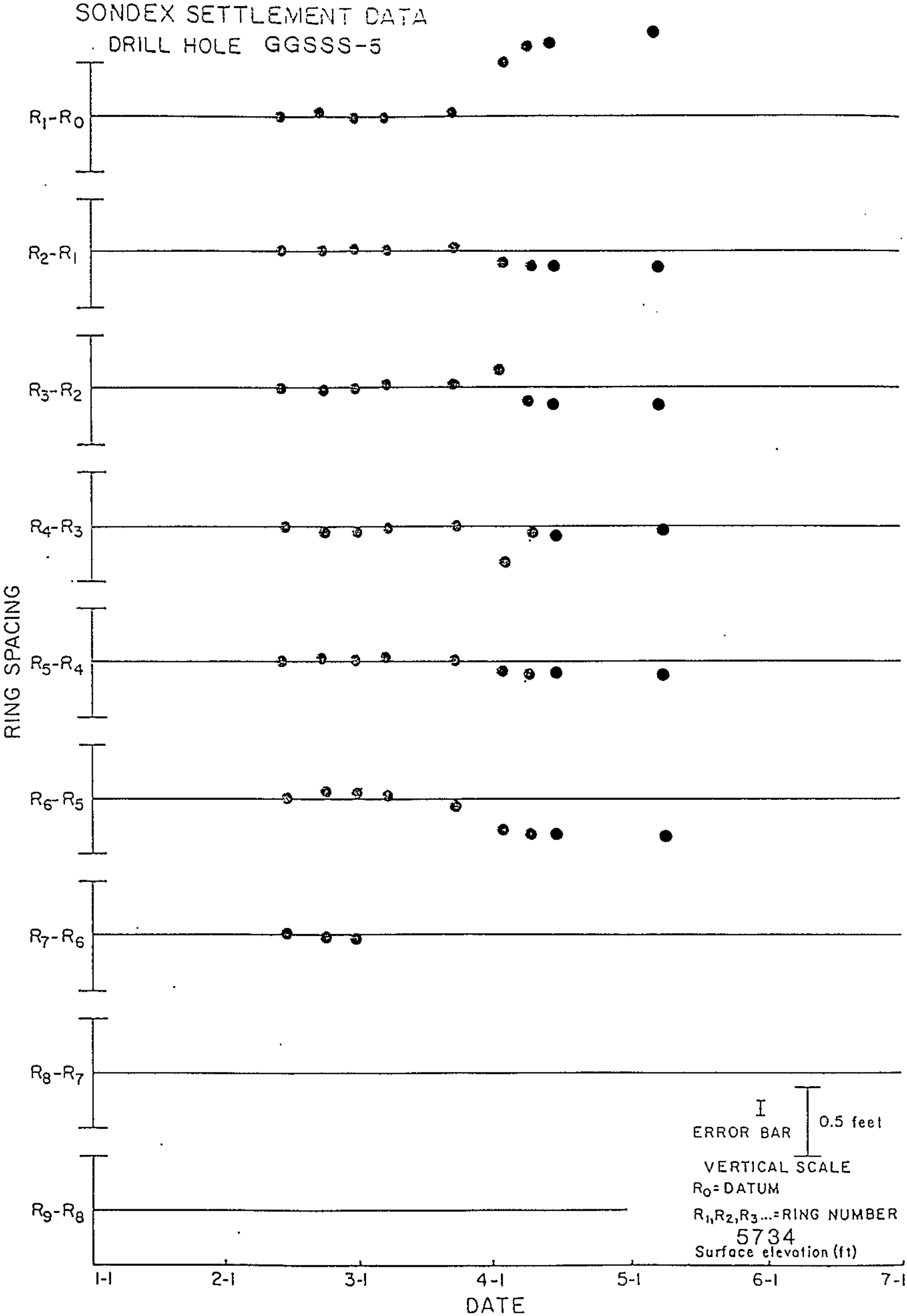

New Mexico Bureau of Mines

28 JUNE 1985

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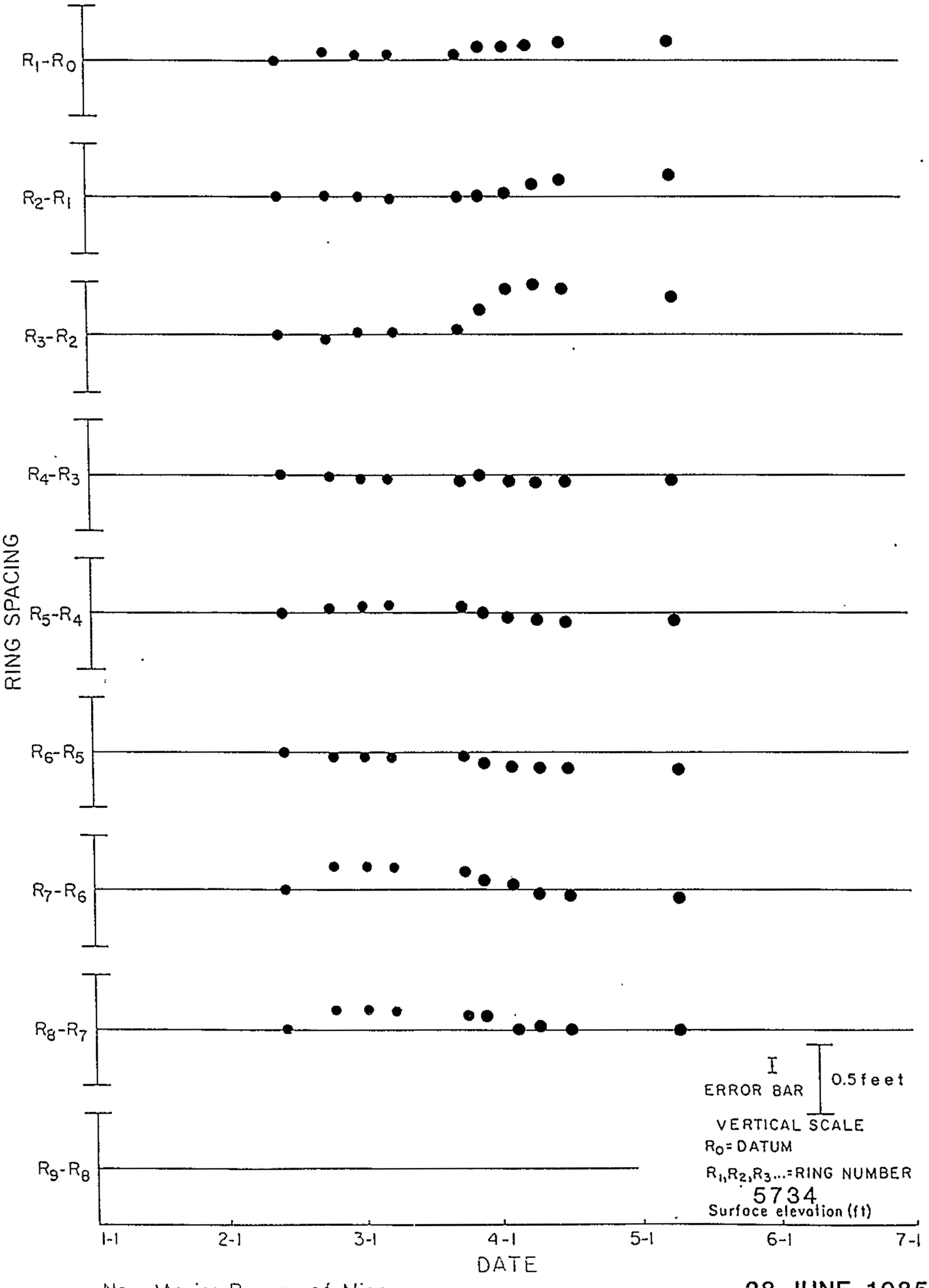

New Mexico Bureau of Mines

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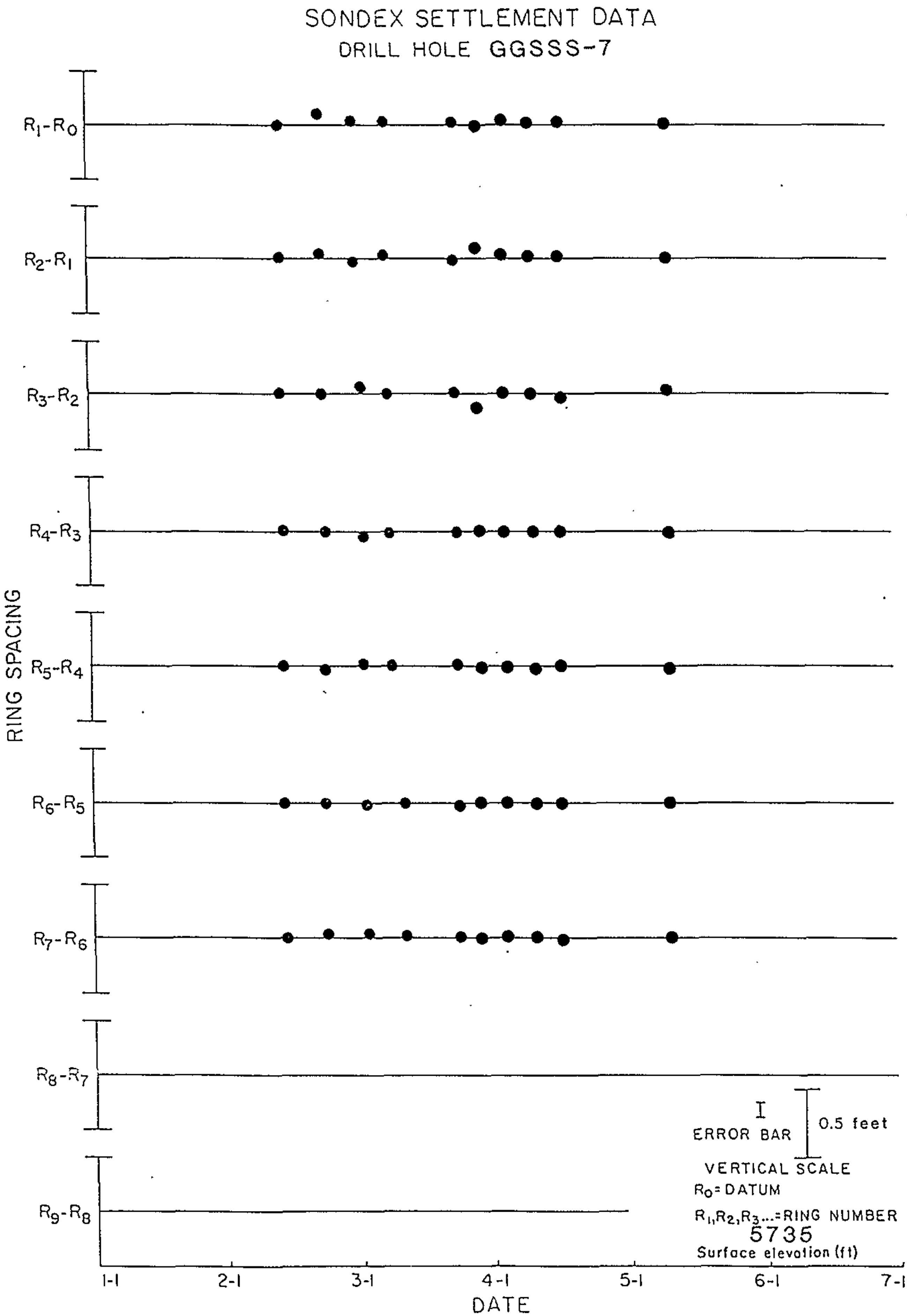

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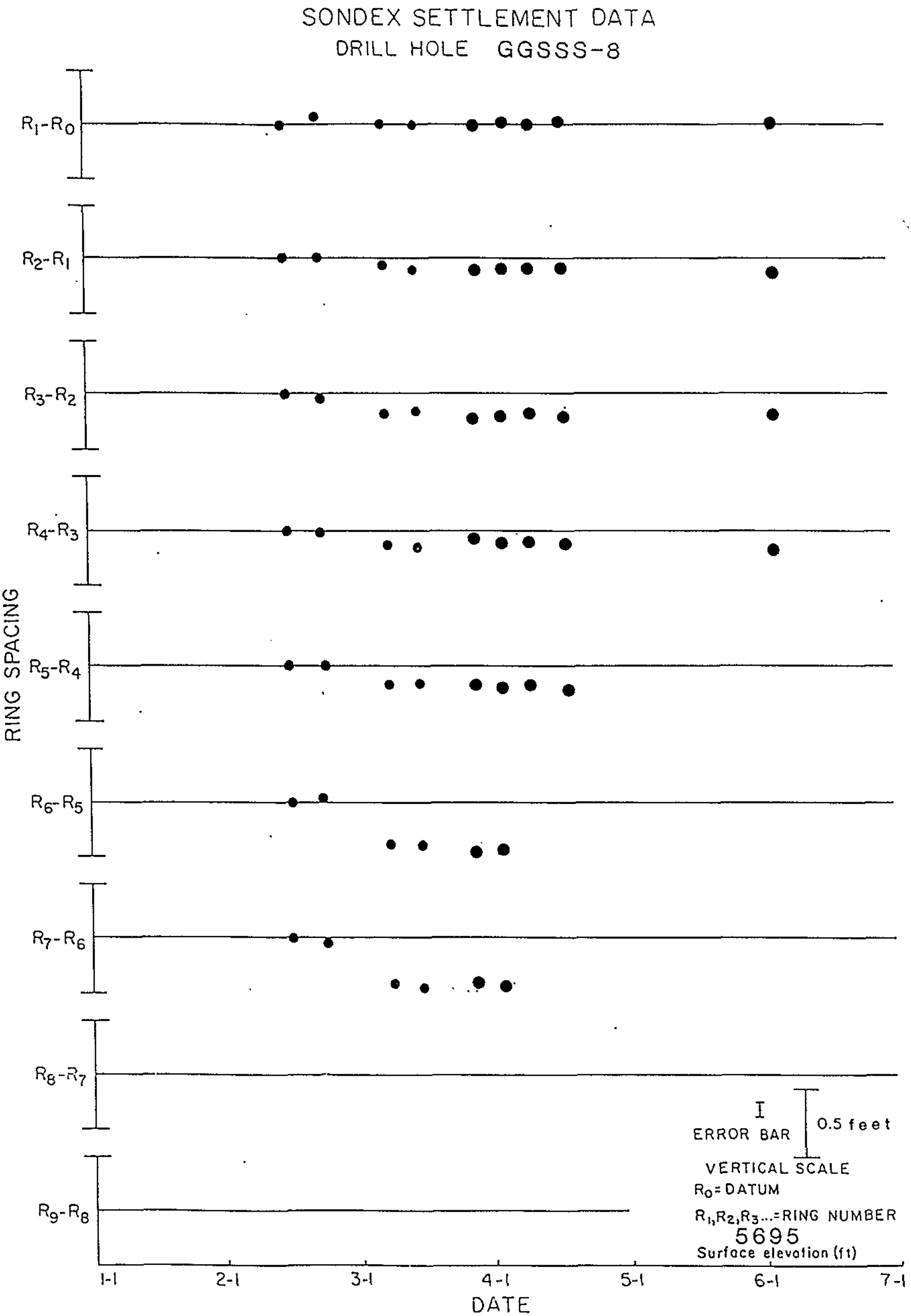

New Mexico Bureau of Mines

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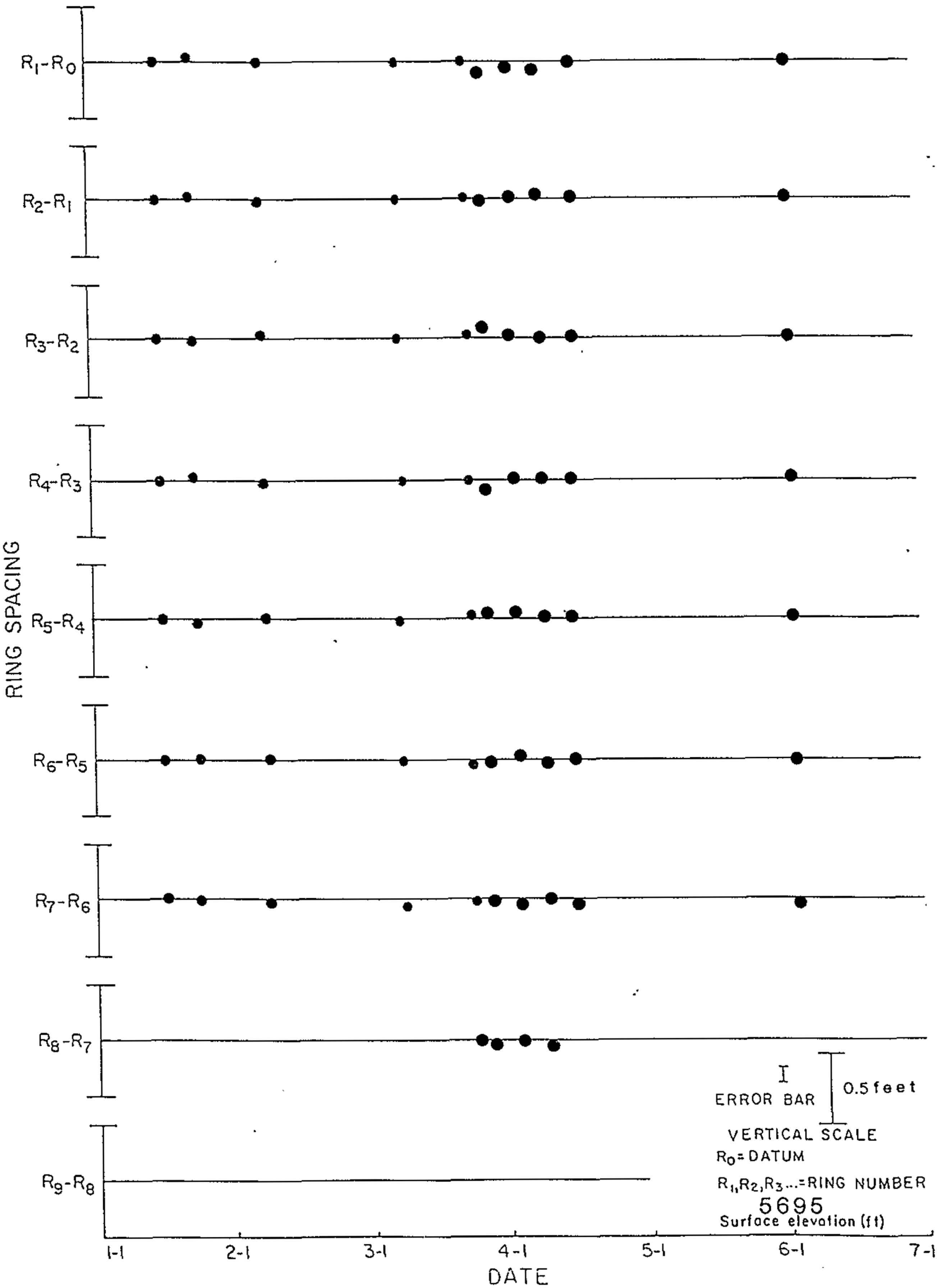

New Mexico Bureau of Mines

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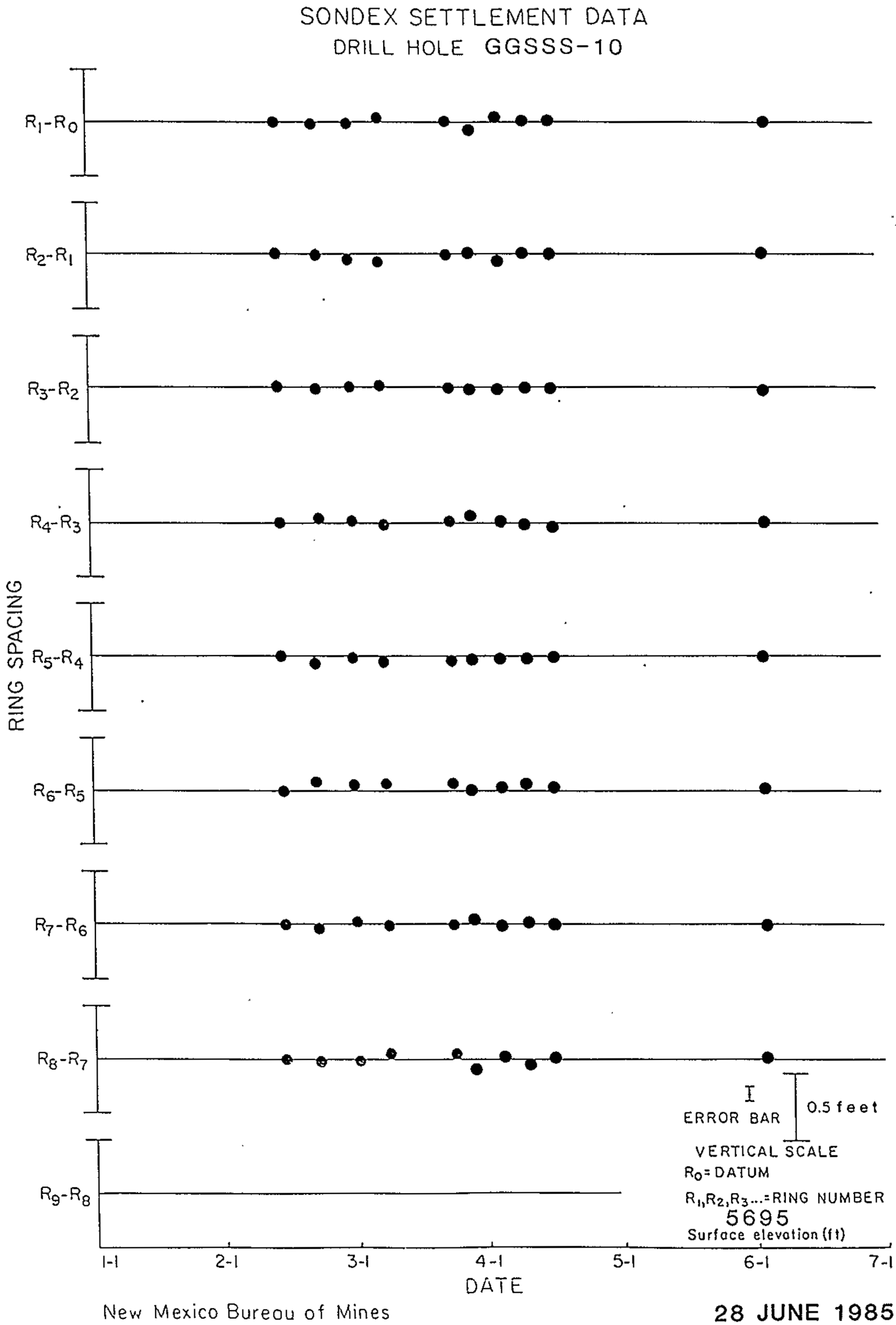
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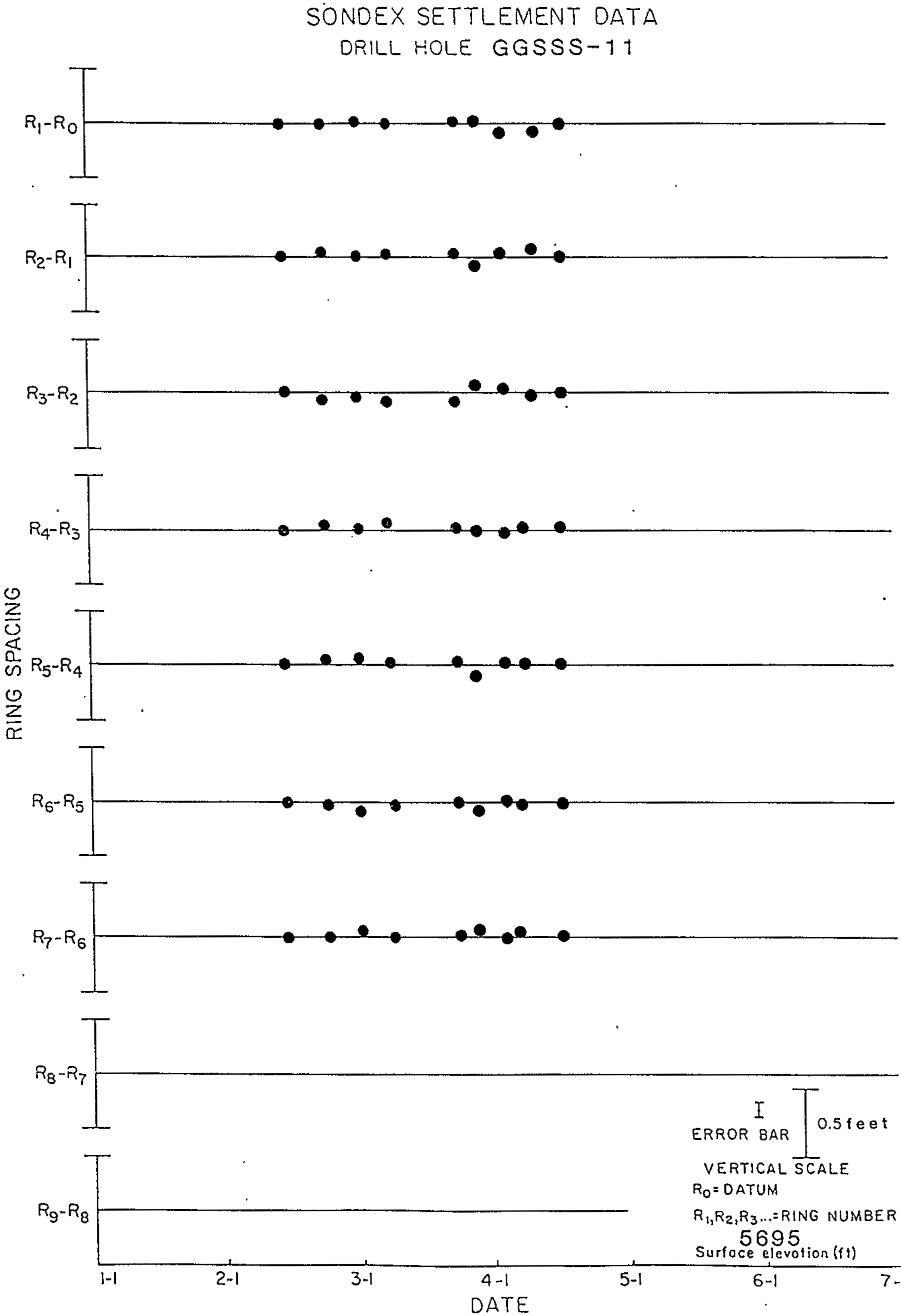
DRILL HOLE GGSSS-10
RING SPACING
R1-R0
R2-R1
R3-R2
R4-R3
R5-R4
R6-R5
R7-R6
R8-R7
R9-R8
ERROR BAR
0.5 feet
VERTICAL SCALE
R0= DATUM
R1,R2,R3...=RING NUMBER
5695
Surface elevation (ft)
1-1
2-1
3-1
4-1
5-1
6-1
7-1
DATE
New Mexico Bureau of Mines
28 JUNE 1985



New Mexico Bureau of Mines

28 JUNE 1985

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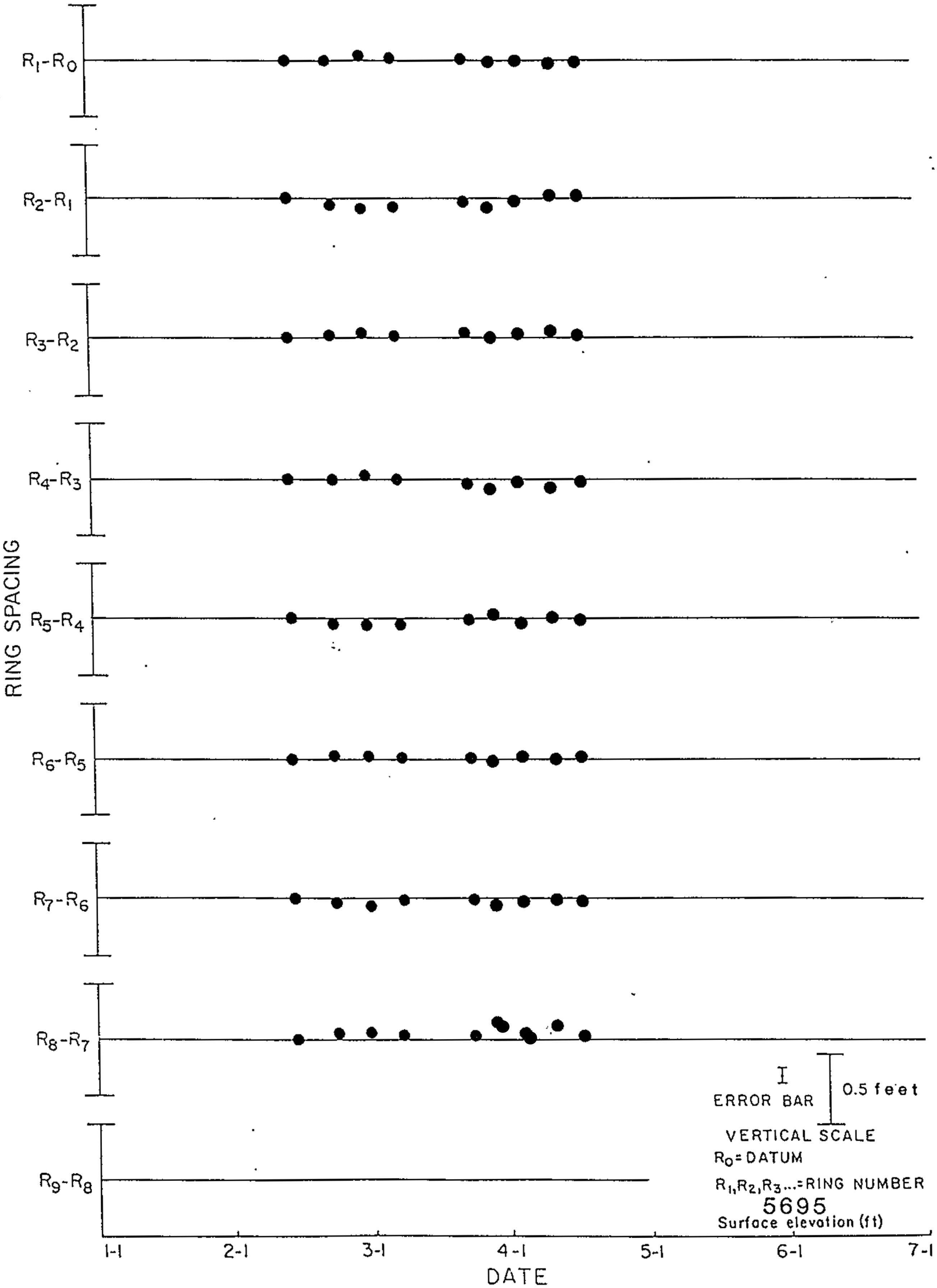

New Mexico Bureau of Mines

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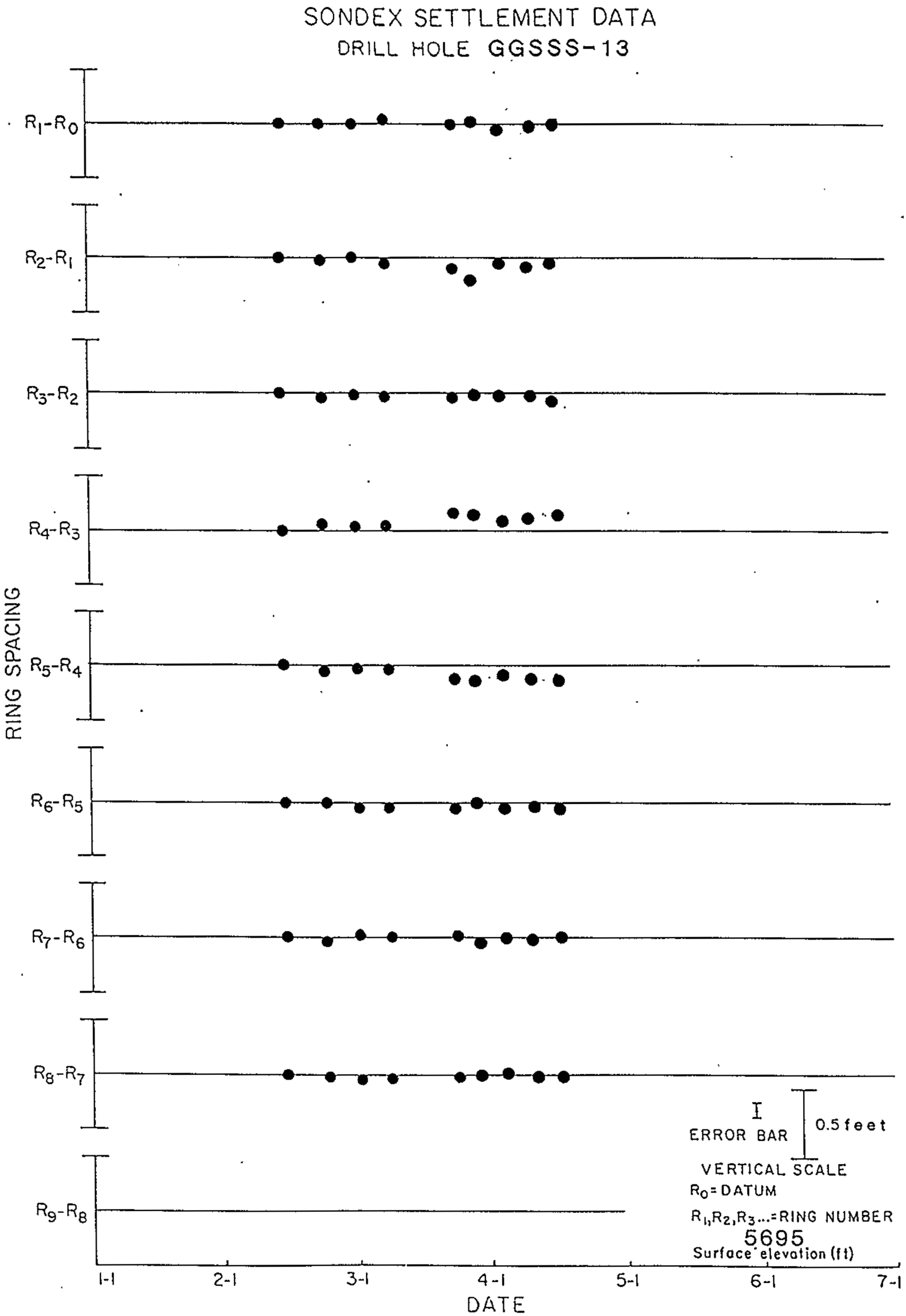

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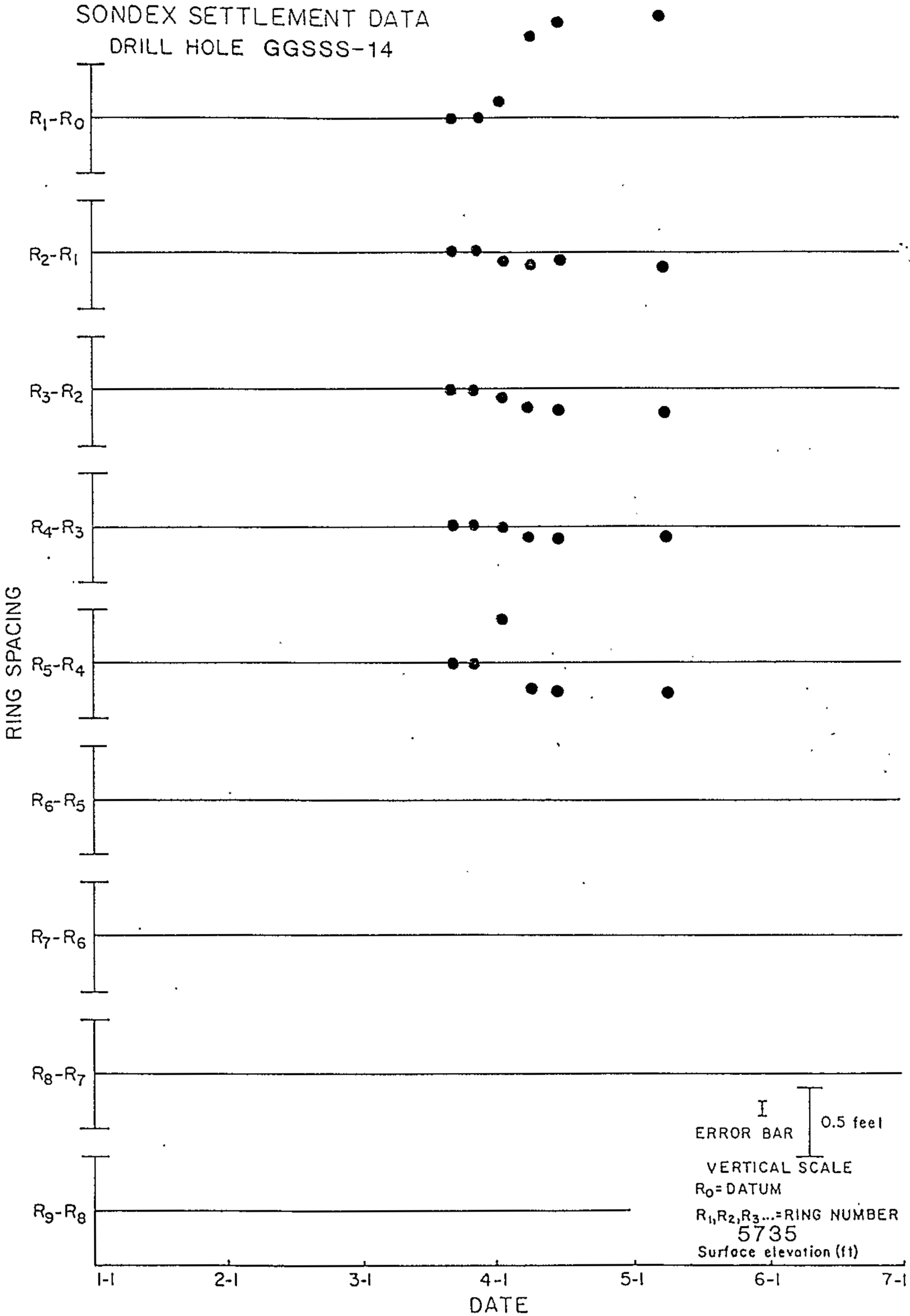

New Mexico Bureau of Mines

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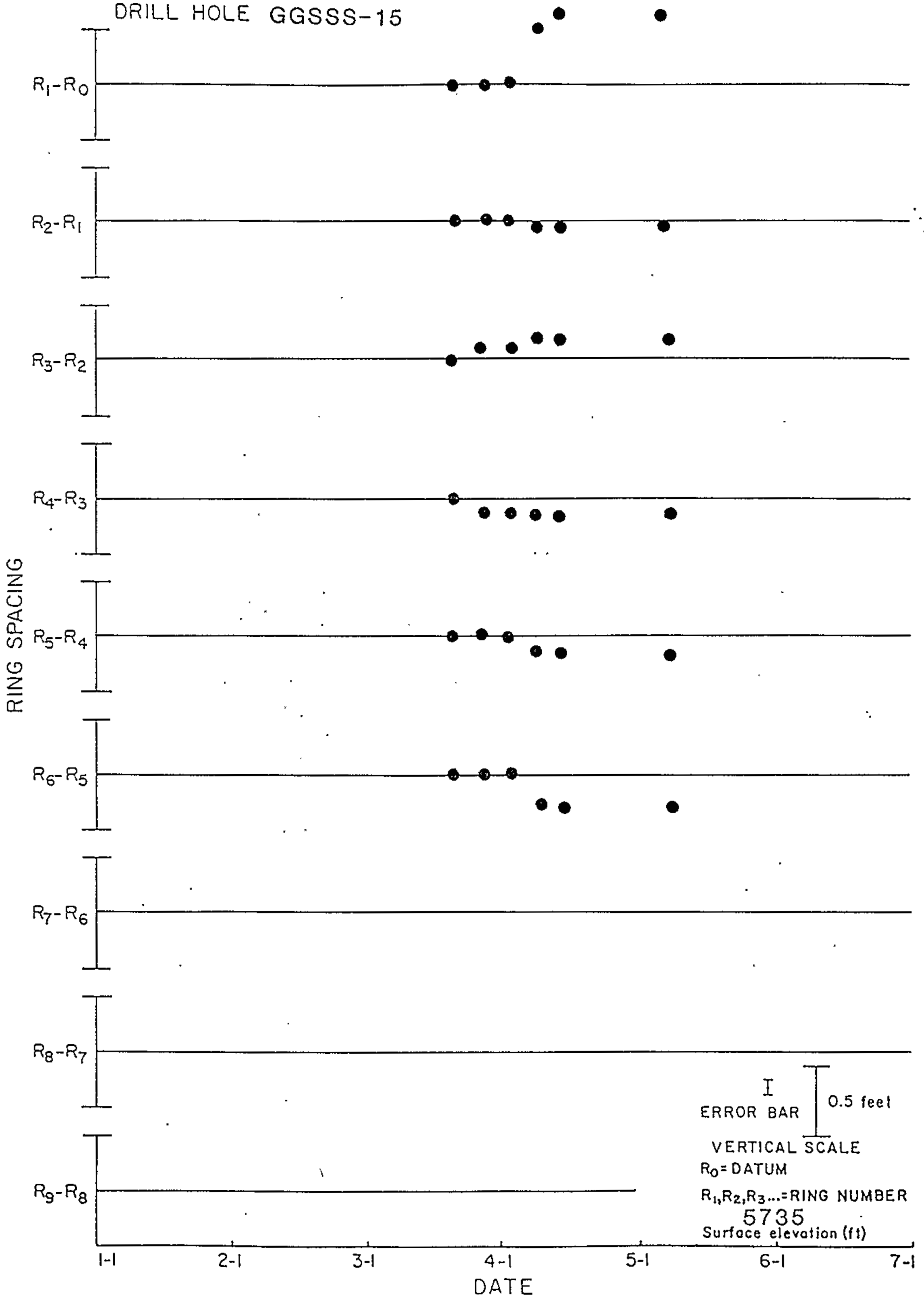
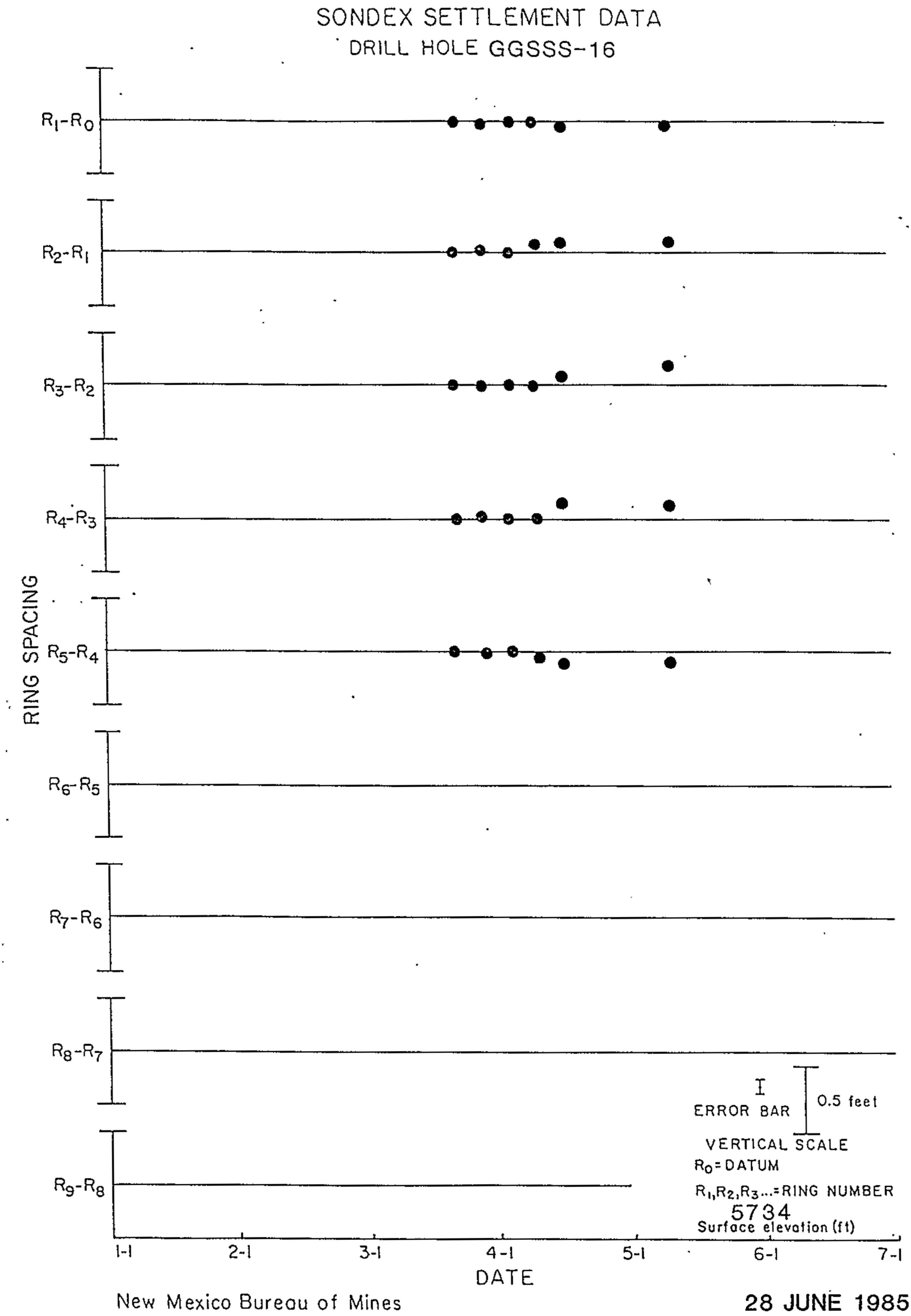
DRILL HOLE GGSSS-15

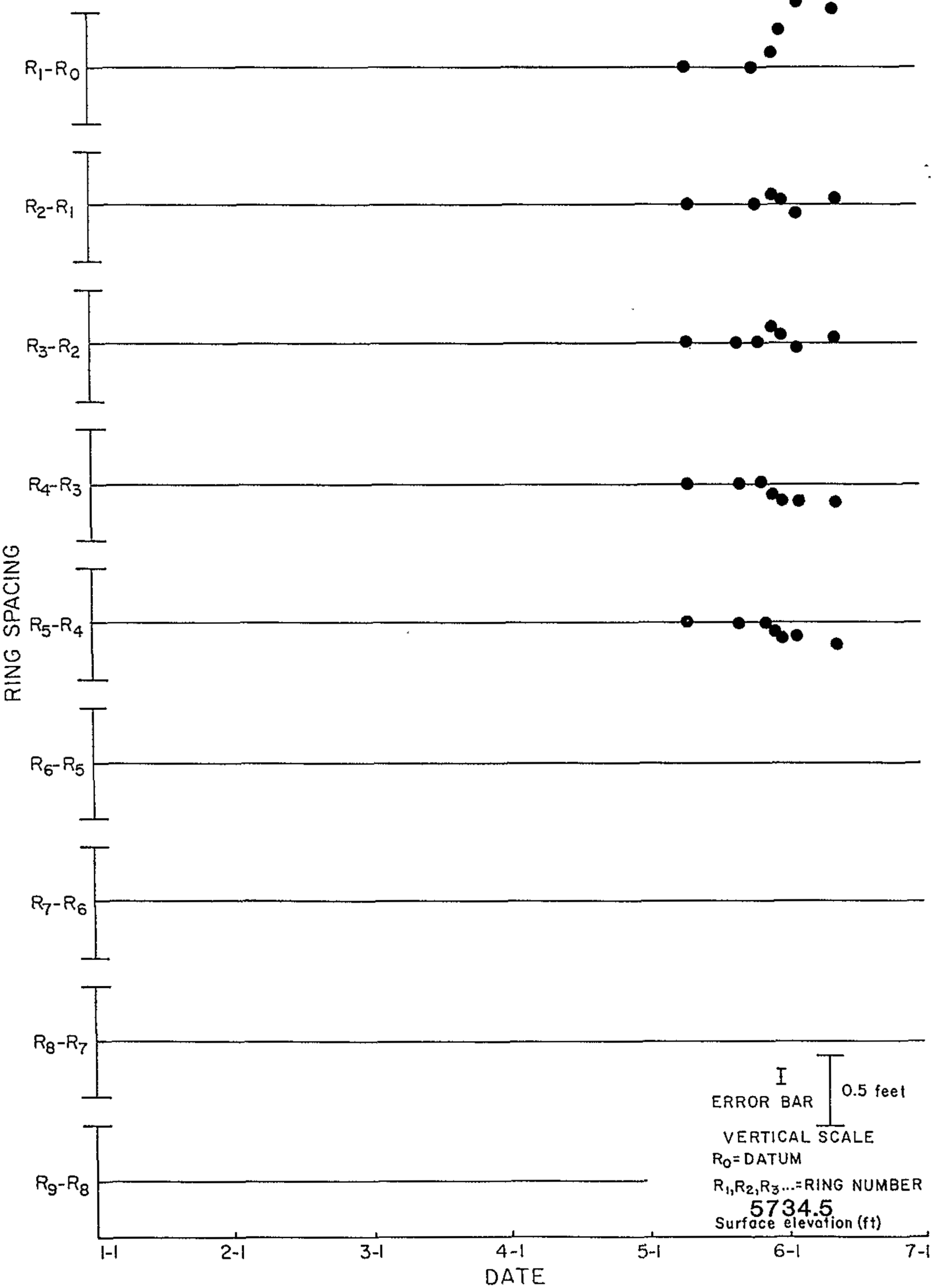


New Mexico Bureau of Mines

28 JUNE 1985


SONDEX SETTLEMENT DATA
DRILL HOLE GGSSS-16
RING SPACING
R_1-R_0
R_2-R_1
R_3-R_2
R_4-R_3
R_5-R_4
R_6-R_5
R_7-R_6
R_8-R_7
R_9-R_8
ERROR BAR
0.5 feet
VERTICAL SCALE
R_0= DATUM
R_1,R_2,R_3...=RING NUMBER
5734
Surface elevation (ft)
1-1
2-1
3-1
4-1
5-1
6-1
7-1
DATE
New Mexico Bureau of Mines
28 JUNE 1985

SONDEX SETTLEMENT DATA
DRILL HOLE **GGSSS-17**



New Mexico Bureau of Mines

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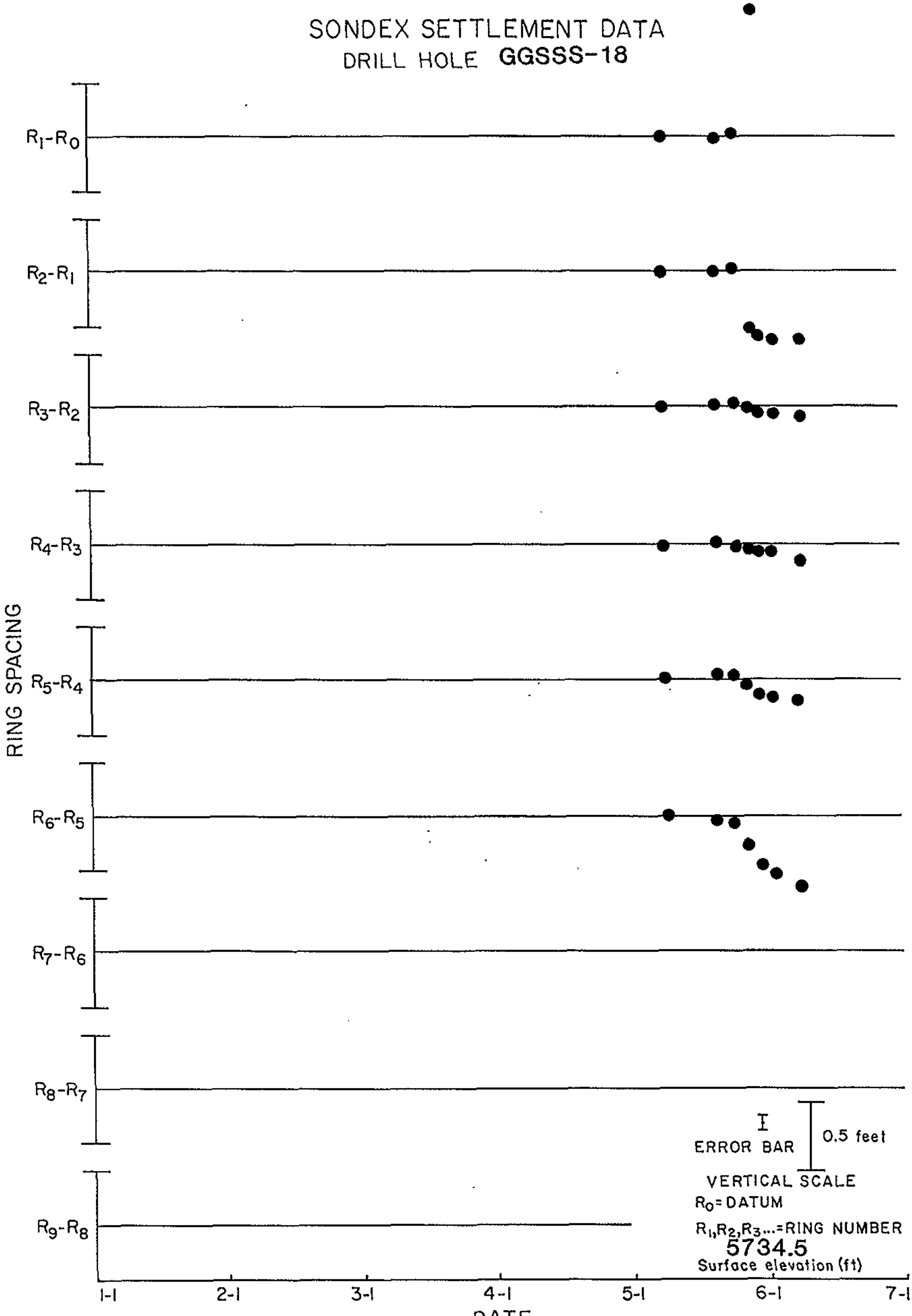

New Mexico Bureau of Mines

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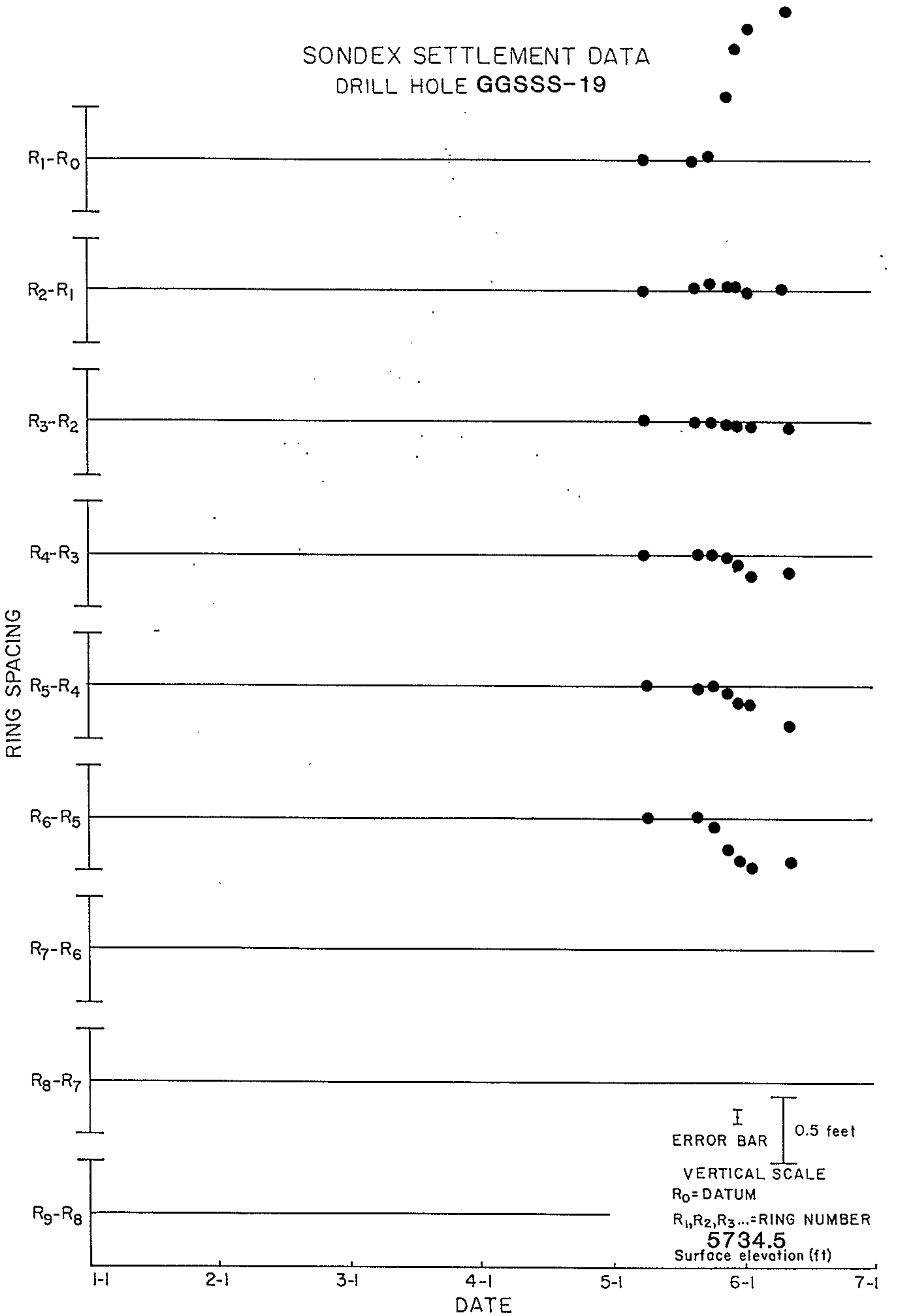

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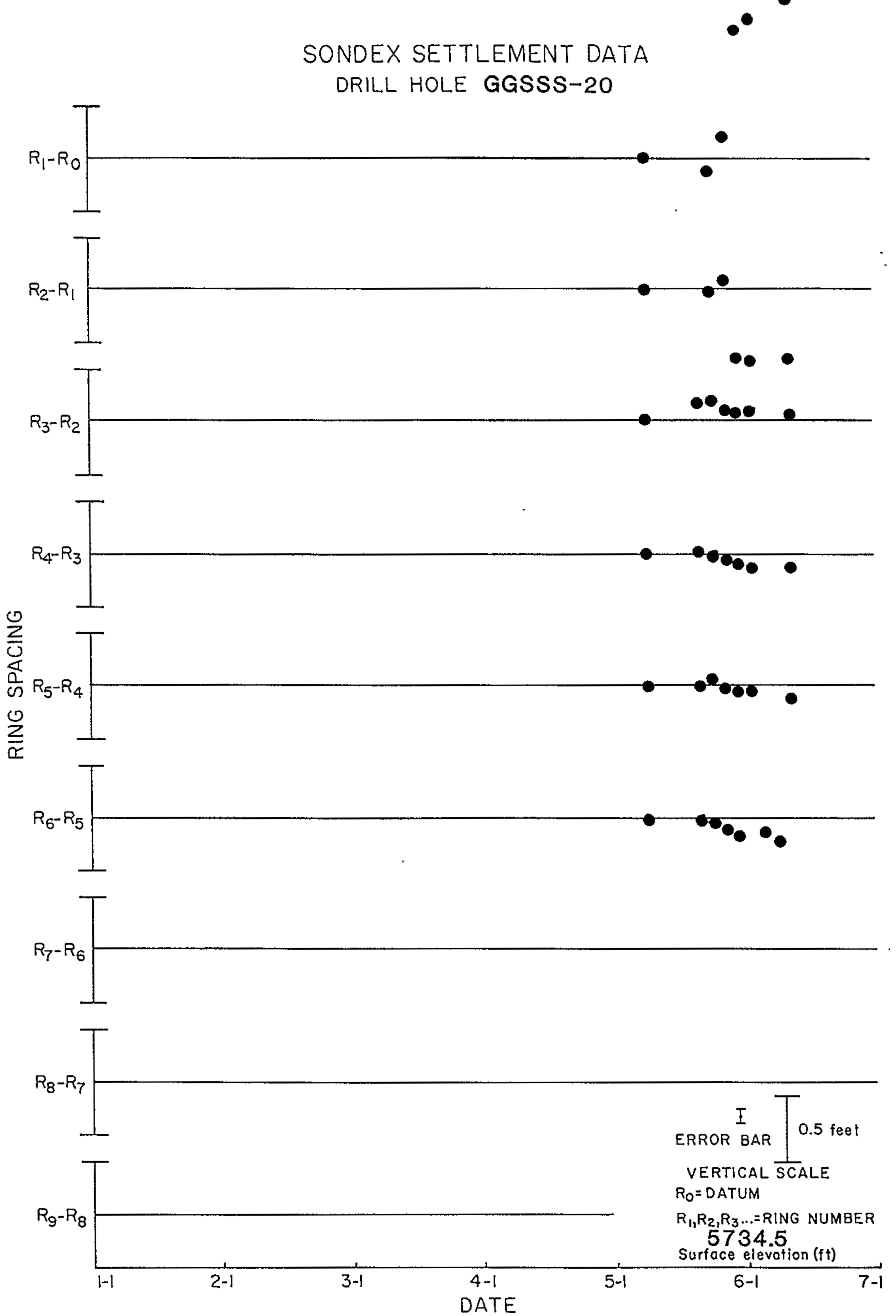

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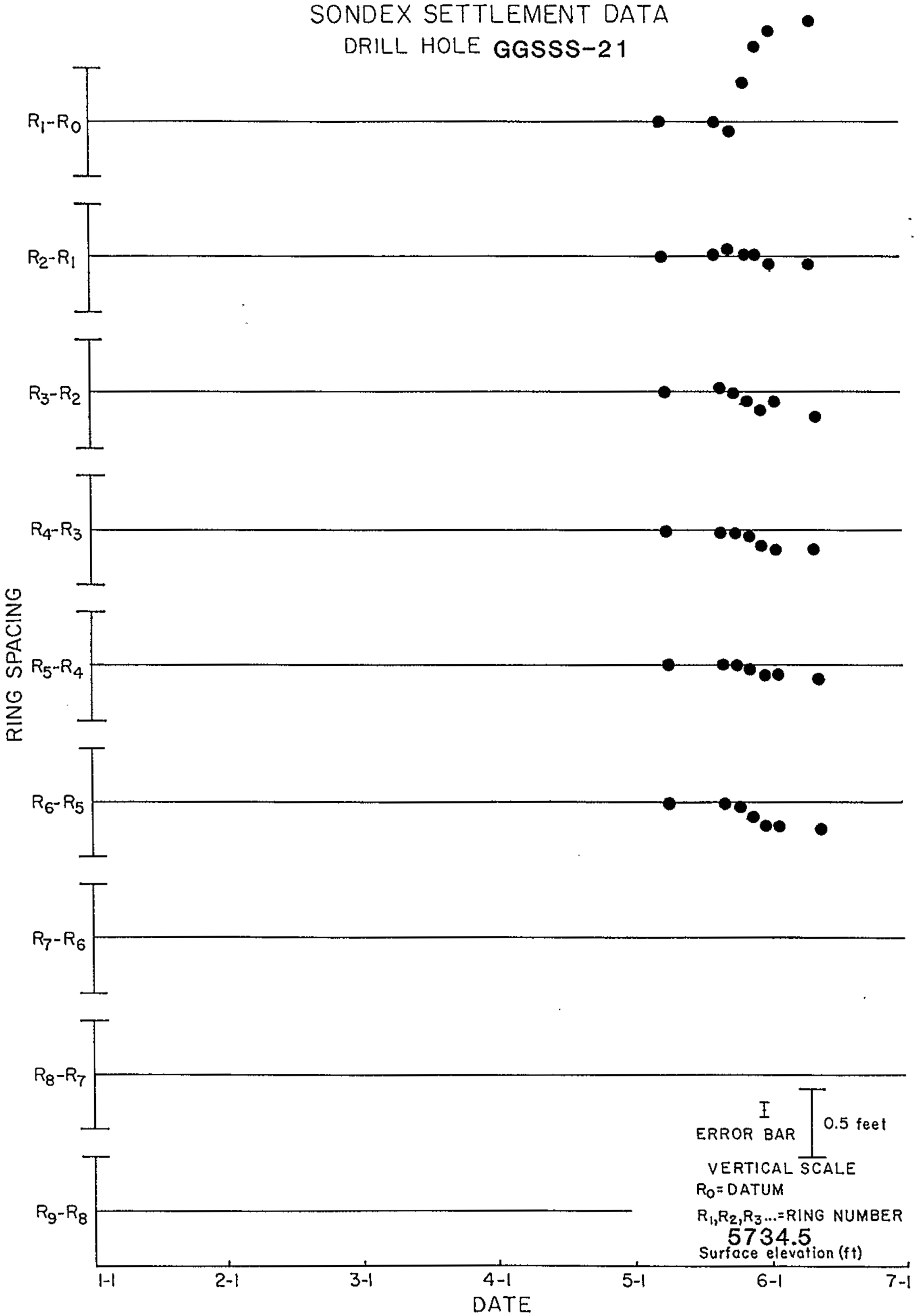


New Mexico Bureau of Mines

28 JUNE 1985

APPENDIX VII

Geophysical Reports - C. Reynolds

Telephone (505) 865-9818

Charles B. Reynolds & Associates
Consulting Geophysicists and Geologists
Post Office Box 1004
Belen, New Mexico 87002

Shallow Seismic Survey

Espanola, New Mexico

January 10, 1985

Introduction - During the period of December 18-21, 1984, a shallow seismic program was recorded in the northeastern outskirts of Espanola, New Mexico, for the New Mexico Bureau of Mines and Mineral Resources. The program included two reflection seismic lines totaling one mile in length (see Figure 1) and three shallow seismic refraction lines totaling 2850 ft in length (see Figure 2). The purpose of the survey was to investigate the subsurface geology of the area in order to aid the engineers in determining the causes and possible remedies for surface subsidence problems experienced in the vicinity.

The reflection survey and results will be discussed first because the reflection data provide larger-scale background information for the more detailed refraction survey.

Reflection Method - The seismic system used is a single-vehicle operation specifically designed for shallow (generally, less than 3,000 ft of depth) reflection investigations. The seismic energy source is a patented "soft" weight of 400 lbs dropped 6-1/2 ft to the ground. The receiver array consists of six groups of receivers attached to cables towed behind the seismic truck, with group centers at distances of 66, 131, 197, 262, 328 and 394 ft behind the impact point of the dropped weight. Each receiver group is made up of five Mark Products GL-21 10 Hz drag geophones spaced 13 ft apart inline, for a group length of 66 ft. The recording instruments are a six-channel E. G. & G. Geometrics Nimbus ES1210F system with frequency filters and G724S digital recorder. Both analog and digital recordings are made at each drop point. The digital recordings are for two seconds with a sample rate of two milliseconds and out-60 Hz filters on recording. Notch filters (60 Hz) are used at all times. Drop points are spaced 33 ft apart along the line being recorded, producing 160 recordings per mile and 600% common depth point stacking.

The seismic data processing is carried out on an IBM PC computer using software written specifically for data recorded by this seismic system. Steps involved included transcription from cassette to the computer, quality verification and editing, calculation of weathering depths, velocities and corrections from refraction breaks, removal of refraction breaks, groundroll and air wave noise by trace normalization and a velocity filter, 600%

CDP stack, correction to a datum of +5900 ft, a dip filter enhancing coherent events dipping less than about 30 degrees either way, 15-30 Hz frequency filters and VA/WT plot. A suite of one-octave frequency filter comparisons was made for selection of the final bandpass filters. Two seconds of data were processed.

Reflection Results - The final 600% record sections form Enclosure No. 1. The field and processing parameters are summarized by the title block. The two lines are displayed together, with a gap at the position of the offset between them (see Figure 1). East is to the right and west to the left. As can be seen, the data quality is good at very shallow depth and becomes poorer with increasing depth.

Reflection Interpretation - Enclosure No. 2 shows the final seismic section as interpreted by the writer. Five prominent seismic events believed likely to be bedding plane reflections are colored with yellow. Interpreted faults are shown as steep green lines.

The first (shallowest or earliest in time) yellow horizon is considered probably the top of the Tertiary Santa Fe group. Its depth probably varies from about 50 ft to about 100 ft. The major elements affecting this horizon are, from right (east) to left (west): (1) a shallow syncline (overlying an apparent deeper graben), which from topographic evidence appears likely to trend northwest, (2) a gentle anticline, centered at about DP 35 on Line ES1, which appears to be draped over a deeper horst, (3) a slight rise centered at about DP 90 on Line ES1, which may be more likely a buried hill or ridge than a tectonic feature, (4) a minor fault, down to the east, with displacement probably less than 25 ft, at about DP 53 on Line ES2 and (5) a second minor fault, down to the west and perhaps of slightly greater displacement, at about DP 30. There is at present no evidence that either of these faults penetrates the overlying Quaternary strata to reach the surface.

The second (next deeper or later) yellow event shows the same general features as the shallowest yellow horizon except that the syncline and drape anticline on Line ES1 are more pronounced, there is evidence of a rapid westward deepening from the drape anticline to the west end of Line ES1, and the displacement of the small fault at about DP 53 on Line ES2 appears to be reversed (possibly suggesting strike-slip or lateral motion). This second yellow horizon is considered probably an important lithologic change within the Tertiary.

The third deepest (or latest) yellow horizon roughly conforms to the second in that here the anticline centered at about DP 35 on Line ES1 appears clearly to be a horst, and the most westerly interpreted fault (at about DP 20 on Line ES2) seems to have much greater displacement than at the two shallower yellow horizons. Another point of interest is that the data above this (the third) yellow horizon seem to be much better than those below, implying that it is a major reflector and hence likely an important lithologic change, such as the base of the Tertiary. The depth of this horizon probably varies from about 2700 ft at DP 30 on Line ES1 to about 3700 ft at the west end of Line ES2.

The fourth and fifth (deepest) yellow events are much poorer than those above. There is a hint that the horst and drape anticline of Line ES1 may be underlain by and presumably genetically related to a possible high-angle reverse fault cutting these two deepest yellowed events. Presumably the fourth and fifth yellow horizons are from within pre-Tertiary (probably Paleozoic) rocks.

Refraction Method - The same seismic energy source and instruments are used for refraction as were described earlier under the discussion of the reflection method. For refraction, six 8 Hz refraction geophones are used, spaced at distances of 50, 100, 150, 200, 250 and 300 ft from the weight drop impact point. Multiple drops at the same impact point are made and summed in the field until the operator is satisfied with the resulting record. The 300 ft refraction spread is then reversed--that is, the weight drop position is moved to the position previously occupied by the far geophone, 300 ft away, and another geophone placed at the first impact point. These reversed profiles are of great importance in quality control and data analysis, and the reciprocal times (the times of first energy arrival at the far geophone in each case) should be very nearly identical, preferably within 0.005 second.

If a given shallow refraction line is more than one 300 ft profile in length, successive profiles are overlapped 150 ft to provide as nearly as possible continuous subsurface coverage.

Refraction Data Analysis - After return from the field, the reversed pairs of refraction records are studied and the first (and second, in some cases) energy arrivals picked and converted to travel times. A decision is made as to how many velocity layers are indicated by each record, and their velocities and zero-distance time intercepts determined by computer fitting of inverse velocity lines using the method of least squares. The thickness of each layer is then calculated by the zero-intercept method, again by computer. Lastly, those refractions which are present on both records of a reversed pair and have acceptable reciprocal times are analyzed by computer wavefront reconstruction. This method yields comparatively detailed and accurate depth, form and velocity for the refractor.

Refraction Results - The refraction records recorded are largely of good quality, with very few traces unusable. In two cases the reciprocal time agreement was poor, but study of the records from successive drops showed that this was caused by compaction of loose, wet soil and was therefore correctable. At various locations as few as three and as many as six velocity layers are indicated.

Refraction Interpretation - Enclosure No. 3 shows the refraction depth sections resulting from study and analysis of the three refraction lines (for locations, see Figure 2).

The shortest line, Line 1, was recorded across the area of subsidence west of the Moya house. This line is only one profile (300 ft) in length. At the south end a surface layer about 17 ft thick with a velocity of about 900 ft/sec was indicated. This layer is apparently not present at the north end; its base, shown as a straight line on Enclosure No.3, may in fact be far from planar between the north and south ends of the line. A second layer with a mean velocity of about 1150 ft/sec underlies the surface layer. Below this is a layer with a mean refraction velocity of about 3026 ft/sec at a depth of about 60 ft, which agrees closely with increased blow-count in the test boring drilled southwest of the Moya house and near Line 1 on December 18, 1984. The slight upward bowing of this refractor as seen on Enclosure No.3 may be due at least in part to the surface depression across which the line was laid. A fourth refractor was recorded at a depth of about 80-85 ft, with a velocity of about 6809 ft/sec and an indicated gentle southward dip component.

Line 2 was recorded from east to west along the lane north of the Moya house (Figure 2). Here the surface layer of about 900 ft/sec velocity thickens from about 6 ft at the east end to about 23 ft at the west end (Enclosure No. 3). The layer underlying it has a mean velocity of about 1198 ft/sec except near the area of the depression, where its mean velocity increases to about 1402 ft/sec. Overall, except for the increased velocity near the depression, this layer's velocity appears to decrease westward. The next deeper velocity layer, with a mean velocity of about 1800 ft/sec, appears to exist only from the area of the depression westward. It also increases in depth westward. Below this layer is another with a mean velocity in excess of 2000 ft/sec which deepens abruptly westward at about position 2W/4E; west of this point its velocity increases to more than 3000 ft/sec, or else the two are not correlative. Below this layer are much faster refractors. One dips eastward near the east end of the line and has an indicated velocity of about 5773 ft/sec, which is near the normal upper limit of velocities for the Santa Fe group at such shallow depths. A short distance west of the depression and at a depth of about 90-115 ft, two refractors with mean velocities calculated at about 10,639 and 8298 ft/sec form an apparent gentle high. These velocities are very high for Santa Fe beds, even though wet, and probably indicate unusually lithified rock for that group. In summary, Line 2 shows a number of anomalous features in the near vicinity of the depression, but evidently centered near its western edge.

Line 3 indicates a surface layer varying from about three feet to about 23 ft in thickness with a slightly higher velocity than at Lines 1 and 2--about 1000 ft/sec. Below this surface layer, in the southern half of the line, is a velocity layer with velocities ranging from about 1389 ft/sec to about 1839 ft/sec. This unit evidently thickens southward from about position 11S/9N and appears to contain isolated thin bodies of higher velocity material (beneath 7N/9S and 7S/5N) which may be channel sands. Still referring to the south half of Line 3, the next layer down dips southward and has a velocity which appears to decrease northward, from about 2186 ft/sec near the south end to about 1787 near the center of the line. North of the center of the line, conditions appear to change abruptly from the relatively regular conditions to the south. The surface layer (about 1000 ft/sec) becomes much more variable in thickness, and deeper refractions vary greatly in velocity and form. Deeper, higher velocity refractors are present here which are not evident in the south half of Line 3. In fact, the area centered at about 13N/15S on Line 3 bears a considerable resemblance to the area of Line ~~3~~2 centered at about 3E/1W.

The refraction data from the reflection records of reflection Lines ES1 and ES2, though not reversed and hence not capable of as definitive analysis, nevertheless offer some possibly useful information. East of DP 30 on Line ES1 (i.e., east of the drape anticline), the main refractor, at a depth of about 50 ft, has a mean velocity of about 3000 ft/sec, typical of dry, shallow Santa Fe beds. No deeper or faster refractor was detected here. Above and west of the drape anticline, however, the main refractor detected has a mean velocity of about 5863 ft/sec, fairly typical of saturated Santa Fe beds. The depth of this refractor, which is calculated at about 100 ft at DP 30-DP 40 on Line ES1 decreases gradually and somewhat irregularly to about 70 ft at the west end of Line ES2. This refractor thus appears likely to represent the water table, rendered somewhat variable to refraction by variations in lithology of the containing rocks.

Conclusions:

A. No evidence of major faults affecting shallow beds (i.e., beds above a seismic event at about 500-1000 ft) is indicated by the reflection data.

B. Two small seismic faults suggested on reflection Line ES2 appear to cut what is interpreted as the top of the Santa Fe group, but may not penetrate the overlying Quaternary beds.

C. Anomalous and somewhat similar shallow velocity conditions are present near the depression behind the Moya house (Line 2) and in the northern half of Line 3.

Respectfully submitted,

Charles B. Reynolds
Charles B. Reynolds
Registered Geophysicist (Calif.)
Certified Professional Geologist

2 Figures
3 Enclosures

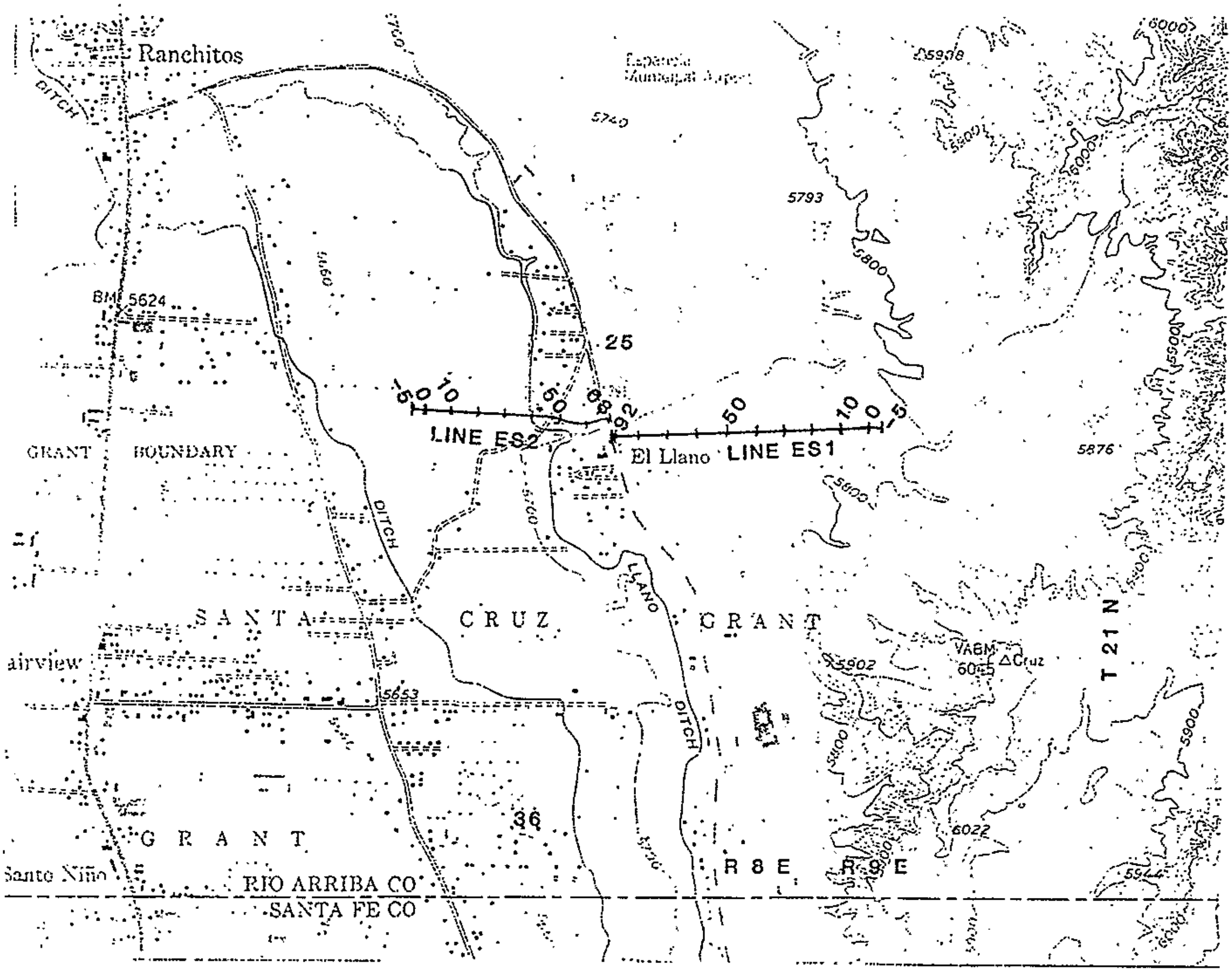


FIGURE 1 Location of Reflection Lines ES1 and ES2, Espanola, New Mexico.

Scale one inch equals 2,000 feet. Topographic elevations in feet above mean sea level

From USGS San Juan Pueblo quadrangle. Contour interval 20 feet.

January 8, 1985 Charles B. Reynolds & Assoc.

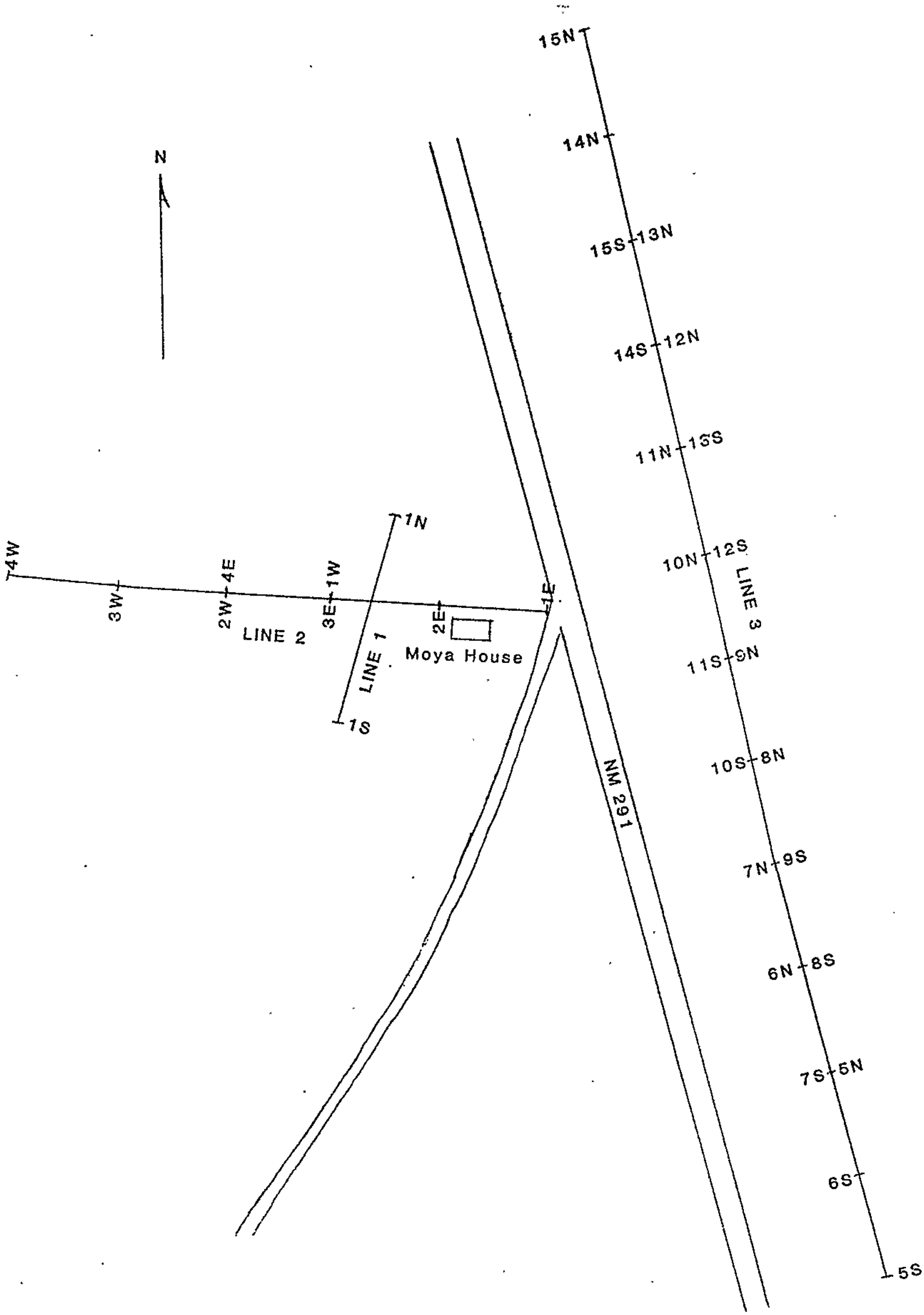
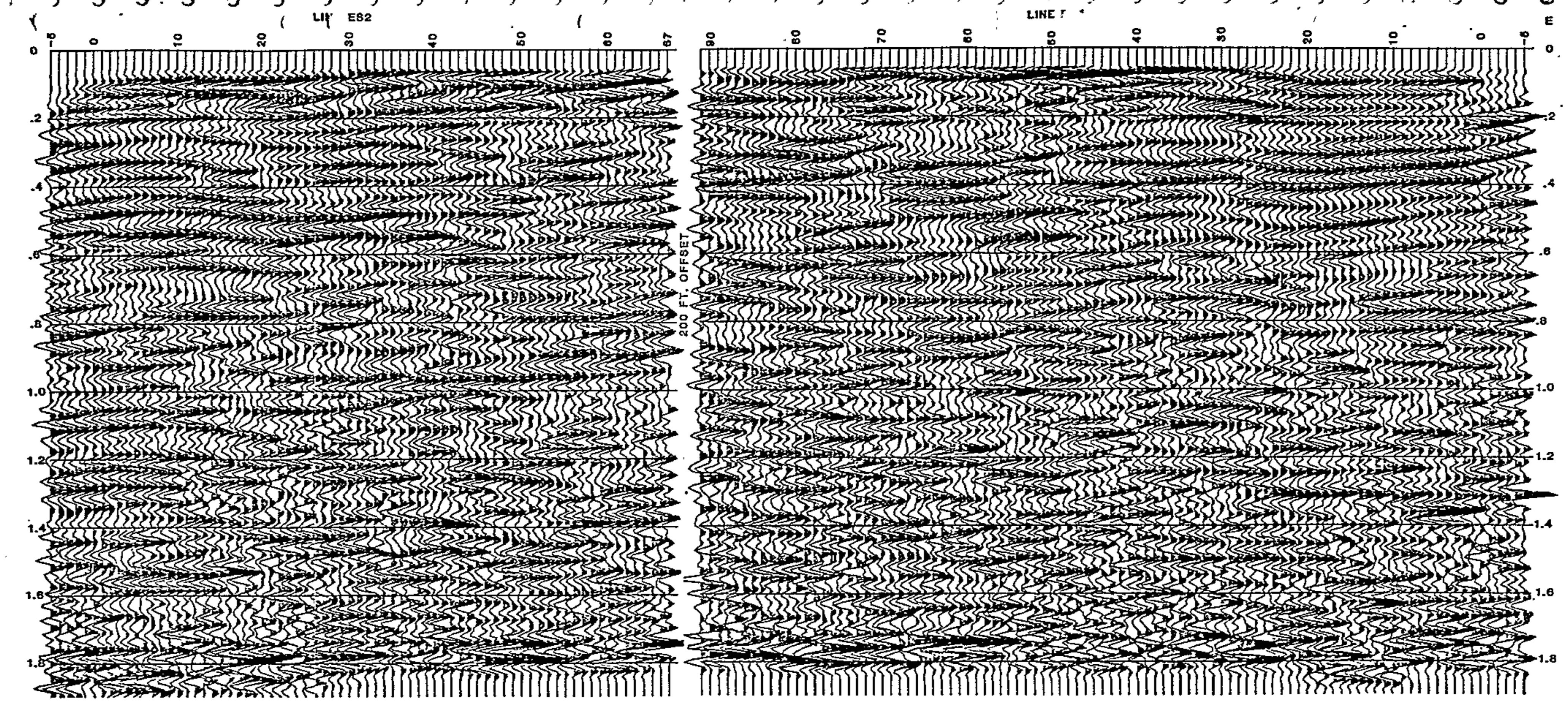


FIGURE 2 Location of Shallow Refraction Lines 1, 2 and 3, Espanola, New Mexico.

Scale one inch equals 200 feet.

January 8, 1985 Charles B. Reynolds & Assoc.



NEW MEXICO BUREAU OF MINES

LINES ES1 AND ES2

ESPANOLA NEW MEXICO

600% FINAL SECTION

FIELD PARAMETERS

RECORDED BY: HS | DATE RECORDED: 12/21/84 | INSTRUMENTS: EG&G ES1210F
GAIN MODE: FIXED | FIELD FILTER: OUT-60 | 60HZ NOTCH FILTER: IN
RECORD LENGTH: 2 SEC | SAMPLE RATE: 2 MS

SPREAD

TYPE: END OVER | CDP FOLD: 6 | NO. GROUPS: 6
DIR. PROGRESS: | NEAR GRP CTR: 66 FT | FAR GRP CTR: 394 FT
SEISES/GRP: 5 @ 13 FT. INLINE | GROUP INTERVAL: 66 FT

ENERGY

SOURCE: 400 LB WT DRP | SP ARRAY: POINT | SP INTERVAL: 33 FT
SP OFFSET: 0 | DROPS/SP: 1

PROCESSING SEQUENCE

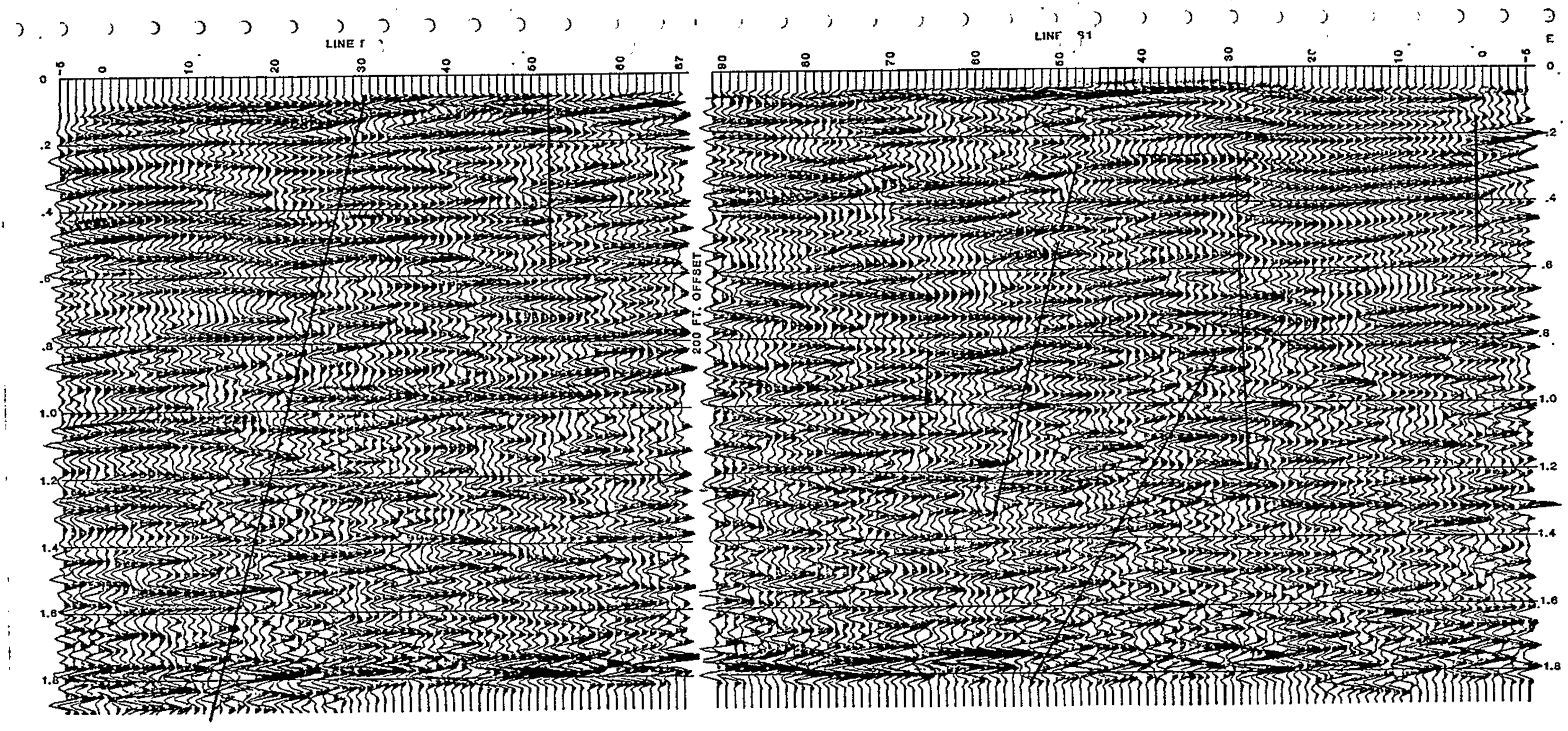
(1) TRANSCR (2) EDIT (3) STKPRP
(4) STK.600% (5) DTMCOR (6) DIPFIL
(7) FILTER 15-30HZ (8) SLOW AGC (9) PLOT VA/WT
(10) (11) (12)

PLOTTER DISPLAY

HORIZ.SCALE: 33 FT/TR | POLARITY: POS. | VERT.SCALE: 3.75 IN/SEC
WX. VEL.: 1500 FT/SEC | DATUM: +5900 | CORRN. VEL.: 5000 FT/SEC

CHARLES B. REYNOLDS & ASSOC., INC.

Enclosure No. I



NEW MEXICO BUREAU OF MINES

LINES ES1 AND ES2
ESPANOLA NEW MEXICO
600% FINAL SECTION

FIELD PARAMETERS

RECORDED BY: HS | DATE RECORDED: 12/21/84 | INSTRUMENTS: EG&G ES1210F
GAIN MODE: FIXED | FIELD FILTER: OUT-60 | 60HZ NOTCH FILTER: IN
RECORD LENGTH: 2 SEC | SAMPLE RATE: 2 MS

SPREAD

TYPE: END OVER | CDP FOLD: 6 | NO. GROUPS: 6
DIR. PROGRESS: | NEAR GRP CTR: 66 FT | FAR GRP CTR: 394 FT
SEISES/GRP: 5 @ 13 FT.INLINE | GROUP INTERVAL: 66 FT

ENERGY

SOURCE: 400 LB WT DRP | SP ARRAY: POINT | SP INTERVAL: 33 FT
SP OFFSET: 0 | DROPS/SP: 1

PROCESSING SEQUENCE

(1) TRANSCR | (2) EDIT | (3) STKPRP
(4) STK 600% | (5) DTMCOR | (6) DIPFIL
(7) FILTER 15-30HZ | (8) SLOW AGC | (9) PLOT VA/WT
(10) | (11) | (12)

PLOTTER DISPLAY

HORIZ.SCALE: 33 FT/TR | POLARITY: POS. | VERT.SCALE: 3.75 IN/SEC
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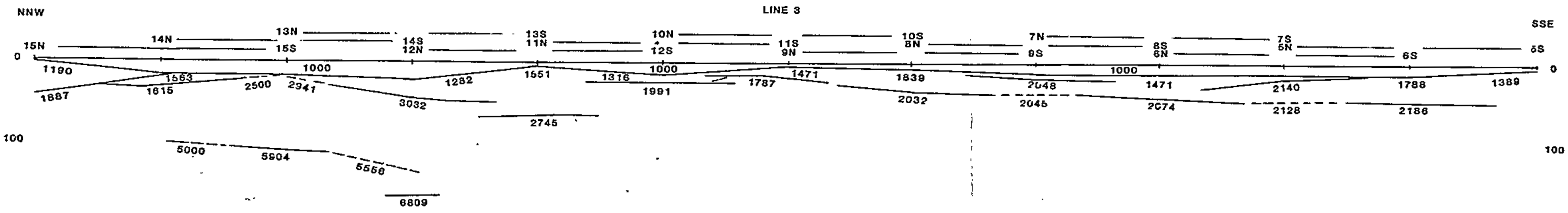
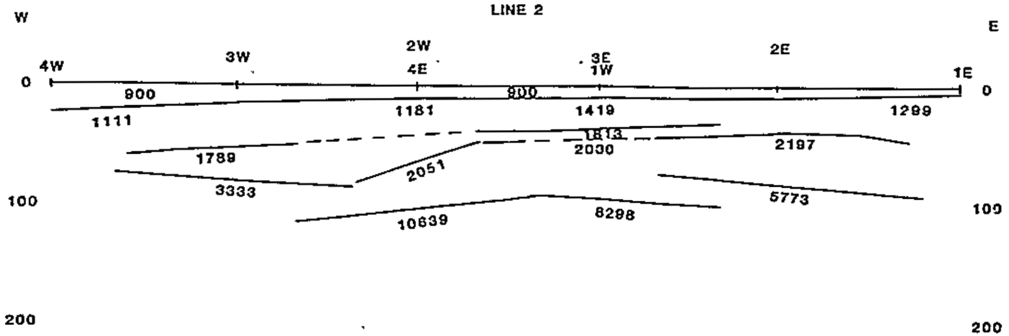
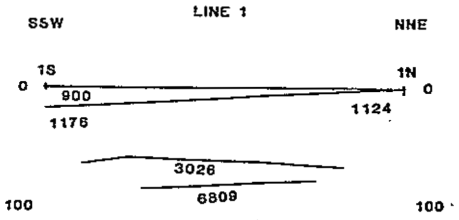
CHARLES B. REYNOLDS & ASSOC., INC.

Enclosure No. 2







NEW MEXICO BUREAU OF MINES

ESPANOLA AREA
ESPANOLA, NEW MEXICO

REFRACTION DEPTH SECTIONS
LINES 1, 2 AND 3

Surface datum
Scale one inch equals 100 feet   Velocities in ft/sec

January 9, 1985   Charles B.Reynolds & Assoc.

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Shallow Seismic Refraction Survey

Espanola, New Mexico

February 12, 1985

Introduction - On January 16, 1985, a second shallow seismic refraction survey was carried out in the northeastern part of Espanola, New Mexico, for the New Mexico Bureau of Mines and Mineral Resources. The survey consisted of two refraction lines, Line 4 (see Figure 1), 1050 ft long, and Line 5 (see Figure 2), 750 ft long. The purpose of the survey was, as with the previous survey (see report dated Jan. 10, 1985), to investigate the shallow subsurface geology of the area as an aid to understanding the causes of surface subsidence problems experienced in the vicinity.

Method - The seismic energy source used is a 400 lb patented "soft" weight dropped a distance of 6-1/2 ft to the ground. The receivers used are Mark Products 8 Hz refraction geophones, with six geophones placed at distances of 50, 100, 150, 200, 250 and 300 ft from the weight drop impact point. The recording instruments are a six-channel E. G. & G. Geometrics Nimbus ES1210F system with frequency filters and field additive (signal enhancement) capability. Analog records were made at each drop position, with a 0.5 second recording period. Recording filters of out-60 Hz and 60 Hz notch filters were used. All refraction profiles were fully reversed, and successive profiles on each line were overlapped 50% (150 ft) to ensure reasonably continuous subsurface coverage.

The resulting recordings were studied, first events were picked and corrected to first arrivals. The several velocity layers indicated were next recognized and their velocities and zero-distance time intercepts determined by computer least squares fitting of inverse velocity lines to the sets of time-distance data pairs. Thicknesses of the successive layers were then calculated by the zero-intercept method. Wavefront reconstructions were made for those refractors (generally the deepest indicated) for which reciprocal times were available. Finally, all the resulting velocity, depth and form information were combined for presentation in visual form as depth sections.

Interpretation - The depth sections for Lines 4 and 5 are shown by Enclosure No. 1.

Line 4 shows three main velocity layers. The shallowest or surface layer has a primary wave velocity of about 1000 ft/sec.

It evidently varies in thickness from about zero to about 28 ft. The next deeper (second) layer appears to have a mean velocity of about 1450 ft/sec, but seems locally to contain thin or discontinuous lenses or streaks of faster material (as fast as about 3300 ft/sec). The thickness of this layer seems to range from about 50 to about 70 ft. The deepest (third layer) evidently has a mean velocity of about 5750 ft/sec. The most striking feature of Line 4 is the presence of unusually shallow higher velocity materials indicated approximately under position 29N/27S.

Line 5 as interpreted also shows three principal velocity layers (Enclosure No. 1). The shallowest or surface layer, again of velocity of about 1000 ft/sec, evidently has a fairly constant thickness of about 14-20 ft in the eastern part of Line 5, but thickens rapidly westward from about position 21E/23W to perhaps as much as 47 ft at the western end of the line. The second (next deeper) layer has an indicated mean velocity of about 2700 ft/sec, much higher than on Line 4. As with Line 4, it appears here also to contain thin or discontinuous lenses or streaks of faster material, perhaps as fast as about 7938 ft/sec (at 21W). The thickness of this second layer on Line 5 appears to vary from about 20 ft to about 50 ft. The third layer, ranging in depth from about 38 ft to about 100 ft, shows an apparent mean velocity of about 6000 ft/sec, but with a wide velocity range, being evidently much slower at shallow depth and much faster at greater depth. In general, the appearance of the western two-thirds of Line 5 suggests a westward-dipping, westward-thickening shallow sedimentary section.

The northeast half of Line 4 and all of Line 5 show velocity distributions which the writer regards as normal for the Rio Grande valley or rift. The indicated shallow high velocity materials under the southwest half of Line 4 are unusual for a valley area.

Conclusions

A. Line 4 shows the common three-layer velocity distribution, consisting of (1) a surface layer of about 1000 ft/sec velocity, (2) a second layer of about 1450 ft/sec velocity and (3) a third layer of about 5750 ft/sec velocity.

B. Line 4 shows, near its southwest end, unusually shallow high velocity material for a valley area.

C. Line 5 also shows the common three layer velocity distribution, though with unusually high velocity (about 2700 ft/sec) in the second layer and with marked westward dip.

Shallow Seismic Refraction Survey
Espanola, New Mexico
February 12, 1985

Recommendation

An effort should be made, using existing drilling and geophysical data, to identify the nature of the shallow high velocity material indicated under the southwest part of Line 4. A further report should be issued following this suggested study. Additional seismic refraction data and further drilling will probably then be required to complete the investigation of this anomalous condition.

Respectfully submitted,

Charles B. Reynolds

Charles B. Reynolds
Registered Geophysicist (Calif.)
Certified Professional Geologist

CBR:mmrd

2 Figures
1 Enclosure

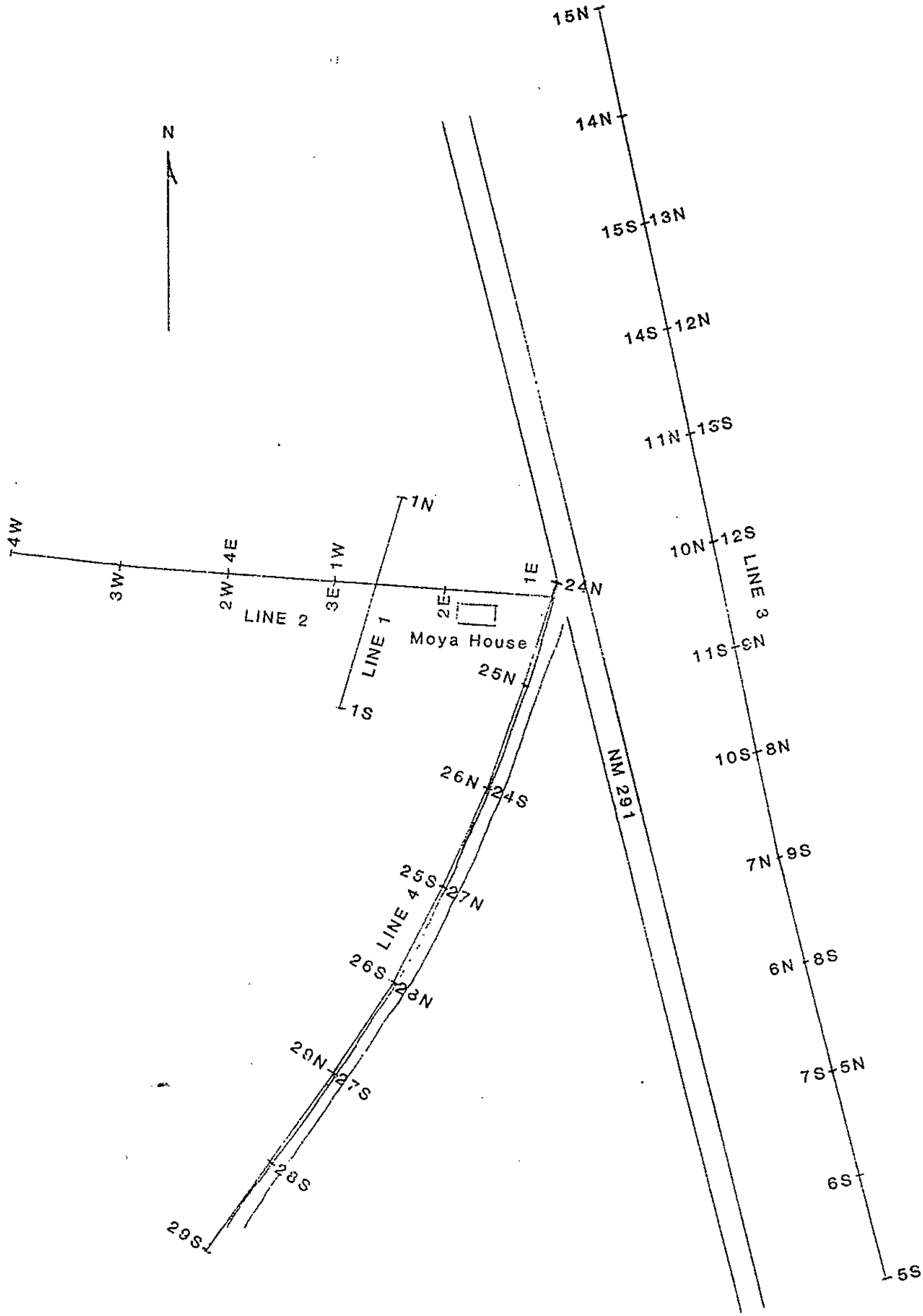


FIGURE 1 Location of Shallow Seismic Refraction Line 4

Espanola, New Mexico

Scale one inch equals 200 feet.

February 7, 1985 Charles B. Reynolds & Assoc.

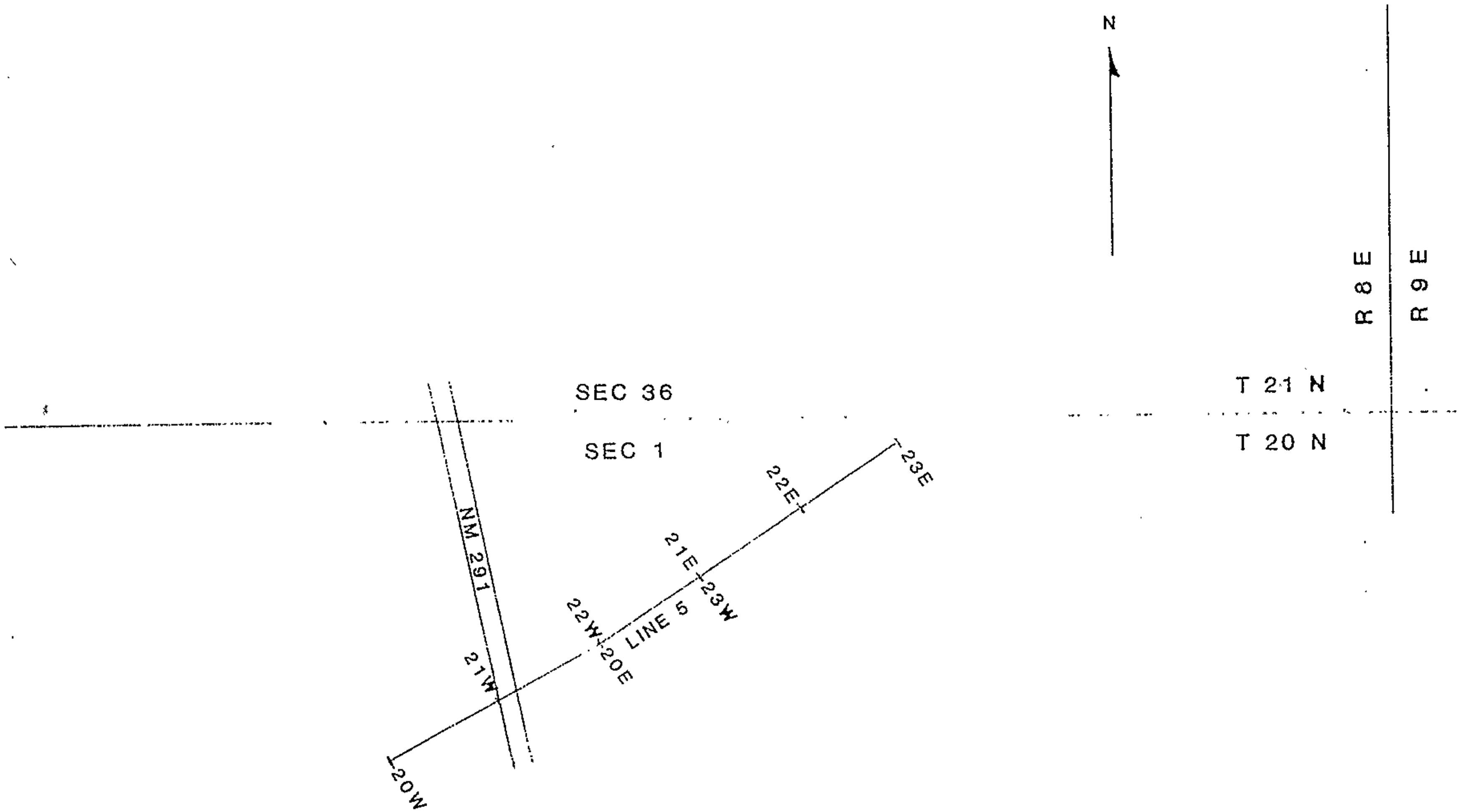
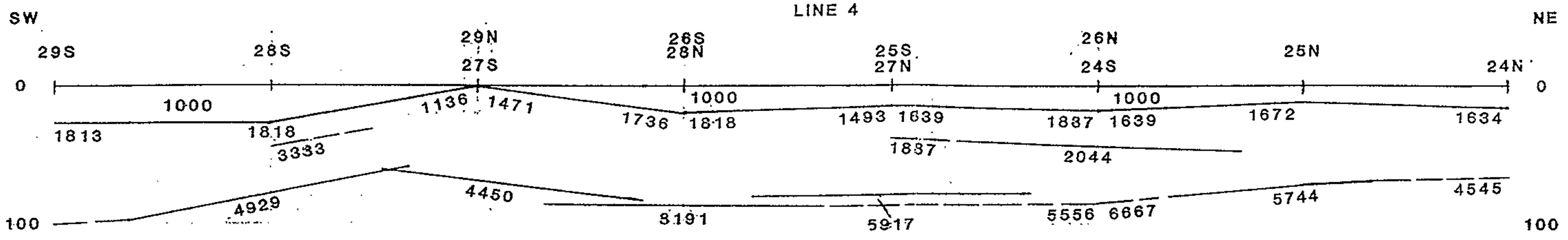


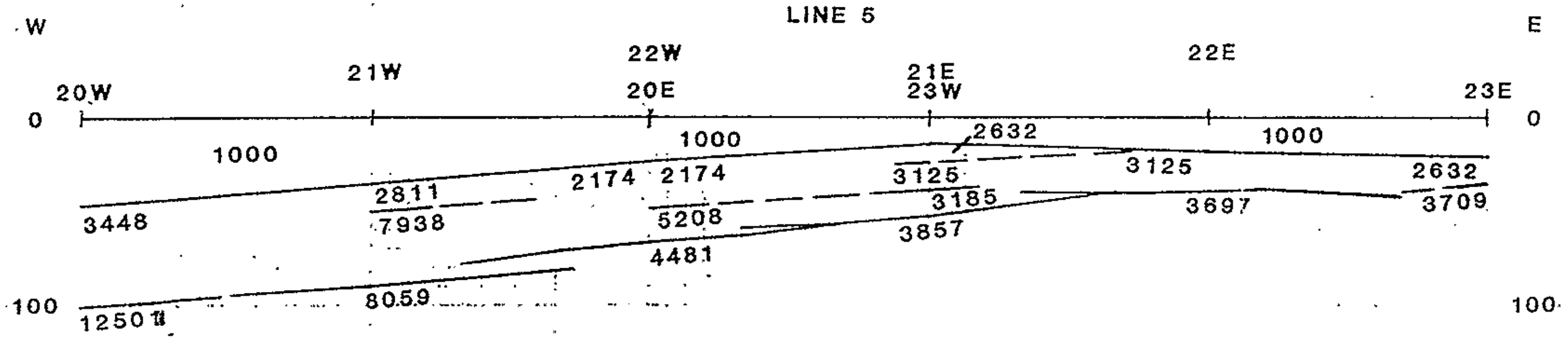
FIGURE 2 Location of Shallow Seismic Refraction Line 5

(Yellington Line, El Llano Project, Espanola, New Mexico)

Scale one inch equals 200 feet

February 7, 1985 Charles B. Reynolds & Assoc.





NEW MEXICO BUREAU OF MINES

ESPANOLA AREA

ESPANOLA, NEW MEXICO

REFRACTION DEPTH SECTIONS

LINES 4 AND 5

Surface Datum

Scale one inch equals 100 feet   Velocities in ft/sec

February 10, 1985   Charles B. Reynolds & Assoc.

Enclosure No. 1

CHARLES B. REYNOLDS AND ASSOCIATES, INC.
Consulting Geophysicists and Geologists
4409 San Andres Avenue NE
Albuquerque, New Mexico 87110
(505) 881-4780

Shallow Seismic Refraction Survey

Espanola, New Mexico

June 11, 1985

Introduction - On May 8-9, 1985, a third shallow seismic refraction survey was carried out in the northeastern part of Espanola, New Mexico, for the New Mexico Bureau of Mines and Mineral Resources. The survey consisted of four refraction lines, Line 7 (see Figure 1), 1350 ft long, and Line 8 (see Figure 2), 600 ft long, Line 9 (450 ft long) and Line 10 (450 ft long). The purpose of the surveys was, as with the previous survey (see report dated Feb. 12, 1985), to investigate the shallow subsurface geology of the area as an aid to understanding the causes of surface subsidence problems experienced in the vicinity.

Method - The seismic energy source used is a 400 lb patented "soft" weight dropped a distance of 6-1/2 ft to the ground. The receivers used are Mark Products 8 Hz refraction geophones, with six geophones placed at distances of 50, 100, 150, 200, 250 and 300 ft from the weight drop impact point. The recording instruments are a six-channel E. G. & G. Geometrics Nimbus ES1210F system with frequency filters and field additive (signal enhancement) capability. Analog records were made at each drop position, with a 0.5 second recording period. Recording filters of out-60 Hz and 60 Hz notch filters were used. All refraction profiles were fully reversed, and successive profiles on each line were overlapped 50% (150 ft) to ensure reasonably continuous subsurface coverage.

The resulting recordings were studied, first events were picked and corrected to first arrivals. The several velocity layers indicated were next recognized and their velocities and zero-distance time intercepts determined by computer least squares fitting of inverse velocity lines to the sets of time-distance data pairs. Thicknesses of the successive layers were then calculated by the zero-intercept method. Wavefront reconstructions were made for those refractors (generally the deepest indicated) for which reciprocal times were available. Finally, all the resulting velocity, depth and form information were combined for presentation in visual form as depth sections.

Interpretation - The depth sections for the four new lines are shown by Enclosure No. 1.

Line 7 shows three main velocity layers. The shallowest or surface layer has a primary wave velocity of about 900 ft/sec. The thickness of this unit varies from about 13 ft to about 29 ft, being thinnest at the east end of the line and apparently thickening abruptly between positions 2E and 3E. The second layer evidently has a mean velocity of about 2,000 ft/sec, though it seems to contain at least one discontinuous faster zone (mean velocity about 3,250 ft/sec). The thickness of the second layer appears to vary from about 100 ft at the east end of the line to as little as about 40 ft at position 5W and perhaps less at the west end of the line. The third or deepest layer varies greatly in measured velocity, from as low as 5,102 ft/sec to as great as 13,351 ft/sec, and a mean velocity of about 7,400 ft/sec. This large velocity range suggests lithologies varying either in type or cementation. Drilling has suggested that this unit may be a set of lag gravels related to a former course of the Rio Grande (Dr. Gary Johnpeer, oral communication, June 6, 1985). The indicated overall westward rise of this layer may be consistent with this concept.

The locations of the three other new refraction lines (Lines 8, 9 and 10) are shown by Figure 2. Line 8 shows a discontinuous low-velocity (800 ft/sec) surface layer which thickens westward where detected. The second layer is apparently of lower velocity (1,700 ft/sec) than at Line 7. The third (deepest) layer, with a mean velocity of about 6,650 ft/sec, appears to show a westward rise as on Line 7. Line 9 shows a westward deepening of the third or deepest layer (about 4,900 ft/sec) below a second layer with a mean velocity of about 1,750 ft/sec and a surface layer of about 800 ft/sec. This line passed close to the north of a wetting-test slab at position 2W. Line 10 shows an abrupt southwesterly deepening of the third layer (about 5,900 ft/sec) from position 2W to position 1W. The top of the second layer was not detected on Line 10 at all, though Line 10 repeated part of earlier Line 5 which did; the reasons for this are not yet clear.

<u>Conclusions</u> - The three surveys carried out at Espanola show that:

A. The surface low-velocity layer (800-1,000 ft/sec) generally thickens westward in the area, though not at a constant rate: there are local rapid changes in thickness and even local thins.

B. The second layer, usually of velocity of about 2,000 ft/sec, appears generally to thicken from the east to about the position of Highway 291 and then thin westward.

C. The third layer, of highly variable velocity but always greater than 3,000 ft/sec, appears to deepen from the east to about Highway 291 and then rise to the west.

D. Local rises or "highs" of the top of the third layer may correspond to shallowing of lag gravels related to an earlier course or courses of the Rio Grande.

E. A combination of seismic, drilling and trenching investigations has revealed no evidence of Holocene fault activity in the area.

Respectfully submitted,

Charles B. Reynolds

Charles B. Reynolds
Registered Geophysicist (Calif.)
Certified Professional Geologist

CBR:mmrd

2 Figures
1 Enclosure

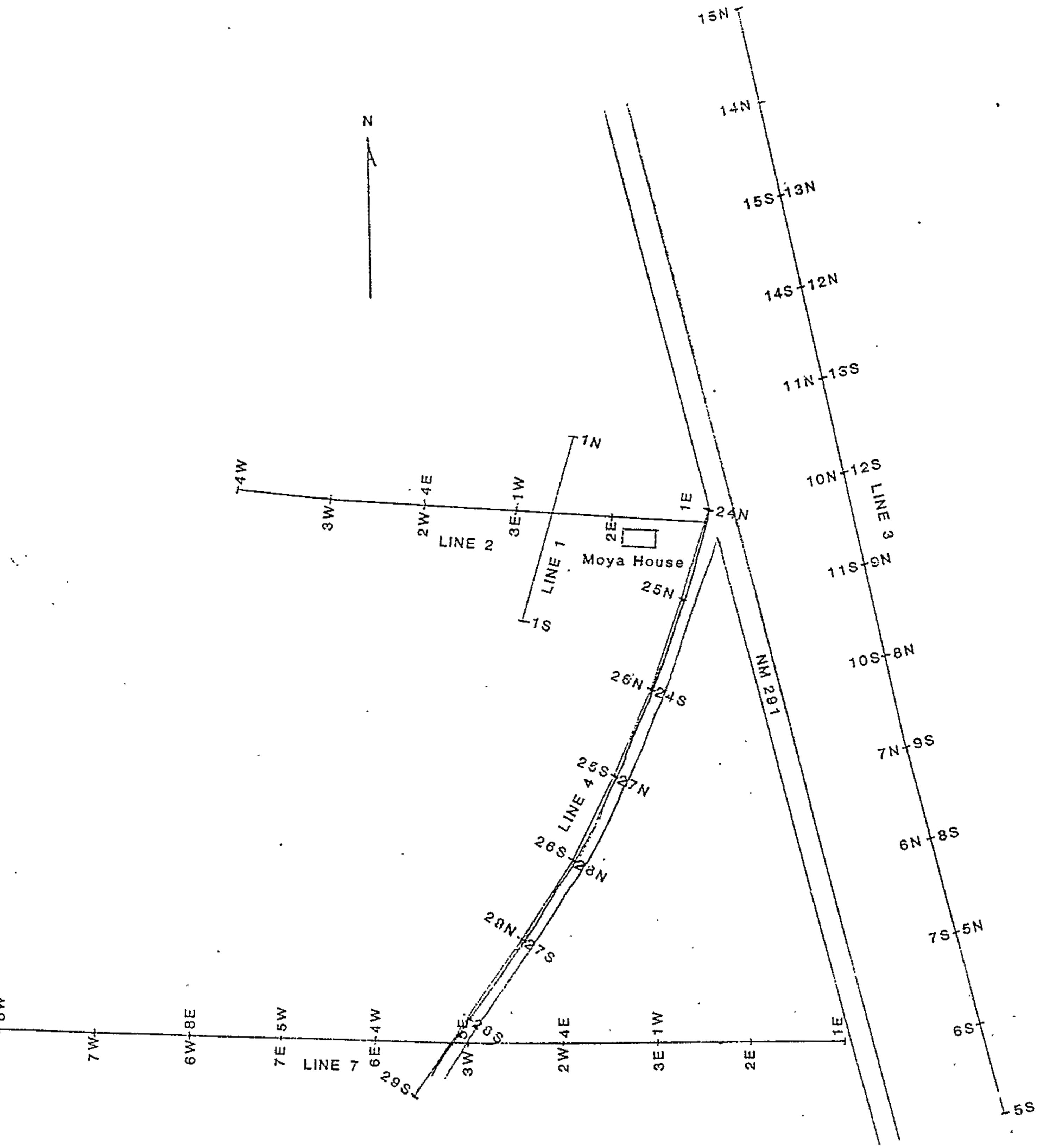


FIGURE 1 Location of refraction line 7.

Espanola, New Mexico

Scale one inch equals 200 feet.

June 1[illegible] 1985 Charles B. Reynolds & Assoc.

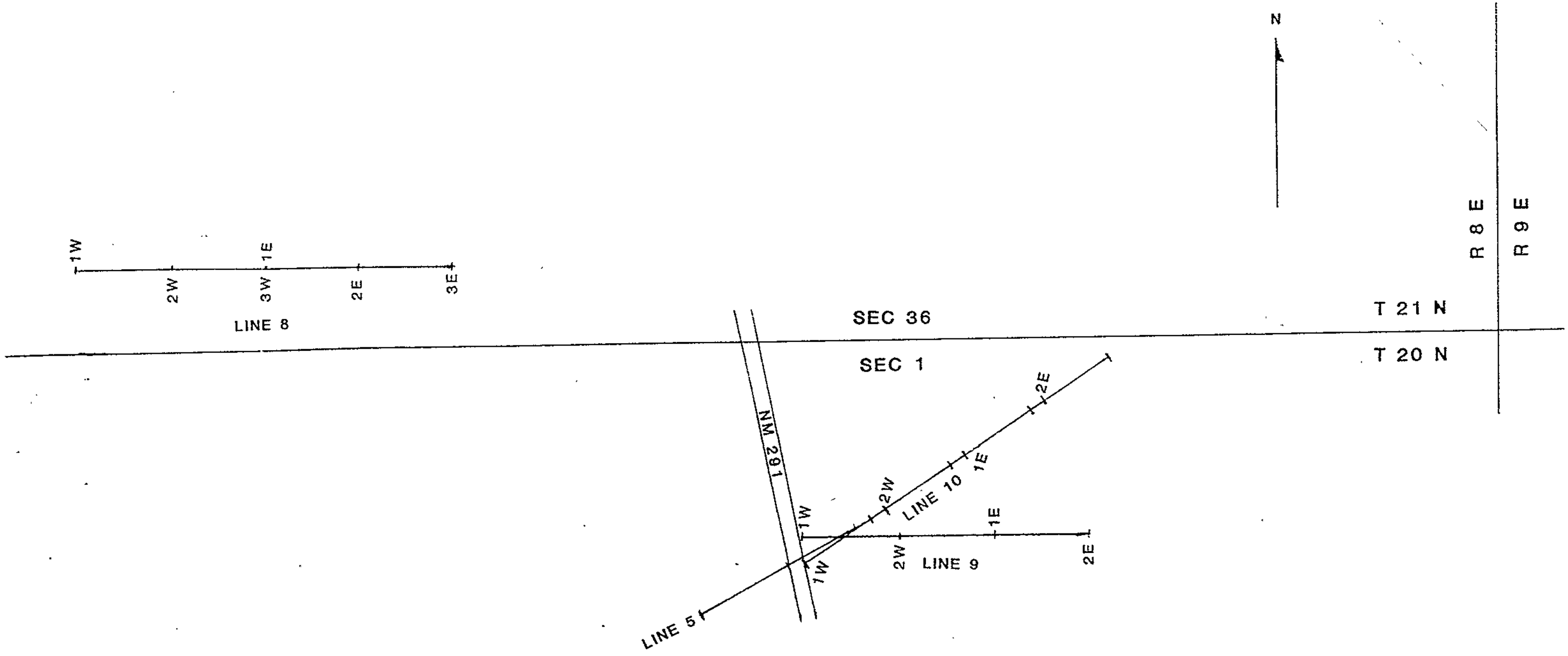
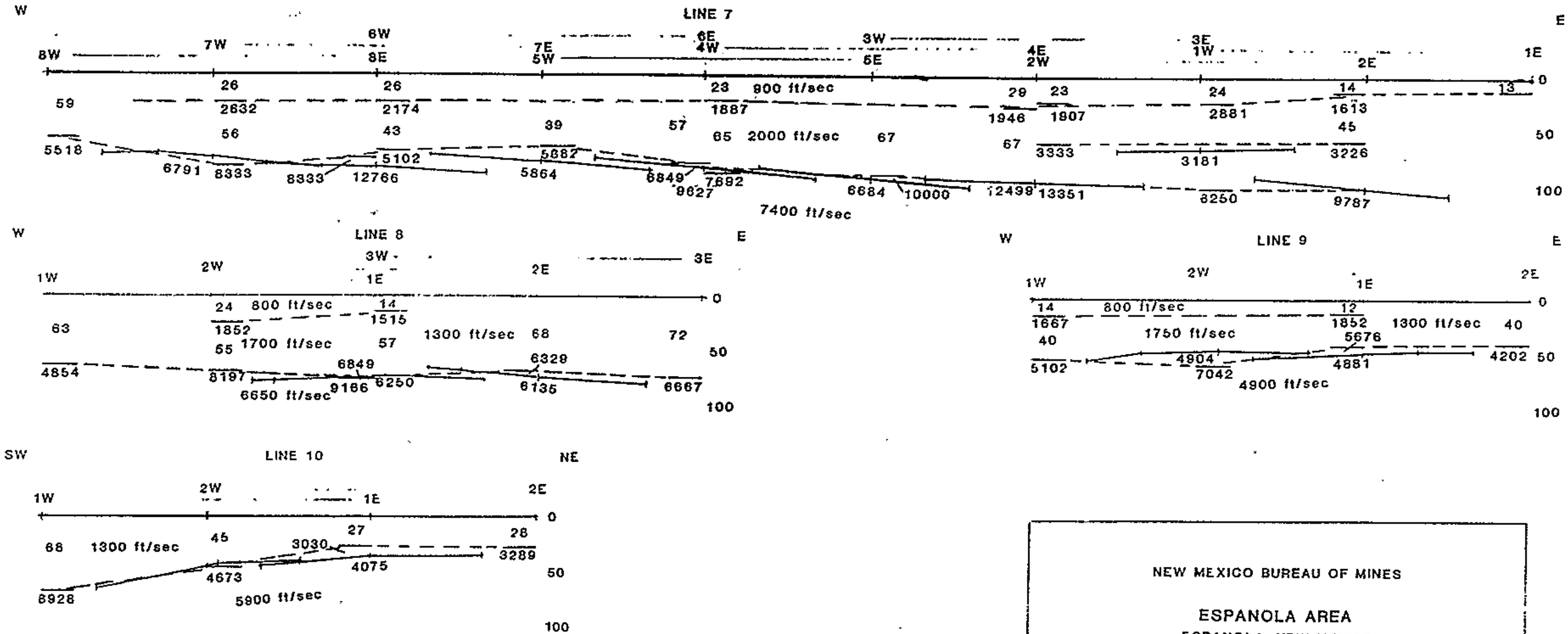


FIGURE 2 Location of refraction lines 8, 9 and 10.

El Llano Project, Espanola, New Mexico.

Scale one inch equals 200 feet

June 11, 1985 Charles B. Reynolds & Assoc.



NEW MEXICO BUREAU OF MINES

ESPANOLA AREA
ESPANOLA, NEW MEXICO

REFRACTION DEPTH SECTIONS
LINES 7, 8, 9 AND 10

Surface Datum
Scale one inch equals 100 feet   Velocities in ft/sec

June 10, 1985   Charles B. Reynolds & Assoc.

APPENDIX VIII

Consulting Reports - R. McNeill

ROBERT L. McNEILL, INC.
3936 GARCIA, N.E.
ALBUQUERQUE, NEW MEXICO 87111
(505) 296-7756

26 January, 1985
File 51RPT1.ENG

Construction Industries Division
Bataan Memorial Building
Santa Fe, New Mexico 87503

Attn: Mr. Fred F. Nevarez
Bureau Chief
General Construction Bureau

Subj: REPORT NO. 1, Preliminary Examination of Nine Condemned Structures, Area of el Llano, Espanola.

Gentlemen:

Please refer to our proposal upon the subject, sent to the New Mexico Bureau of Mines on 30 December 1984 (File 51PRP1.BDV), with copy to your Bureau. We understand that we will report to and be responsible to your Bureau for this structural phase of the effort, but that our contract will be with the Bureau of Mines. We do not presently have such a contract in hand, but we have verbally authorization to proceed, and thus we are proceeding to work in view of emergency and hardship nature of the situation, and hope that you will get the contractual matters worked out soon. We have completed Phases I and II of the work outlined in that proposal, and have in addition met with you and Mr. Murray of the Attorney General's office to review our preliminary findings. It may be appropriate here to point out that Phases I and II were intended only to document the damage, and to inspect the homes to determine if they could be made rehabitable. This letter will formally convey to you the findings of these first two phases. We understand that we are not authorized to proceed to Phase III (accomplishing the actual designs and estimates for the repairs), or to Phase IV (proceeding to assist in letting contracts and getting the work done), until we have been given authorization by your Bureau.

We have been helped greatly in our work by the excellent sketches and records kindly furnished to us by Mr. Ralph R. Leyba of your staff; and also by Mr. Neil Hollander of the staff of the Prison, who acted as photographer upon several occasions.

Considering the excellent records and sketches made by Mr. Leyba, we consider it unecessarily repetitious for us to describe the details of all the homes here. Instead, we will describe only the salient features which control the results of these phases of the study, determining if some or all of the homes can be restored and reoccupied. Such a determination involves Technical, Financial, Political, and Legal considerations. Because we are only competent in the first, Technical, part, please do not construe anything we say or do to be an opinion upon the other three considerations, in which you have your own experts.

Before discussing the specific homes, it might be helpful if we were to discuss certain aspects of the study that apply to all of the homes. First, it is our preliminary opinion that none of the rehabilitation measures we will mention here will necessarily be permanent. That is because a permanent rehabilitation probably involves two quite separate processes: 1, stabilization of the supporting ground; and then 2, stabilization and strengthening of the home. As you are aware from your experience in construction, the first process is not very well understood for collapsing soils, and it is for that reason that the Bureau of Mines, with consultation from Dr. Warren Bennett of the Highway Department and from us, has planned and is putting into action an experiment to determine if feasible methods can be found to stabilize the soils in the el Llano area. If the experiment is successful, and the ground under the homes in the area can be successfully stabilized, then the question of permanently stabilizing the homes can be addressed; and it is our experience that there is a great deal of good knowledge and experience on that subject. Second, if the appropriate authorities decide to proceed with any or all of the suggestions we make herein regarding interim repairs to the homes so that the families may temporarily reoccupy them, there is still the possibility that settlements can start and stop irregularly until if and when the ground is stabilized. For that reason, we feel it mandatory that all utility lines be installed with flexible connections so that they can accomodate to appreciable settlements. We are not experts in utility connections, and we recommend that you consult the local utility companies on those matters.

As a result of our studies, we feel that the homes can be grouped into two categories for the purposes of defining temporary repairs so that the homes could be reoccupied until permanent measures are established. These two categories are:

CATEGORY A: Structures for which we feel the suggested temporary measures would have a high probability of success, and which involve only shimming, jacking, reinforcing, and such, along with cosmetic repairs of cracks, and the monitoring of the possible future movements of those cracks. If it would be agreeable to the residents, we would suggest only a caulking (rather than full cosmetic repairs to the cracks), to be monitored on a regular basis to furnish data upon what is happening to each home/area.

CATEGORY B: Structures for which we feel the suggested temporary measures would have a modest probability of success, but because of our and your lack of knowledge of how the homes have evolved in their expansions, maintenances, and repairs over the years, also has a finite probability that the suggested measures might worsen the present conditions. The measures would involve installing tie rods and/or cables with turnbuckles, including some external reinforcing members to help distribute the resulting loads to what appear to be the stronger parts of the homes.

We will now proceed to discuss each home individually. We will identify each home by a number, 1 through 9, and we will furnish you, in a separate letter, the number identifications of the various homes by what we understand to be the family names. We do this so that our technical opinions herein do not affect the financial, political, or legal positions of the families involved.

CATEGORY A

Structure 1

The stem wall at the SW corner has settled down from the building wall so that it is possible to probe between the two. That corner should be shimmed to transfer the cantilever load from the building wall and floor back onto the stem wall, which presumably is supported at depth by a footing. The cracks inside the house, especially those in the south interior and exterior walls, should be caulked and then monitored for further movement after the SW corner has been shimmed. There appears to be a ponding area on the south side of the concrete-block shop building to the west of the home. It is quite possible that that ponding is causing the ground to collapse, pulling the block building and the home to various degrees into the resulting depression. That depression should be filled with compacted impervious soil, and positive surface drainage should be maintained to carry all waters away from all structures.

Structure 2

The small addition at the rear (west) end of the home is pulling away from the main structure, and could be a hazard if occupied. We therefore suggest that it be sealed off and not used. The fireplace on the south wall of the living room, and extending into the north wall of the adjoining bedroom has a split firebox, and the chimney (which is in the bedroom) is tilting and leaning to the south causing compression failure of the ceiling of the bedroom. The fireplace and chimney should either be braced or removed to prevent their toppling over. The cracks in the home should be caulked and monitored for further movement.

Structure 3

The home is framed with NS floor girders supported on what appear to be surface-founded vertical concrete blocks and other nonfixed supports. The sanitary wastewater appears to empty into a depression a few feet from the NE wall of the home; and the grey wastewater appears to empty into a depression a few feet from the south end of the home. The home apears to be tilting into those two depressions. Thus those wastewater facilities should be inspected, and probably moved to some distance away from the home. The home appears capable of being shored up or moved; but this should be done only if proper foundations are provided in such a way that the home could at some later date be re-leveled.

Structure 4

The garage and breezeway at the NE corner of the house appear to be settling into the northeast, and should be closed off from further use until a permanent dispostion for these homes is determined. The connections between those outliers and the main structure should be cut and properly braced so as to avoid any further secondary damage to either home, and the resulting joints should be caulked and monitored. The EW crack at about the center of the main structure should be caulked and monitored. The new solarium addition on the SW corner of the main home appears to be settling into the southwest, and should not be occupied, but is probably a worthwhile risk on a pass-through-only basis. The retaining wall on the west side of the yard is tilting over to the west, and the low (west) side is a depression which ponds water. That depression should be filled, and positive drainage should be provided away from the home in all directions. There seems to be a depression, apparently off the property, to the NE of the distressed area of the garage and breezeway; and the plants over that area seem to be more healthy than other plants in the area. Because we were only asked to look at the subject homes, we have done no further study of that apparent depression; but we feel that should be done.

Structure 5

The home has a wood floor with a crawl space. It appears that there has been a leak in a wastewater line under the floor at the west end of the home. The ground there has dropped, apparently necessitating the removal of the original concrete-block entrance stairs, causing arcuate ground cracks which appear to center upon that sewer leak under the house. The interior footings appear to be vertical surface-founded concrete blocks, and several have failed apparently due to the settlement of the west end. There is a black plastic pipe running under the floor and exiting near the SW corner of the home. That corner appears to be experiencing more distress than the remainder of the west wall, all of which is experiencing appreciable distress. A few tens of feet to the west of the home, and on the west side of a partially completed garage, there is an open pit. That pit should be filled with impervious compacted soil, and positive surface drainage should be provided away from the entire structure. Someone has cast a number of massive concrete foundations of unknown depth and character under the west end of the home. As a temporary measure, these might be beneficial as jacking blocks to hold or perhaps even raise the settling west end. The block stem wall at the SW corner, near which the black plastic pipe exits the home, should be removed and replaced. Before these things are done, however, the connections of the floor girders to the interior piers should be assessed, because it appears that a number of them might have to be replaced also, even for these temporary repairs, by proper footings, properly tied to the structural members, and at the proper depths.

CATEGORY B

Structure 6

This is an old adobe structure, with the walls bulging out at the tops on the west and north sides. It has wood floors of unknown support and crawl space, and shows evidence of historic cracking and patching. It appears to be settling to the southwest. It appears that all interior walls are load bearing, and there are sills at all doors. It has a new, corrugated pitched roof, but the interior ceilings, and therefore presumably the original roof, are supported by vigas, which can be seen protruding on the outside of the home. We feel that there is a reasonable chance of stabilizing the home for the time being by bolting it together at the ceiling level and under the wood floor by tie rods passing in both directions. This would require installing a false lower ceiling to hide the tie rods, and, depending upon the crawl space under the wood floor, might require the installation of a new, higher, floor, if the crawl space is not adequate for the installation of the tie rods. The installation of the higher floor would probably not be difficult because of the height of the door sills. The tie rods would have to be supported outside to distribute the loads across the walls, probably by timbers or steel members. Certain of the tie rods would have to be strain-gaged in order that the loads could be monitored with time.

Structure 7

This home appears to have been added to several times, and is settling mostly to the west, where there is a large depression in the ground with concentric scarplets which intrude into the structure. The temporary treatment in this case would be similar to Structure 6, probably with the same uncertainties.

Structure 8

The temporary treatment in this case would be similar to Structures 6 and 7.

Structure 9

This home appears to be settling to the southeast and east, with a tension component more to the east. It is adobe, with a concrete floor. There was a garage on the SE side, but that has been converted to bedrooms. The ceilings are low, so that the installation of top-and-bottom tie rods would probably leave inadequate headroom. The structure could possibly be stabilized by wrapping it top and bottom with turnbuckled cables, after strengthening the openings and cutouts by bracing or other means. The cables would have to be supported outside to distribute the loads across the walls, probably by timbers or steel members. All of the cables would have to be strain-gaged in order that the loads could be monitored with time.

We will be happy to meet with you, your staff, and the community to explain these opinions and findings, and to explain any of the details and uncertainties upon which these opinions are based. If members of the community have verifiable better information, we would be most grateful to have it before continuing to Phases III and IV, should you authorize that work. We feel that much of the reconstruction work we have outlined here could be done by the available neighborhood work force; but we also feel that it would be advisable to select a local Prime Contractor or Contractors to coordinate and be responsible for the end results of the ground stablilization and structural repairs. Neighborhood knowledge of the ages, conditions, qualities, and past performances of the structures is very important, along with the construction observation we have recommended in our proposal.

It is our present understanding that you have scheduled a Public Meeting at the Espanola City Hall for 0930 on February 4, 1985. If it would be helpful to the situation, we will be happy to attend that meeting. Please inform us if that would be a desirable thing to do. For technical reasons, we suggest strongly that it would be definitely be appropriate to invite all of the involved geo-scientists from the New Mexico Bureau of Mines and the New Mexico State Highway Department to attend and to participate in the discussions. You may have in mind inviting the Governor's representitaves, the local Peoples' representatives, and other interested parties. I and Mr. Holt will assume that the interested parties will have read this report, so that we will plan to make no formal presentation. We will, of course, be prepared to answer any technical questions which you, the Assistant Attorney General, and local political leaders deem appropriate for us to answer. We will not, however, be able to answer financial, political, or legal questions, which are not within our area of expertise.

While we appreciate and understand that the residents desire direct and final solutions to the situation, and while we would very much like to provide those solutions now, we feel that it could be misleading to say that we understand the situation well enough to give firm recommendations at this time.

This is the end of our REPORT NO. 1, covering Phases I and II of our proposal, and the consultations we have had with you, Dr. Bennnet, and Mr. Murray, Esq. We await your further authorization as to how to proceed.

Very truly yours,

RANDY HOLT & ASSOC., Inc.

By Randolph E. Holt
Randolph E. Holt
Consulting Engineer

ROBERT L. McNEILL, Inc.

By R L McNeill
Robert L.McNeill
Consulting Engineer

cc: New Mexico Bureau of Mines
New Mexico State Highway Department

ROBERT L. McNEILL, INC.
3936 GARCIA, N.E.
ALBUQUERQUE, NEW MEXICO 87111
(505) 296-7756

30 December, 1984
Assignment 49ESPS

New Mexico Bureau of Mines and Mineral Resources
New Mexico Institute of Mining and Technology
Socorro, New Mexico 87801

Attn: Dr. G. D. Johnpeer
Engineering Geologist

Subj: REPORT NO. 1, Study of Settlements, Espanola

Gentlemen:

I have at your request visited the sites of severe settlements which you have pointed out to me in Espanola, have inspected several of the structures in the area, have observed the boring of the first hole, and have inspected some of the soil samples recovered from that boring along with the field-test data obtained during the sampling process. That bore hole was located southwest of the Moya residence, near the center of a bowl-shaped depression about 3 to 4 ft deep. It was reported to me that a water main broke at about the location of the center of the depression at about the same time that the depression was detected, although the chronology varies slightly from teller to teller. I do not presently think that the latter point is of essential engineering significance, so I will not give it further attention at this time, but expect to give it attention later on.

The subsurface soils revealed by the first boring are silty sands to sandy silts, with occasional clay partings or lenses, and they are extremely wet, compared to what I would expect based upon my experience in the area, to depths of about 55 to 60 ft. They are Loose to Very Loose to depths of about 60 to 65 ft. Based upon these data, it is my preliminary opinion that the upper soils, from the surface to perhaps depths of 60 to 65 ft in this area, are subject to hydrocompaction, and in the depth range of 55 to 60 ft have settled due to a (possibly very slow) leak in the water main. If that leak is fixed, then it seems reasonable at this time to adopt the preliminary working hypothesis that the depression is essentially localized, will probably expand only slightly downward (because there appear to be only a few feet of hydrocompactive soils beneath the plume of high moisture content), and will probably expand only slightly areally (because the present moisture will tend to plume down, the lateral migration being due only to capillary suction). Based upon that working hypothesis, and of course subject to close review as further data are obtained, I agree with and endorse your plan to implement a short-term program of step-out borings designed to determine if there are other adjacent areas of similarly over-wetted soils, or if the situation is confined, at least in the extreme, to this one area. I also agree with and endorse the use of auger borings and the disturbed sampling using the Standard Penetration sampler in this short-term program because it is quick, simple, and cheap; but I would also recommend that you do moisture-content tests upon all of the recovered samples, and gradation tests upon many or most of them. You and I have set the locations for six of those step-out borings in those areas which we can identify as candidates for possible wetting; and we have agreed to modify those locations, and/or the notion of a step-out program, and/or the working hypothesis, and/or any other aspect of the program as the data emerge. In order to implement the flexibility to modify, I have recommended that you proceed to authorize the ordering of the special sample tubes required for double-concentric barrel sampling, in case those might be required should this working hypothesis be wrong, and if the situation is not localized. Because the water lines could be a major culprit in this situation, both now and in the future, I further recommend that: (1) all water mains, laterals, and any other lines which may be attached to the pressurized system be pressure-tested for leaks; (2) the lines be inspected, probably by cutting out sections, corrosion and/or other forms of physical degradation which could lead to future leaks.

As noted above, I have inspected several of the adjacent structures, noting their type and sequence of construction, and their general condition including cracks and patches. Many, perhaps most, of the structures appear to have been owner-constructed, and in many cases appear to have been constructed in stages which may have spanned decades. All of the structures which I have inspected thus far have had cracks, and have evidence that many of the cracks appear to have been patched several times over long periods of time (probably many years). Thus it is not necessary to postulate a recent areal settlement phenomenon to explain much of the structural distress. On the other hand, it would not be advisable to reject that point of view at this time and based upon the data presently available, because some of the cracks I observed appear to be rather new (months, or a few years). This preliminary opinion reinforces your decision, based upon my recommendation, to go ahead with the step-out boring program to try to scope the subsoil situation.

Several of the residences have been evacuated (condemned?), based upon decisions taken upon the initial realization of the situation; and my experience with similar situations indicates that that was probably the prudent thing to do in view of the uncertainties at that time. My experience and training in structural engineering lead me to sense that several of the structures could probably be re-occupied with a small risk, but I would feel more comfortable in that sense if we had the advice of a structural expert who could share the new knowledge we have gained, and who could help you to reach a decision on this matter. We have discussed and agreed upon the necessity of an orderly structure-monitoring program, and the help of a structures expert would be very beneficial in that regard. I really do not know if the State Agency who made the initial decisions to evacuate has such On-Staff experts. I would certainly be willing to meet with them to discuss the soil/structure interaction effects of the data to date, and the data to be revealed by the future work. If that Agency does not have such experts, I would be happy to mention the Structural Engineer with whom I have done considerable work in similar situations.

You kindly showed me your first report on the matter, and I would like to endorse one of your comments, regarding the possibility that totally satisfactory repair and rehabilation may not be practical with the present structures. They appear to be founded upon the near-surface soil upon laid-rock or concrete-block foundations, which are sometimes continuous and sometimes discontinuous, and the walls appear to be either adobe or concrete block. The floors appear to be unconnected to the walls, the walls appear to have dubious connections to the footings, and often the drainage around and towards the structures appears to be non-positive away from the structure. In the one case where we have a clear excavation around a wall foundation, there appears to be no foundation: the block wall was resting upon the ground at a depth of about 6 in. I suspect that the restoration of these structures to modern-construction conditions might not be less than a BRAB-type slab, which could be relevelled with time if there occurs more settlement, and then the construction of a light superstructure (which does not seem to be normal to the general construction in the neighborhood) with bracing to assist the rigid slab in resisting the settlements which might take place over the next decades or centuries due to leaking water pipes, and possibly other utilities which might be introduced into the area or upslope.

Very truly yours,
ROBERT L. McNEILL, Inc.

By ______________
Robert L. McNeill

cc:Dr. W. T. Bennett, NMSHD
Mr. F. F. Nevarez, CID

ROBERT L. McNEILL, INC.
3936 GARCIA, N.E.
ALBUQUERQUE, NEW MEXICO 87111
(505) 296-7756

30 December, 1984
Assignment 49ESPS

New Mexico Bureau of Mines
Socorro, New Mexico 87801

Attn: Dr. G. D. Johnpeer
Engineering Geologist

Subj: REPORT NO. 2, Companion Testing of Shelby-Tube Samples, Espanola

Gentlemen:

At a meeting on 28 December, 1984, attended by Drs. W. T. Bennett, G. D. Johnpeer, and R. L. McNeill, the notion was put forth of the NMSHD doing some companion testing of the same samples which will be tested by the Fox laboratory. I feel such testing would be most meaningful if every care is taken to assure that the companion tests are performed upon the samples of the same soil. That is best done by the following steps, which I recommend be made the rule for the companion-testing effort:

1. The tubes should be cut transverse to the long axis, the cut end should be clearly designated, and the tests to be considered as companion tests should be performed only upon the aliquot directly adjacent to the cut end.

2. The remains of all companion samples should be sent by both laboratories to one of the laboratories, where gradation tests should be performed in a uniform way to assure that the aliquots were indeed the same, at least in gradation.

I have discussed the matter with Mr. Vineyard at Fox, who has indicated complete willingness to participate in such a companion program, and also to do all of his tests according to the present NMSHD procedures for the sake of uniformity. I endorse that position, and therefore make the following suggestions:

A. Before any testing is done by anyone, NMSHD and Fox should make sure that their procedures are the same.

B. Before the main Fox testing program begins, some companion testing for key elements (e. g., density, water content, modified consolidation, etc.) should be done to make sure that the procedures are yielding consistent results in both laboratories.

I have had considerable (hands-on) experience in laboratory testing, and would be most happy to help with the early coordination of these two efforts and the companion-testing program, if that would be of help to the project.

Very truly yours,
ROBERT. L. McNEILL, Inc.

By ____________________
Robert L. McNeill

cc: Dr. W. T. Bennett, NMSHD
Mr. Martin Vineyard, Fox

ROBERT L. McNEILL, INC.
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ALBUQUERQUE, NEW MEXICO 87111
(505) 296-7756

05 January, 1985
Assignment No. 49ESPS

New Mexico Bureau of Mines
Socorro, New Mexico 87801

Attn: Dr. G. D. Johnpeer
Engineering Geologist

Subj: REPORT NO. 3, Hydrocompaction Experiment, Espanola

Gentlemen:

This report is to present to you my thoughts on a controlled experiment in hydrocompaction at the subject site. These thoughts flow from the meeting with you and Dr. Bennett on 28 December 1984. At that meeting, it was agreed that I would assemble this letter as background for a near-future meeting to finalize the initial parts of the experiment so that we can get moving. In that spirit, I am sending a copy directly to Warren Bennett. My thinking is conditioned by what I perceive to be the purpose of such an experiment, and which I here state:

PURPOSE OF HYDROCOMPACTION EXPERIMENT

Determine if it is feasible to permanently rehabilitate damaged structures in the subject area by settling the supporting soils by hydrocompaction, then repairing the structures.

Most of the structures have walls of unreinforced masonry (most are adobe bricks), have floors of wood or unreinforced concrete (sometimes combined) , were owner-constructed, have utilities, and old patched cracks, indicating that some settlement has already taken place. I would see the repair sequence as follows:

-Possibly take some preventative measures to mitigate the additional damage which will occur during the hydrocompaction-induced settlements. Such might include bracing across openings, and strapping or cabling around the structure to give some prestress tensile capability.

-Perform the hydrocompaction.

-Measure settlements and behavior of the structure throughout the hydrocompaction process, and for a period of time after the process.

-After the appropriate waiting period, repair the structure.

I will address only the hydrocompaction part of the scenario above, and will use the abbreviation HC for hydrocompaction, when used either as a verb or a noun.

If the process is to succeed, the final ground supporting the structure will have to be level, given types of structures involved. That requirement appears to be contradictory to our knowledge of the results of HC, which are usually quite inhomogeneous and uneven. It may be possible to achieve the necessary results, however, if three key conditions are met:

1. The soils are homogeneous. This condition is definitely not met by the soils of el Llano, but those soils may be adequately similar in the rather small area of a structure to receive HC treatment (say, 150 ft square in plan, and 60 ft deep) that the desired behavior may be attained.

2. The surfaces at depth which are not susceptible to HC are reasonably smooth and flat. This would be determined ahead of any decision to HC because a smooth, tilted surface or an undulating surface would probably be a fatal flaw.

3. The water is introduced uniformly.

The first two points are existing conditions, but the last one can be controlled to some extent in the field. It is to that point that I feel a major part of the experimental effort should be directed, as I will now discuss.

The water could be introduced into the ground in two general ways, by surface wetting (flooding or sprinkling), and/or by drywells (holes, usually filled with sand or gravel, and in this case kept filled with water). In either case, it is desireable to confine the subsurface plume of wetting to the extent reasonable in order that there is a reasonable chance of confining the HC settlements to the desired location. Probably the only way to confine the plume is to limit the amount of water introduced to only that necessary, and that likely means designing the program to be accomplished as quickly as possible. It would be desirable for the technique to be all-weather. In all cases, all waters introduced into the ground should be carefully and documentably metered, taking appropriate account for evaporation and other pertinent effects.

<u>Surface Wetting</u>

This method has the advantage of being cheap and easy to do, but might be affected by freezing. Data from the literature show that the method takes longer than using dry wells, but clearly that would depend upon the soil profile and the spacing of the wells. Depending upon the site profile, the subsurface wetting due to surface wetting is sometimes quite nonuniform, in that the plume of wetting appears to be mainly controlled by tendencies for lateral flow at the interface of layers of higher permeability over layers of relatively lower permeability. The desired downward flow is impeded until the water gets through the layer of lower permeability. If that layer were a few inches of fat clay, the process could take years, and in the meantime water would be flowing laterally possibly to cause mischief at other locations. Unless the water were ponded inside the structure in some way, or unless the soils had considerable capillary suction to pull the water horzontally and uniformly under the structure, surface wetting could in some cases worsen rather the correct the situation.

Dry Wells

This method has the advantage that essentially the entire volume is shocked with the water as uniformly as is reasonable, and the HC process occurs rather quickly, thus limiting the amount of water introduced into the ground. This technique also has the advantage that it can be done in winter with little chance of freezing, provided the surface facilities are adequately protected, and that holes can be located inside the house thus enhancing the uniformity of the wetting A key question is the required spacing of the holes, because the number of holes increases as the square of the spacing. The other advantages, compared to the surface-wetting method, are obvious. The disadvantage is the extra cost, especially if holes are to be drilled inside the structure. Apropos of the latter point, I think that slant borings could be arranged so as to limit or even eliminate the need for in-structure borings in many cases. I also suspect that the costs of borings are going to be second-order compared to the other costs of the rehabilitations of these structures.

Based upon the above considerations, I preliminarily see the goals of an HC experimental program to be:

1. Will the resulting surface after HC be reasonably level in this area or parts of it?

2. Will surface-wetting methods be adequately effective in this area, compared to the dry-well method?

3. If the dry-well method is superior, what hole spacings are required?

Having stated the goals in the form of questions in their logical order, let me now approach them from the bottom up, because the answer to 3. will define the work for 2., which answer will define the work for 1. The area for the experiment should be thoroughly investigated to assure the that the old subsurfaces are smooth and flat, and that there are no gross detectable anomolies in the soil profile. It would be nice if the area included a dedicated structure; but if that were not available, a dummy structure could easily be constructed by pouring a concrete slab and weighting it. In fact, the goals of the experiment could be accomplished even if no structure of any kind were present.

3. Dry-Well Hole Spacings

Drill a dry-well hole to a depth which is at least 10 ft into non-HC-susceptible materials. Drill a Sondex hole 3 ft away from the dry well. Fill the dry well with water, and keep it filled for the entire experiment. At selected time intervals, drill exploratory (SPT) holes for blow count and water content radially out from the dry well, the object being in each case to define the extent and shape of the wetted plume as a function of time. Monitor the Sondex hole and the surface levels so that the settling layers* and the surface bowl of settlement can be accurately mapped as a function of time. Continue until the settlements, on a semi-logarithmic basis, have essentially ceased.

Based upon the above, design and carry out a similar experiment, but with five or more dry wells, of adequate areal coverage to provide a hint to question 1. of the goals.

2. Surface Wetting

This must be carried out in an area similar to and adjacent to the dry-well experiments, but not close enough so that the experiments interfere. This would probably be carried out simultaneously with the dry-well experiments. I do not recommend sprinkling, but instead recommend diking and flooding. The area should approach the area of an actual case (e. g., 150x150 ft), and several Sondex holes should be installed, both inside and outside the flooded area. At selected time intervals, drill exploratory (SPT) holes for blow count and water content inside the flooded area (taking care the these holes do not ruin the experiment) and radially out from the flooded area, the object being in each case to define the extent and the shape of the wetted plume as a function of time. Monitor the Sondex holes and the surface levels so that the settling layers and the surface bowl of settlement can be accurately mapped as a function of time. Continue until the settlements, on a semi-logarithmic basis, have essentially ceased.

The results of this part of the experiment will possibly answer goal 1. If they do not provide that answer in an unambiguous way (which I expect they will not), then do a full-scale extension of 3. above, to assess if the resulting ground surface will be adequately level.

As we have agreed, this is written as a discussion paper, and I will look forward to those discussions. I believe that, with this as a backbone, we should be able to establish the plan to get started with just one more meeting between you, Warren Bennett, and me.

Very truly yours,
ROBERT L. McNEILL, Inc.

By ______________
Robert L. McNeill

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24 June, 1985
File 51RPT3.ENG

New Mexico Bureau of Mines
Socorro, New Mexico 87801

Attn: Mr. G. D. Johnpeer
Engineering Geologist

Subj: REPORT NO. 3, Full-scale experiments with hydrocompaction, Espanola.

Gentlemen:

You have completed, with my and Mr. Holt's consultation, two fundamental field experiments involving hydrocompaction. The two experiments were: (1) determine if it would be feasible to hydrocompact soils by shocking them by the injection of water, and to determine if the resulting settled area would be flat-bottomed; and (2) based upon the results of (1), determine if slabs, loaded to simulate the effects of a small structure (e. g., police station, fire house, substation, pumping facility), could be made to settle essentially level, and if they could be raised to be level if required. Experiment (2) involved two slabs, one constructed according to the conventional design and construction techniques prevailing in New Mexico (and, in fact, most of the Southwest), and the other according to the recommendations of the Building Research Advisory Board of the federal government. The second (BRAB) slab is provided with interior footings in a waffle-like configuration, and is reinforced somewhat more than a conventional slab.

Your work has showed that it is possible to bring the surface down essentially level to a diameter of about 10 ft (for the site selected); and, if the water-injection holes are located at about 10-ft centers (for the site selected), slabs can be brought down essentially level. You have further demonstrated that the conventional slab is frangible and probably could not be re-leveled if differential settlement occurred; but that the BRAB slab could easily be re-leveled by the relatively routine practice of mud-jacking.

Your work has, in my opinion, gone as far as it could could given the limitations on time and funding; but it has identified possible practical options that are so important that they must be pursued. These would include: (1) is it possible to bring the ground down level by shock hydrocompaction at other sites; and (2) is it possible to bring down existing structures of various constructions and ages, particularly those which may be infrastucture.

It has been a pleasure to work with your Staff on this project, and we hope that our efforts have been of some benefit to the Governments and Citizens of New Mexico.

Very truly yours,

ROBERT L. McNEILL, Inc.

By______________________
Robert L. McNeill

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24 June, 1985
Assignment No. 49ESPS

New Mexico Bureau of Mines
Socorro, New Mexico 87801

Attn: Mr. G. D. Johnpeer
Engineering Geologist

Subj: REPORT NO. 4, Final report of geotechnical work at site of settlements in Espanola.

Gentlemen:

I have, on an on-call basis, reviewed your work at the subject area, and have reviewed and studied the data which you have obtained. I have also participated in several informational presentations which have been held, and I have met with your staff at Socorro to consult and to plan the outlines and specific parts of your reports on the situation. It is my impression that you have kept me fully apprised of the work, and that my recommendations have been fully considered.

Based upon your work, which after review I accept entirely, there is no doubt in my mind that the majority of the settlements which have occurred recently are due to hydrocompaction, and have occurred episodically in the past. It appears that there is a master set of cracks in the ground, parallel to the irrigation ditches, which reflect the tensions upslope of the ditches caused over the last centuries of settlements due to irrigation downslope of the the ditches. There are, in addition, localized cracks, and differential settlements, where water is introduced into the ground over prolonged periods of time upslope of the most-upslope ditch. Such situations include, but of course are not limited to, leaking water tanks, leaking water-conveyance systems (mains; and, in other areas, sewers), leaching fields, and ponding in depressions. In my view, in this study area, the contributions to the observed settlements of traffic vibrations, seismic explorations, and gravel extraction near the river are trivial to the point of nonexistence.

What is of importance from this study is the definition of tests and techniques which will be of benefit to the various Governments and Citizens of New Mexico in identifying soils which could be susceptible to settlement upon the sustained introduction of water. You have collected much of the basic data for that definition, but the constraints of time and funding have not allowed you to analyze those data adequately in depth for their generic implications. The information is there, but it will require much more work on your part to nail it down so that it is reliably usable by the Governments and Citizens of New Mexico. My practice is showing me that the problem of collapsible soils is by no means unique to New Mexico, and that, as Society continues expansion into the Southwest, the problem is going to become quite common. You may therefore may wish to consider cooperating in your ongoing studies with adjacent states and with the federal agencies who will have to deal with the problem if it is not adequately addressed before development.

It has been my pleasure to work with your Staff, who are a credit to the Bureau and to our State. The work you have done will benefit our State, and is a distinct contribution to both practical engineering and to science.

Very truly yours,

ROBERT L. McNEILL, Inc.

By ______________________
Robert L. McNeill

APPENDIX IX

Age Data

1) Age dates
2) Stratigraphic Units - Española Basin

THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA 85721

DEPARTMENT OF GEOSCIENCES
LABORATORY OF ISOTOPE GEOCHEMISTRY
TEL. (602) 621-6014

Mr. David Love
Environmental Geologist
New Mexico Bureau of Mines & Mineral Resources
Socorro, NM 87801

14 March 1985

Dear Mr. Love:

We have completed our carbon isotopic analysis on your sample submitted for "rush" analysis in our conventional carbon - 14 laboratory. Result is as follows:

A-4199	Charcoal (ESPBH - H)	2330 ± 70 $\delta^{13}C = -18.0\ ^{o}/oo$

Sincerely,

A. Long
Associate Professor

AL:klu

Enclosure

SAMPLE DESCRIPTION: El Llano Project DIC-3141

Site Name ______ # ______

Sample # Site # 2

Feature # ______

Latitude: 36 °01' ______ "N.

Longitude: 106 °02' ______ "W.

Depth 292 cm bs

Charcoal chunks from Rio Arriba Co., N.M.; Sl. reworked chunks of cc in gray sandy matrix 20cm thick, along band 10 m long

Coll. 1 / 10 / 85 by David W. Love

Subm. by David W. Love, N.M. Bureau of Mines & Mineral Resources, New Mexico Tech., Socorro, N.M. 87801

SAMPLE PREPARATION:

Charcoal, Wood, Peat, Gyttjas, Cores & Sediments:

All samples are first examined and cleaned of obvious impurities. The sample is treated for humic acids with 2N NaOH at 100°C. for thirty minutes, decanted, filtered, washed, and picked for rootlets while wet. Free carbonates are removed with 2N HCl at room temperature for approximately forty-eight hours. The sample is then decanted, filtered, washed, again picked for rootlets while wet, dried at 90°C., and picked for rootlets and remaining impurities under 30X magnification.

Shell: Wet combustion in 50% H_3PO_4. Amount discarded by leaching ______ %

X-ray analysis ______ Thin section ______ C12/C13 ratios ______

Bone: Demineralization in 1% HCl. Details of collagen extraction provided upon request.

REMARKS: Clean on cut pick

Rootlets present? ______

Free Carbonates? No observable rxn.

Other Contaminants: "Rodent Burrows in arroyo wall.

Other Treatments ______

COMBUSTION:

Amount of CO_2 generated		18 in. Hg.. 48 T.	
Amount of lithium added		.12	grams
Weight of vial and sample	85535C	19.5250	grams
Weight of vial	5199.48m	17.5000	grams
Weight of benzene	#10	2.0250	grams
Weight of carbon		1.8682	grams
Weight of benzene + scintillation solution		4.4000	grams

RADIOCARBON AGE: 2990 **B.P.** ± 60/70

1040 BC

DICARB RADIOISOTOPE CO., 4912 Stonehenge Lane, Norman, OK 73071 (405) 329-9338

SAMPLE DESCRIPTION: El Llano Project DIC-3142

Site Name ____________ # ________

Sample # Site #3 Charcoal from Rio Arriba Co., N.M.

Feature # ________

Latitude: 36 ° 02 ' ____ " N.

Longitude: 106 ° 01 ' ____ " W.

Depth 204 cm bs

Coll. 1/14/85 by David W. Love

Subm. by David W. Love, New Mexico Bureau of Mines & Natural Resources, New Mexico Tech, Socorro, N.M. 87801

SAMPLE PREPARATION:

Charcoal, Wood, Peat, Gyttjas, Cores & Sediments:

All samples are first examined and cleaned of obvious impurities. The sample is treated for humic acids with 2N NaOH at 100°C. for thirty minutes, decanted, filtered, washed, and picked for rootlets while wet. Free carbonates are removed with 2N HCl at room temperature for approximately forty-eight hours. The sample is then decanted, filtered, washed, again picked for rootlets while wet, dried at 90°C., and picked for rootlets and remaining impurities under 30X magnification.

Shell: Wet combustion in 50% H_3PO_4. Amount discarded by leaching ________ %

X-ray analysis ________ Thin section ________ C12/C13 ratios ________

Bone: Demineralization in 1% HCl. Details of collagen extraction provided upon request.

REMARKS:

Rootlets present? ________

Free Carbonates? sl rxn

Other Contaminants: ________

Other Treatments ________

very small sample, about 2 grams after cleaning. Large sigma is due to small sample size.

COMBUSTION:

Amount of CO_2 generated	55356 C	-25	in. Hg.. #2 T.
Amount of lithium added	5499.45 m	4	grams
Weight of vial and sample		18.1430	grams
Weight of vial	#10	17.5000	grams
Weight of benzene		.6430	grams
Weight of carbon		.5932	grams
Weight of benzene + scintillation solution		4.4000	grams

RADIOCARBON AGE: 370 **B.P.** ± 100

AD 1580

DICARB RADIOISOTOPE CO., 4912 Stonehenge Lane, Norman, OK 73071 (405) 329-9338

Era	System	Series	Stratigraphic unit	Lithology	Thickness (meters) San Juan Basin	Thickness (meters) Nacimiento Uplift	Remarks
Cenozoic	Quaternary	Holocene	Unnamed local sedimentary deposits	Alluvium in valleys; stream gravel on low terraces; colluvium on slopes	3-30	3-15	
		Pleistocene		Stream gravel on high terraces; alluvium on high pediments	0-30	0-15	
			Bandelier Tuff	Welded and nonwelded rhyolite ash flows		0-150	Rocks spatially associated with Rio Grande depression
	Quaternary or Tertiary	Pleistocene or Pliocene	Unnamed local sedimentary deposits	Gravel on high-level pediment, west and northwest sides of Nacimiento Uplift		0-30	
	Tertiary	Pliocene	Puye Formation	Sand, volcanic gravel, tuffaceous beds, and river gravel		15-215	
		Pliocene and Miocene	Tschicoma Formation	Dacite, rhyodacite, and quartz latite of Jemez Mountains volcanic pile		0-900	
			Lobato Basalt	Olivine-augite basalt		0-180	
			Santa Fe Formation of Smith, Bailey, and Ross, 1970. Mainly equivalent to Miocene Tesuque Formation	Partly consolidated cross-bedded sand, arkosic sand, and volcanic-pebble gravel and sand; pinkish brown to buff		0-1200+	
		Miocene and Oligocene	Abiquiu Tuff of Smith, 1938	Tuffaceous sandstone, volcanic-pebble conglomerate and, at the base, conglomerate of Precambrian and Paleozoic clasts; light gray		0-360+	
		Oligocene(?) and Eocene	El Rito Formation of Smith, 1938	Sandstone, shale, and conglomerate of Precambrian clasts; red to brown; nonmarine		0-120	Regionally extensive rocks older than Rio Grande depression
		Eocene	San Jose Formation	Shale, sandstone, conglomerate; nonmarine	60-550		
		Paleocene	Nacimiento Formation	Shale, sandstone, conglomerate; nonmarine	160-530		
			Ojo Alamo Sandstone	Sandstone and conglomerate; nonmarine	20-60		
Mesozoic	Cretaceous	Upper	Kirtland Shale and Fruitland Formation	Shale and sandstone; nonmarine	30-135		
			Pictured Cliffs Sandstone	Sandstone; marine	0-70		
			Lewis Shale	Claystone, siltstone, and some thin limestone; marine	150-680		
			Mesaverde Group	Sandstone, shale, and some coal; marine and nonmarine	170-560		
			Mancos Shale	Claystone, siltstone, and some thin limestone; marine	700-760		
			Dakota Sandstone	Sandstone, some shale and conglomerate; marine and nonmarine	45-60	0-60	
	Jurassic	Upper	Morrison Formation	Sandstone and shale; nonmarine	100-180	0-180	
		Middle	Todilto Formation	Gypsum and underlying limestone; nonmarine	18-38	Present	
			Entrada Sandstone	Sandstone; nonmarine	70	0-70	
	Triassic	Upper	Chinle Formation	Claystone, siltstone, sandstone, and basal conglomeratic sandstone; red and brown; nonmarine	300-320	0-300	
Paleozoic	Permian	Lower	Cutler Formation	Sandstone, shale, and conglomerate; arkosic; red and brown; nonmarine	150-290	150-290	
	Pennsylvanian	Upper and Middle	Madera Formation	Limestone, shale, and arkosic sandstone; mainly marine	0-300	0-300	
		Lower	Sandia Formation	Sandstone, shale, and some limestone; marine and nonmarine	0-60	0-60	
	Mississippian	Upper and Lower	Arroyo Penasco Group	Limestone and thin basal sandstone; marine	Present	0-55	
Precambrian		Granite, tonalite, gneiss, schist, metavolcanic rocks, quartzite, and local mafic and ultramafic rocks					

STRATIGRAPHIC UNITS EXPOSED IN SAN JUAN BASIN, NACIMIENTO UPLIFT, AND NORTHWEST MARGIN OF ESPAÑOLA BASIN. Thicknesses of the Oligocene(?) through Pliocene units in the Nacimiento uplift column are those from the uplift to the northwestern part of the Española Basin.

from Baltz (1978).

Era	System	Series	Stratigraphic unit	Lithology	Thickness (meters): Espanola Basin	Thickness (meters): Sangre de Cristo Uplift, Santa Fe block	Thickness (meters): Sangre de Cristo Uplift, Pecos block	
Cenozoic	Quaternary	Holocene	Unnamed local sedimentary deposits	Alluvium in valleys and colluvial deposits on slopes	3-30	3-15	3-15	
Cenozoic	Quaternary	Pleistocene	Unnamed local sedimentary deposits	Glacial till and gravel in high valleys; gravel on low terraces	0-15	0-20	0-20	
Cenozoic	Quaternary	Pleistocene	Unnamed local sedimentary deposits	Stream gravel on high terraces	0-30	0-20	0-15	Rocks spatially associated with Rio Grande depression
Cenozoic	Quaternary	Pleistocene	Santa Fe Group: Basaltic rocks of Cerros del Rio; Unnamed local sedimentary deposits	Airfall pumice and ash related to Bandelier Tuff	0-6			Rocks spatially associated with Rio Grande depression
Cenozoic	Quaternary or Tertiary	Pleistocene or Pliocene	Santa Fe Group: Basaltic rocks of Cerros del Rio; Unnamed local sedimentary deposits	Piedmont-slope gravel and local fan breccia	0-25			Rocks spatially associated with Rio Grande depression
Cenozoic	Tertiary	Pliocene	Santa Fe Group: Ancha Formation	Piedmont-slope gravel, sand, and silt. Clasts mainly Precambrian rocks	0-100			Rocks spatially associated with Rio Grande depression
Cenozoic	Tertiary	Miocene	Santa Fe Group: Tesuque Formation	Partly consolidated sand, silt, and gravel; arkosic; pink to light reddish brown and tan. Contains pebble to cobble gravel of Precambrian metamorphic and igneous rocks and Paleozoic sedimentary rocks. Contains locally abundant layers of volcanic ash and some conglomerate of latite and andesite clasts. Local flows of olivine basalt are interbedded with sediments	0-1500 (maximum not known accurately)			Rocks spatially associated with Rio Grande depression
Cenozoic	Tertiary	Miocene and Oligocene	Espinaso Formation of Stearns, 1953	Partly consolidated sand, silt, and volcanic-pebble gravel and interbedded latite and andesite flows	0-160 (locally 600 at southwest)			Rocks spatially associated with Rio Grande depression
Cenozoic	Tertiary	Oligocene(?) and Eocene	Galisteo Formation at south and El Rito Formation of Galusha and Blick (1971) at north	Sandstone, siltstone, claystone, and pebble to cobble conglomerate. Clasts derived from Mesozoic, Paleozoic, and Precambrian rocks	0-15 (locally 900 at southwest)			Regionally extensive rocks older than Rio Grande depression
Mesozoic	Cretaceous, Jurassic, and Triassic		Mesozoic rocks are present around southern margin of Espanola Basin. Unknown in subsurface to north	Mainly sandstone and shale with minor units of limestone; marine and nonmarine. See Figure 5	Not known			Regionally extensive rocks older than Rio Grande depression
Paleozoic	Permian	Upper and Lower	Bernal Formation San Andres Limestone Glorieta Sandstone Yeso Formation	Sandstone, red to gray; gray limestone; gray sandstone; and red to gray sandstone, shale, and limestone. Mainly marine	Not known	0-120	60-120+	Regionally extensive rocks older than Rio Grande depression
Paleozoic	Permian	Lower	Sangre de Cristo Formation	Arkosic conglomerate, sandstone, and shale, mainly red; nonmarine	Not known	0-90	915	Regionally extensive rocks older than Rio Grande depression
Paleozoic	Pennsylvanian	Upper	Alamitos Formation of Miller and others, 1963; Madera Formation: Upper member	Shale, arkosic sandstone, and limestone; marine and nonmarine	Not known except on southeast margin of basin where thicknesses are similar to those of the Santa Fe block	0-250	360-390	Regionally extensive rocks older than Rio Grande depression
Paleozoic	Pennsylvanian	Middle	La Pasada Formation of Miller and others, 1963; Madera Formation: Lower member	Shale, limestone, and sandstone; marine	Not known except on southeast margin of basin where thicknesses are similar to those of the Santa Fe block	0-45	180-1300	Regionally extensive rocks older than Rio Grande depression
Paleozoic	Pennsylvanian	Lower	La Pasada Formation of Miller and others, 1963; Sandia Formation	Shale, sandstone, conglomerate, and thin limestone; marine and nonmarine	Not known except on southeast margin of basin where thicknesses are similar to those of the Santa Fe block	0-75	90-490	Regionally extensive rocks older than Rio Grande depression
Paleozoic	Mississippian	Upper	Tererro Formation	Limestone and limestone breccia; marine	Not known except on southeast margin of basin where thicknesses are similar to those of the Santa Fe block	0-10	0-25	Regionally extensive rocks older than Rio Grande depression
Paleozoic	Mississippian	Lower	Espiritu Santo Formation	Limestone and sandstone; marine	Not known except on southeast margin of basin where thicknesses are similar to those of the Santa Fe block	0-12	0-15	Regionally extensive rocks older than Rio Grande depression
Precambrian			Granite, granodiorite, gneiss, quartzite, and amphibole schist					

STRATIGRAPHIC UNITS EXPOSED IN SOUTHEASTERN ESPAÑOLA BASIN AND SOUTHWESTERN SANGRE DE CRISTO UPLIFT.

from Baltz (1978).

APPENDIX X

Geologic Sections

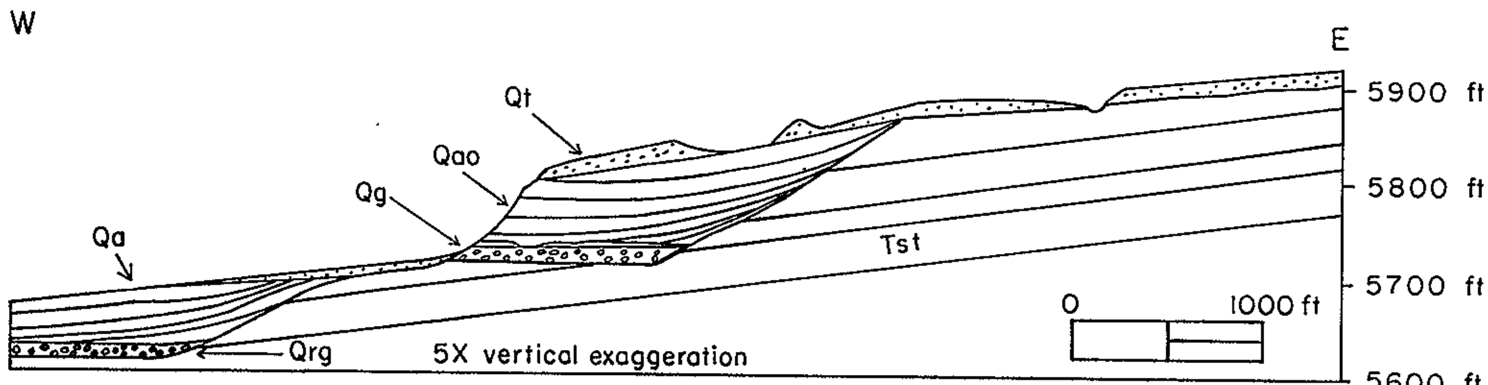

Figure A-1. Cross section of bluffs east of San Juan Pueblo showing terrace gravel of ancestral Rio Grande (Qg) on dipping bedrock (Tst), buried by the alluvial fan deposits (Qao) with coarser alluvium at the top (Qt). Alluvium of present valley border (Qa) grades west to present Rio Grande and buries former gravel and flood plain of Rio Grande (Qrg).

28 JUNE 1985

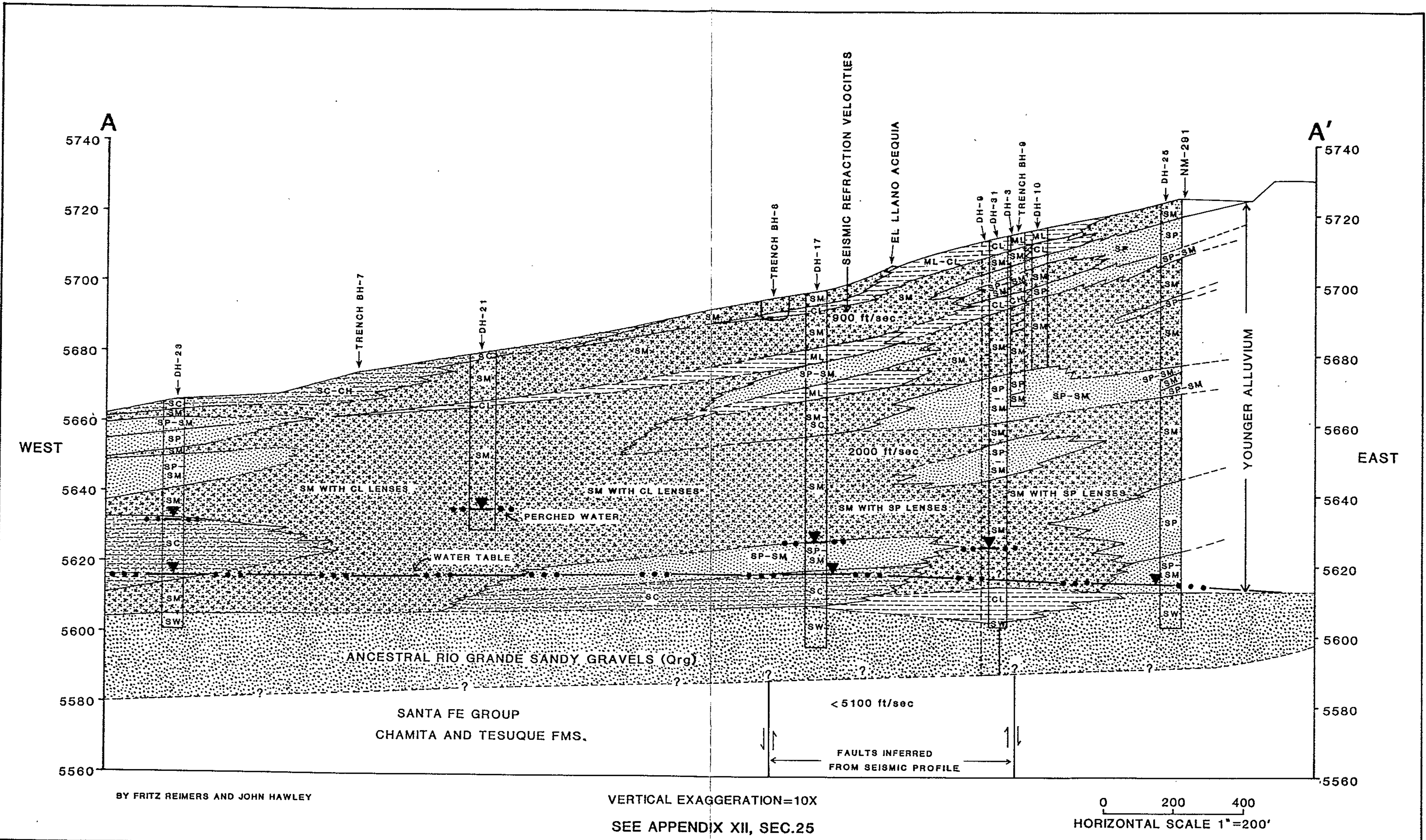

Figure A-2. East-West geologic cross section through El Llano.

28 JUNE 1985

APPENDIX XI

Water Table Maps

OFR-226

EL LLANO AND VICINITY GEOTECHNICAL STUDY

FINAL REPORT

VOLUME III

Prepared for:

Office of Military Affairs
Civil Emergency
Preparedness Division
P.O. Box 4277
Santa Fe, NM 87501

Prepared by:

Gary D. Johnpeer, David W. Love, John W. Hawley,
Danny J. Bobrow, Mark Hemingway, and R. W. Reimers,

New Mexico Bureau of Mines and Mineral Resources
Socorro, NM 87801

28 June 1985

APPENDIX XII

Activity Location Maps

EL LLANO AND VICINITY GEOTECHNICAL STUDY

FINAL REPORT

VOLUME IV

Prepared for:

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28 June 1985

APPENDIX XIII

Seismicity Data for Northern New Mexico

1) Española Area
2) Modified Mercalli Intensity Scale of 1931

Table A1. Seismicity in the Española Area

Year	Data Source	Date			Time			Lat.	Long.	Mag.	MM
1969	1	69	07	04	14	43	34.0	36.1	106.1	4.4	IV
1970	1	None			--	--	--	--	--	--	--
1971	1	71	12	06	05	18	13.70	36.06	106.32	4.2	V
1971	1	71	12	06	5	30	--	36.1	106.3	--	IV*
1971	1	71	12	06	11	20	--	36.1	106.3	--	III*
1971	1	71	12	06	22	40	--	36.1	106.3	--	III*
1971	1	71	12	10	--	--	--	36.1	106.3	--	III*
1971	1	71	12	10	05	45	--	36.1	106.3	--	III*
1972	1	72	03	28	01	53	33.7	36.17	106.06	no magnitude assigned felt,	
1973	1	73	03	17	07	43	05.5	36.09	106.17	4.5	III*
1974	2	74	02	20	20	43	1.80	35.95	106.1460	2.0	
1975	2	--	--	--	--	--	--	no close quakes		--	
1976	2	--	--	--	--	--	--	no close quakes		--	
1977	2	77	01	09	13	02	58.50	36.0980	106.0790	1.3	
1978	2	--	--	--	--	--	--	no close quakes		--	
1979	2	--	--	--	--	--	--	no close quakes		--	
1980	3	80	05	16	8	09	27.33	36.0000	106.1008	.8	
1980	3	80	06	15	19	58	4.89	36.0410	106.0835	.8	
1980	3	80	06	20	8	14	16.93	36.0068	106.1128	.4	
1980	3	80	06	28	23	04	10.10	35.9943	106.0832	.1	
1980	4	80	10	28	12	32	2.13	35.9670	106.0887	.4	
1981	5	81	09	16	04	04	56.06	36.0103	106.1442	0.0	
1982	6	82	09	03	03	27	07.64	35.9855	106.1032	1.2	
1983		--	--	--	--	--	--	no close quakes		--	
1984	7	--	--	--	--	--	--	no close quakes		--	
1985	7	85	01	26	11	50	56.899	36.0566	105.9416	.4	

Sources:

1. Stover and others (1983)
2. Wechsler and others (1980a)
3. Wechsler and others (1980b)
4. Wechsler and others (1981)
5. Cash and others (1982)
6. Cash and others (1984)
7. Preliminary data, subject to revision (Dan Cash, 1985, written communication)

MODIFIED MERCALLI INTENSITY SCALE OF 1931

I. Not felt - or, except rarely under especially favorable circumstances. Under certain conditions, at and outside the boundary of the area in which a great shock is felt: sometimes birds, animals, reported uneasy or disturbed; sometimes dizziness or nausea experienced; sometimes trees, structures, liquids, bodies of water, may sway--doors may swing, very slowly.

II. Felt indoors by few, especially on upper floors, or by sensitive, or nervous persons. Also, as in grade I, but often more noticeably: sometimes hanging objects may swing, especially when delicately suspended; sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly; sometimes birds, animals, reported uneasy or disturbed; sometimes dizziness or nausea experienced.

III. Felt indoors by several, motion usually rapid vibration. Sometimes not recognized to be an earthquake at first. Duration estimated in some cases. Vibration like that due to passing of light, or lightly loaded trucks, or heavy trucks some distance away. Hanging objects may swing slightly. Movements may be appreciable on upper levels of tall structures. Rocked standing motor cars slightly.

IV. Felt indoors by many, outdoors by few. Awakened few, especially light sleepers. Frightened no one, unless apprehensive from previous experience. Vibration like that due to passing of heavy or heavily loaded trucks. Sensation like heavy body striking building or falling of heavy objects inside. Rattling of dishes, windows, doors; glassware and crockery clink and clash. Creaking of walls, frame, especially in the upper range of this grade. Hanging objects swung, in numerous instances. Disturbed liquids in open vessels slightly. Rocked standing motor cars noticeably.

V. Felt indoors by practically all, outdoors by many or most: outdoors direction estimated. Awakened many, or most. Frightened few--slight excitement, a few ran outdoors. Buildings trembled throughout. Broke dishes, glassware, to some extent. Cracked windows--in some cases, but not generally. Overturned vases, small or unstable objects, in many instances, with occasional fall. Hanging objects, doors, swing generally or considerably. Knocked pictures against walls, or swung them out of place. Opened, or closed, doors, shutters, abruptly. Pendulum clocks stopped, started or ran fast, or slow. Moved small objects, furnishings, the latter to slight extent. Spilled liquids in small amounts from well-filled open containers. Trees, bushes, shaken slightly.

VI. Felt by all, indoors and outdoors. Frightened many, excitement general, some alarm, many ran outdoors. Awakened all. Persons made to move unsteadily. Trees, bushes, shaken slightly to moderately. Liquid set in strong motion. Small bells rang--church, chapel, school, etc. Damage slight in poorly built buildings. Fall of plaster in small amount. Cracked plaster somewhat, especially fine cracks chimneys in some instances. Broke dishes, glassware, in considerable quantity, also some windows. Fall of knick-knacks, books, pictures. Overturned furniture in many instances. Moved furnishings of moderately heavy kind.

VII. Frightened all--general alarm, all ran outdoors. Some, or many, found it difficult to stand. Noticed by persons driving motor cars. Trees and bushes shaken moderately to strongly. Waves on ponds, lakes, and running water. Water turbid from mud stirred up. Incaving to some extent of sand or gravel stream banks. Rang large church bells, etc. Suspended objects made to quiver. Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc. Cracked chimneys to considerable extent, walls to some extent. Fall of plaster in considerable to large amount, also some stucco. Broke numerous windows, furniture to some extent. Shook down loosened brickwork and tiles. Broke weak chimneys at the roof-line (sometimes damaging roofs). Fall of cornices from towers and high buildings. Dislodged bricks and stones. Overturned heavy furniture, with damage from breaking. Damage considerable to concrete irrigation ditches.

VIII. Fright general--alarm approaches panic. Disturbed persons driving motor cars. Trees shaken strongly--branches, trunks, broken off, especially palm trees. Ejected sand and mud in small amounts. Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters. Damage slight in structures (brick) built especially to withstand earthquakes. Considerable in ordinary substantial buildings, partial collapse: racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling. Fall of walls. Cracked, broke, solid stone walls seriously. Wet ground to some extent, also ground on steep slopes. Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers. Moved conspicuously, overturned, very heavy furniture.

IX. Panic general. Cracked ground conspicuously. Damage considerable in (masonry) structures built especially to withstand earthquakes: Threw out of plumb some wood-frame houses built especially to withstand earthquakes; great in substantial (masonry) buildings, some collapse in large part; or wholly shifted frame buildings off foundations, racked frames; serious to reservoirs; underground pipes sometimes broken.

X. Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks. Landslides considerable from river banks and steep coasts. Shifted sand and mud horizontally on beaches and flat land. Changed level of water in wells. Threw water on banks of canals, lakes, rivers, etc. Damage serious to dams, dikes, embankments. Severe to well-built wooden structures and bridges, some destroyed. Developed dangerous cracks in excellent brick walls. Destroyed most masonry and frame structures, also their foundations. Bent railroad rails slightly. Tore apart, or crushed endwise, pipe lines buried in earth. Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI. Disturbances in ground many and widespread, varying with ground material. Broad fissures, earth slumps, and land slips in soft, wet ground. Ejected water in large amounts charged with sand and mud. Caused sea-waves ("tidal" waves) of significant magnitude. Damage severe to wood-frame structures, especially near shock centers. Great to dams, dikes, embankments often for long distances. Few, if any (masonry) structures remained standing. Destroyed large well-built bridges by the wrecking of supporting piers, or pillars. Affected yielding wooden bridges less. Bent railroad rails greatly, and thrust them endwise. Put pipe lines buried in earth completely out of service.

XII. Damage total--practically all works of construction damaged greatly or destroyed. Disturbances in ground great and varied, numerous shearing cracks. Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive. Wrenched loose, tore off, large rock masses. Fault slips in firm rock, with notable horizontal and vertical offset displacements. Water channels, surface and underground, disturbed and modified greatly. Dammed lakes, produced waterfalls, deflected rivers, etc. Waves seen on ground surfaces (actually seen, probably, in some cases). Distorted lines of sight and level. Threw objects upward into the air.

(from Stover and others, 1983)

APPENDIX XIV

Bibliography of Collapsible Soils

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APPENDIX XV

Shell Western Exploration Report

Shell Western E&P Inc.
A Subsidiary of Shell Oil Company

P.O. Box 831
Houston, TX 77001

February 26, 1985

New Mexico Bureau of Mines
& Mineral Resources
Attention Dr. George S. Austin
Socorro, New Mexico 87801

Dear Dr. Austin:

Enclosed is a cover document with technical attachments that defines Shell's operations in the Espanola Basin. Major topics covered include the standards we applied during acquisition, the contact we had with community residents and leaders, and the particle velocities we observed at the geophones while detonating our sources. I believe that these are the topics agreed upon during our meeting on February 11.

It is possible that we could make any suggested expansions and still meet your March 15th project deadline. I would be interested in your comments and further in obtaining a copy of the New Mexico Bureau of Mine's report when it is available.

Sincerely,

S. A. Jones
Manager Geophysics
Rocky Mountain Division

SAJ:cas

Enclosure

Shell Western Operations in the Espanola Basin,
El Llano, New Mexico, 1984

Shell Western E&P Inc.
Rocky Mountain Division

Introduction

In November, 1984, Shell Western E&P Inc. acquired a seismic line in the Espanola Basin near El Llano, New Mexico. Recent subsidence in the Basin has led to damage of habitations and utilities. Some concern has been expressed that Shell Western's operations have been related to the damage. It is SWEPI's position, based on 20 years of experience in New Mexico and sound technical work, that our operations had no negative impact on the community. At the request of the New Mexico Bureau of Mines, SWEPI has provided the following document to both explain our operational procedure and to detail our safety procedures, our data acquisition and the data which confirms Shell's safe operations.

Shell's Interaction With The Community

Months before data acquisition a Shell Western representative known as a Permit Man visits the community. While there he rents an office and a shop for the SWEPI crew, contacts the appropriate government officials, and contacts private landowners. His primary responsibility is to explain SWEPI's procedures, arrange SWEPI's legal access, and agree on any fees to be paid to the owners. Shell Western's intention is to comply with all guidelines and restrictions imposed by the community as well as state and federal regulations in order to ensure our ability to work in the area in the future.

During the data acquisition the community has access to the entire seismic crew, preferably through the senior SWEPI staff for business matters but also with any crew member on an informal basis. It is common for members of the community to watch data acquisition, as was the case in El Llano. Once the data has been acquired, the SWEPI Permit Man mails payment to the concerned parties. All governmental agencies and landowners involved have key SWEPI personnel phone numbers and can call collect to report any problems and make any claims for damages that the landowner feels Shell Western has caused. Because the Permit Man carefully describes this followup to each involved landowner, Shell Western assumes that if the check is cashed and we are not contacted, there are no unresolved problems.

SWEPI has not been contacted by any private landowners that were involved in SWEPI's November 1984 program or its 1983 Rio Chama program in the Espanola Basin.

Overview of the Seismic Method

Exploration is vitally concerned with using indirect measurements to develop a geologic picture of the strata beneath the surface. The seismic method depends upon an acoustic wave reflecting off deep rock boundaries and returning to the surface where it is measured by sensitive velocity devices (geophones). The source of the acoustic wave is generally a mechanical vibration or a detonation of a buried explosive.

These buried sources are placed at predetermined ground locations. The locations are determined after consideration of special precautions by the senior staff of the field crew, with the concurrence of the geophysical staff in SWEPI's Houston office for any unusual cases. The surveyors mark the locations with plastic flagging for the geophone stations and the source locations. Drills mounted on trucks drill holes for the sources and load the explosive at depth, ensuring that the charge is at the bottom of the hole and that the hole is properly plugged.

A crew known as as the Instrument Crew follows behind the drills and is responsible for the actual data acquisition. A cable is laid along the length of the line, a computer truck is connected to the cable, and geophones are laid out and clipped into the cable. A special technician handles detonating the buried charges. To do so he must wire up the charge to special equipment which provides the proper signal to the charge at the proper time. He is also responsible for safety at the impulse source location. As the charge detonates, the earth near the location will tremble very slightly (see Attachment II) and an acoustic wave will travel down into the earth strata. Only a wave which travels directly from the source through the top ground layers would be noticeable, as a minor thump, to a person at a geophone or off-line and then only up to a distance of approximately 500 feet away. For five seconds the computer truck listens and records the geophones' response to the minute vibrations of the upcoming reflected sound waves. The reflected sound waves are noticeable only to very sensitive instruments. As the Instrument Crew finishes part of its recording and moves up the line a Backup Crew follows picking up all equipment and cleaning up the seismic line.

Within confines of the El Llano populated area, Shell Western placed charges no larger than 5 pounds at depths no shallower than 30 feet. Further, the charge sizes were reduced to 1 pound where appropriate and all hole depths were chosen to protect the water wells in the area. Attachment I details crew operations and Attachment II details charge location and size.

Structural Safety Procedures

Shell Western has a commitment to operate in such a way that no damages occur to either publicly or privately owned structures, both for the community's and Shell Western's benefit. Our primary guidelines are based upon particle velocity - i.e. rate of ground motion - with the upper allowable limits determined by U.S. Bureau of Mine standards. To implement a limiting of the ground motion in our operations we have an informal set of guidelines that includes a distance from acoustic wave source to houses, wells, water table, etc. Further, we adjust these guidelines to make them more restrictive for areas where the ground motion might be higher due to the near surface character or to meet the landowner's additional requirements. Attachment II details the actual limits used in our acquisition in November. Attachment III includes an analysis of the ground motion induced by Shell's operations and the Standard that describes safe operating limits under Federal guidelines.

It is evident from our sensitive measurements that the ground motion rate induced by our Operations is a factor of 20 lower than Federal guidelines at a very close distance from the source. It is also clear that at distance of 3000 feet the motion is a factor of 1600 lower. A meeting between SWEPI and representatives of the New Mexico Bureau of Mines has determined that SWEPI operations were at least 3000 feet south of the nearest damaged house condemned by the New Mexico CID.

Conclusion

SWEPI was able to operate in the Espanola Basin in a manner that protected community property and still met SWEPI's data requirements:

1. Ground motion rate induced by SWEPI was well within Federal guidelines.

2. SWEPI acquired data within short distances of undamaged wells and structures.

3. SWEPI operations were a minimum of 3000 feet from the nearest damaged structure.

ATTACHMENT I

SWEPI SEISMIC CREW 120 SCHEDULE FOR 1984 ACQUISITION IN THE ESPANOLA BASIN, STATIONS 3301 TO 3502

A LINE LOCATION MAP IS INCLUDED IN ATTACHMENT II DETAILING KEY GEOPHONE STATION LOCATIONS WITH RESPECT TO THE LANDMARKS AND STRUCTURES OF THE VALLEY.

PERMITTING DUTIES: 8-1-84 THRU END OF ACQUISITION

1. CONTACTED LANDOWNERS THAT WE NEEDED TO CROSS, RECEIVED PERMISSION, AND AGREED ON A FEE.

2. CONTACTED ALL APPROPRIATE GOVERNMENTAL AGENCIES. ALSO ESTABLISHED CONTACT WITH ANY RESEARCH GROUPS, UNIVERSITIES, ETC. THAT MIGHT BE ACQUIRING DATA IN THE AREA. INDIVIDUALS AND GROUPS ARE LISTED BELOW.

VIDAL MARTINEZ	CITY MANAGER
JIM FARMER	CITY PLANNER
TOM MARTINEZ	CITY UTILITIES
RUPERT SANCHEZ	CITY LAND FILL
GEORGE BACA	N.M. HIGHWAY DEPT. DIST. 5
PETE ROSARIO	N.M. HIGHWAY DEPT. DIST. 5
JIM CRAIG	EARTH & SPACE SCIENCE GROUP, LOS ALAMOS

3. MADE SURE THAT THE CREW FOLLOWED ALL PERMIT RESTRICTIONS.

4. MAILED PERMIT FEE CHECKS AFTER THE LINE WAS FINISHED.

SURVEYING DUTIES:

1. PUT IN PIN FLAGS AT EACH STATION AND ENERGY SOURCE POINT.

2. SURVEYED STATIONS AND ENERGY SOURCE POINTS.

DRILL CREW DUTIES:

1. CONVENTIONAL DRILL DESCRIPTION:

   MAYHEW 500 MOUNTED ON A 4-WHEEL DRIVE F600

DATE	STATIONS DRILLED AND LOADED
10-23-84	3301
10-26-84	3461 - 3471
10-27-84	3424 - 3425
	3457 - 3458
10-28-84	3426 - 3433
10-30-84	3350 - 3352

2. HELI-PORTABLE DRILLS:
   (SHELL WESTERN USED PORTABLE DRILLS TO THE WEST AND EAST OF THE VALLEY).

   TOTAL WEIGHT 3600 LBS. PLUS SUPPORT BASKETS. SKID MOUNTED (NOT ON WHEELS). MOVED IN THREE SECTIONS WITH A HELICOPTER.

DATE	STATIONS DRILLED AND LOADED
10-25-84	3484 - 3490
10-26-84	3487 - 3502

3. HOLES WERE PLUGGED WITHIN 3 DAYS AFTER DRILLING.

INSTRUMENT CREW: STATIONS 3301 - 3502

1. GEOPHONES AND CABLE PLACEMENT AND PICKUP - 11-09-84 THRU 11-12-84

2. DATA ACQUISITION - 11-11-84

3. CLEANUP - STATIONS 3301 THROUGH 3502 WERE CLEARED OF DEBRIS AS THE BACK CREW WENT THROUGH ON 11-12-84.

FINALIZATION OF OPERATIONS:

1. FINISHED ENTIRE LINE: 11-14-84

2. CREW LEFT TOWN 11-15-84.

3. LAST MAN LEFT TOWN 11-17-84.

ATTACHMENT II

SHELL WESTERN SEISMIC CREW 120 STANDARDS FOR PROTECTION OF STRUCTURES AND WELLS DURING ACQUISITION OF LINE 165

OBJECTIVES AND LIMITATIONS

1. SWEPI DESIRED TO PLACE A SOURCE ON THIS LINE AT EVERY OTHER GEOPHONE STATION, IF POSSIBLE. ANY DEVIATION FROM THIS SPACING CAUSES A "SKIP" AND IS DETRIMENTAL TO THE DATA. SHELL DESIRED TO PLACE THE SOURCE AT A 200 FOOT DEPTH WHERE OTHER RESTRICTIONS DID NOT APPLY.

2. SWEPI DECIDED TO REDUCE THE SOURCE SIZE FROM ITS NOMINAL 40 POUNDS IN THE VOLCANICS AREA TO THE WEST AND GRANITE AREA TO THE EAST TO A MINIMUM OF 1 POUND IN POPULATED AREAS.

3. SWEPI CHARTED WELL DEPTHS TO ENSURE THAT NO SOURCES WOULD BE IN THE WATERTABLE.

4. SWEPI DECIDED THAT NO CHARGE LARGER THAN 3 POUNDS WOULD BE DETONATED CLOSER THAN 400 FEET FROM A STRUCTURE, UTILITY, OR WELL. SHELL DETERMINED THAT 1 POUND SOURCES WITHIN 200 FEET OF STRUCTURES WOULD BE WITHIN GUIDELINES.

DETAILS FROM THE LINE SURVEY NOTES AND AERIAL MAPS

1. THE VALLEY AREA IN QUESTION IS DEFINED BY THE STATIONS 3300 TO 3500. FIGURE 1 IS A MAP DEFINING THE LINE LOCATION BY STATION NUMBER WITH RESPECT TO THE ROADS, STRUCTURES, ETC.

2. LINE 165 CROSSED BLM AND FOREST SERVICE LAND BUT NONE BETWEEN STATIONS 3301 AND 3500.

3. SWEPI DETERMINED THAT THE VALLEY ENERGY SOURCE HOLES WOULD BE 35 TO 90 FEET DEEP.

4. HOLES WERE DRILLED TO LESS THAN THE STANDARD DEPTH WHERE A KNOWN WATER TABLE OR A NEARBY WATER WELL THAT DEMANDED EXTRA CAUTION.

5. STATIONS 3350, 3351, AND 3352 HAD 1 LB. CHARGES AND THE NEAREST BUILDING IS APPROXIMATELY 200 FEET AWAY.

6. THERE IS A 120 FOOT WATER WELL NEAR STATION 3412 AND THE NEAREST CHARGE WAS 2 LBS. AT STATION 3424 (600 FT. AWAY).

7. THERE IS A HOUSE AT STATION 3446 AND A MAJOR ROAD AT STATION 3447. THE CLOSEST SOURCE WAS A 3 LB. CHARGE AT STATION 3457, 500 FEET AWAY.

8. A COMMUNITY WATER TOWER IS APPROXIMATELY 300 FT. FROM STATION 3479. FURTHER THE LINE CROSSED A PIPELINE TO THE TOWER BETWEEN STATIONS 3479 AND 3480. THE NEAREST SHOT TO THE TOWER WAS 10 LBS. AT STATION 3484 (400 FEET AWAY).

9. THE CITY GAVE PERMISSION TO LAND OUR HELICOPTERS APPROXIMATELY A QUARTER OF A MILE SOUTH OF THE TOWER.

10. THERE WERE NO COMPLAINTS RESULTING FROM SWEPI OPERATIONS.

COMPLETE LISTING OF SOURCE LOCATIONS

INCLUDED BELOW ARE THE LOCATIONS, DEPTHS AND SIZES OF THE SEISMIC CHARGES USED ON LINE 165 BETWEEN SHOT POINTS 3301 AND 3498. DUPONT SEISMOGEL WAS USED AS THE EXPLOSIVE.

SHOT POINT	HOLE DEPTH IN FEET	CHARGE SIZE IN LBS.
3301	30	2
49 STATION SKIP FROM 3302 TO 3348 DUE TO TO MAN-MADE STRUCTURES		
3350	49	1
3351	49	1
3352	49	1
72 STATION SKIP FROM 3354 TO 3422 DUE TO TO MAN-MADE STRUCTURES		
3424	58	2
3425	58	2
3426	58	2
3427	58	2
3428	58	2
3429	58	2
3430	58	2
3431	58	2
3432	58	2
3433	58	2

24 STATION SKIP FROM 3434 TO 3456
DUE TO TO MAN-MADE STRUCTURES

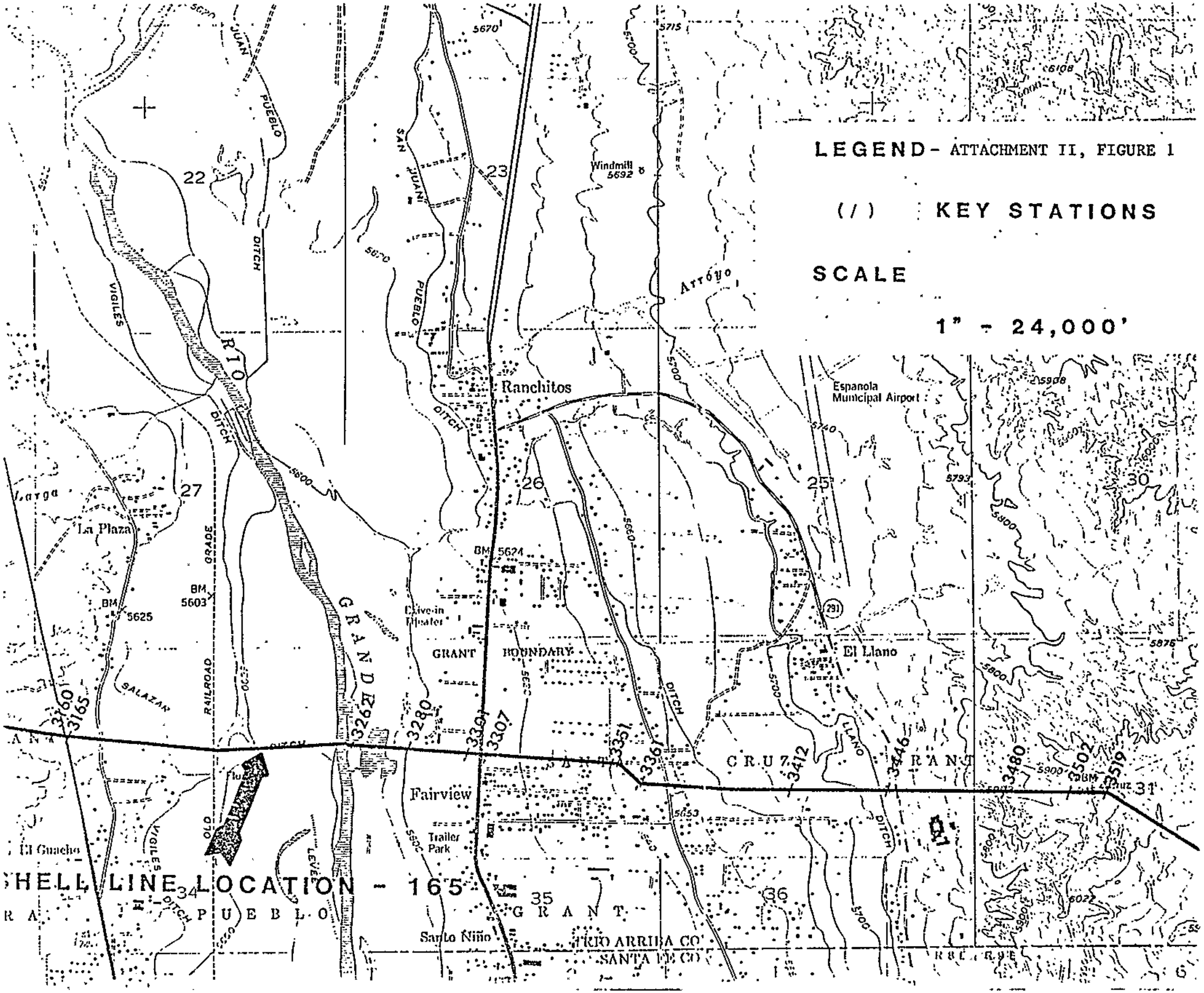
3457	98	3
3458	98	3
3461	98	3
3462	98	3
3464	98	3
3466	98	3
3468	97	5
3469	97	5
3470	97	5
3471	97	5
13 STATION SKIP FROM 3472 TO 3482 DUE TO TO MAN-MADE STRUCTURES		
3484	96	10
3485	75	10
3487	79	15
3488	83	15
3490	92	15
3492	94	15
3494	93	15
3496	96	15
3498	90	20

DETECTIBILITY AT THE SURFACE OF DETONATED BURIED CHARGES:

OBSERVERS IN THE FIELD AT THE TIME OF THE ACQUISITION OF LINE 165 REPORTED THE FOLLOWING OBSERVATIONS:

1. AT A DISTANCE OF 1000 FEET FROM THE BURIED CHARGES, NOTHING COULD BE DETECTED OR HEARD.

2. WITHIN A DISTANCE OF 500 FEET FROM SOME OF THE BURIED CHARGES, A MINOR THUMP COULD BE DETECTED. ACTUAL FORCE OF THE SMALL SHOCK WAS DEPENDENT UPON CHARGE SIZE AND DEPTH (SEE ATTACHMENT III).


LEGEND- ATTACHMENT II, FIGURE 1
(/) KEY STATIONS
SCALE
1" - 24,000'
SHELL LINE LOCATION - 165
Ranchitos
Espanola Municipal Airport
Windmill 5692
Arroyo
La Plaza
Fairview
El Llano
Trailer Park
Santo Niño
El Guacho
RIO GRANDE
GRANT BOUNDARY
CRUZ GRANT
PUEBLO GRANT
RIO ARRIBA CO
SANTA FE CO
SAN JUAN PUEBLO DITCH
VIGILES
SALAZAR
RAILROAD GRADE
LLANO DITCH
Drive-in theater
BM 5624
BM 5603
BM 5625
3160
3165
3262
3280
3301
3307
3351
3361
3412
3446
3480
3502
3519
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ATTACHMENT III

SHELL WESTERN SEISMIC CREW 120 ANALYSIS OF GROUND MOTION VELOCITY OBSERVED DURING ACQUISITION OF LINE 165

Peak Particle Velocities

The U.S. Bureau of Mines has established a vibration standard (RI-8507) for impulse or explosive sources and residential structures in terms of maximum peak particle velocity. This criteria was established by Siskind, et.al. (1980) in their study of residential building damage due to blast induced ground motion.

A graph of the damage criteria is shown in Figure 1. The graph shows safe levels of blasting vibrations for houses using a combination of velocity and displacement measurements. The peak particle velocity limits range from 0.2 to 2.0 inches per second. The Bureau of Mines defines the damage threshhold as the most superficial interior cracking that develops in all homes independent of blasting. The Bureau concludes that a maximum safe level for peak particle velocity is 0.5 inches per second, below which the chance of damage would be exceedingly small.

SWEPI's Party 120 has analyzed several shots from their line 165. Figures 2 thru 7 show graphs of velocity (inches per second) versus distance for the analyzed shots, with a label specifying charge size and hole depth. It should be noted that these shots were chosen to give a fair representation of the charge sizes and hole depths associated with Shell acquisition for line 165. In all cases the peak particle velocity recorded is well below the Bureau's suggested maximum of 0.5 inches per second. In fact, the maximum peak particle velocity found on these shots was 0.06 inches per second directly above shot 3502.

Conversations and a meeting with the staff of the New Mexico Bureau of Mines have shown that Shell's operations were at least 3000 feet from the nearest house that was condemned by the New Mexico CID in December of 1984. It is interesting to note that the maximum peak particle velocity found on any shot at a distance of 3000 feet was less than 0.0003 inches per second. It is Shell's position that no damage was induced by our operations on any of the houses condemned by the State of New Mexico, and the available data demonstrates that we are below the safety limit by a multiplicative factor of 1667.

5. Determine the conversion from millivolts recorded to particle velocity.

Amplitudes in millivolts were converted to particle velocity in inches per second by a conversion factor based on our geophone sensitivity.

The geophone array consisted of twelve geophones, six in series per string and two strings connected in parallel. This configuration yields a geophone sensitivity of 1.94 x 10-4 inches per second per millivolt.

Conversion from millivolts to inches per second is achieved by using the following relation:

$$V = G \times A$$ where

V = particle velocity in inches per second

G = geophone sensitivity = 1.94 x 10-4 inches per second per millivolt

A = amplitude in millivolts

6. Plot peak particle velocity versus distance for each shot.

Peak particle velocity was plotted as a function of radial distance (from the top of the charge) on a log-log scale (see figures 2 thru 7).

Reference:

Sisking,D.E., M.S.Stagg, J.W. Kopp, C.H. Dowding, 1980, Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting: Bureau of Mines Report of Investigations NO. 8507.

Description of SWEPI's Peak Particle Velocity Analysis

1. Choose appropriate shots.

   The shots analyzed were a sample of those in the area of interest and vary in charge size from one to forty pounds. The shots are listed in Table 1.

Table 1

Shot	Charge size
3350	1 lb.
3424	2 lbs.
3464	3 lbs.
3468	5 lbs.
3490	15 lbs.
3502	40 lbs.

2. Make sure that there was no clipping of amplitudes recorded.

   The shots were recorded by a Sercel SN348 Telemetry acquisition system with a fixed gain of 24 db. This setup allows a maximum recorded amplitude of 448 millivolts. The maximum amplitude found on the shots analyzed was 298 millivolts, well below the maximum instrument level of 448 millivolts. Therefore, we conclude that there was no clipping of signal amplitude, and that the peak amplitudes recorded are meaningful.

3. Depulse the shots.

   The instrument low cut filter was set at 12.5 Hz with a 12 db/octave roll off. Mark L-28 10 Hz geophones were used, also with a 12 db/octave roll off.

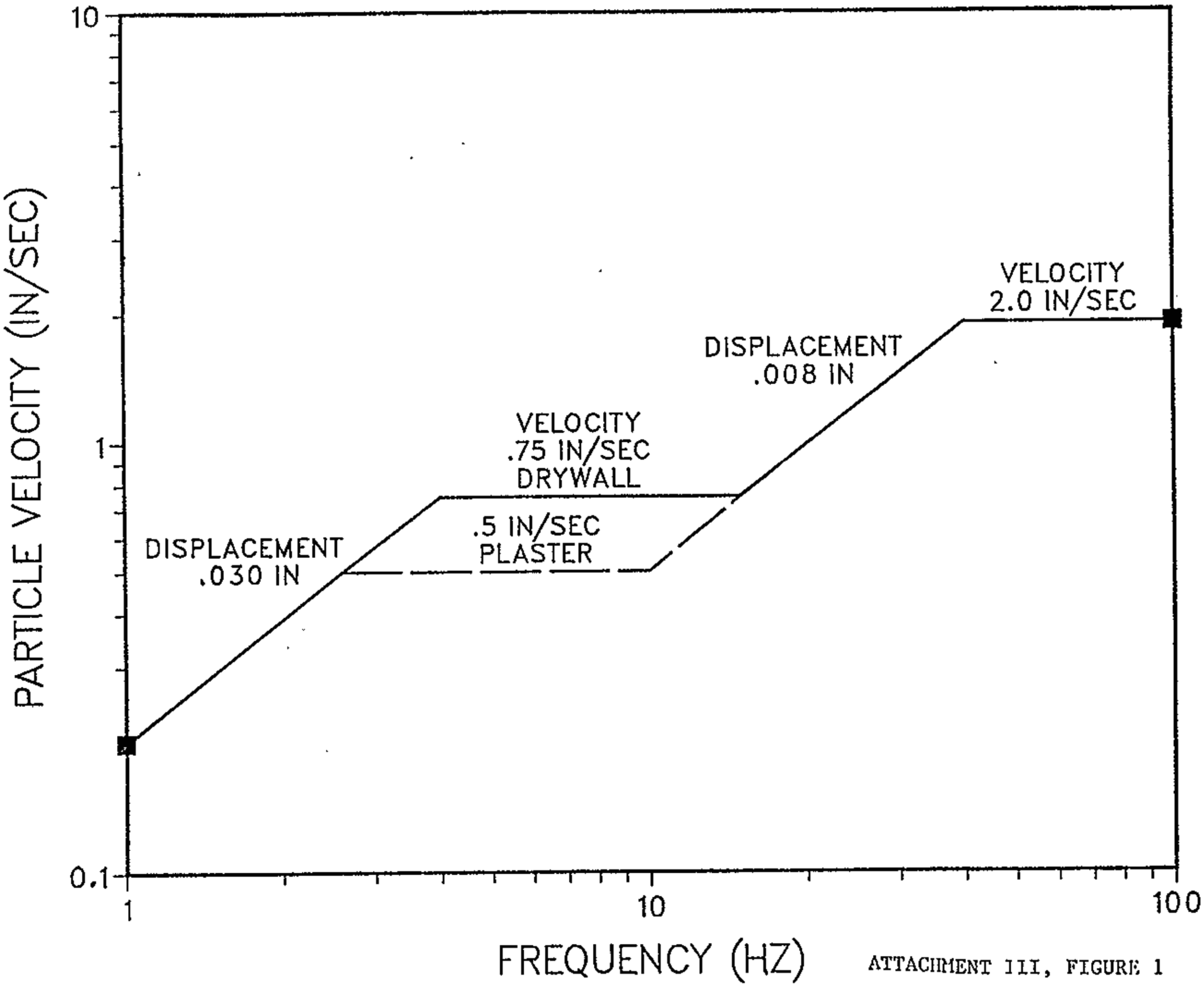
   An internal Shell Western depulse program was used to remove the effect of the instrument and geophone filters, i.e. to boost the low frequencies to equal their amplitudes prior to recording.

   Figures 8 and 9 show the effect of depulsing to boost the low frequencies. In the display after the depulse the initial arrivals have a stronger amplitude than those before the depulse, as does the low frequency ground motion.

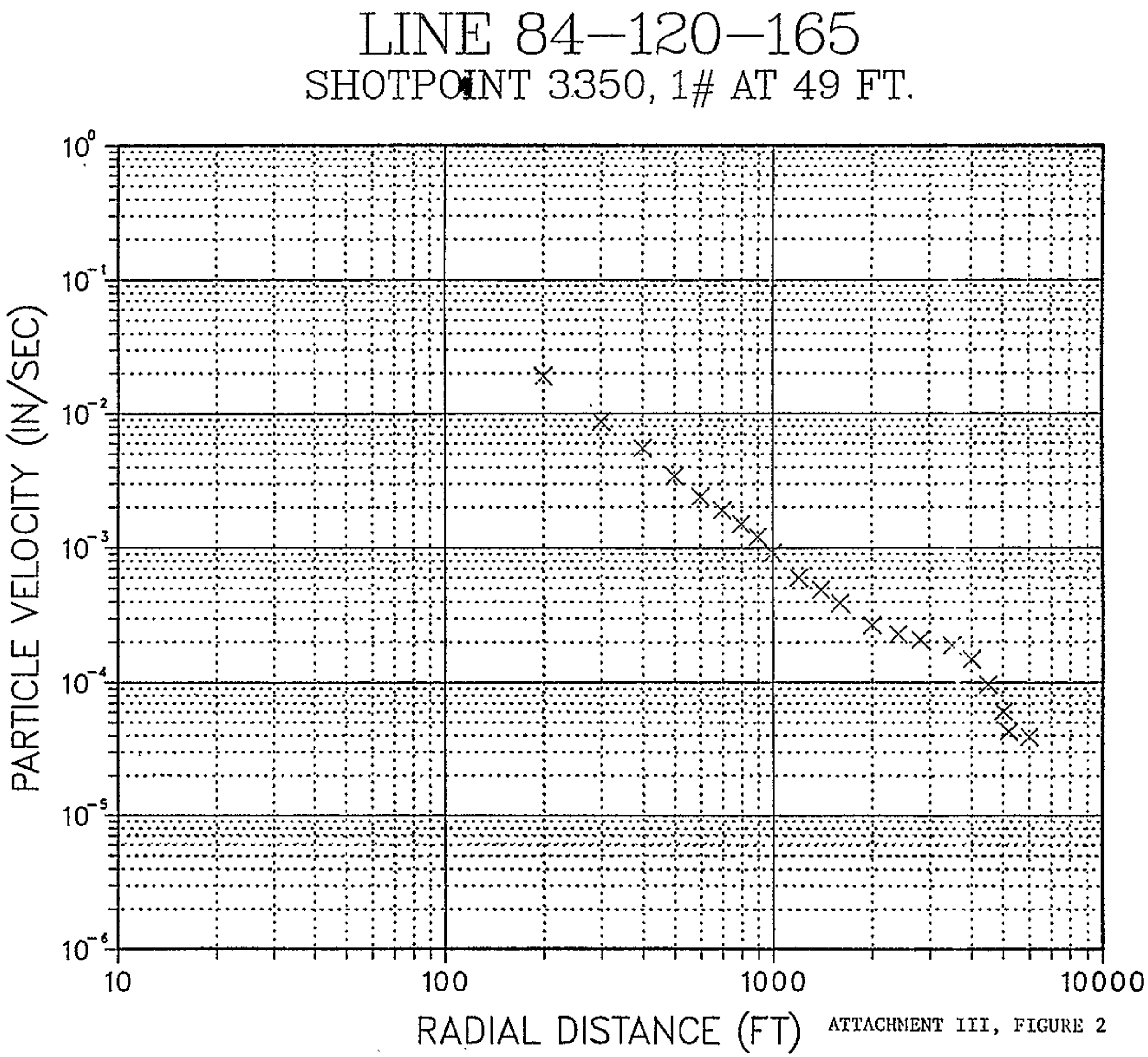
4. Determine the peak amplitude recorded in millivolts for a suite of distances from each shot.

   A Shell Western program that outputs peak amplitude versus distance was run on the shots. Peak amplitude in millivolts was output every 100 feet for each shot.

U.S. BUREAU OF MINES, RI-8507
GROUND VELOCITY STANDARD



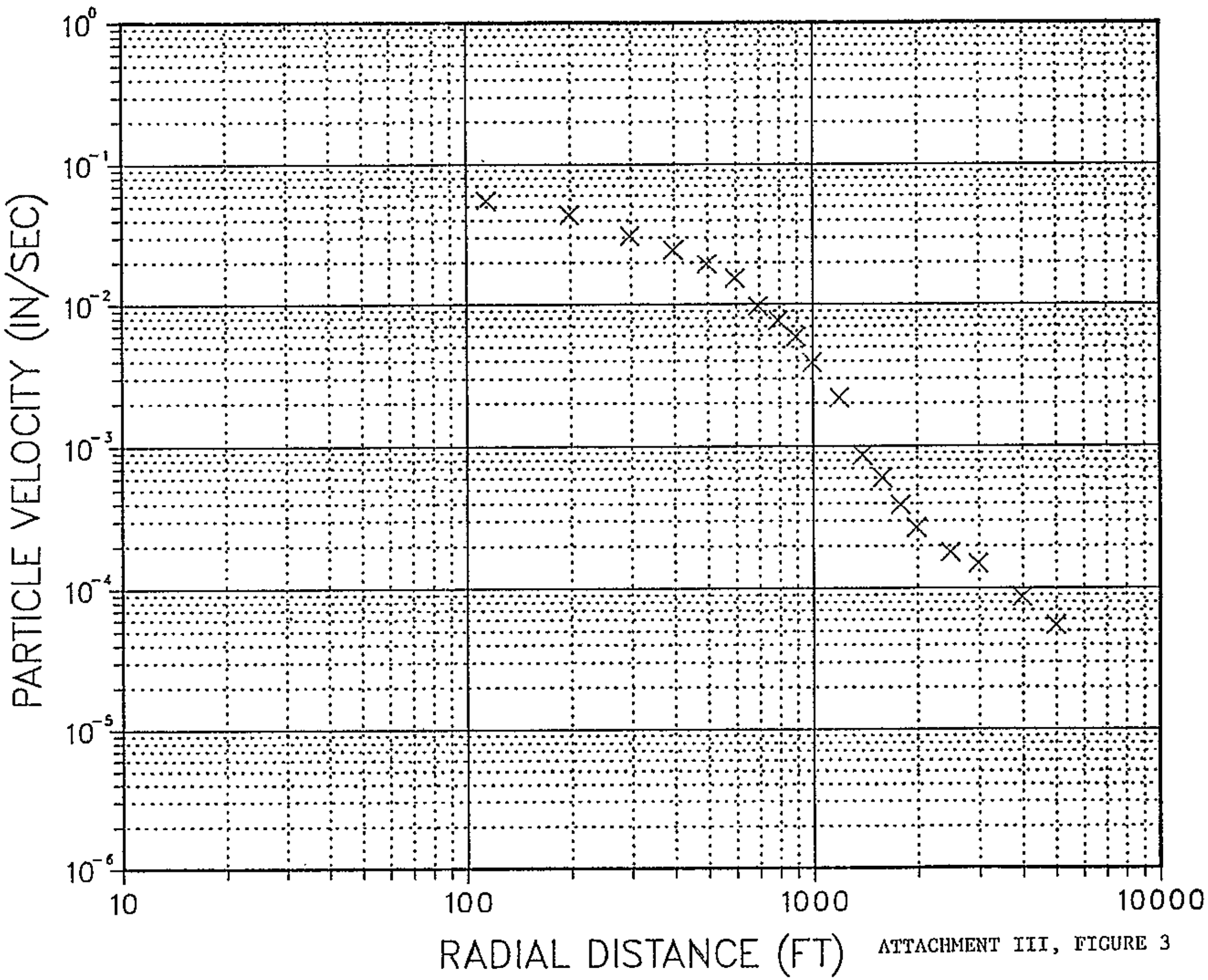
ATTACHMENT III, FIGURE 1



ATTACHMENT III, FIGURE 2

LINE 84–120–165

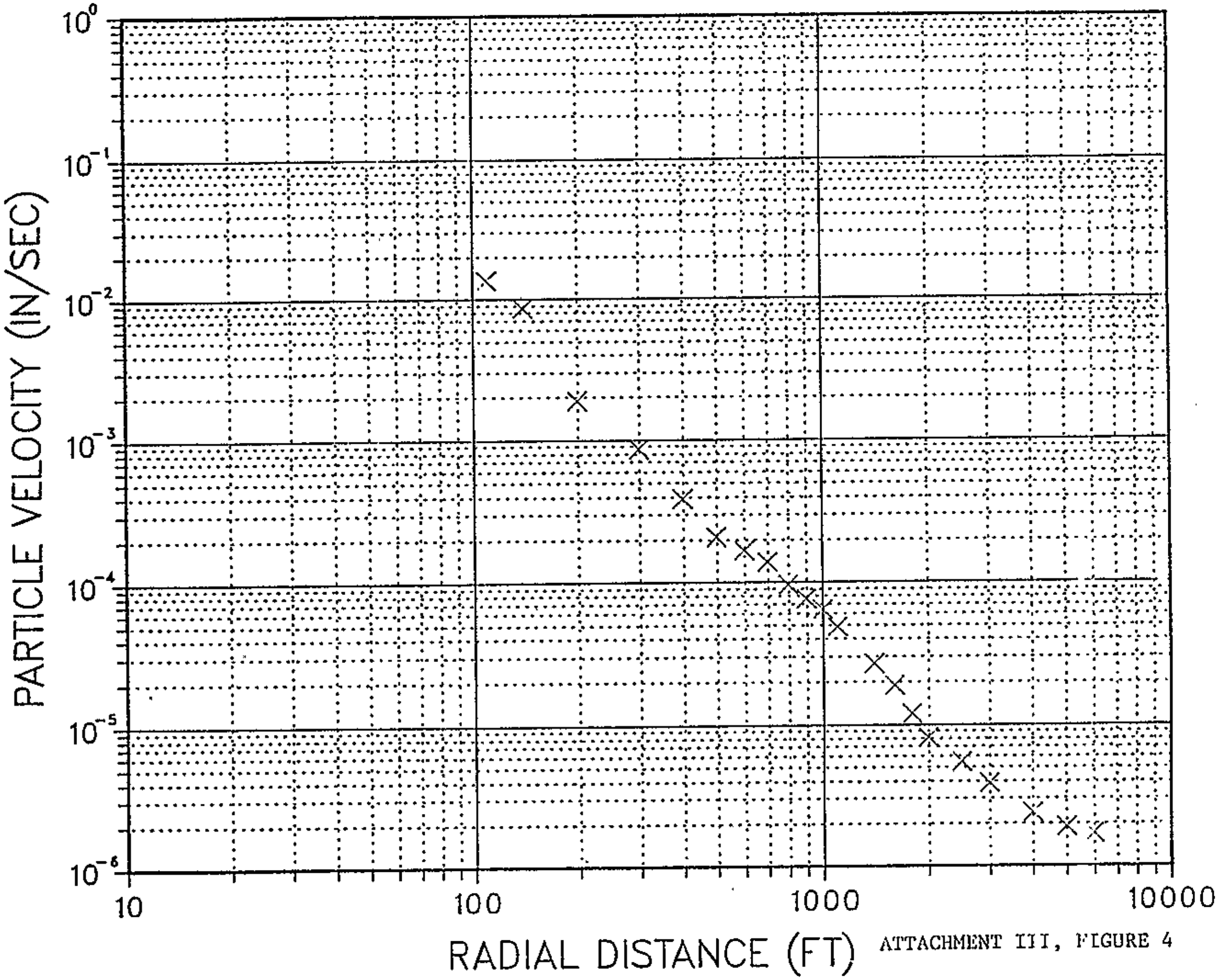
SHOTPOINT 3424, 2# AT 58 FT.



ATTACHMENT III, FIGURE 3

LINE 84-120-165

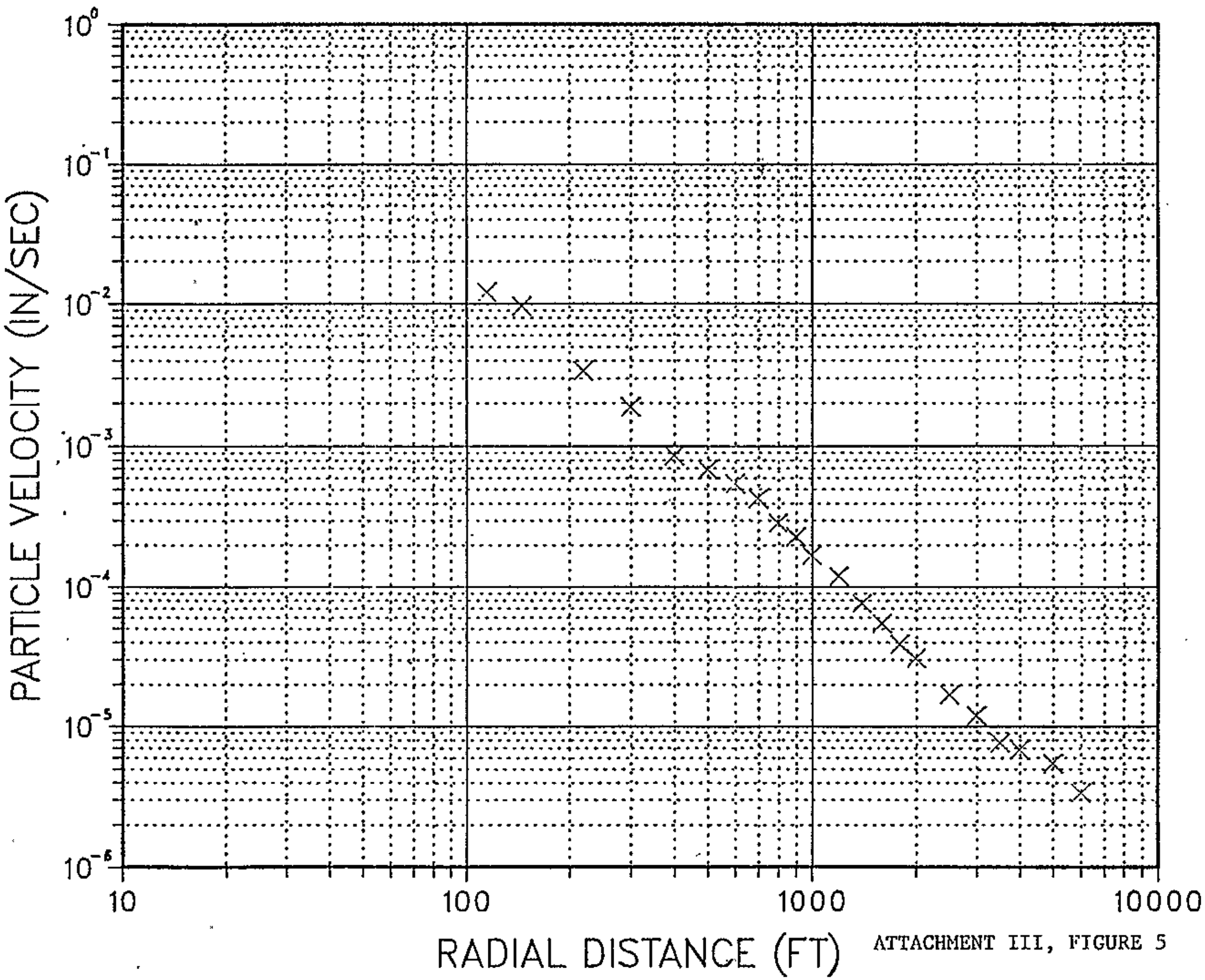
SHOTPOINT 3464, 3# AT 100 FT.



ATTACHMENT III, FIGURE 4

LINE 84–120–165

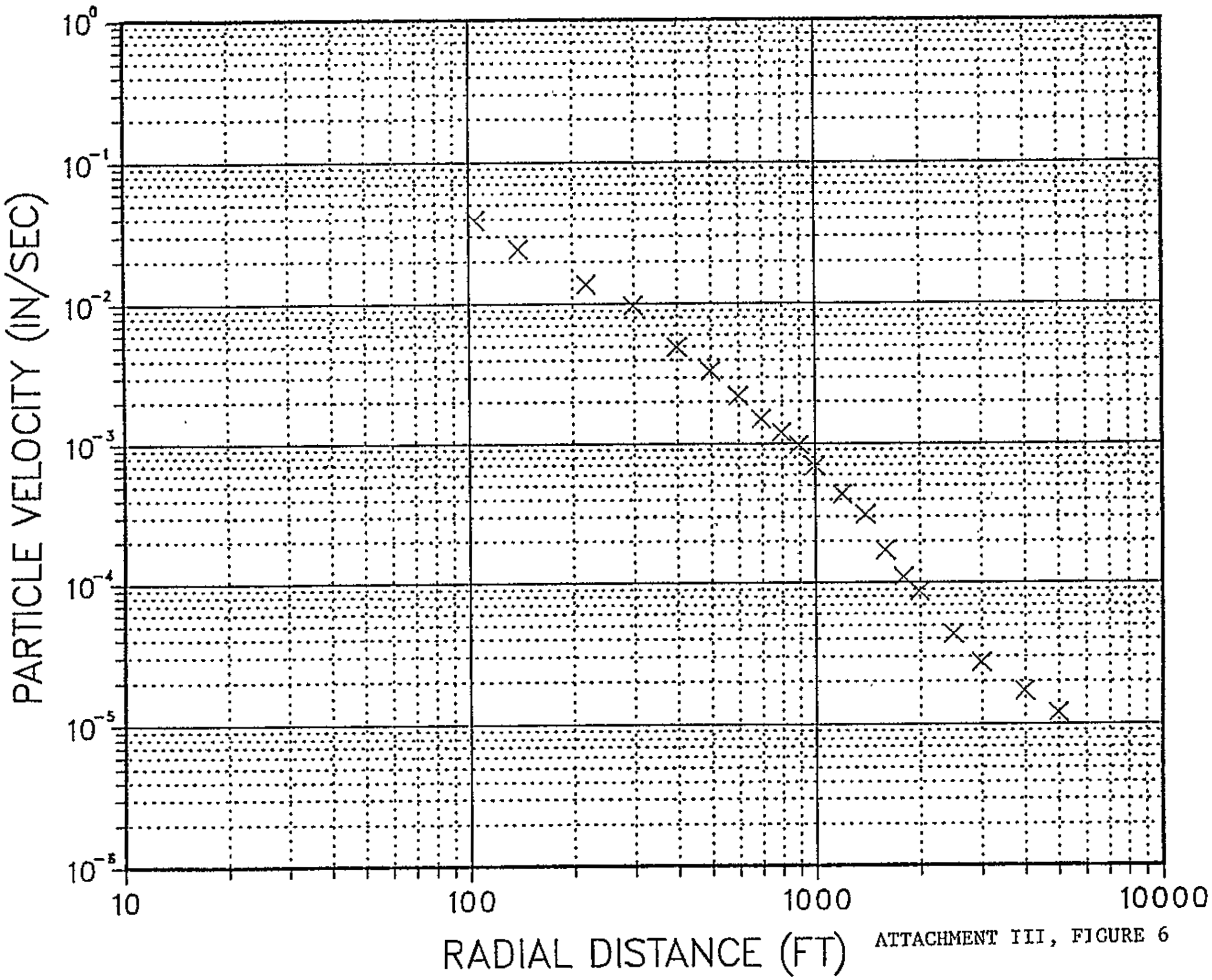
SHOTPOINT 3468, 5# AT 100 FT.



ATTACHMENT III, FIGURE 5

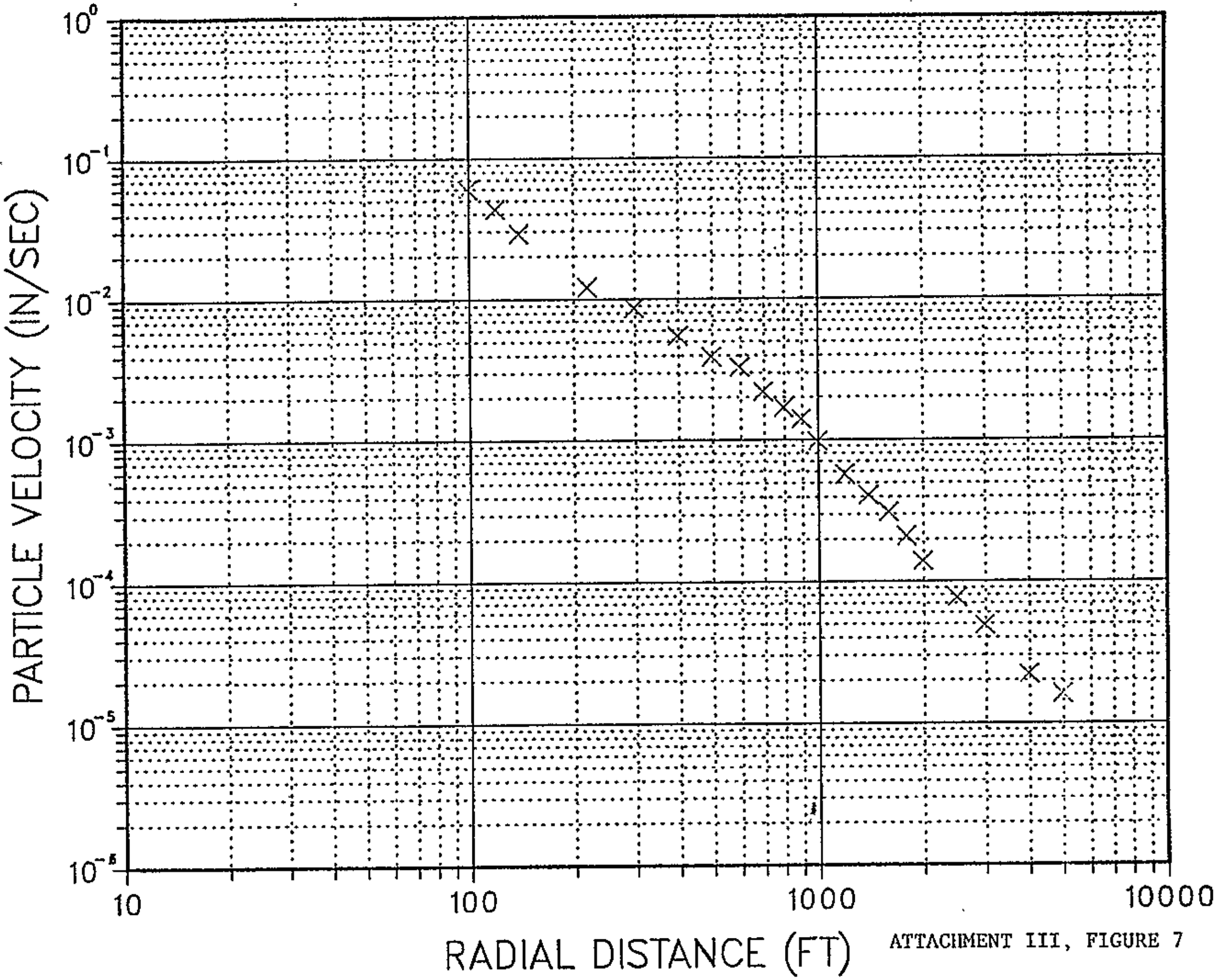
LINE 84–120–165

SHOTPOINT 3490, 15# AT 92 FT.

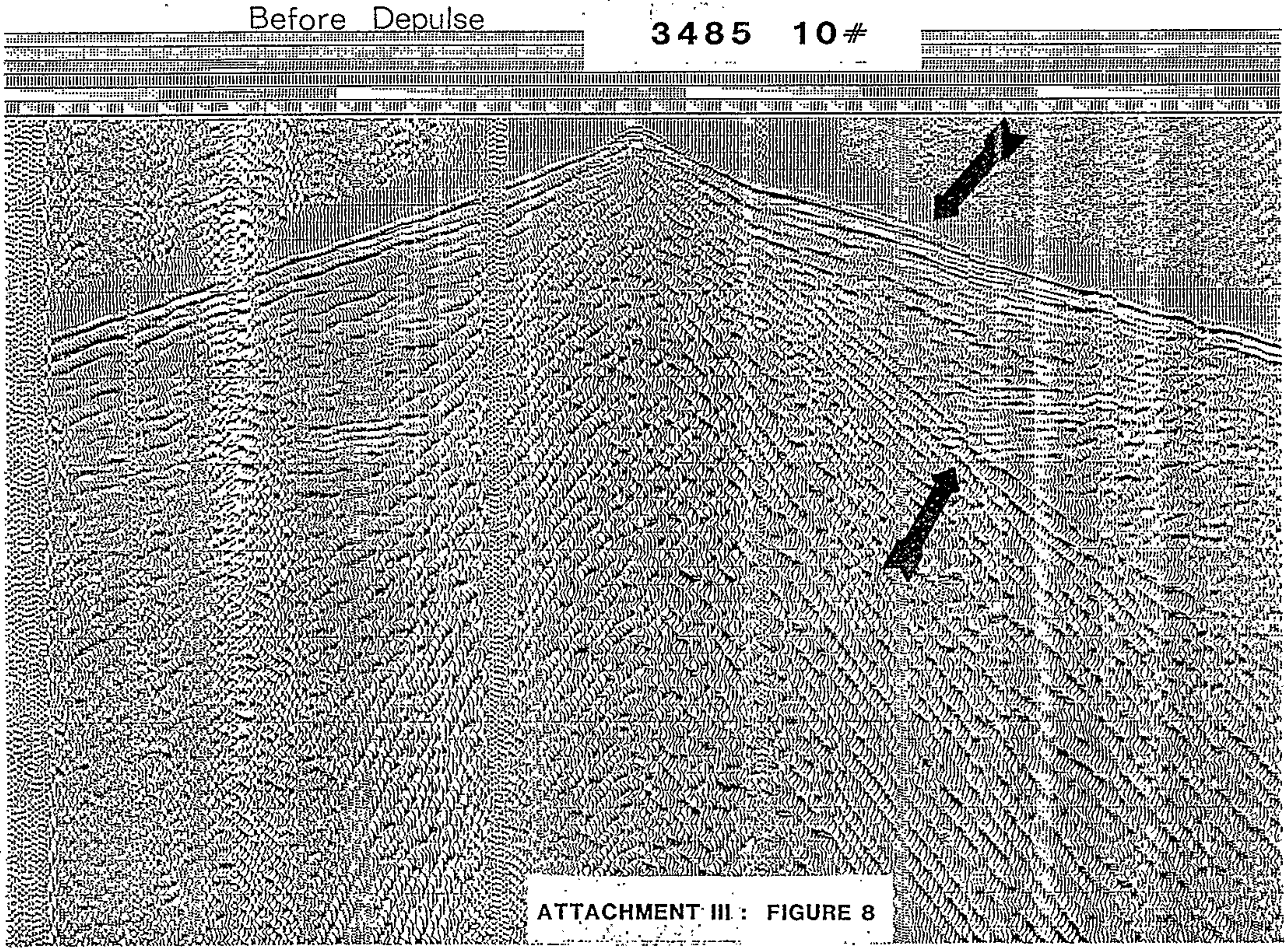


ATTACHMENT III, FIGURE 6

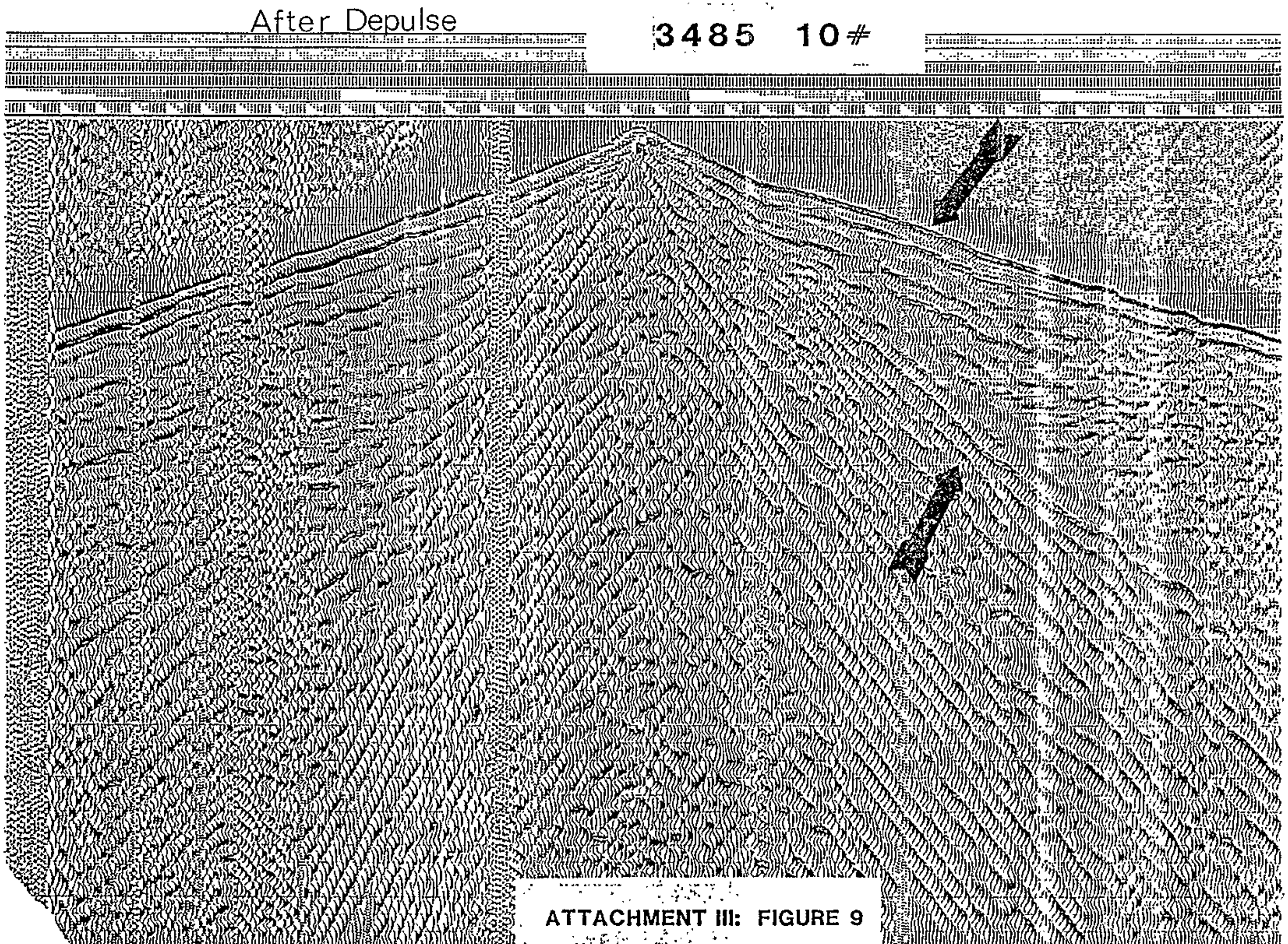
LINE 84–120–165
SHOTPOINT 3502, 40# AT 100 FT.



ATTACHMENT III, FIGURE 7



ATTACHMENT III : FIGURE 8



ATTACHMENT III: FIGURE 9

APPENDIX XVI

Acequia Report - Charles Carrillo

Acequia Systems of El Llano New Mexico

A Historical Review

by

Charles M. Carrillo
Felipe R. Mirabal

Prepared for New Mexico Bureau of Mines
and Mineral Resources

March 1985

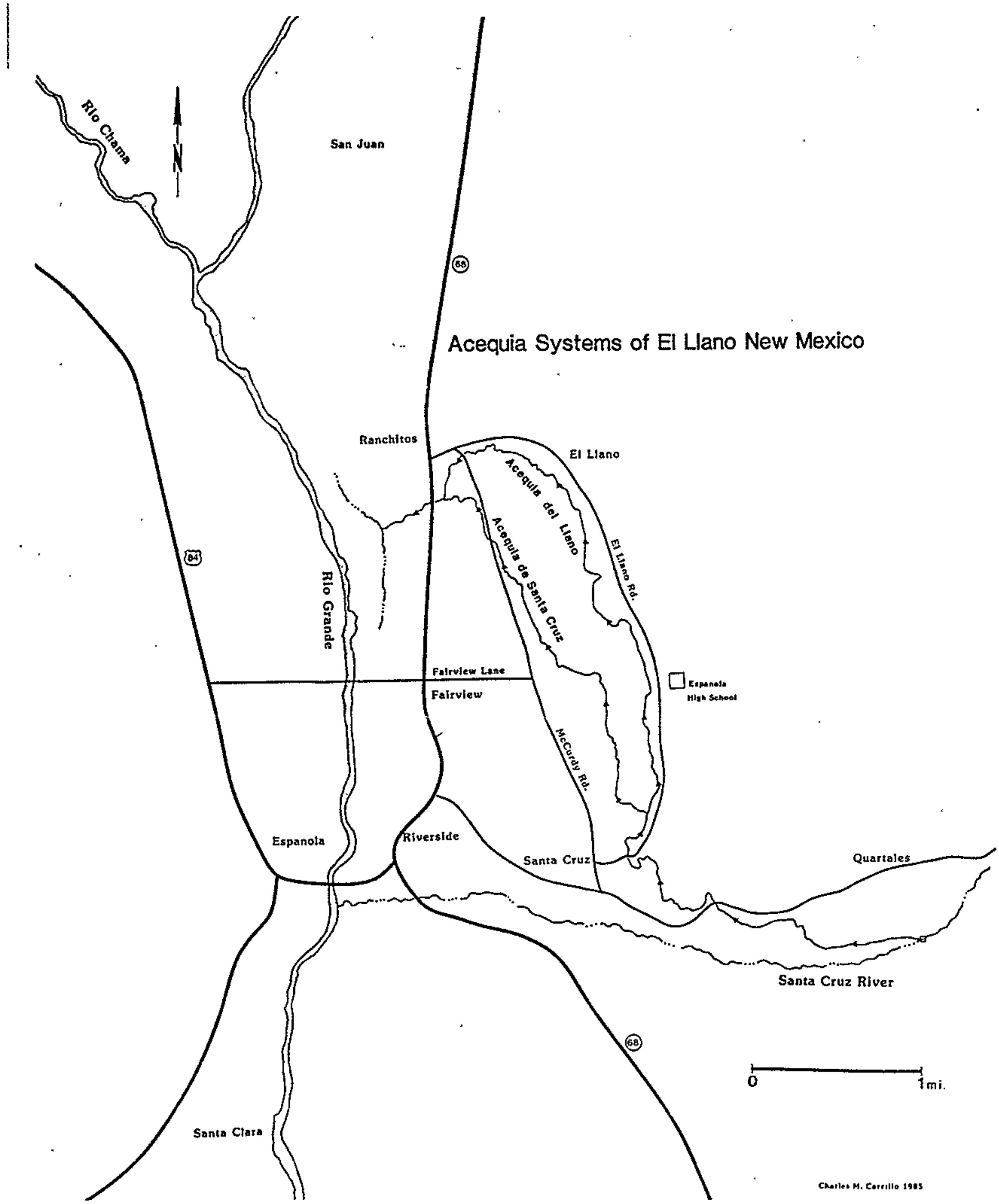
Introduction

Although no comprehensive systematic documentary account of acequia systems in New Mexico has been published, there exists an extensive body of unpublished materials that can be derived from archival sources. Additionally, ethnohistoric information can contribute substantially to our knowledge and understanding of acequia systems of New Mexico.

The present study concerns the acequia system in El Llano New Mexico, of which there is little or no documentation. This overview will examine the history of human land use and occupation prior to European contact, the early colonial period 1598-1680, the reoccupation of New Mexico in 1692 and establishment of La Nueva Villa de Santa Cruz de la Cañada de los Españoles Mexicanos de Rey Nuestro Señor Don Carlos and the permanent irrigation systems in the study area known as La Acequia de Santa Cruz and La Acequia de Llano. A brief examination of the Spanish codification of 1681 known as the Recopilación de leyes de los Reyes de las Indias and the implication for establishment of irrigation systems will be discussed. This will be followed by an overview of traditional Hispanic land tenure practices. A discussion of local subsistence practices will follow. Finally recommendations for future work will be presented.

Research Methodology

Since little or no documentation exists concerning the water systems of El Llano, numerous repositories having documents relating to the study area were consulted. They included the University of New Mexico Library Special Collections Coronado Room, and the New Mexico


Acequia Systems of El Llano New Mexico
Rio Chama
N
San Juan
68
Ranchitos
El Llano
Acequia del Llano
Acequia de Santa Cruz
El Llano Rd.
84
Rio Grande
Fairview Lane
Fairview
Espanola
High School
McCurdy Rd.
Espanola
Riverside
Santa Cruz
Quartales
Santa Cruz River
68
0
1 mi.
Santa Clara
Charles M. Carrillo 1985

State Records and Archives Center. The Santa Cruz Irrigation District Office Manager Jose T. Maestas provided additional information. Numerous informants from the study area were consulted and include: Ernesto Gutiérrez, Lester R. Whitney, Robert Espinosa, and Truman Brigham.

Charles M. Carrillo acted as principal investigator, while Felipe R. Mirabal provided archival assistance concerning the establishment of Santa Cruz and irrigation ditches during the colonial period.

In total, 30 man days were required for the overview. The present historical overview is not an exhaustive comprehensive study. However, the information within this report contains a significant primary data base for future studies.

Prehistoric Indians

At the peak of prehistoric Pueblo development, the main centers of Pueblo population, such as Chaco Canyon, were abandoned, and the main center of the Pueblo population shifted to the east. Soon small pueblos were established in the Rio Grande and Pecos valleys. Archaeological evidence indicates that Pueblo peoples practiced irrigation farming methods that helped to solve problems of subsistence.

> Sections of the middle and northern Rio Grande Valley that showed little or no use by the Anasazi prior to 1100 were occupied for the first time during Pueblo III, by Anasazi horticulturalists (Cordell 1979:142).

During Pueblo III, AD 1100-1300, Pueblo peoples established small villages in the vicinity of the study area.

Spanish Contact

Initial contact figures estimate that there were approximately 40,000 Pueblo Indians when the Spanish arrived. The first Spanish explorer in New Mexico was Fray Marcos de Niza who arrived in 1539. The account of Niza brought about the Coronado expedition in 1540. Other expeditions followed; then in 1598, Juan de Oñate occupied the Tewa pueblo of Okeh. "At San Juan Pueblo, where Juan de Oñate established the first settlement of Spaniards in 1598, the Indians depended largely upon rainfall for their crops, although some ditches were seen nearby" (Simmons 1972:138). He renamed the pueblo San Juan de los Caballeros. Across the Rio Grande from Okeh, near the mouth of the Chama, the Spaniards settled in the Pueblo of Yuque-Yunque. The site was named San Gabriel. In 1610 the capital of the new colony was moved from San Gabriel to Santa Fe.

> Early in 1598 Juan de Oñate, scion of a wealthy mining family, led a body of 400 soldiers, colonists, friars, and Mexican Indian servants northward to occupy the upper Rio Grande Valley. The motive behind Spanish expansion into this area was primarily a missionary one, based upon the desire to bring christianity to one of the last large bodies of sedentary, agricultural Indians remaining unconverted in the Viceroyalty of New Spain (Simmons 1979:179).

Spanish population in the study area continued to grow throughout the 17th century. Most Spanish settlers lived in scattered ranches near the Tewa Pueblos. It is likely that many settlers employed the use of Pueblo irrigation systems, although it is probable that they also constructed new acequias in the study area prior to 1680.

Years of a growing antagonism between Pueblo and Spanish peoples culminated when the Pueblo people revolted on August 10, 1680.

Apparently the settlement of Santa Cruz was well known at the time of the Pueblo Revolt. "Otermin despatched messengers in all directions warning the friars and settlers to flee to Isleta, while those living north were to come either to Santa Fe or to Santa Cruz de la Canada" (Twitchell 1912:210). In 1692 Diego de Vargas was appointed governor of New Mexíco. By 1693-94 he had reestablished the colony of New Mexico and soon after settlements were reestablished into the study area.

Recolonization: Santa Cruz de la Cañada and Adjacent Areas

The bloody events of the infamous Pueblo Revolt in 1680 had their origins in a variety of religious, cultural, social and economic causes. A circumstance that aided the Pueblos was the Spaniards' state of unpreparedness. There was no presidio or regular military garrison in the Province of New Mexico -- all defense would come from the informal militia composed of Spanish citizens who busied themselves with their farms and ranches. The call to arms gathered these men too late to defend effectively the Spanish population on the feast of San Lorenzo, August 10th, which marked the beginning of the great Revolt. Those who survived the inter-Pueblo attack in northern New Mexico made their way to the capital of Santa Fe. Bewildered, helpless and thirsty (for the Pueblos had succeeded in cutting off Santa Fe's water supply), the Spaniards by order of Governor Antonio de Otermín made their way south. The Pueblos had succeeded in removing the Spaniards. Two years later in Mexico City, the royal attorney Martín Solís de Miranda after examining documentation of the Revolt concluded, "The many oppressions which [the Indians] receive from the Spaniards have been the chief reason for the rebellion (Simmons 1980:15; Page 1980:89-90; Sando 1979:197).

After the Pueblo Revolt the Tanos Indians from the Galisteo Valley occupied the site of Santa Fe. The Pueblo Indians were forced to vacate the capital by don Diego de Vargas Zapata Lujan Ponce de León who led the reconquest and reestablishment of New Mexico from 1692 to 1704. These Indians were to leave the capital and establish the pueblos of San Cristóbal and San Lázaro at Santa Cruz. The Tanos were moved once again in 1695 to make room for a contingent of families who came to settle in New Mexico from Zacatecas, the Valley of Mexico and elsewhere. The Tanos were given land in the Chimayó area but would be moved once again by order of Governor Cuervo in 1706 (Reeve 1961:322; Ellis 1980:31-32).

On April 19, 1695 a proclamation was issued in Santa Fe announcing the creation of a new settlement for the newly arrived settlers (Santa Cruz Parish 1983:9; Espinosa 1940:36-38). The proclamation read as follows:

> "Don Diego de Vargas Zapata Lujan Ponze de Leon, governor and captain-general of this kingdom and provinces of New Mexico, its new restorer, conqueror at his own expense, reconquerer and settler of the same, castellan of its forces and garrisons, by His Majesty, etc.,
>
> "The Thanos Indians, of the pueblo of San Lazaro, having by virtue of my order and direction, as expressed in the same and forwarded for its due execution on the twentieth of March 1st of this present year to my lientenant-governor and captain-general, Colonel Luis Granillo, as it appears in the proceedings which by virtue of the said order were had, and the said Indians having consulted with their governors and asked me for the grant of the tract of the Cañada de Chimayo and left to me the said pueblo of San Lazaro and San Cristoval, and I having succeeded in having that of San Lazaro vacated in order to employ and occupy it with the families which his excellency the viceroy, the Conde de Galve, has sent for the settlement of this said kingdom of New Mexico, and they having arrived on the twenty-third of June of the past year one thousand six hundred and ninety-four, their number being in accordance with their list and muster roll, in order that they might be supported and lodged

> until said kingdom was safe, and they came into this said city to the number of sixty-six and one-half families, and in order that they may be together without the intrusion of any others, in view of their union, and in order that they may be contented, they having come from one place and country to this said city, I placed them in the first grade, and I designate the said pueblo, its dwelling houses, its cleared agricultural lands, drains, irrigation ditches, and dam or dams which the said native Indians had and did have for irrigation and the security of raising their crops, and I also designate and grant, in the name of His Majesty, the dams which they may leave open and those which they may open, and the woods, pastures, and valley which the said natives had and enjoyed, without prejudice to the farms and ranches which lie within its limits and district, and all that which it covers and may contain as far as the pueblos of Nambe, Pojoaque, Jacona, San Ildefonso, Santa Clara, and San Juan de los Caballeros, giving these as the boundaries of the tract which the said settlement shall enjoy, hold, and have, and which I make a seat and town, and also possession of the houses which may be given or assigned to them in person: and furthermore, the honorary title of 'Villa Nueva de Santa Cruz de Españoles Mexicanos del Rey Nuestro Señor Carlos Segundo' (Twitchell 1912:21-22).

These new settlers brought with them much-needed farm implements such as picks, shovels, hoes and axes. Each family was given half a fanega of corn for planting (Twitchell 1912:22). Vargas also promised that those who volunteered for a grant of land would be given some. In the course of time, individual allotments were made to various citizens in the Santa Cruz area, which included the El Llano area. Governors Garvas and Cubero alloted land to José Mascareñas at different times from 1694 to 1706. He received land between the pueblos of Santa Clara and San Juan. Cubero granted land to Francisca de la Mora at the pueblo of San Cristóbal in 1697. In 1699 Captain Alonso Rael de Aguilar received land at Cuyamunque Pueblo. Ignacio de Roybal received land in 1702 on the site of the former pueblo of Jacona along the Nambé (or Pojoaque) River. Juan de Maestas was granted land near Pojoaque Pueblo in 1699. Captain Sebastián Martín and Antonio Martín registered land a short distance up river from San Juan Pueblo in 1703. In 1714 Antonio de Salazar petitioned for land across the Río Grande which had been in the possession of his grandfather, Captain Alonso Martín Barba. In 1739 Vicente Durán de Armijo of Santa Fe was given land alongside of Nambé Pueblo. A veteran-pioneer of the reconquest, Captain Nicolás Ortiz received land south of San Ildefonso Pueblo in 1742. An increase of allotments caused a number of settlements to be created in the Española Basin (Reeve 1961:323; AASF: San Juan and Santa Cruz Baptismal Registers). By the 1740s Santa Cruz acquired more than 100 families. O'Crouley's account of New Spain in 1774 briefly mentions the Province of New Mexico; he states of Santa Cruz:

> The town of Santa Cruz de la Cañada is eight leagues northwest of the capital. Its population includes more than three hundred families of Spaniards who deal in wheat and Indian corn, which this country produces in abundance, and some small livestock (Galvin 1972:57).

Fray Francisco Atanasio Dominguez in his report of 1776 of the New Mexico missions mentions of Santa Cruz de la Cañada:

> In view of the location as described, it is obvious that what compromises the villa will have lands in accordance with the site, since it offers such, noting that some settlers use the foresaid water for their irrigation and others find the Río del Norte [Río Grande] more convenient. As a result of the fine location described, some lands were better than others, and therefore (barring accidents) there is a copious harvest. Here there are good orchards of fruits such as pears, grapes, peaches, and others that resist the cold, and there is also a fine crop of these (Adams 1956:83).

He concludes his observations of Santa Cruz with a population schedule -- the census states that 125 families with 680 persons were living in the villa. San Juan Pueblo was the next mission in Dominguez' report. He says of the lands:

> The Indians have lands above and below the pueblo and corresponding lands on the other bank of the Río del Norte. They extend for a league above the pueblo and a league below it, and the same distance along the other bank . . . and they are irrigated by a ditch common to settlers and Indians, for they take it from the said river very far up about two

leagues or more (Adams 1956:89-91).

He concludes his account of San Juan with a census and states, "a very large group of settlers recognize this mission for their spiritual administration." He tallies the following settlements as follows: San Juan is composed of 61 families with 201 persons, Rio Arriba 51 families with 299 persons, Moya 5 families with 38 persons, Bosque Grande 36 families with 187 persons, Canoa 7 families with 30 persons, and Embudo with 14 families of 69 persons (Adams 1956:89-91).

Marc Simmons in an interesting article on colonial farming in New Mexico mentions

> One of the chief problems facing the settlers throughout the colonial years was the scarcity of land suitable for tilling. The most fertile soil lay in the principal stream and river valleys, and there, too, could be found the only large and reliable source of water available for ditch irrigation. Such lowlands, however, comprised only about 1 percent of the total land area of the province. And most of that, within the upper Rio Grande drainage, was already under cultivation by the Pueblos.
>
> Spanish colonial law strict in prohibiting anyone from encroaching upon lands of the Indians. Indeed, it is assumed that Oñate's first settlers usurped fields belonging to San Juan Pueblo and that, at least in part, it was the slow-moving wheels of the legal system which obliged them in 1609 or early 1610 to move southward to the, then, unoccupied valley of the Santa Fe River.
>
> As Pueblo population steadily declined during the colonial years -- owing principally to warfare, famine, and pestilence -- irrigable farms were left vacant and could be reassigned to Spaniards under the laws regulating land grants. Nevertheless, the European population expanded so rapidly, particularly in the last century of the period, that finding enough cropland to answer the agricultural needs of settlers remained an acute problem (Simmons 1983:5).

All farming implements of the colonial period were of the most elementary form since they were all homemade. Most wrought iron was imported or too expensive for an ordinary laborer. All carts, plows, spades and hoes were made of wood. Two-handle steel plows did not arrive in New Mexico until the late 1840s during the Santa Fe Trade. All villagers were self-reliant (Dickey 1949:8).

In 1849 the account of don Pedro Bautista Pino was published in Mexico City. His Noticias were his report to the Spanish Cortés or legislature which met in Cádiz, Spain in 1812. Pino served as deputy to the court and made the costly and lengthy trip to Spain only to report about an obscure and distant province. His account is a description of New Mexican colonial life and environment. Pino says of the produce in the area that, "it is proper that found in other countries of the same temperature and that beyond it being of prime necessity for the maintenance of its inhabitants excellent grains and abundant legumes are produced." Of the fruits Pino states, "they are few but are of good quality; there are very good apples, apricots, strawberries, wild blackberries, plums, grapes, peaches, chokecherries, excellent melons, and watermelons" (Pino 1849:121).

Although Santa Cruz de la Cañada was one of the four major population centers in the late 1760s its church served only genízaros or detribalized Indians who took the Spanish way of life as the only Indians under its jurisdiction. This situation helped in the secularization of the parish (Kinniard 1979:37). Bishop Tamarón in his episcopal visit of June 1760 mentions that 1,515 Spaniards and mixbloods were scattered up and down the valley (Kessell 1980:82). As settlement in the Española Basin continued to expand the network of the traditional system becomes more intricate (Cortazar 1984:38; AASF: Loose Documents 1826#9).

Instructions for the establishment of Spanish towns in the New World were given in a royal codification of 1680. This codification was known as Recopilación de leyes de los Reyes de las Indias. The first requirement for colonization of village sites in New Mexico after the recolonization in 1692, was the construction of irrigation systems. Numerous royal ordinances along with the Recopilación provided instruction based on irrigation practices traditionally employed in Spain since the days of the Roman Empire for laying out ditches and regulating the distribution of water for both domestic and agricultural use. The Recopilación also provided that all waters in the New World were common to all local inhabitants. It also contained passages obligating local officials to supervise irrigable lands and the distribution of water in communal ditches. Included in the Recopilacion were laws that governed individual water users in the manner in which they would cooperate with other users in the maintenance of irrigation systems. Many of the same principles originally applied to La Nueva Villa de Santa Cruz de la Cañada de los Españoles Mexicanos del Rey Nuestro Señor Don Carlos Segundo are still practiced in El Llano. Ditches are still held in communal ownership where the apportionment of maintenance labor and allotment of water use is still supervised by an elected mayordomo or ditch boss.

In 1914 the Supreme Court of New Mexico made the following observations concerning the ancient institution of acequias of New Mexico:

> "The community irrigating ditch or acequia is an institution peculiar to the native people living in that

> portion of the Southwest which was acquired by the United States from Mexico. It was a part of this system of agriculture and community life long before the American occupation. After the Territory of New Mexico was organized, the legislature, by the act of January 7, 1852 (Laws 1851-52 [1851-52], p. 276), provided for the government of community acequias, and doubtless incorporated into the written law of the Territory, the customs therefore governing such communities.
>
> New Mexico being in the arid region, the early settlements were established along the banks of perennial rivers, or in the mountain valleys where water from springs and creeks was reasonably certain to be available for irrigation at the needed times. As a protection against Indians, settlements were made in communities, and the people built their houses and established their towns and plazas close together and cultivated the land in small tracts adjacent to the settlement. When a settlement was established, the people by the joint effort would construct an irrigation ditch, sufficiently large to convey water to their lands for the irrigation of crops. Each individual owned and cultivated a specific tract of land, sufficient to provide food for the needs of his family, and from the main ditch laterals were run to the various tracts of land to be watered. The distribution of water and the repair of the ditch was in charge of a mayordomo, or officer elected by the water users under the ditch. This official would require the water users to contribute labor toward the repair of the ditch and its maintenance, and also distributed the water to the various irrigators equitably, in proportion to the land to be irrigated as his necessities required when a land owner under a community acequia conveyed his real estate, his right to the use of water as a member of the community passed with the real estate (Snow v. Abalos, 18.N.Mex. 681, 691, 692-693, 140 pac. 1044 (1914).

As in most Hispanic communities the community irrigation systems or acequias became the eventual instrument for providing water for most of the irrigated land. In most cases community ditches have been regulated by elected or appointed officials. The mayordomo (ditch boss, supervisor) oversaw the yearly maintenance of the acequias, which included annual cleaning and allocation of water.

Dates of Acequias in the El Llano Area

The two acequias that carry water through the study area are quite old. Archaeological data from surrounding areas indicate that Pueblo peoples were established as horticulturalists in the Rio Grande Valley after AD 1100.

Soon after Juan de Oñate established the first settlement of Spaniards in 1598, ditches were established in the vicinity, often incorporating older Pueblo ditches. The settlement of Santa Cruz de la Cañada soon grew up along the Santa Cruz River, and the Santa Cruz acequia was established. Because of a growing demand for agricultural land, settlers in the Santa Cruz area soon established the El Llano acequia. This acequia ran somewhat parallel to the Santa Cruz acequia and emptied into the Rio Grande in the area now known as Ranchitos.

> "The pueblo ditch was approximately 300 years old when Mexico gained control of the valley. It was used as an Indian pueblo ditch previous to that time. Approximate ages of the other ditches are as follows: Santa Cruz and Llano 300 years old (Tewa Basin Project 1936:6).

Apparently research conducted during the 1930s showed that the acequias of Santa Cruz and El Llano were constructed sometime during the 1630s. In 1680 the Pueblos revolted and it was not until 1692 that a successful recolonization took place. In 1694 Diego de Vargas forced Tano Indians to vacate lands in Santa Cruz. These lands were soon reoccupied by Spanish colonists from Mexico. Archival data indicates that the new colonists were pleased to find dwellings, cleared agricultural land, drains, irrigation ditches and dams which the Tano Indians had built.

At the time of American Independence in 1776, Dominguez described a thriving community at Santa Cruz, and commented "Here there are good orchards of fruit such as pears, grapes, peaches and others that resist the cold, and there is also a fine crop of these" (Adams and Chavez 1956:83).

Archival data, therefore indicates that the Santa Cruz and El Llano ditches have been operative since the mid 1600s. These ditches are still maintained and few changes have apparently occurred since the Spanish colonial period. Users have installed modern headgates and concrete diversions at hundreds of laterals.

In 1964 the entire Santa Cruz acequia was concrete-lined, eliminating much of the constant seepage that had occurred over the past centuries. At present only a portion of the El Llano ditch is lined. There are few wasteway structures in the present ditches. Surplus water is often allowed to run through the long lengths of the ditches. This contributed to seepage before the ditches were concrete-lined.

Users first obtain water in March and the ditches are used until late October.

<u>History of Santa Cruz Irrigation District 1900-1931</u>

A number of interesting events took place during the 1st quarter of the 20th century concerning irrigation practices in the Santa Cruz watershed area. In 1919 a number of landowners from the lower valley petitioned for an adjudication of water from the Santa Cruz River. Apparently upper valley landowners, namely those from Chimayo, protested the adjudication. The protest was upheld in court on the basis that the division of water in the past was, in its judgement, just. In 1924 an individual by the name of Conger organized landowners in the lower valley

> The people built a highline ditch out of the Rio Grande fourteen miles long, but no rights to the water coming out of the river were established. The scheme failed when interests in the Mesilla Valley protected this new withdrawal of water from the Rio Grande. The application for formation of a conservancy district was likewise denied (Santa Cruz Irrigation District 1937:2).

In 1925 landowners of the lower valley were once again organized, this time by John Block. Mr. Block promoted the idea of a storage reservoir on the Santa Cruz River. Mr. Block sought the advice of an individual by the name of Seth, a lawyer from Santa Fe. He drew up a petition for the formation of an irrigation district. Some 417 landowners in the valley signed the petition while approximately 75 did not. Those who did not resided in the Chimayo area. A district was formed and the State Legislature of New Mexico provided $5000.00 for a feasibility study for a reservoir in the upper valley. In September 1926 the Ajax Construction Company of El Paso, Texas began construction on the Santa Cruz Reservoir; 18 months later the company declared bankruptcy. The Anderson Brothers of El Paso completed the construction of the dam in 1931.

El Canal

While there are presently two main ditches that carry water into the El Llano area, the acequia de Santa Cruz and the acequia de Llano, there are literally hundreds of small sangrias (veins) that divert the water to various fields. All water used in these acequias is diverted from the Santa Cruz River. While it appears that water in both ditches runs uphill through El Llano, the acequias actually follow the contours of the land and bring water from the east to the north.

Numerous informants in the vicinity recalled that there once existed another large acequia in El Llano that was to bring water from the Rio Grande, and carry the water southward into the community. The remains of a large acequia are visible on recent areal photographs.

Mr. Ernesto Gutiérrez of El Llano N.M. (age 71) remembered that as a young boy he heard stories of an acequia known as "El Canal" that originated in Velarde N.M. and ran south along the talus slopes east of the Rio Grande into the El Llano community. Mr. Gutierrez stated that his father who was born in 1873 often talked about the old canal that apparently was established even before his time. The canal apparently failed for two reasons: 1) large arroyos originating in the foothills east of the canal often washed out during flash floods, leaving sections of the canal unusable, and 2) no water rights were ever established for the users of "El Canal." Mr. Gutiérrez recalled that the canal was established by "Anglos" from back east and that the canal originated in Valarde at the "Presa de la acequia de los Chicos" (ditch flume of the ditch of Chicos). Apparently the canal was excavated by local men using only hand tools, and was never used to carry water (Gutiérrez 1985).

Mr. Lester Ray Whitney, a board member of the acequia de Santa Cruz provided additional information on the abandoned acequia. Mr. Whitney (age 64) is a native of the area and has been an active member of the acequia association since 1956. He stated that the old acequia which came from Velarde was built by Mormons. His informant was Charles Peterson who died in 1940. He recalled hearing stories about the old acequia, and that it failed because of washouts at arroyo crossings (Whitney 1985).

Mrs. Lois Worlton of Los Alamos N.M. revealed that a Mormon community was established in the Española Valley as early as 1893. A chapter was operative in Fairview in 1907. Fairview is adjacent to the El Llano area. H. Vern Payne attorney, an active member of the Mormon community in Albuquerque was consulted. He was aware that a Mormon ditch once existed in Fairview and suggested that the ditch was most probably constructed soon after the Mormon community was established.

Mrs. Worlton commented that it was very typical of Mormon communities to construct irrigation ditches. She added that the Fairview area was chosen because it provided excellent opportunities for raising fruit.

Additional research is required to establish the history of Mormon irrigation systems in the study area.

Hispanic Tradition

Traditional Hispanic village settlement patterns of the colonial period resulted in tracts of agricultural land being assigned to families, which were often perpendicular to major water courses. Grantees would receive a private allotment for a homesite and also a strip of agricultural land adequate for supporting his family.

> "These strips were usually one hundred fifty _varas_ wide, a _vara_ being approximately thirty-three inches. The length of the strip extended from the irrigation ditch at the high end

> of the field to an area as close to the riverbank as cultivation could be done, since short irrigation ditches were dug upstream of the fields and ran roughly parallel to the stream from which they obtained their water. As the population grew, ditches were sometimes many miles long and brought water, by the means of long flumes, to fields distant from the river bank. Despite the shortage of even the simplest tools, irrigation ditches were at times so well engineered that they could carry water over hills (Swadesh 1974:18).

It is a custom among Hispanic families in New Mexico to divide land equally among direct hiers both male and female, thus reasonably large tracts of land equally divided and subdivided among hiers for a few generations became long narrow strips of property. Agricultural tracts within the study area are no exception as most of these tracts were historically used for subsistence farming. Although subsistence farming is no longer practiced in the area, historically as late as 1945 the majority of inhabitants in El Llano were subsistence farmers. Large portions of agricultural land are still farmed, although alfalfa has replaced many garden crops.

Agricultural Practices in the Study Area

Historically the subsistence farmer in the study area was not specialized in single crops production. People engaged in a variety of agricultural pursuits which were usually noncommercial. Crops included chili, garden vegetables, corn, legumes, a variety of melons, wheat, and fruits. Chili was once the most important crop in the study area, both as a subsistence crop and as a cash crop. In 1940 the following account appeared:

> Wheat is a typical crop to this subsistence farming. It is often grown on plots so small that an ordinary two-horse riding plow would encounter difficulties in turning, so the land is broken with a small one-horse turning plow (USDA,

Bureau of Agricultural Economics 1940:65).

At the present time irrigated lands within the study area support a variety of agricultural pursuits. Numerous apple orchards dot the landscape. During the summer months, gardens are a common sight throughout the area.

Water is initially diverted into the Santa Cruz acequia in the spring, usually during the month of March. From there water is diverted into the El Llano acequia. Throughout the summer months and into the fall, water is continually supplied to the two systems. Sometime in September or October the water supply is discontinued, leaving the acequias empty during the winter months.

The Santa Cruz and El Llano Ditches Water Rights

The following information was obtained from Jose T. Maestas, Manager of the Santa Cruz Irrigation District, February 1985, March 1985.

Board Members elected to the Santa Cruz ditch in 1984 include:

Ricardo Quintana - Mayordomo (Ditch Boss)
Lester R. Whitney
Truman Brigham
Ross Lopez

Board Members of the El Llano Ditch include:

Robert Espinosa - Mayordomo (Ditch Boss)
Truman Brigham
Eddie Lopez
Sam Salazar

Water Rights and Usage Santa Cruz Irrigation District 1975

The following information is contained in the United States District Court Case No. 7488 Santa Cruz Water Rights, New Mexico State Engineer 1975

Acequia Santa Cruz
State Engineer File No. 1659
Santa Cruz 530.41 acres, Indian Land 7.00 Total 537.41
Acequia Santa Cruz diverts from the north bank of the Santa Cruz River within the Santa Cruz Grant, New Mexico Coordinate System Central Zone
X = 570.585 and Y = 1,814,340 Santa Fe County, N.M.

Duty of Water: Not to exceed 2.8 acre-feet in total of 537.41 acres irrigated

Amount of water not to exceed 1,504.75 acre-feet in any one year, plus such reasonable conveyance loss from the point of diversion from Rio de Santa Cruz to the individual farm headgates as may be determined thereafter by court (New Mexico State Engineer 1975:34).

Acequia de Llano
State Engineer File No. 1659
El Llano 472.18 acres of irrigated land, plus 22.98 acres of Indian land.
Priority of Diversion: The acequia de llano is located in the Santa Cruz Grant. The position of this diversion on New Mexico Coordinate System, Central Zone is
X = 570.585 and Y = 1,814.340.

Duty of Water: Not to exceed 2.8 acre-feet on a total of 495.6 acres irrigated.

Amount of Water: Not to exceed 1,386.45 acre-feet in any one year, plus such reasonable conveyance loss from the point of diversion from Rio de Santa Cruz to the individual farm headgates as may be determined by court (New Mexico State Engineer 1975:39).

A total of 2,891.20 acre-feet of water is alloted the combined ditches of Santa Cruz and El Llano. The water is derived from the Santa Cruz River near Quartales N.M., approximately 3 miles east of Santa Cruz. Water in the Santa Cruz River derives from the Santa Cruz Dam which was completed in 1931. Before the dam was constructed runoff in the Santa Cruz watershed from the slopes of the Sangre de Cristo Mountains was at best unpredictable. Since the construction of the dam and regulation of water, water usage has been fairly constant in the Santa Cruz and El Llano ditches. Excess water in both the Santa Cruz and El Llano ditches is carried into Ranchitos, N.M., where it ultimately drains into the Rio Grande.

Recommendations for Future Work

The present report represents a historical overview of the acequia systems operative in the El Llano community. Numerous archival repositories were consulted, yet there remain additional archival resources that should be checked. While the present overview provides an adequate primary data base for understanding the historic use of acequias in the study area, additional research is recommended.

This should include the following research:

1. An indepth study of prehistoric horticultural practices of the study area.
2. Archival search in the Court of Private Land Claims and the Office of the Surveyor General of the United States. 1848-1920.
3. Archival research at the State Engineer's Office of New Mexico.
4. Archival searches concerning the establishment of the Mormon community and its irrigation system in Fairview, N.M.
5. Archaeological testing of abandoned water systems in the El Llano area.
6. Additional interviews with local residents are crucial for understanding present land use patterns.

The recommended archival, archaeological, and ethnohistorical research will provide an excellent and comprehensive data base concerning human land use patterns in this area of New Mexico.

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APPENDIX XVII

Moya Survey Data

APPENDIX XVII TABLE A-1

CONTINUED MONITORING OF SURVEY STATIONS WITHIN MOYA SUBSIDENCE AREA

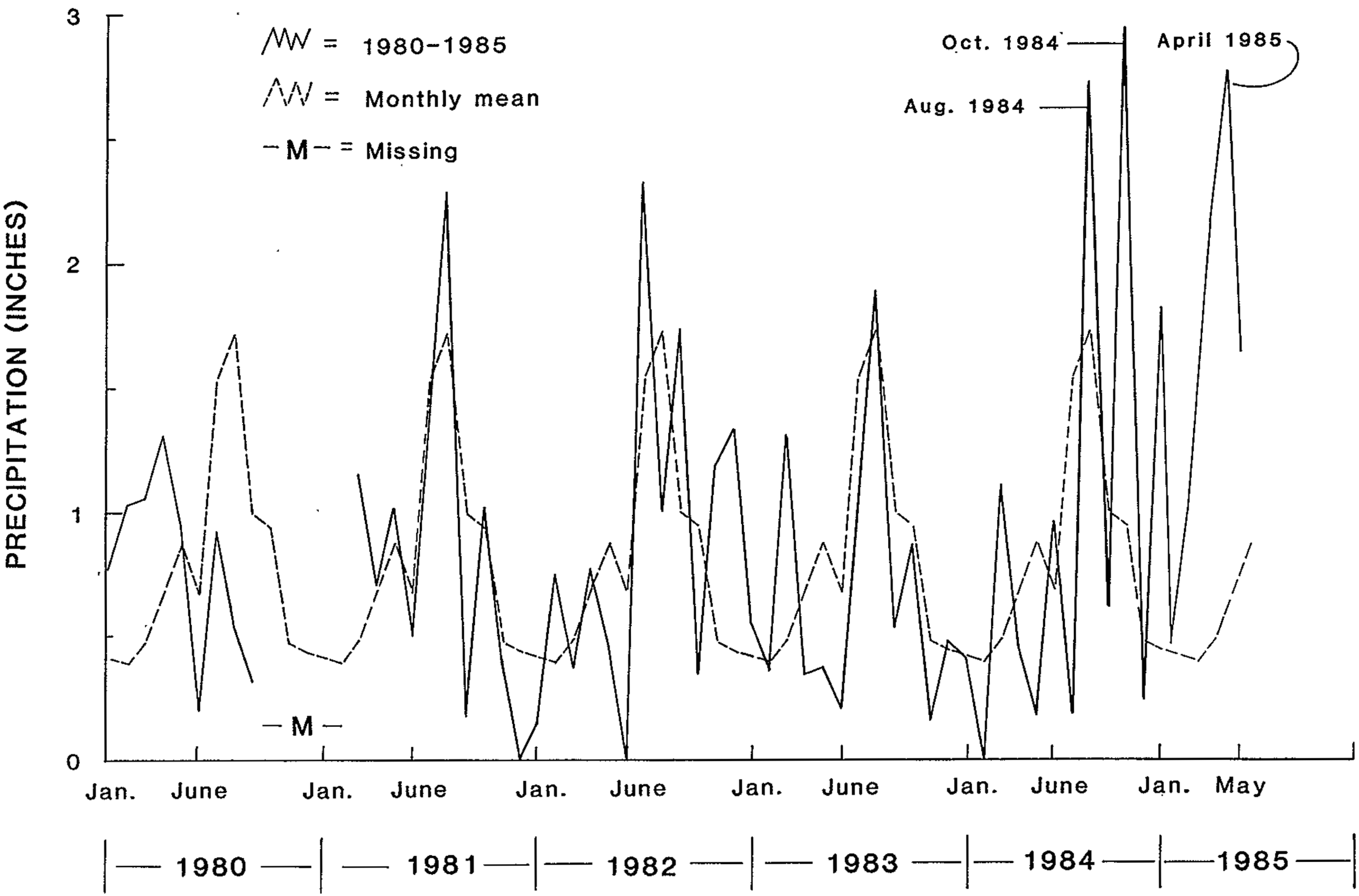
EXPLANATION OF TABLE

Rebars were set and surveyed at 56 locations (survey stations) in the Moya subsidence area (see inset map, Appendix XVII) and their elevations were resurveyed for three months to see whether subsidence continued. As can be seen by comparing elevations through time, the error in measurement is on the order of 0.1 feet. No consistent decrease in elevation within the pit or around the margins was detected.

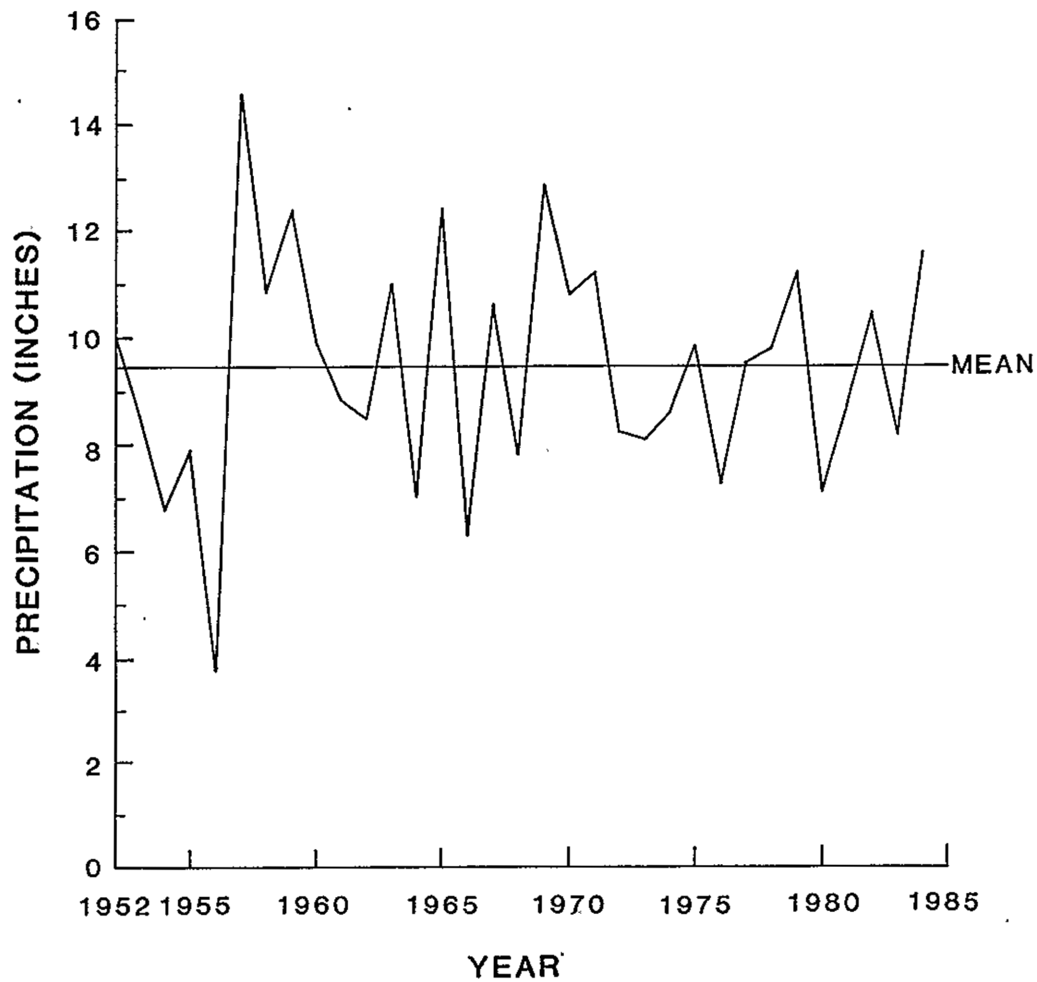
REBAR NUMBER	DATE AND ELEVATION			
	1/4/85	1/18/85	2/20/85	3/21/85
1	15.10	15.15	15.26	15.21
2	13.76	13.72	13.80	13.77
3	14.41	14.51	14.59	13.93
4	13.24	13.20	13.21	13.19
5	13.70	--	12.36	13.93
6	11.14	--	11.24	11.20
7	12.45	--	12.73	12.76
8	11.33	--	11.48	11.40
9	10.05	--	10.53	10.48
10	10.39	--	10.84	10.91
11	9.42	--	9.87	9.94
12	9.86	--	10.33	10.35
13	15.43	--	15.55	15.55
14	13.41	--	13.43	13.42
15	16.48	16.45	16.58	16.59
16	15.61	15.54	15.63	15.64
17	15.80	--	15.78	15.79
18	12.80	12.70	12.69	12.71
19	15.21	--	15.18	15.17
20	13.97	--	13.82	13.81
21	14.21	--	lost	
22	13.62	--	--	13.56
23	12.05	--	11.80	11.76
24	12.45	--	lost	
25	13.82	--	lost	
26	13.26	--	lost	
27	12.80	--	12.55	12.61
28	11.34	--	11.16	11.19
29	11.37	--	11.89	11.94
30	10.28	--	--	9.97
31	8.91	--	8.70	8.75
32	11.34	--	10.78	10.84
33	10.46	--	lost	
34	9.66	--	10.37	10.44
35	8.37	--	8.97	8.98
36	13.35	--	13.32	13.34
37	12.30	--	--	12.35
38	12.03	--	12.11	12.06
39	11.90	--	11.91	11.90
40	11.90	11.80	11.88	11.84
41	14.39	14.28	14.38	14.31
42	13.19	--	--	13.20
43	12.23	12.21	12.20	12.17
44	15.55	--	15.67	15.70
45	14.87	--	14.87	14.86
46	15.42	--	15.55	15.57
47	15.76	--	15.88	15.88
48	16.88	--	17.01	17.05
49	16.44	--	16.60	16.64
50	15.63	--	15.74	15.73
51	15.98	--	16.03	16.02
52	12.51	--	12.48	12.46
53	12.46	--	--	12.56
54	12.55	--	--	12.45
55	13.75	--	--	13.82
56	13.11	--	12.99	12.98
Pipe, S. fence	--	--	15.71	15.73
Pipe, in hole	--	11.15	11.13	--
Pipe, east of road	--	--	--	22.21

APPENDIX XVIII

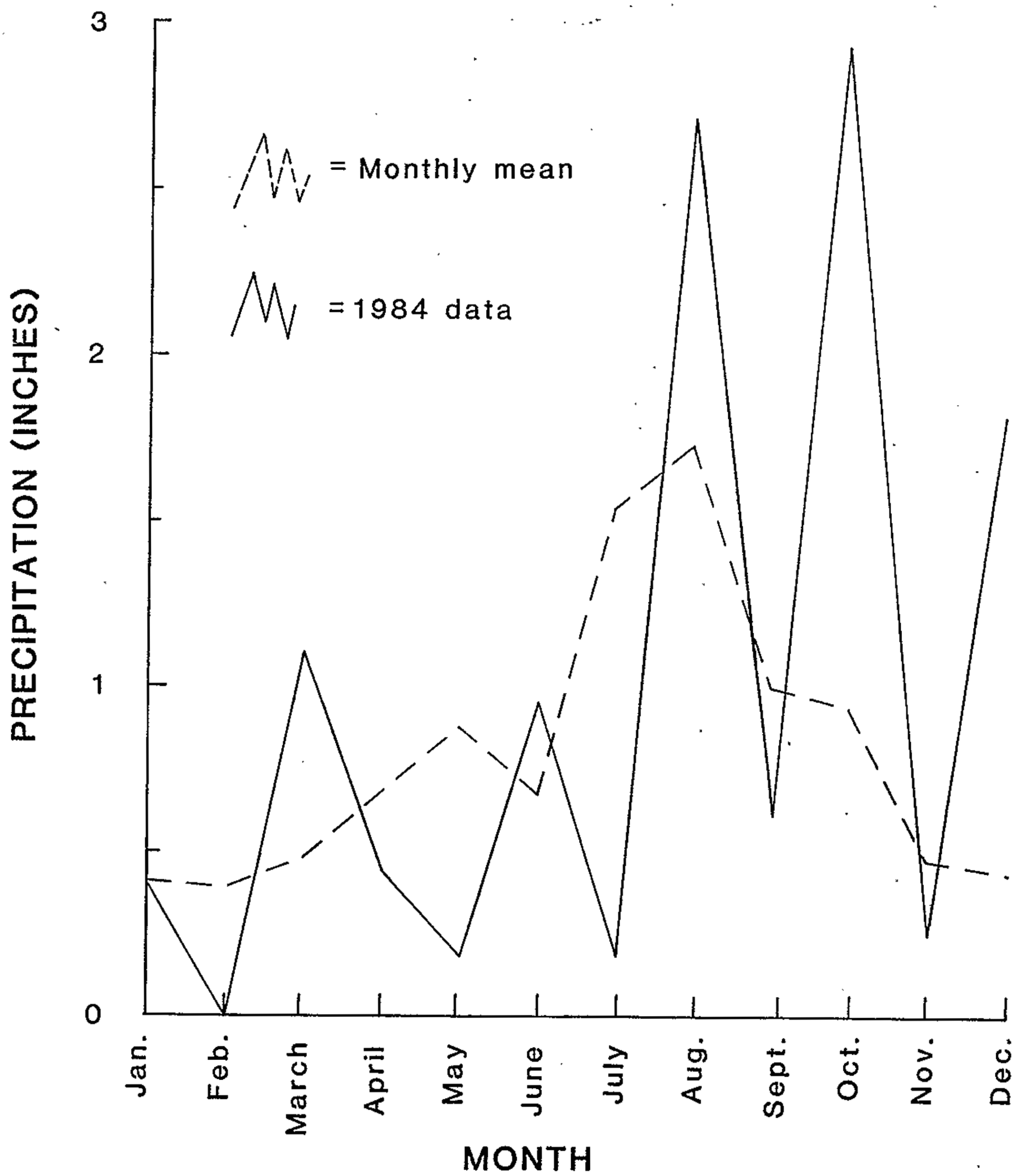
Climatic Data



Appendix XVIII Figure A-1 Monthly precipitation 1980-1985, the dashed line represents the mean monthly precipitation 1895-1976 (Gabin and Lesperance, 1977). 28 JUNE 1985



Appendix XVIII Figure A-2 Total annual precipitation for Española and vicinity 1952-1984; also shown is a line representing the mean annual precipitation 1895-1976 (Gabin and Lesperance, 1977). 28 JUNE 1985



Appendix XVIII Figure A-3 Monthly precipitation for 1984, the dashed line represents the mean monthly precipitation 1895-1976 (Gabin and Lesperance, 1977). 28 JUNE 1985

APPENDIX XIX

X-Ray Diffraction Data - George Austin

New Mexico Bureau of Mines & Mineral Resources
Socorro, NM 87801

A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

rmation: 505/835-5420
ications: 505/835-5410

May 16, 1985

MEMO

TO: Gary Johnpeer

FROM: George Austin

SUBJECT: Clay-size Fraction Analysis for ESP Samples

Analyses of the clay-size fraction (less-than-2 micrometers) of samples from the Espanola Subsidence Problem area are enclosed. The test is semi-quantitative (parts in 10) for the contained clay mineral groups. Symbols of Tr indicate trace amounts, a dash indicates less than trace amounts, Qtz is quartz, Calc is calcite, and Feld is feldspar. The analyses are correct to a few percent, but clay minerals found in quantities less than 2 or 3% will not show as trace amounts. The nonclay minerals in the less-than-2 micrometer fraction are shown in decreasing order of abundance. Underlined minerals are present in abundance, minerals in parentheses are present in small amounts, and a question mark in parentheses after a mineral indicates a possible presence of that mineral. However, clay minerals make up a majority of each sample.

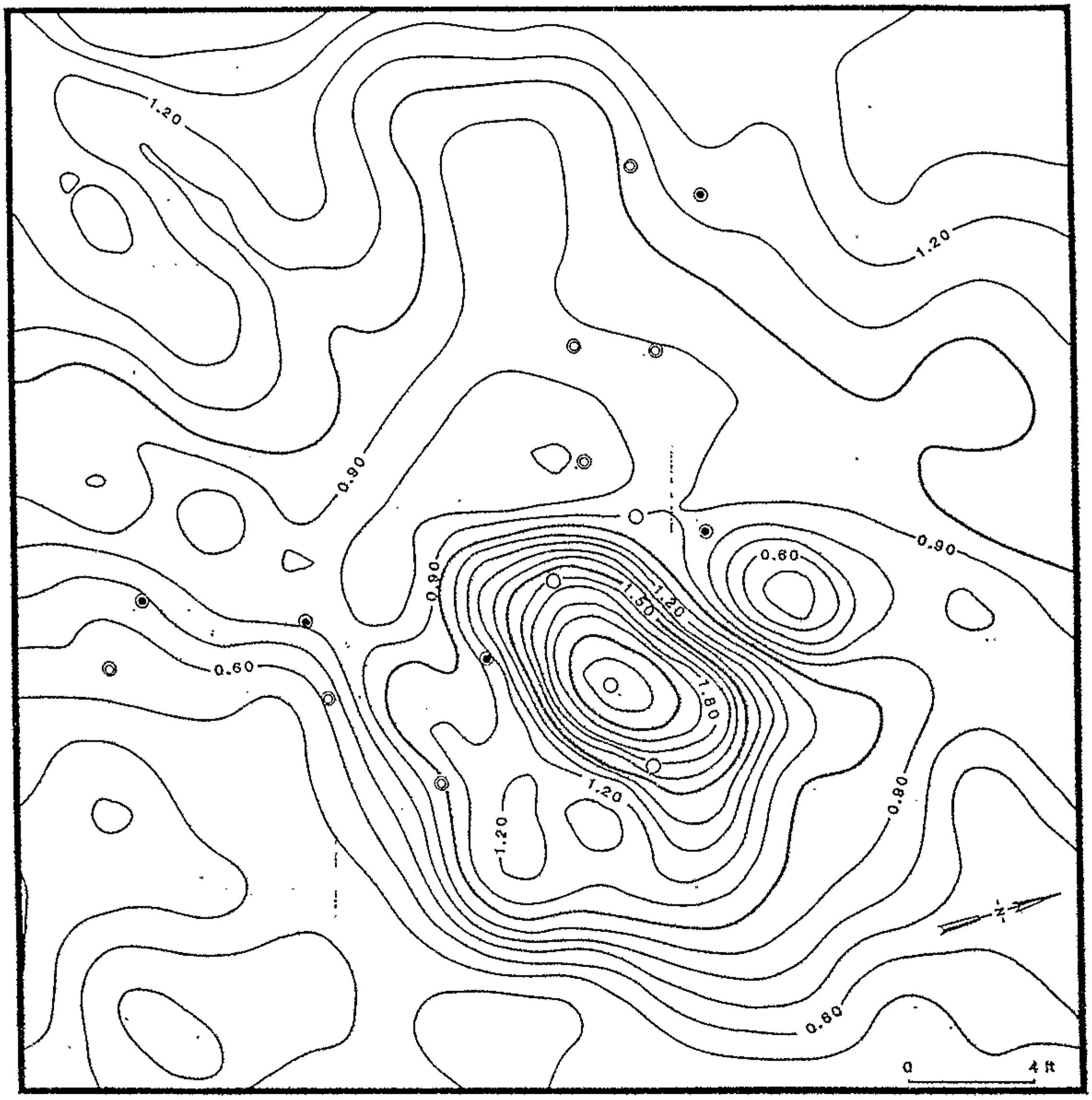
Sample #	Smectite	Illite	Mixed-Layer Illite-Smectite	Kaolinite	Other
ESPDH-1 @ 5'	6	2	1	1	Qtz, Calc, Feld
ESPDH-1 @ 17.5'	6	2	1	1	Qtz, Calc
ESPDH-2 @ 12.5'	4	2	2	2	Calc, Qtz
ESPDH-2 @ 17.5'	4	3	Tr	2	Calc, Qtz, Feld
ESPDH-3 @ 20'	3	4	-	3	Calc, Qtz, Feld
ESPDH-4 @ 14'	6	2	1	1	(Qtz), Calc(Tr)
ESPDH-13 @ 24'	7	2	-	1	Qtz and Calc
ESPDH-18 @ 9'	8	1	-	1	Qtz and Calc
ESPDH-20 @ 24'	5	3	Tr	2	Qtz, Calc
ESPDH-22 @ 4'	2	4	Tr	3	Calc, Qtz, Feld
ESPDH-23 @ 5'	3	4	1	2	Calc, Qtz, Feld
ESPDH-24 @ 26'	4	3	1	Tr	Calc, Qtz, Feld
ESPDH-25 @ 5'	3	2	3	2	Calc, Qtz, Feld(?)
ESPDH-25 @ 14'	3	3	3	1	Calc, Qtz, Feld

Sample #	Smectite	Illite	Mixed-Layer Illite-Smectite	Kaolinite	Other
ESPDH-27 @ 18.5'	4	2	2	2	Qtz, Calc, (Feld)
ESPDH-27 @ 23'	4	3	1	2	Calc, Qtz
ESPDH-29 @ 10'	8	1	Tr	1	Calc, Qtz
ESPDH-29 @ 20'	5	2	2	1	Calc, Qtz
ESPDH-30 @ 24'	4	3	1	2	Qtz, Calc, Feld
ESPDH-34 @ 24'	5	3	Tr	2	Calc, Feld, Qtz
ESPDH-35 @ 24'	2	3	2	3	Qtz, Calc, Feld
ESPDH-37 @ 8'	10	-	-	Tr	Calc, Qtz, Feld
ESPDH-37 @ 23'	4	3	2	1	Calc, Qtz, (Feld)
ESPDH-41 @ 20'	3	3	2	2	Qtz, Calc
ESPDH-42 @ 29'	4	2	2	2	Qtz, Calc
ESPDH-44 @ 4'	3	2	3	2	Calc, Qtz, Feld
ESPDH-45 @ 14.5'	3	3	2	2	Qtz, Calc
ESPDH-45 @ 24'	3	4	Tr	3	Calc, Qtz, Feld(?)
ESBH-3A @ 2.5'	4	2	2	2	Qtz, Calc, Feld
ESBH-7A @ 0.5'	6	2	1	1	Qtz and Calc
ESBH-7B 2.2'	4	2	2	2	Qtz, Calc, Feld
ESBH-9A @ 1'	6	2	-	2	Calc, Qtz, Feld
GGSSM-1 @ 10'	3	3	2	2	Qtz, Calc, Feld(Tr)
GGSSM-3 @ 1'	2	2	2	4	(Qtz), (Calc)
GGSSM-3 @ 20.5	2	4	1	3	Calc, Qtz, Feld
GGSSM-3 @ 28'	2	3	1	4	Qtz, Calc
GGSSM-5 @ 21.5'	3	2	3	2	Qtz, Calc
GGSSM-7 @ 23.5'	3	3	2	2	Qtz, Calc, Feld(Tr)
GGSSM-8 @ 19'	3	2	3	2	Calc, Qtz, Feld(Tr)

Sample #	Smectite	Illite	Mixed-Layer Illite-Smectite	Kaolinite	Other
GGSSNP-6 @ 9'	2	2	3	3	Calc, Qtz, Feld(Tr)
GGSSNP-10 @ 24'	3	3	2	2	Qtz, Calc, Feld
GGSSNP-15 @ 19'	3	2	3	2	Calc, Qtz, Feld(?)
GGSSS-4 @ 2-4'	2	3	3	2	Qtz, Calc, Feld
GGSSS-7 @ 4'	1	4	2	3	Calc, Qtz, Feld
GGSSS-15 @ 9'	2	4	1	3	Calc, Qtz, Feld

APPENDIX XX

Topographic and Crack Location Maps for GGSS-Areas 1-4



Appendix XX Figure A-1 Contour map of GGSS-Area 1.

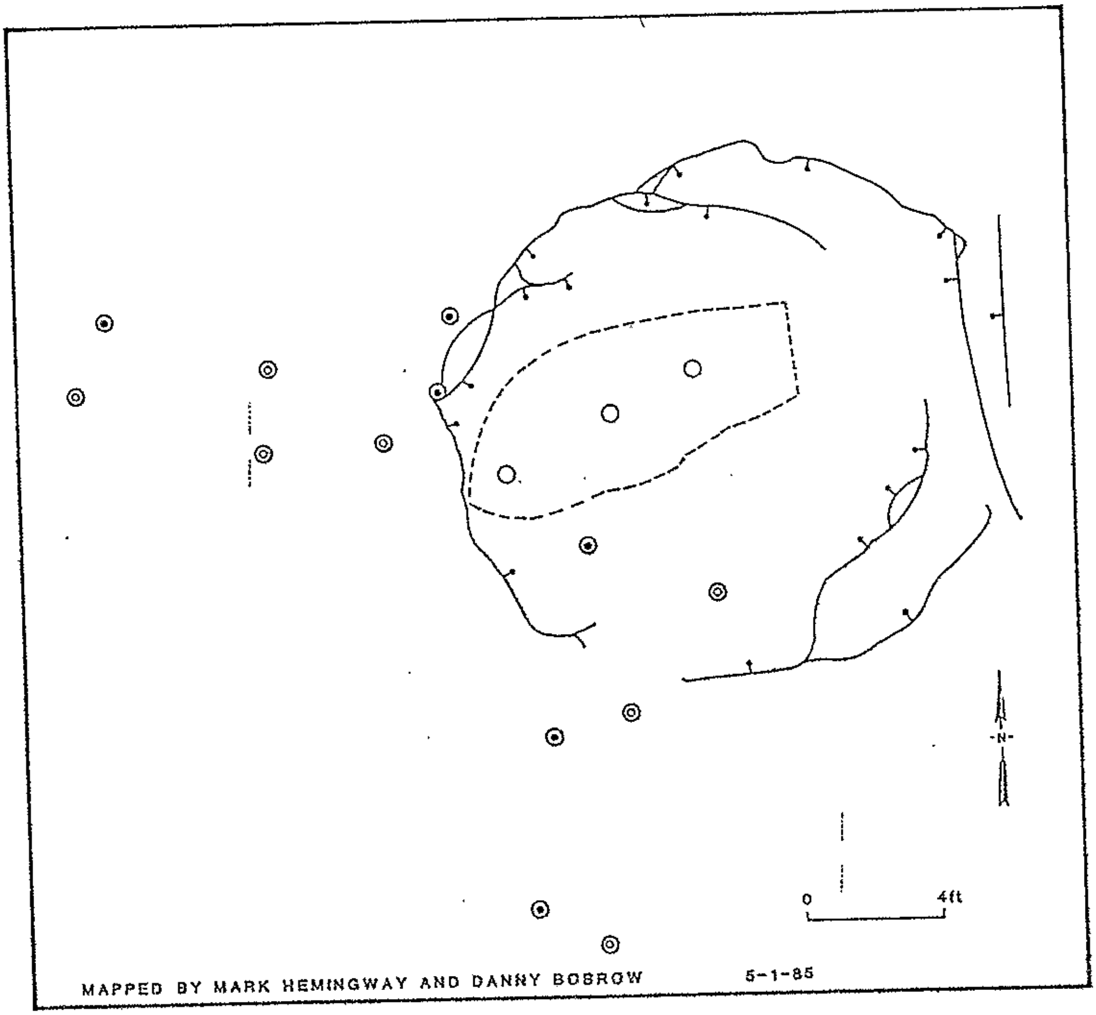
Contours represent depth below datum elevation of 5733 feet.

Contour interval 0.1 feet

Monitoring Wells

- ○ injection and water
- ◎ moisture and density
- ◉ settlement

28 JUNE 1985



Appendix XX Figure A-2 Crack location map of GGSS-Area 1.

28 JUNE 1985

Crack location with ball on downthrown side

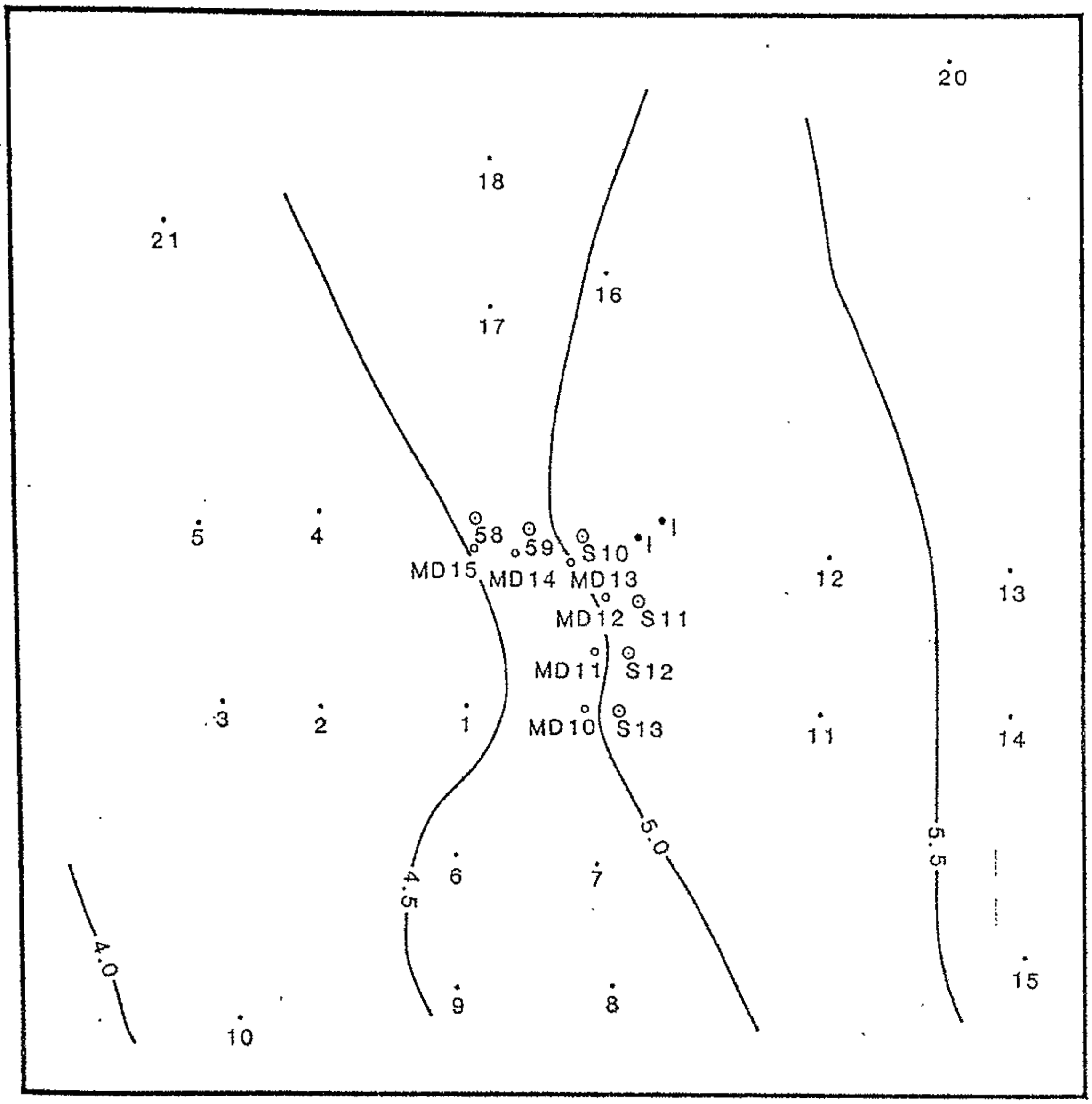
Berm for ponding water

Monitoring Well Symbols

Water injection

Moisture and density

Settlement



Appendix XX Figure A-3 Detailed contour map of GGSS-Area 2.

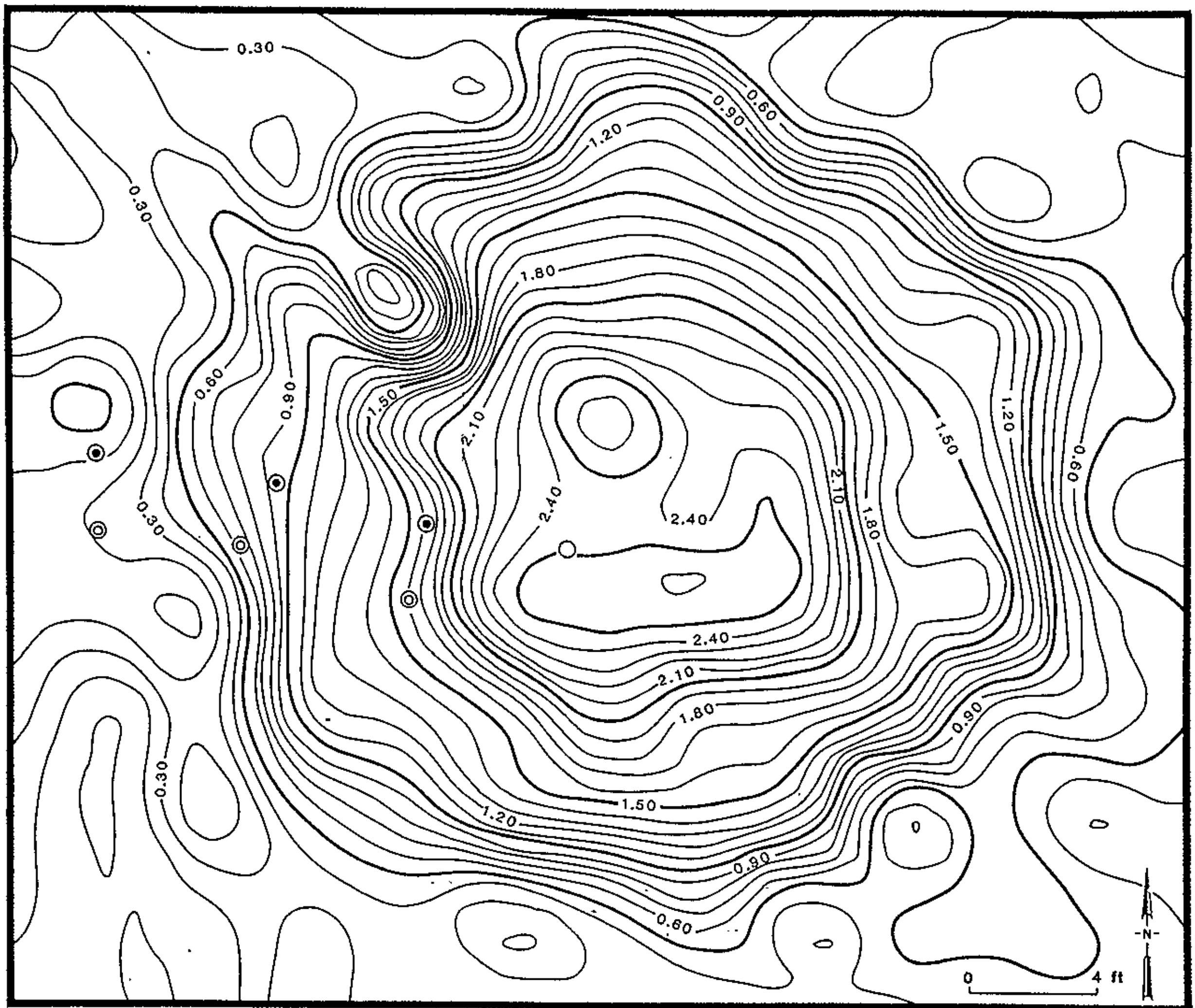
EXPLANATION

—4.5— 0.5 foot contour line (equal elevation)
S8 ⊙ settlement monitoring well
I • injection well
MD ∘ moisture and density monitoring well
8 · rebar control point
Reduced from survey data obtained on 3-21-85.

0 10ft

See Appendix XII for location of GGSS Areas.

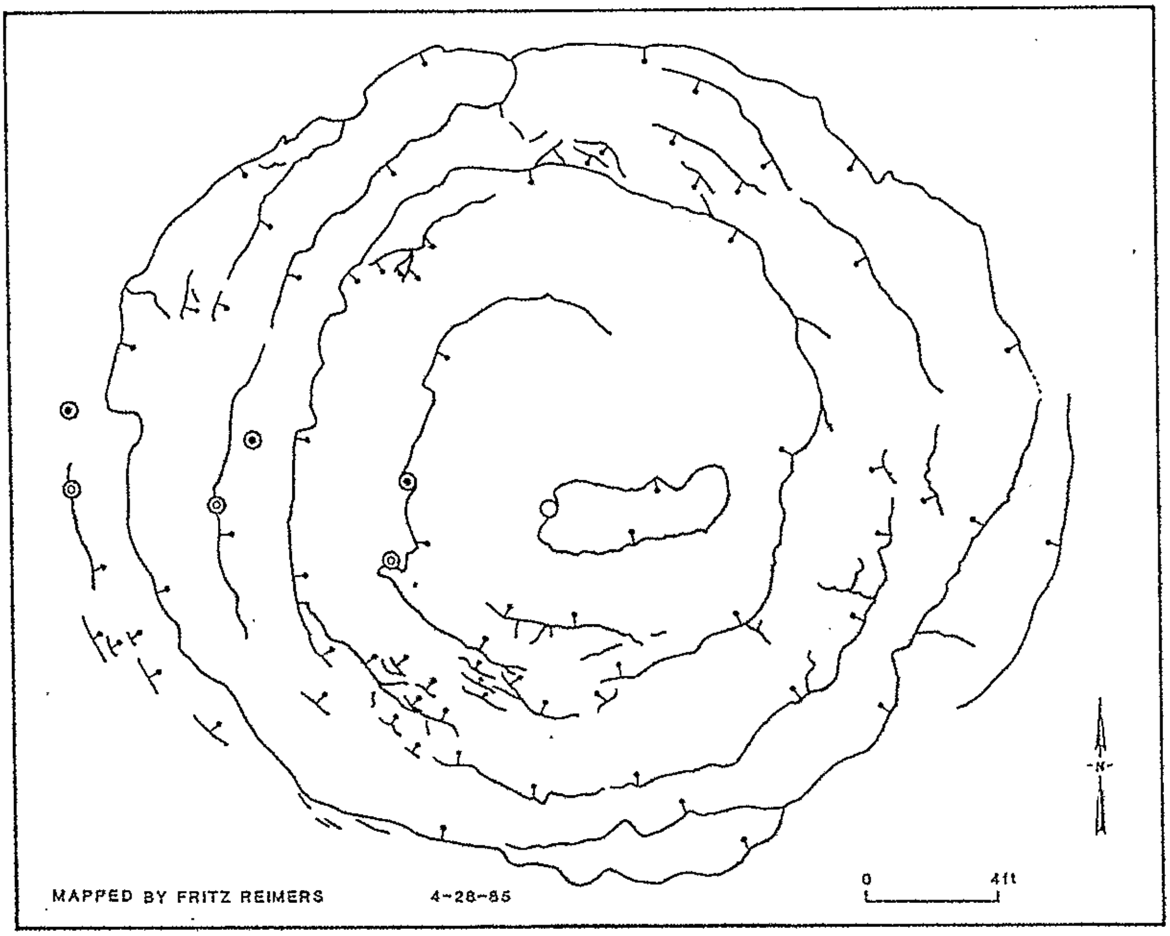
28 JUNE 1985



Appendix XX Figure A-4 Contour map of GGSS-Area 3.
Contours represent depth below datum elevation of 5733 feet.

28 JUNE 1985

Contour interval 0.1 feet
Monitoring Wells
○ injection and water
◎ moisture and density
◉ settlement



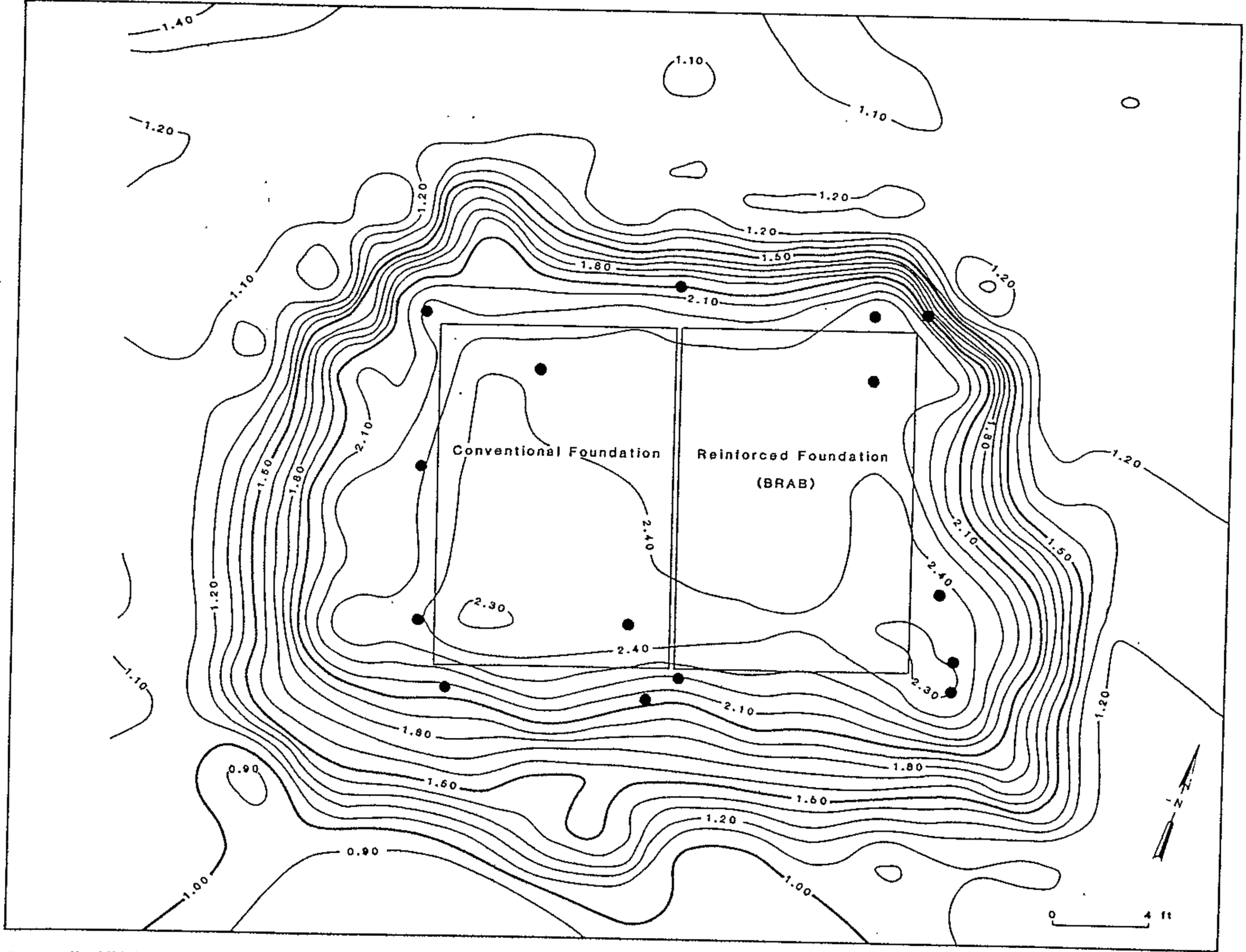
Appendix XX Figure A-5 Crack location map of GGSS-Area 3.

28 JUNE 1985

Crack location with ball on downthrown side

Monitoring Well Symbols:

- Water Injection
- Moisture and density
- Settlement

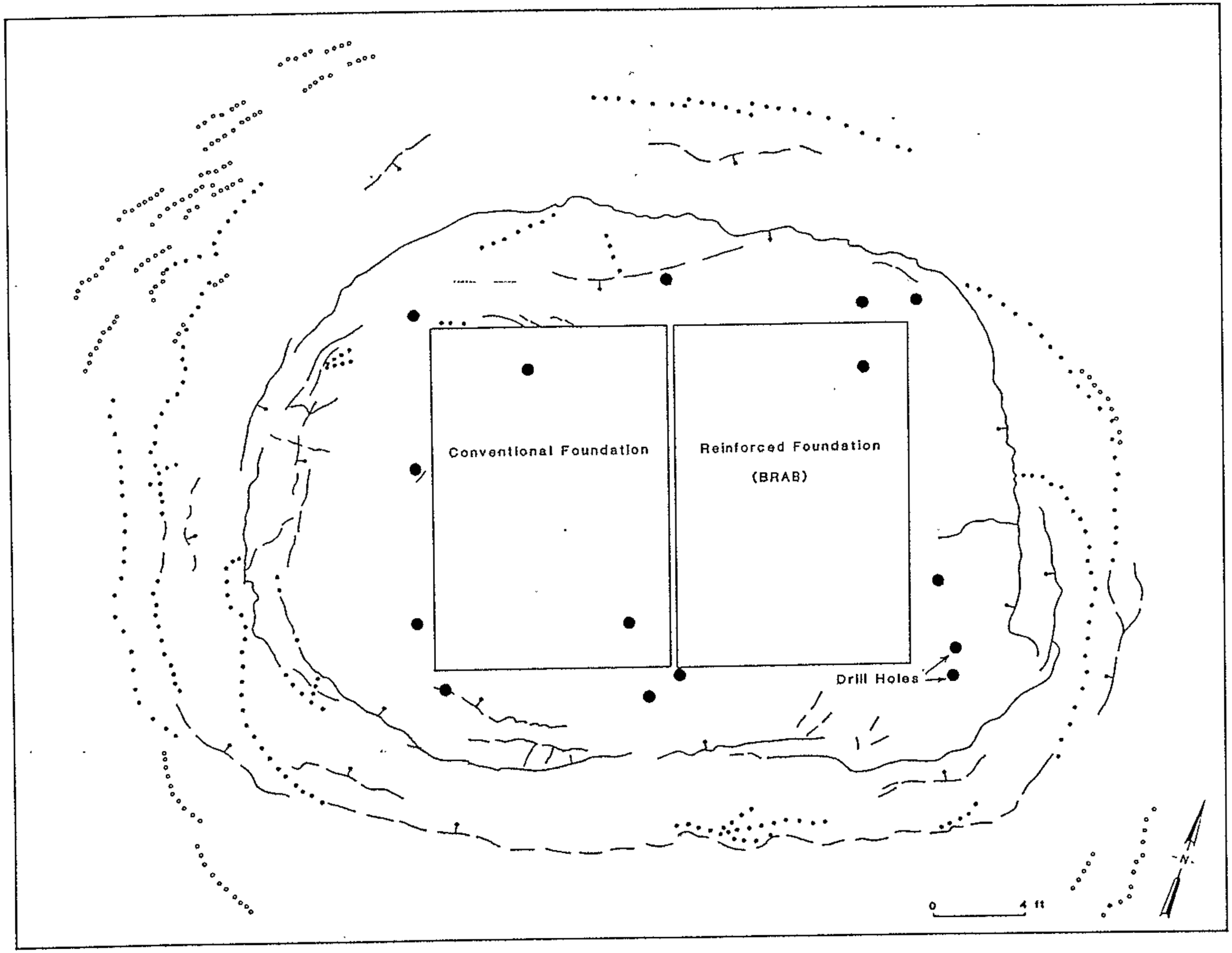


Appendix XX Figure A-6 Contour map of GGSS-Area 4.

Contour interval 0.1 feet
Contours represent depth below datum elevation of 5,734.5 feet.

● Drill Holes

28 JUNE 1985



Appendix XX Figure A-7 Crack development map of GGSS-Area 4.

Cracking Key
May 28, 1985
May 31, 1985
June 10, 1985
June 15, 1985

28 JUNE 1985

APPENDIX XXI

Calibration Study of Settlement at GGSS AREA 3 -

D. Stevens and R. Knowlton

Laboratory, Field, and Numerical Studies to Predict Soil Collapse for the El Llano Geotechnical Investigation Near Espanola, NM

by

Daniel B. Stephens, Associate Professor of Hydrology

and

Robert G. Knowlton, Jr., Graduate Research Assistant

Department of Geoscience and Research and Development Division
New Mexico Institute of Mining and Technology
Socorro, NM 87801

June 1985

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LIST OF FIGURES

INTRODUCTION

The investigation of soil collapse was initiated at the request of the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) in Socorro, New Mexico, in February 1985. Previous investigations by them suggested that fluid seepage from septic tanks and water supply line breaks were the principal causes of collapsing soil and house foundation failure near Espanola, NM. Therefore, we were requested to conduct quantitative methods to predict soil collapse by studying water movement in unsaturated soil.

Having a means to predict soil collapse would permit an assessment of various remedial action procedures, such as by subsurface injection of water adjacent to foundations to induce a uniform collapse. A model to predict collapse could also be used to design a system of unsaturated zone injection wells for pre-construction treatment of collapsible soils.

Objectives

The original objectives of the proposed research plan were to:

1. compare model predicted collapse with observed collapse in a controlled field experiment, using laboratory analyses of soil properties;
2. calibrate the model to predict collapse using field behavior;
3. apply the model to various remedial action alternatives to select the most likely method to stabilize the soil foundation material.

Scope of Investigation

The investigation was conducted with the cooperation of staff of the NMBMMR, in particular Mr. Gary Johnpeer, Mr. Mark Hemingway, Mr. Danny Bobrow, and Mr. Fritz Reimers. The NMBMMR staff is to be commended for its cooperation in providing essential background geotechnical information and field assistance.

The first phase of our project entailed a design of the field experiment to introduce water into the subsurface in which increases in moisture content and collapse could be monitored. In the second phase, we installed a dry well fitted with injection apparatus, and access tubes for monitoring soil moisture by neutron probes were emplaced. Soil samples were collected for laboratory analyses. This field work occurred on March 7-8. In the third phase of the investigation, a numerical model was selected and an empirical means to predict collapse was developed. During this phase, the model was run using laboratory data as input, for the purpose of comparing model predicted behavior with that observed in the field.

The following sections of this report briefly describe the site and discuss in detail the field experiment, laboratory analyses and numerical simulation results. For more details on the nature of the geotechnical problem, mechanisms of collapse, and geologic conditions, please refer to the Final Report of the El Llano Geotechnical Investigation by the NMBMMR, June 1985.

SITE DESCRIPTION

The site of the field experiment is designated as within GGSS Area 3 by the NMBMMR. It is on the property of Mr. Richard Cook in the northeastern section of Espanola, NM. The location of the fluid injection and monitoring instrumentation is west of the Cook Hacienda and about 25 meters east of NM Highway 291. The area is undeveloped and is sparsely vegetated with native grasses and some shrubs.

Sediments in the upper 10 meters at the site consist mostly of fine sand mixed with variable amounts of silt and traces of gravel. These collapsible sediments are of Holocene age and appear to be derived from alluvial fan depositional processes. The underlying sediments, comprising the Santa Fe Group, are more indurated and are not considered collapsible. The field moisture content is about 0.18 cm^3/cm^3 in the upper 60 cm; but below this depth, the field moisture content averages about 0.15 cm^3/cm^3 to at least 10 m.

RELATED RESEARCH

Mechanisms which control collapse of soil have been described by several investigators. Dudley (1970) provided a good review of the problem, and Booth (1975) showed that initial dry bulk density and moisture content are the most important factors. Burland (1965) pointed out that the concept of effective stress, originally proposed by Terzaghi (1936) to explain soil consolidation, cannot be applied to the soil collapse phenomenon. Moore and Millar (1971) and Barder et al. (1973) concluded that in partially saturated soils, collapse can be attributed to a reduction in shear strength which accompanies wetting. That is, as the soil wets, the soil particles move to more stable positions, with a resulting decrease in void ratio. In the effective stress concept, a soil wetted under a constant load should experience a decrease in effective stress, and hence, it should increase in volume; this is clearly not the case with collapsing soils. Numerical models of saturated-unsaturated flow in deforming porous media utilize the effective stress concept for predicting consolidation as a function of pore pressure. Models such as these (e.g., Narisimhan and Witherspoon, 1977) are not directly applicable to predicting soil collapse.

To evaluate the potential for collapse, Jennings and Knight (1975) used data from a standard consolidometer test and defined a collapse potential, CP, as

$$CP = \frac{\Delta e_c}{1 + e_o} x\ 100 \qquad (1)$$

where e_0 is the initial void ratio after loading for 24 hours under a 10 cm^2/g stress, and Δe_c is the change in void ratio which occurs after a sample at field moisture content becomes saturated at a loading of 2×10^4 g/cm^2. Based on their experience, for 1% < CP < 5%, the collapse potential is considered moderate; severe trouble could occur if CP > 10%. They also showed schematically that in a consolidation cell the amount of deformation at a constant loading increased with increasing moisture; however, actual measurements of compression have only been reported for field moisture content and saturated conditions.

METHODS OF ANALYSIS

Field Experiment

A 15 cm diameter borehole was augered with a drill rig to a depth of about 3.05 m; the interval was sampled continuously using thin-walled shelby tubes. Slotted plastic screen 5 cm in diameter was centered in the borehole; and the annulus was back-filled with gravel.

PVC plastic access tubes for the neutron moisture probe (Model 501DR, Campbell Pacific Nuclear, Pacheco, CA) were installed in 10 cm diameter auger holes and back-filled with cuttings. Three access tubes were located along a line from the center of the borehole at distances of about 1.5 m (5 feet), 3.0 m, (10 feet), and 4.5 m (15 feet). Holes for measuring collapse were drilled at the same distances adjacent to the access tube holes.

The neutron probe was calibrated against gravimetric water content on samples collected from the neutron probe access tube auger holes at the test site. A calibration was also made at similarly constructed auger holes backfilled with river sand at a site about 30 m to the north which was used previously for water injection by NMBMMR staff. The calibration results were very poor using the data at the test site. From 42 data points at the second site 30 m to the north, the following relationship was developed between the neutron probe reading, NP, and gravimetric moisture content analyzed in the laboratory, GM:

$$GM(g/g) = -0.083 + 1.583\ NP(cm^3/cm^3) \qquad (2)$$

The r-square value for equation 2 is only 0.71, which indicates considerable scatter of data. The scatter is in part due to the fact that only background moisture content data were used in the calibration; an improved calibration would occur if measurements near saturation were included.

Laboratory tests showed that PVC casing considerably attenuates neutrons from the moisture probe compared with aluminum access tubing. Two core samples were collected from depths of 30 and 61 cm outside the NMIMT soil laboratory where PVC and aluminum access tubes were installed. The volumetric water content by oven drying was about 0.19 cm^3/cm^3; the neutron probe read about 0.23 and 0.14 cm^3/cm^3 through the aluminum and PVC casing respectively.

The volumetric moisture content determined through PVC was about 38% less than that in measured through aluminum; but only about 26% less than the gravimetric determination. The PVC casing also tended to decrease sensitivity to observed changes in moisture content. For example, in the laboratory experiment, as the soil was ponded, the volumetric moisture content recorded by the neutron probe through the PVC casing increased from about 0.14 to 0.20 cm^3/cm^3, whereas through the aluminum tubing the increase was from about 0.24 to 0.34 cm^3/cm^3.

Collapse was intended to be monitored two ways; first, using a collapsible tubing (Sondex) installed in auger holes drilled adjacent to the neutron probe access tubes; and second, using survey monuments constructed from lengths of reinforced steel driven into the ground. In the final analysis, the Sondex did not accurately reflect the observed collapse, and the surveying methods used by NMBMMR staff were not sufficiently accurate to locate the monuments. Thus, a third method was eventually employed by NMBMMR staff to determine the collapse. In this method, a grid of string was laid out horizontally at the initial land surface datum over the area surrounding the borehole so that collapse could be determined by measuring the vertical distance from the collapsed land surface to the datum at the grid intersections.

The water used for injection was delivered to the site from the Cook Hacienda well via a pipeline. A constant head in the well was maintained just at land surface using a stock tank valve with a float set in a reservoir connected to the 5 cm diameter well casing. Flow rate was determined by a flow meter. Water injection began on March 22, 1985 and continued until April 6, 1985. During this time the flow meter and Sondex tubing collapse was read by Mr. Felipe Valdez of Espanola under the direction of NMBMMR staff; neutron probe readings were made by Mr. Robert Knowlton on March 29 and April 8, as well as prior to injection.

Laboratory Analyses

Shelby tube samples were collected during drilling of the injection borehole from land surface to about 3 m. The samples were fitted with manometers at approximately 10 cm depth intervals and placed in a constant head permeameter to determine saturated hydraulic conductivity (Figure 1). Carbon dioxide gas was injected through the shelby tube sample prior to the application of Socorro tap water, in order to minimize entrapped air. These and other laboratory analyses were conducted at the New Mexico Tech Soil-Water Research Laboratory under the direction of Dr. Daniel B. Stephens; Mr. Robert

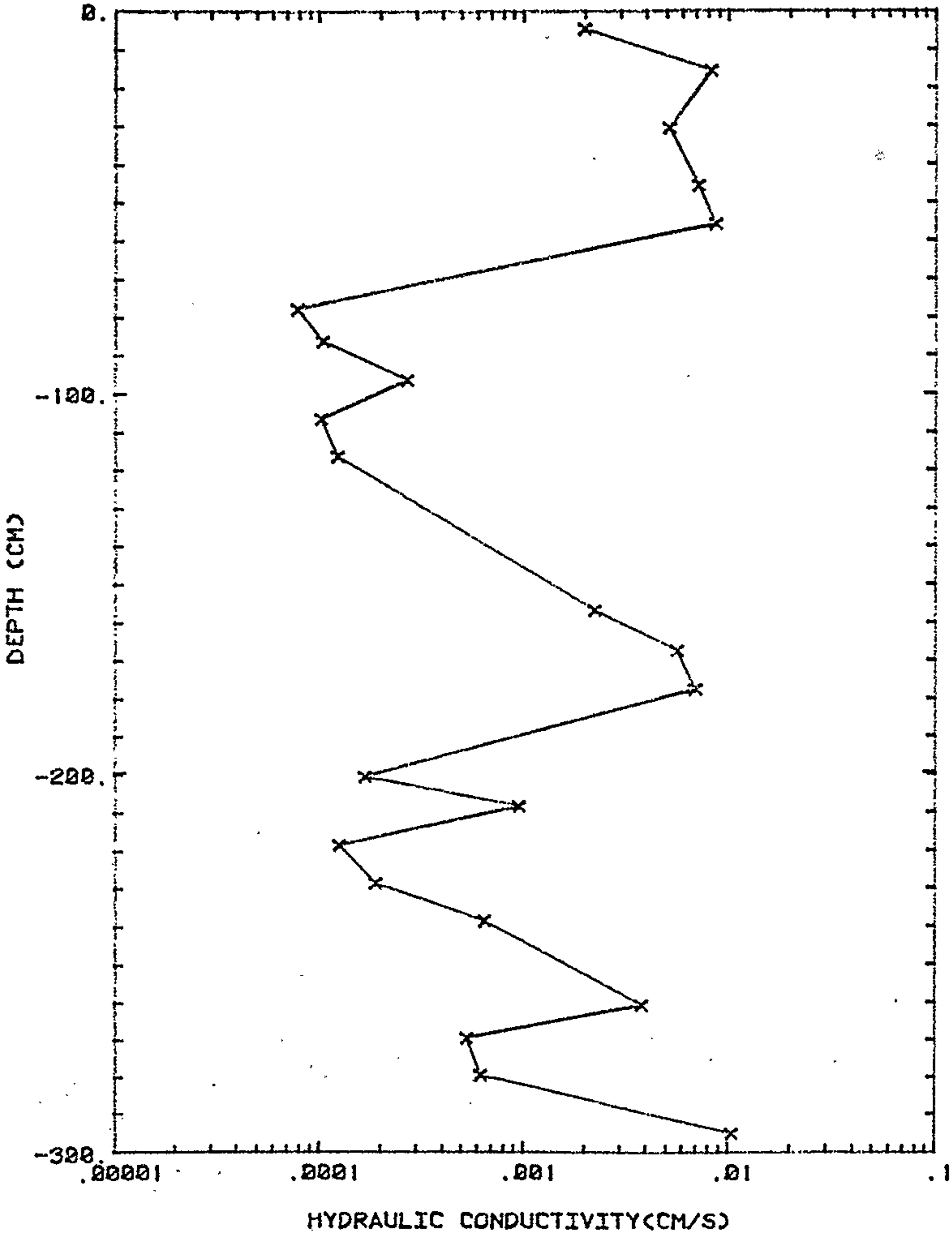

Figure 1. Saturated hydraulic conductivity from shelby tube samples.

Knowlton supervised and conducted the analyses.

Soil moisture retention characteristics were determined on six ring samples 94 cc in volume. Four of the samples were obtained by pushing the rings into the ends of the shelby tube samples at depths of 61, 122, 183 and 244 cm. One ring sample was obtained at the 45 cm depth from an undisturbed, 2.7×10^4 cm^3 block of soil retained in fiber glass which was returned to the laboratory. The other ring sample was obtained at a depth of 122 cm from a borehole adjacent to the neutron probe access tube located 4.5 m from the injection borehole. Soil moisture retention during imbibition (Figure 2) was determined using the hanging water column approach by placing the ring samples on a Buchner funnel connected to a burret (Vomocil, 1965).

Unsaturated hydraulic conductivity was calculated from the moisture retention data using a model developed by Mualem (1976) and a numerical procedure described by van Genuchten (1980) (Figure 3). Unsaturated conductivity was also measured on the 94 cc ring samples in the hanging column apparatus by the one-step outflow method (Jaynes and Tyler, 1980) (Figure 4).

Consolidation (void ratio vs. applied stress) was evaluated using a fixed ring-type odeometer cell (Model BS1377, Engineering Laboratory Equipment, Evanston, IL). Two samples were carved for the odeometer cell from the base of the large, fiber-glassed block of soil which was obtained from a shallow pit near the infiltration site at a depth of about 15 to 45 cm below land surface. Consolidation tests were conducted under natural moisture content (0.18 cm^3/cm^3) and saturated conditions (0.35 cm^3/cm^3) (Figure 5). Loadings began at 63.4 g/cm^2 and increased to 8150 g/cm^2; the duration of each loading usually exceeded 24 hours (Figure 6).

The particle size distribution was determined by sieving the contents of the six 94 cc ring samples used previously to evaluate soil-moisture

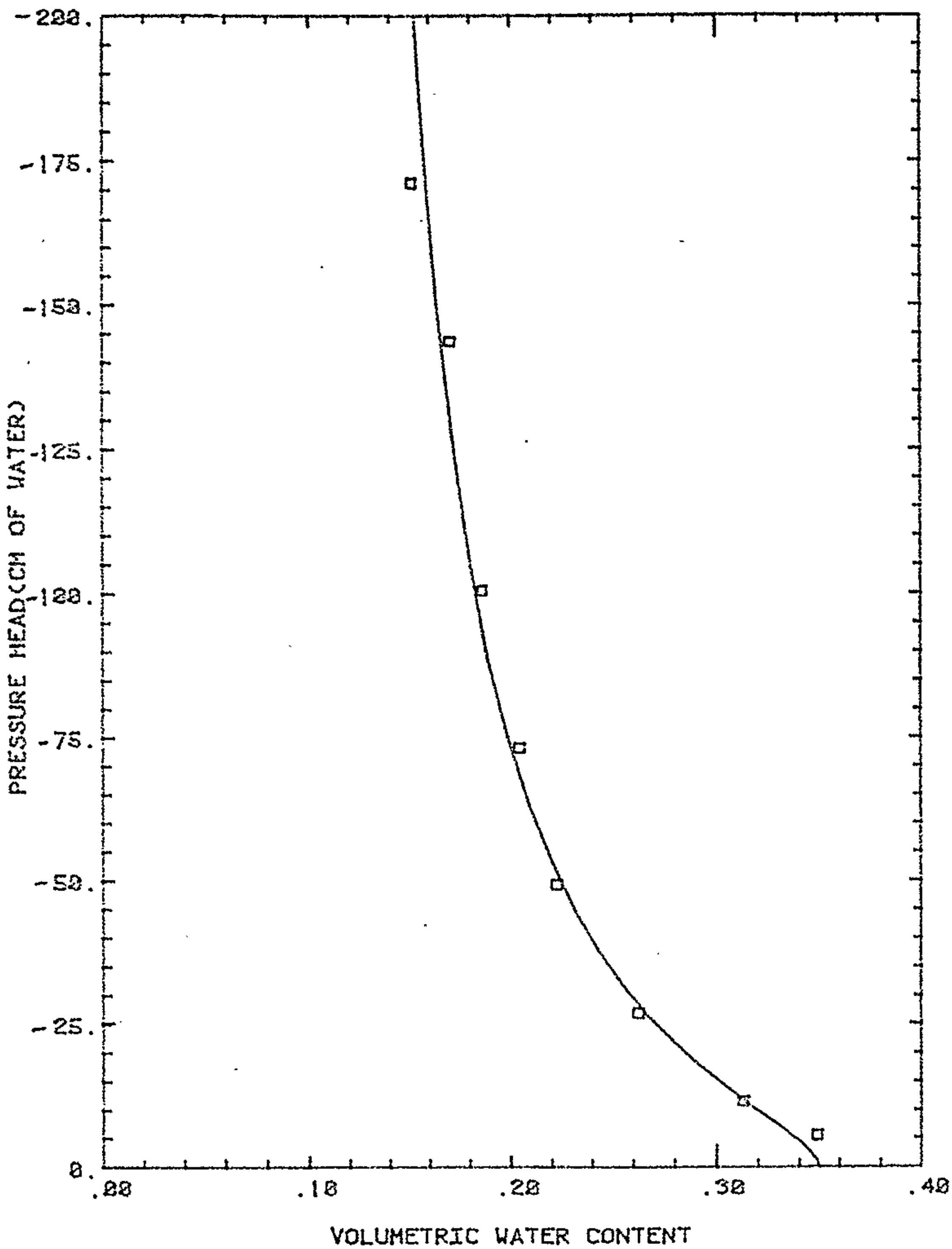

Figure 2a. Soil moisture retention during imbibition: Sample 6-D; Depth 45 cm.

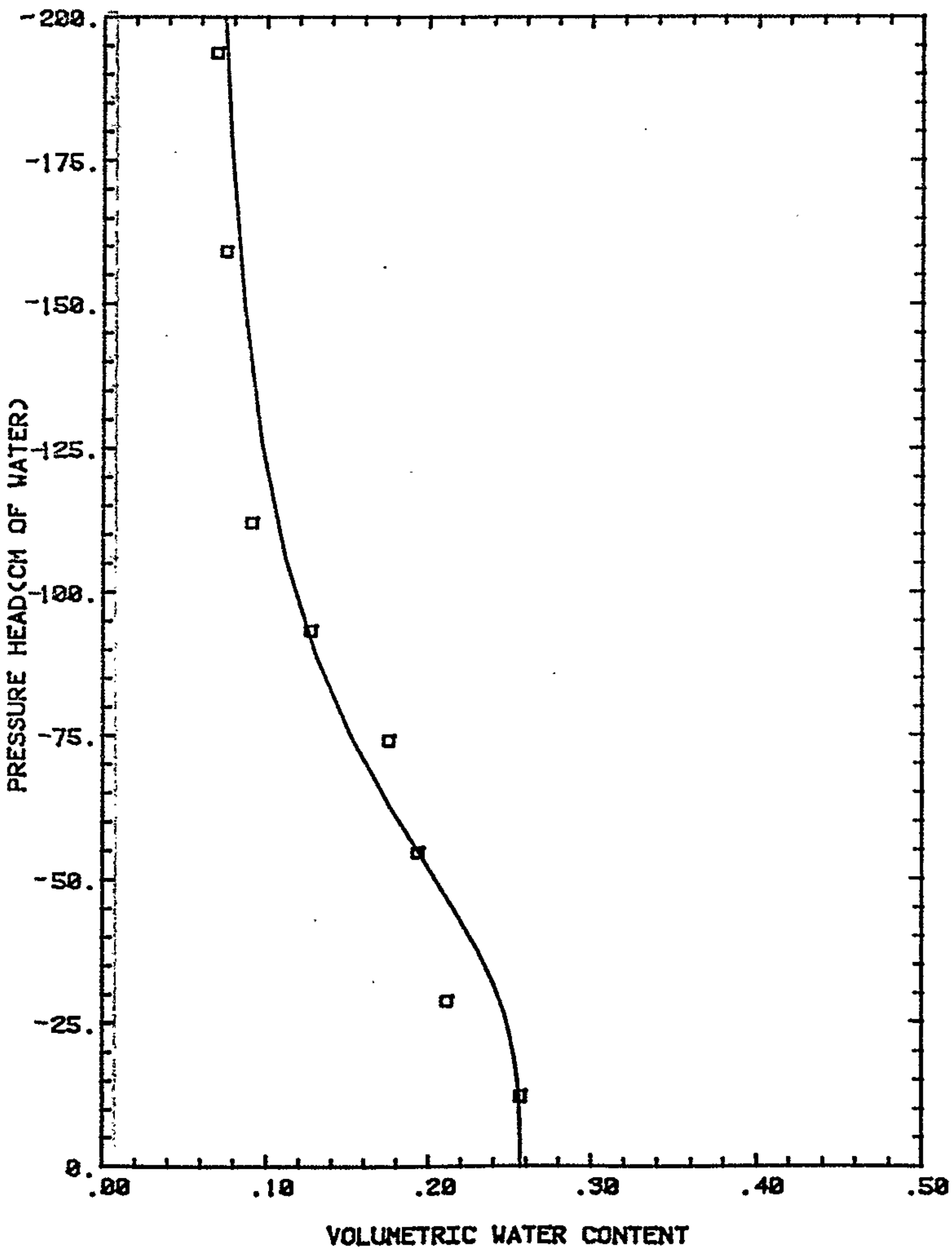

Figure 2b. Soil moisture retention during imbibition: Sample 5-D; Depth 61 cm.

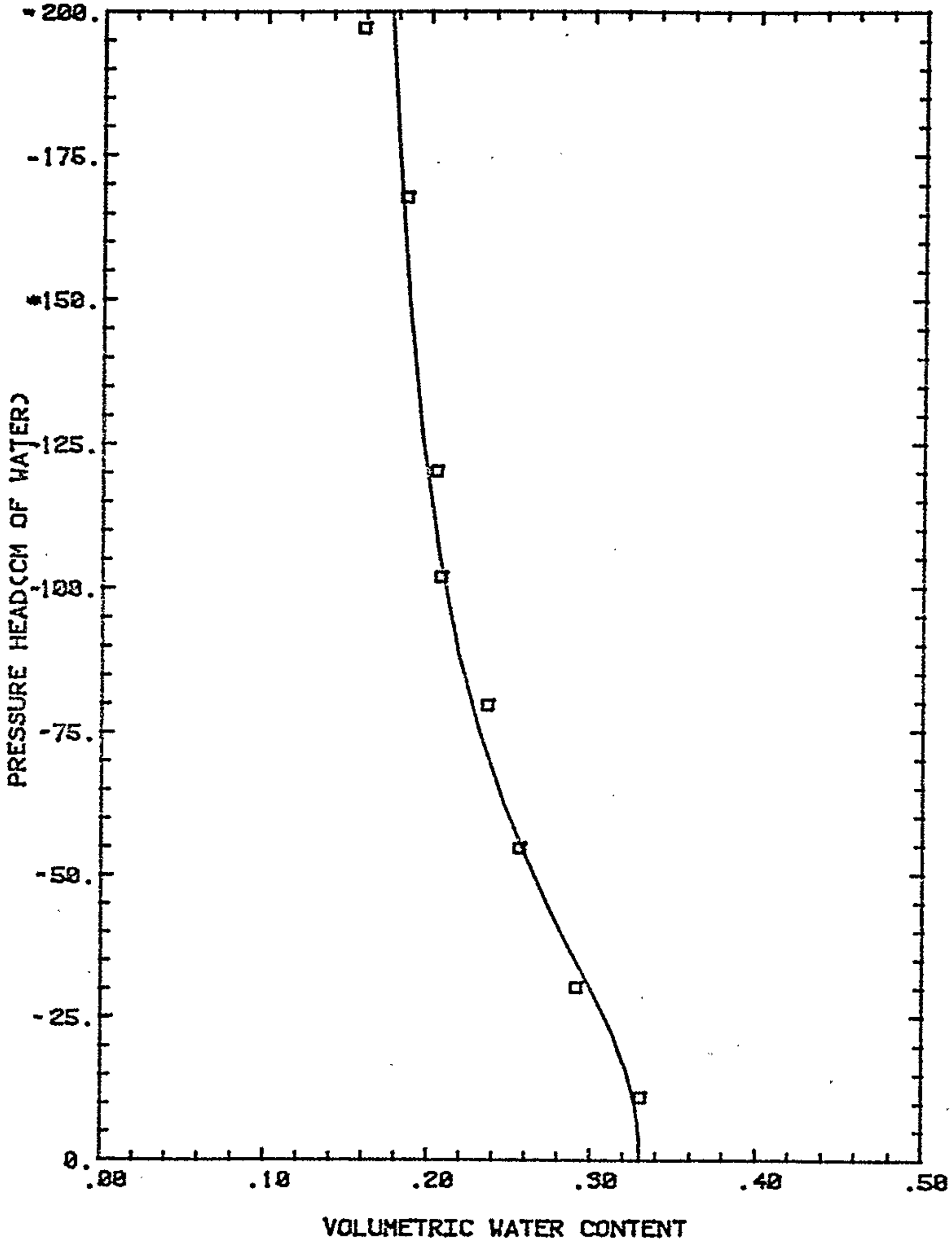

Figure 2c. Soil moisture retention during imbibition: Sample 3-D; Depth 122 cm.

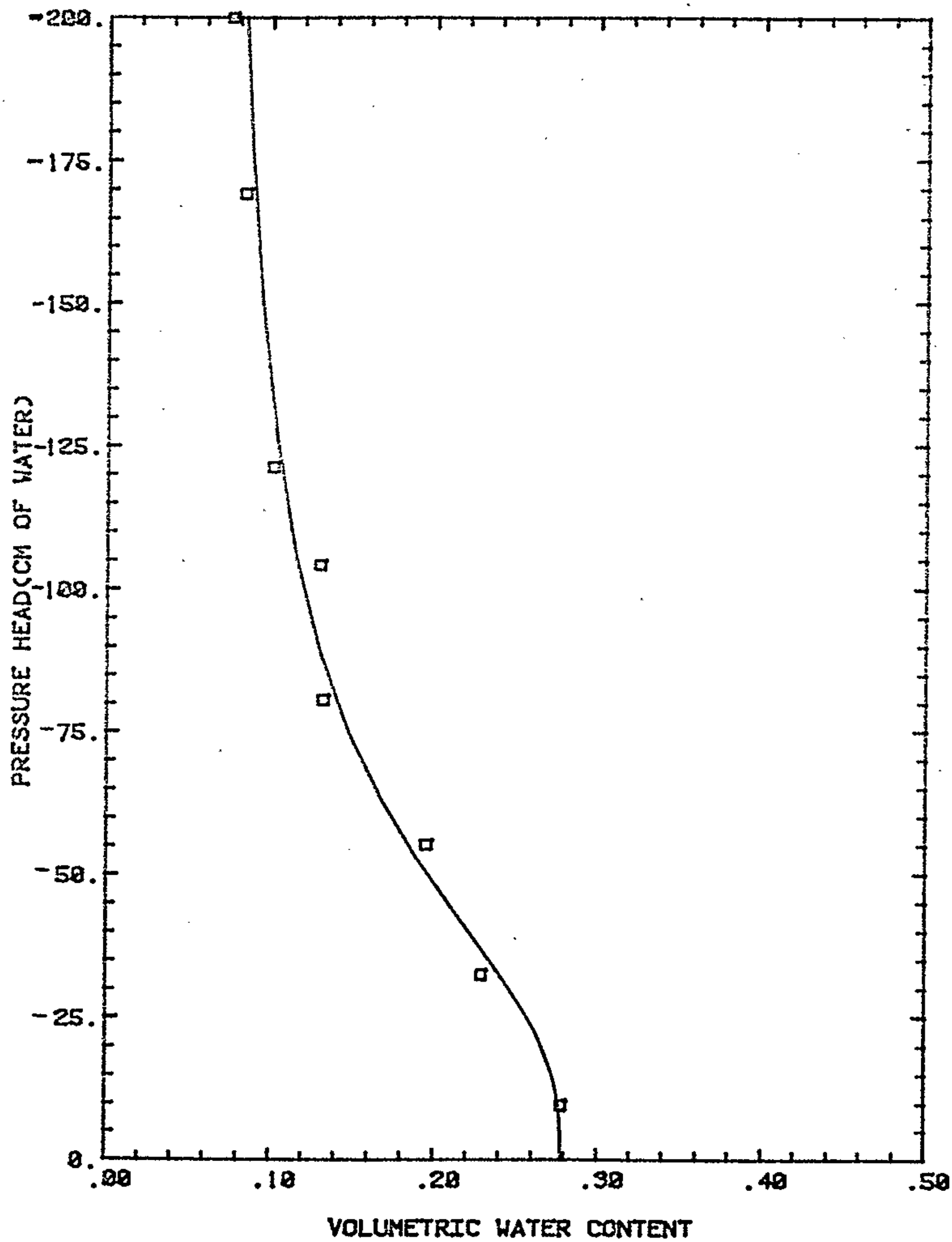

Figure 2d. Soil moisture retention during imbibition: Sample 33-D; Depth 122 cm.

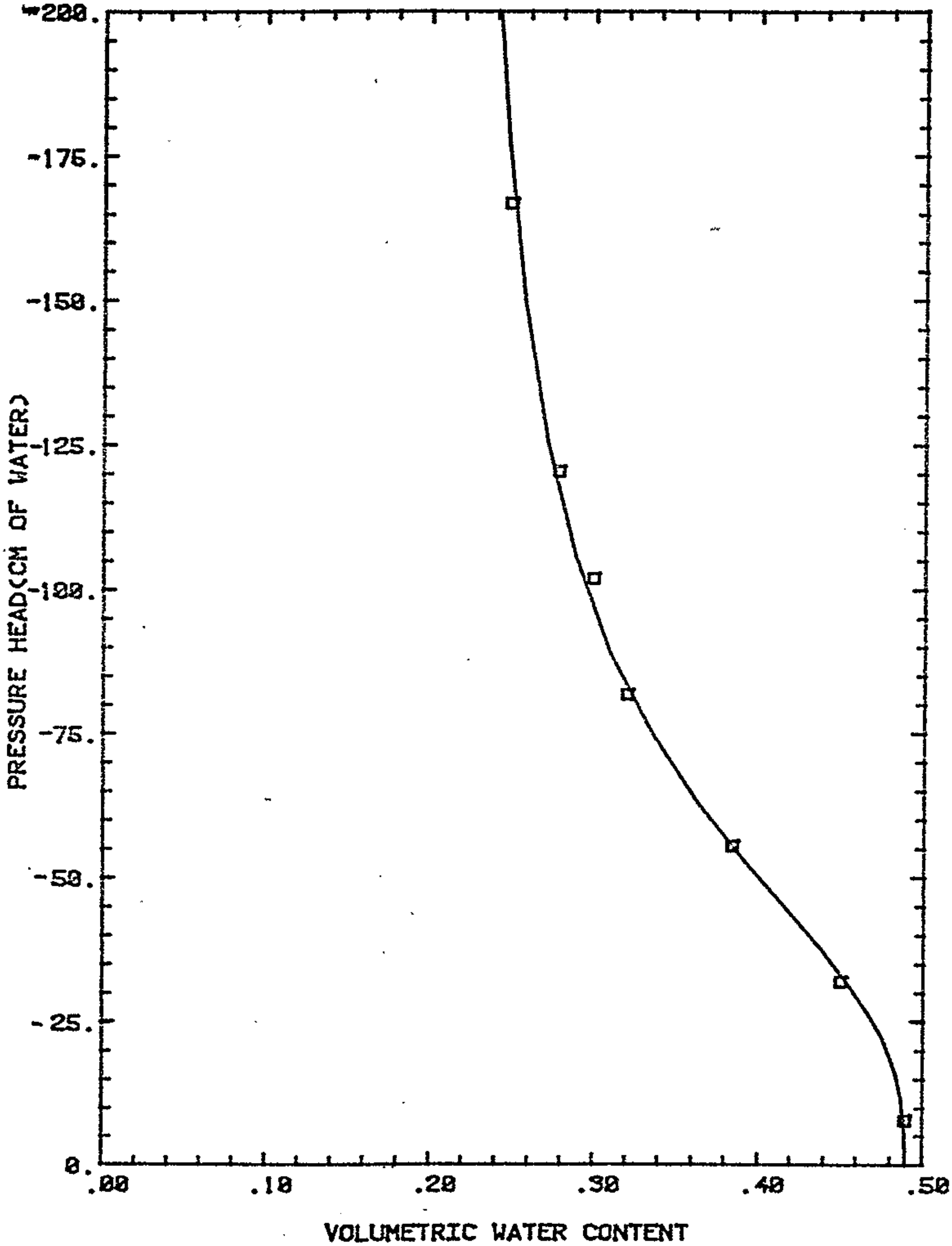

Figure 2e. Soil moisture retention during imbibition: Sample 34-D; Depth 183 cm.

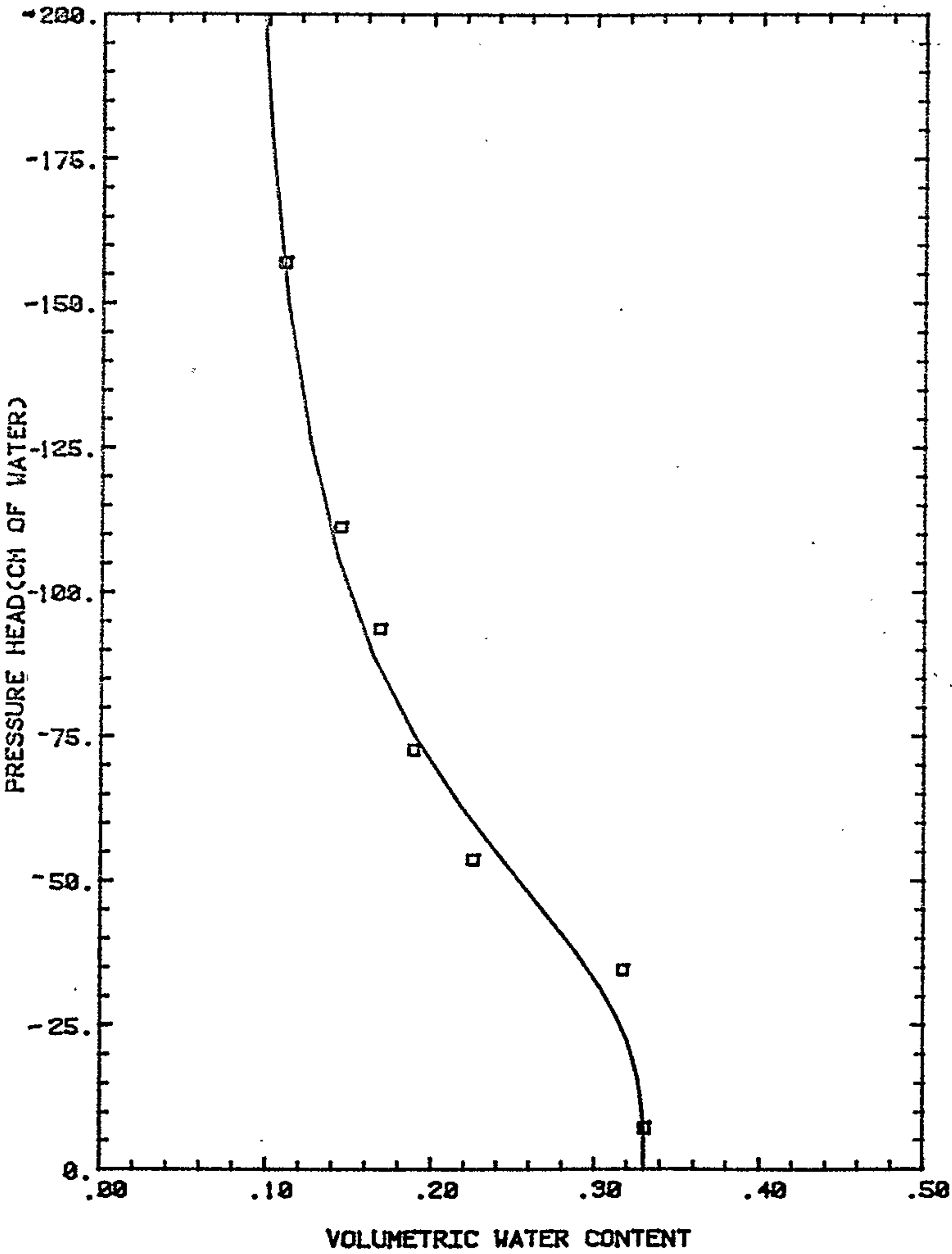

Figure 2f. Soil moisture retention during imbibition: Sample 40-D; Depth 244 cm.

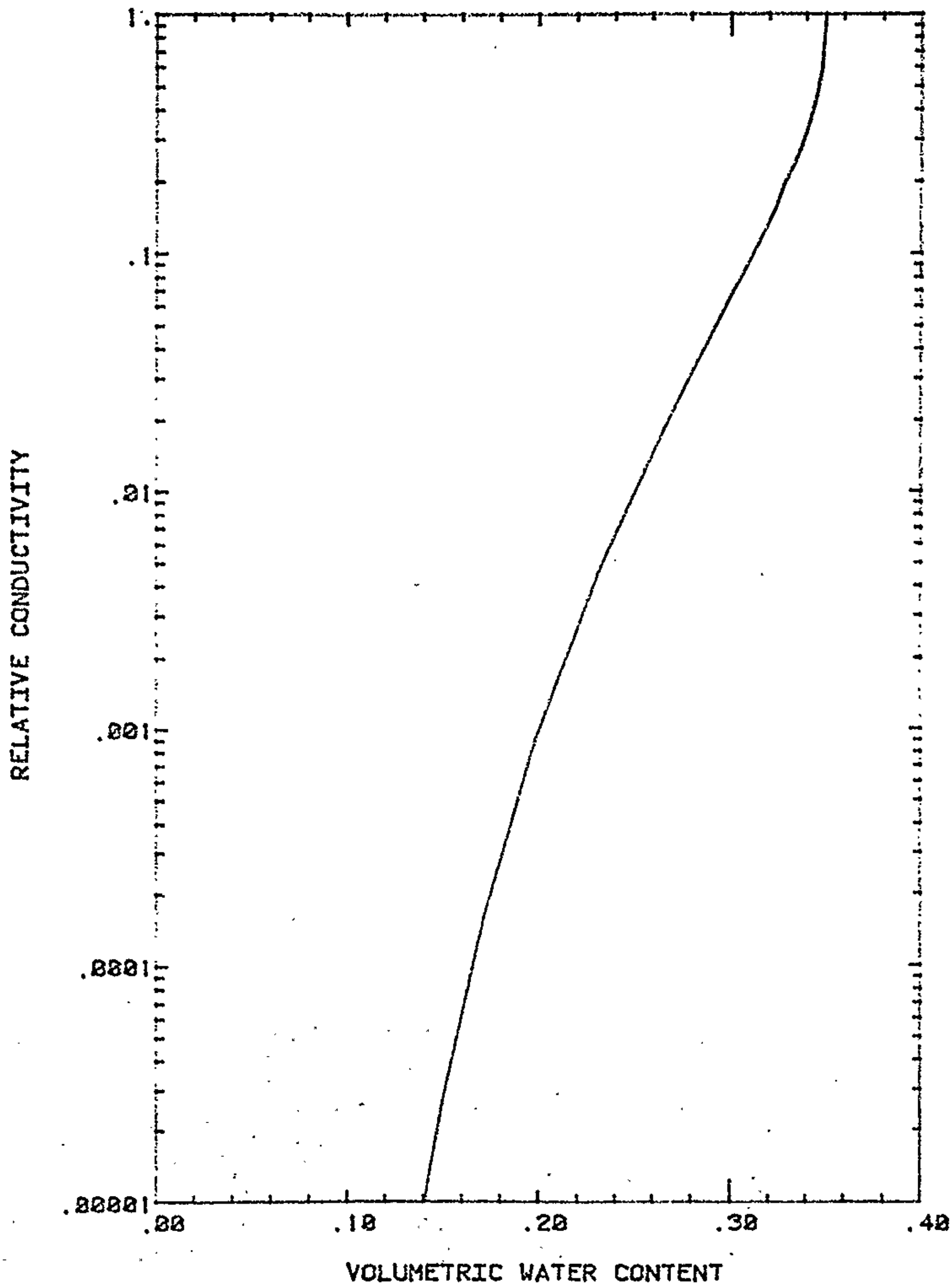

Figure 3a. Unsaturated hydraulic conductivity calculated from moisture retention data using a model by Mualem (1976). Sample 6-D; Depth 45 cm.

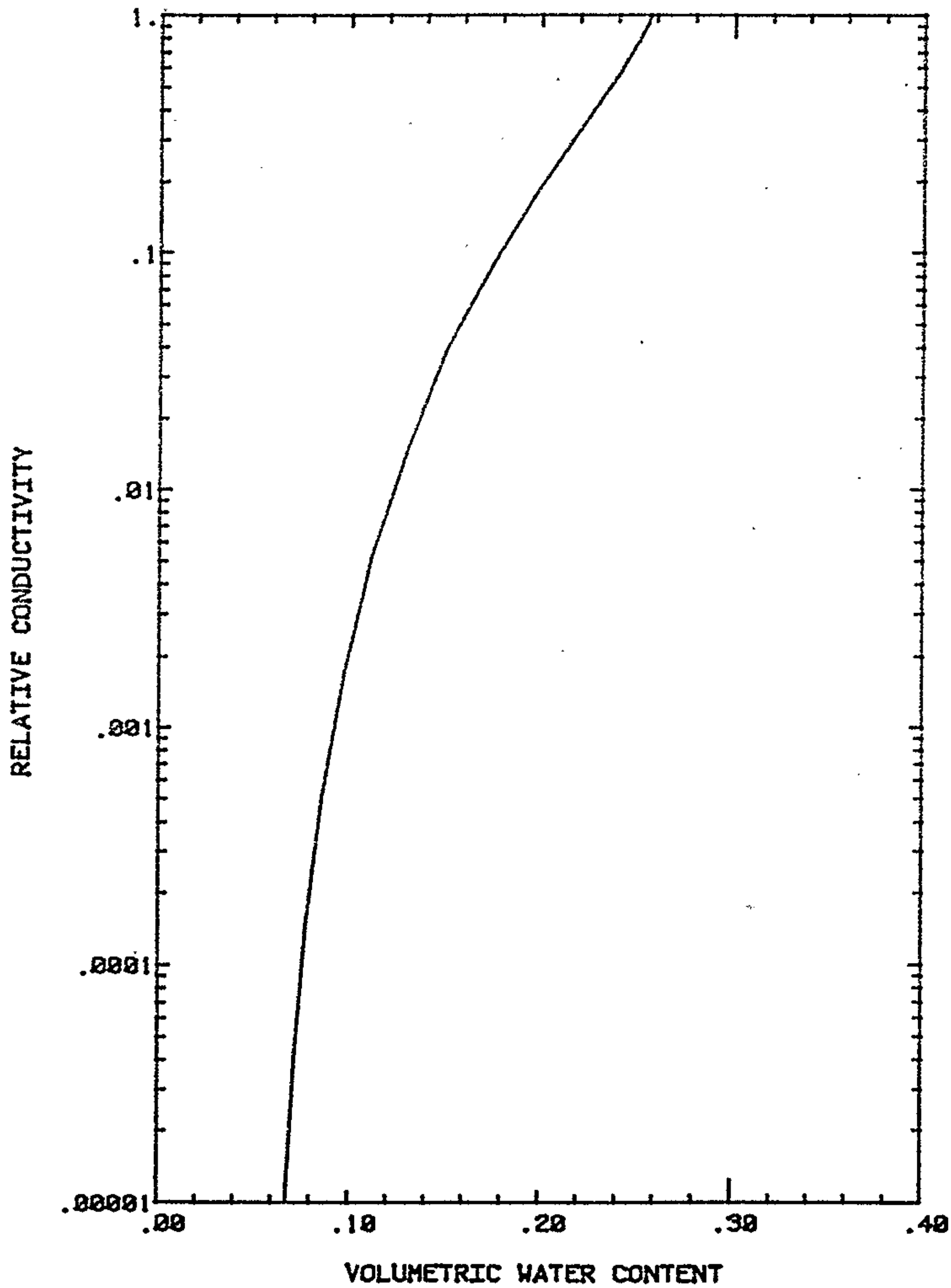

Figure 3b. Unsaturated hydraulic conductivity calculated from moisture retention data using a model by Mualem (1976). Sample 5-D; Depth 61 cm.

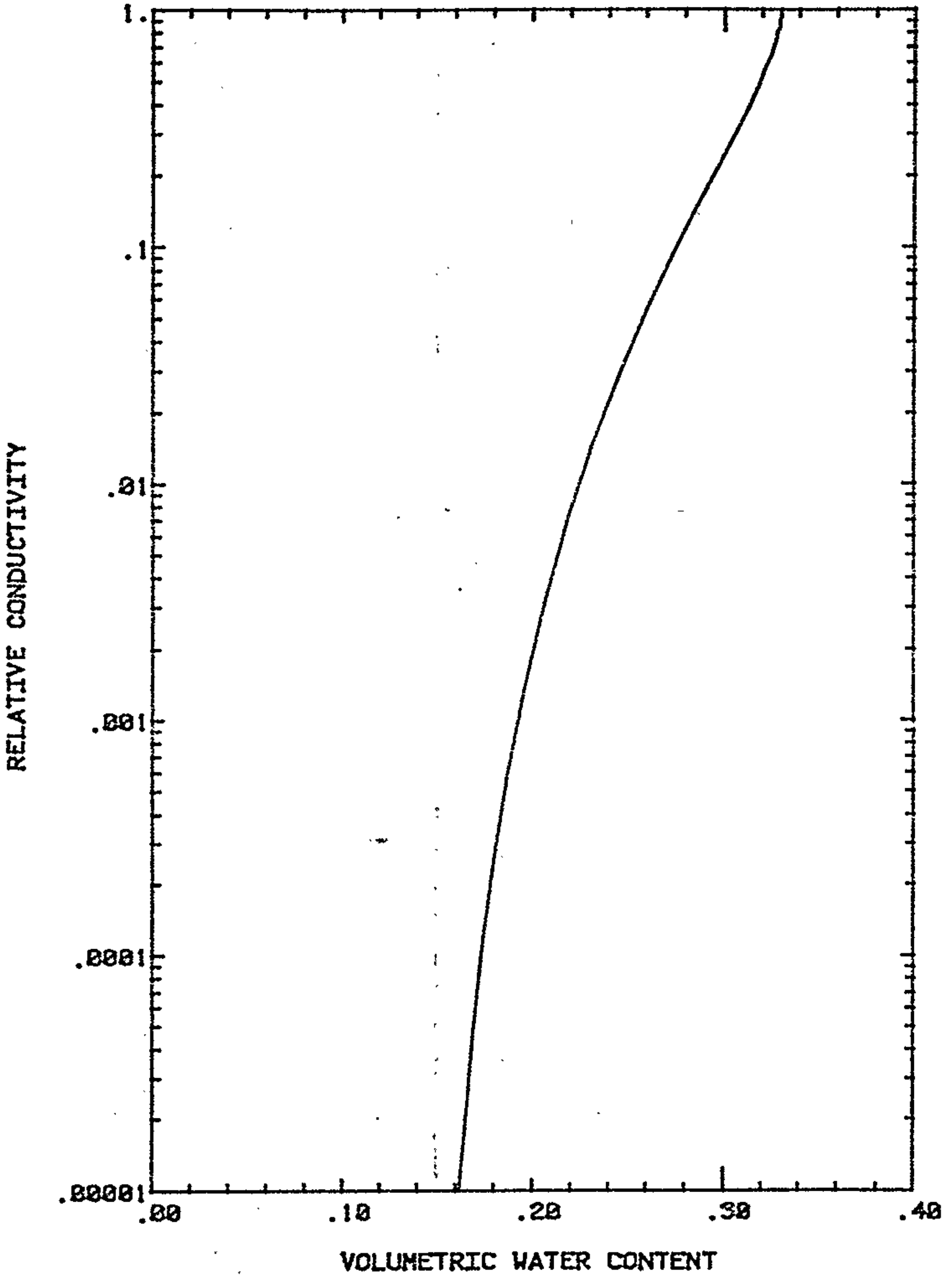

Figure 3c. Unsaturated hydraulic conductivity calculated from moisture retention data using a model by Mualem (1976). Sample 3-D; Depth 122 cm.

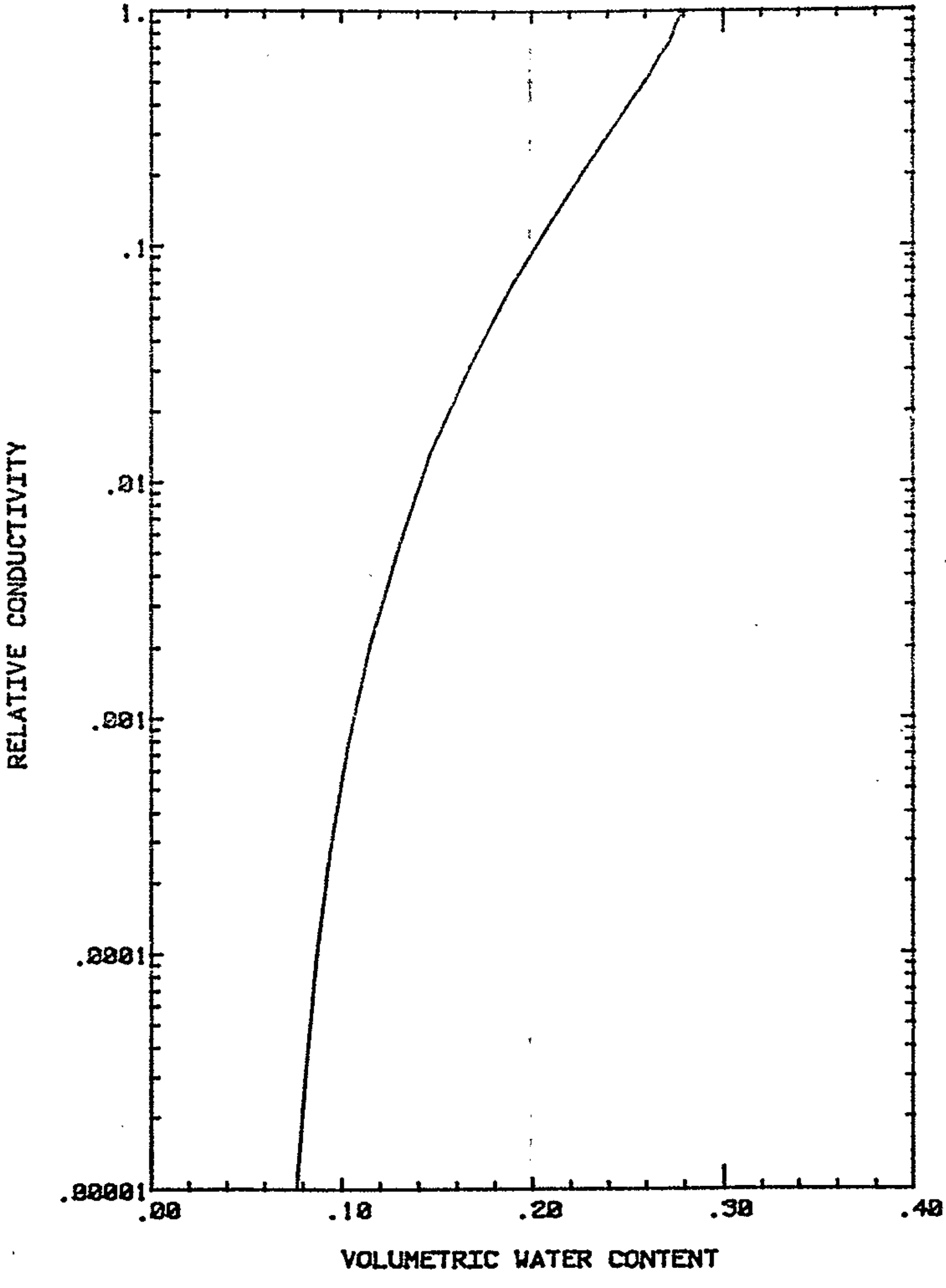

Figure 3d. Unsaturated hydraulic conductivity calculated from moisture retention data using a model by Mualem (1976). Sample 33-D; Depth 122 cm.

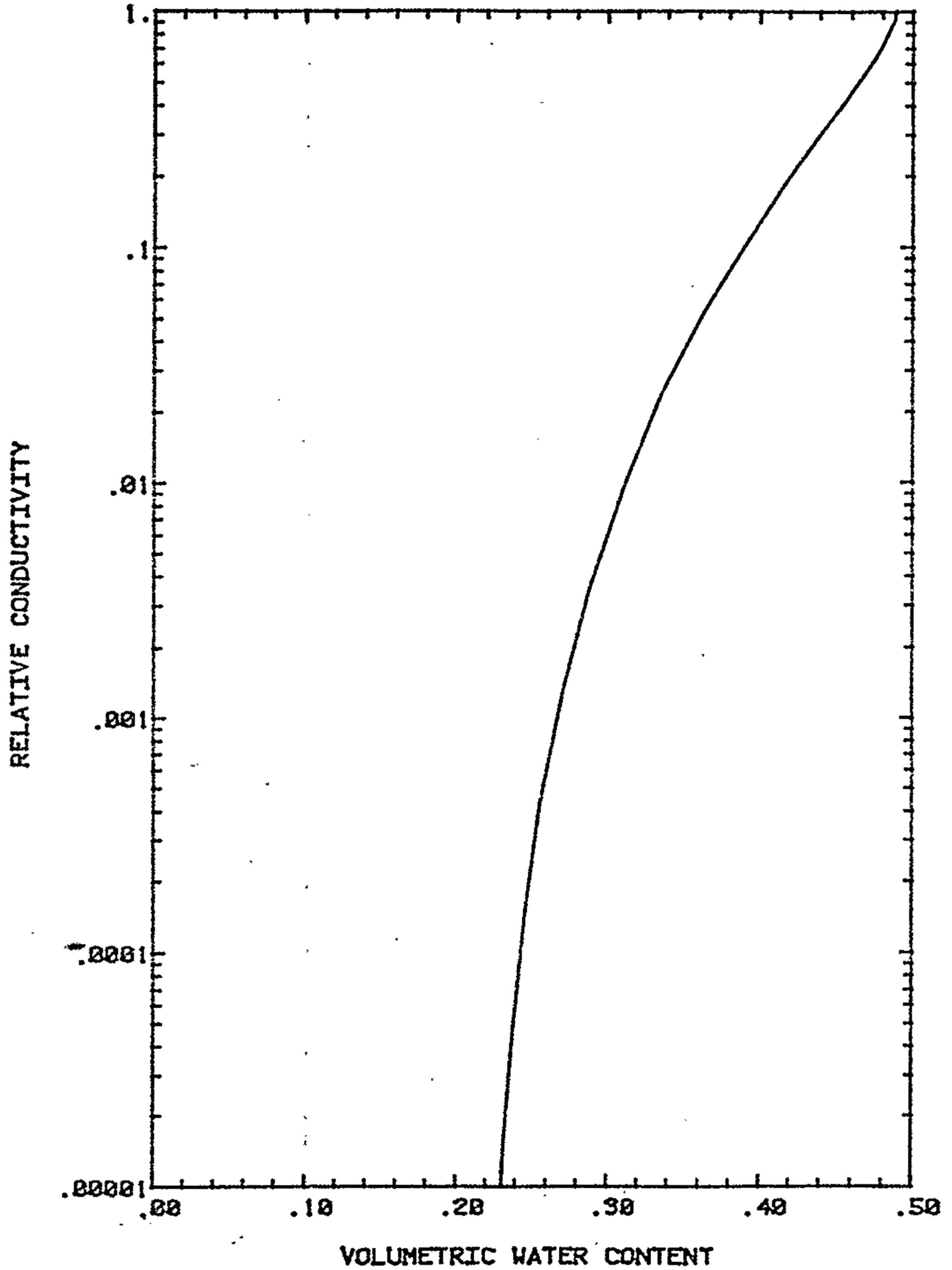

Figure 3e. Unsaturated hydraulic conductivity calculated from moisture retention data using a model by Mualem (1976). Sample 34-D; Depth 183 cm.

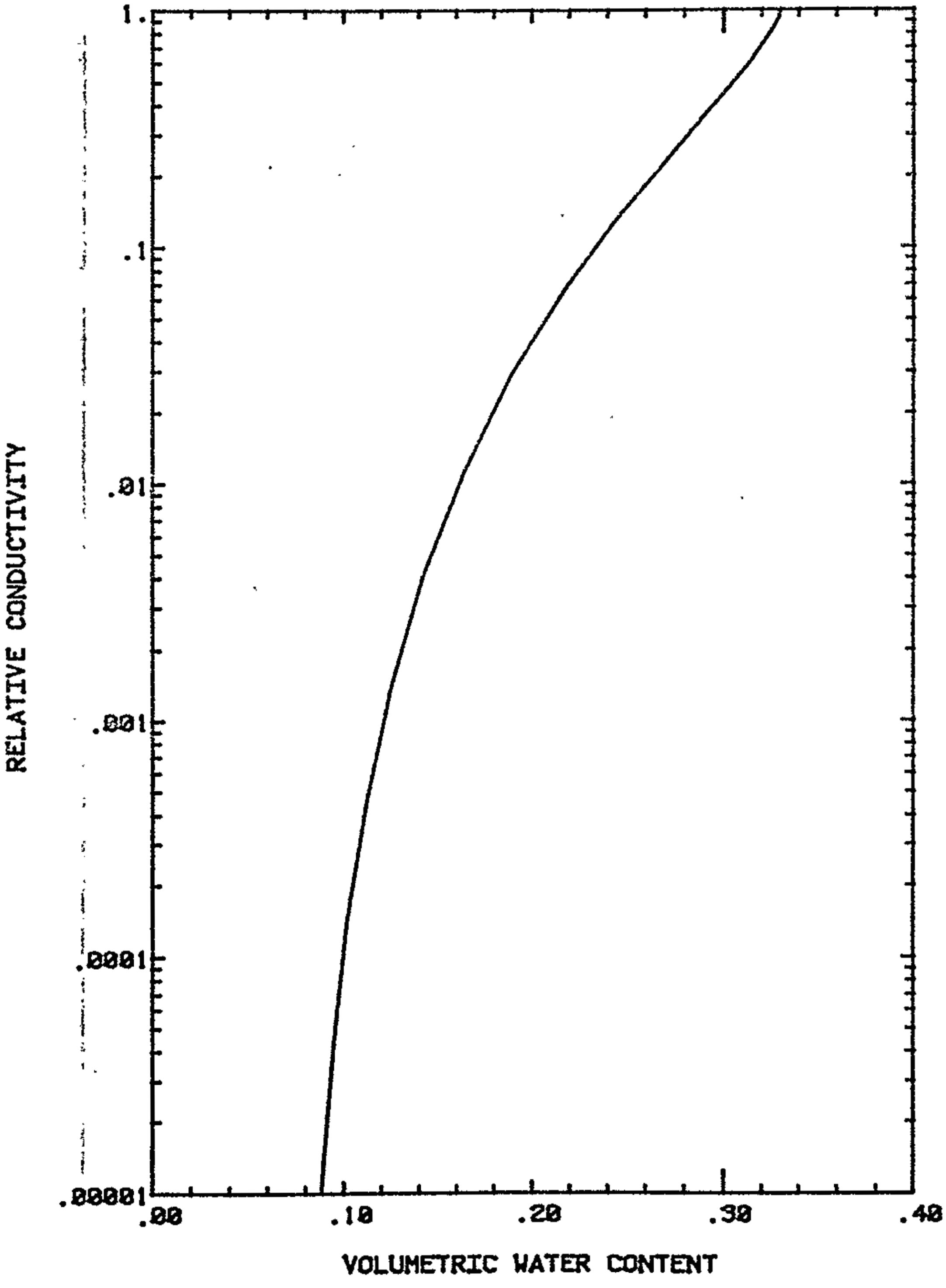

Figure 3f. Unsaturated hydraulic conductivity calculated from moisture retention data using a model by Mualem (1976). Sample 40-D; Depth 244 cm.

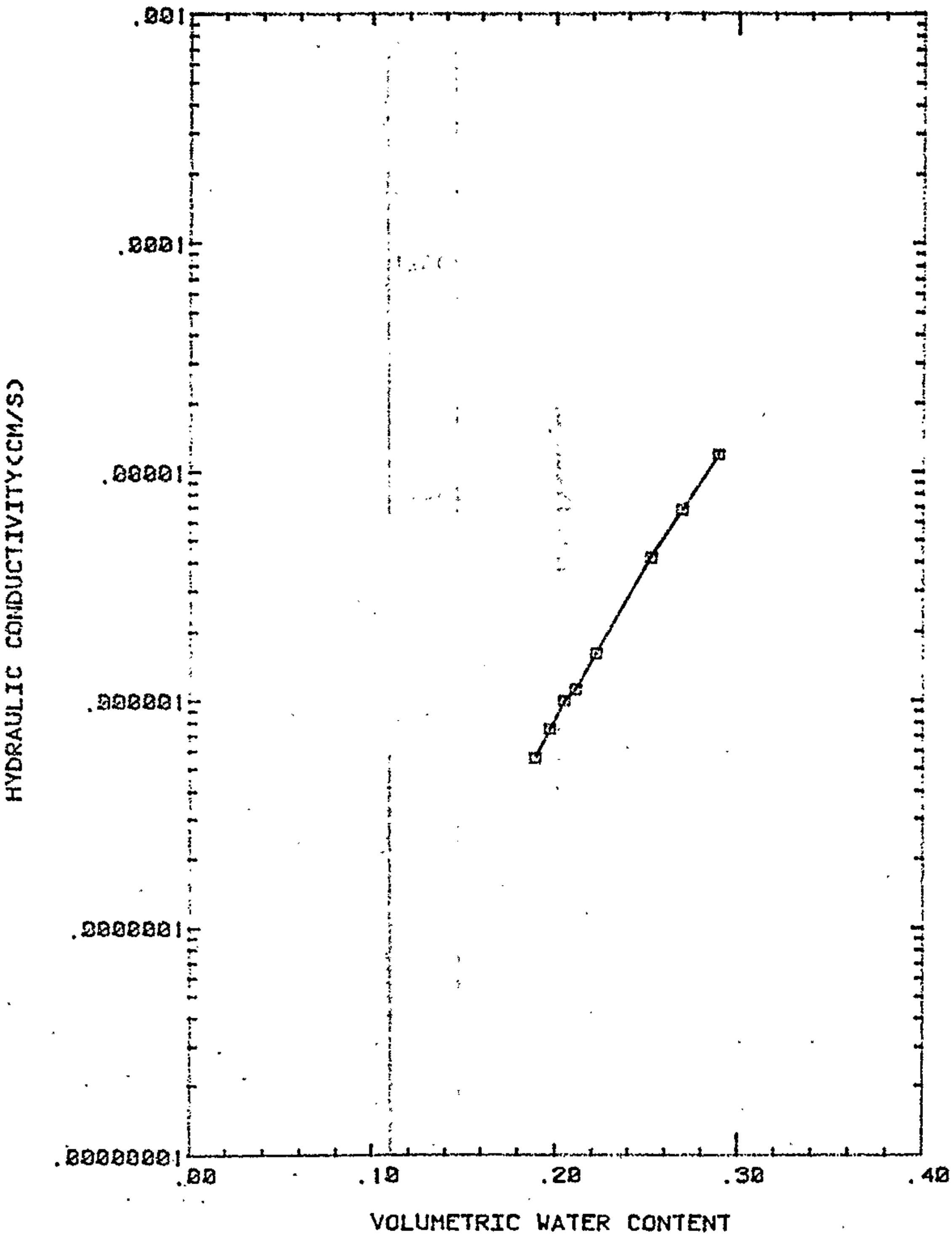

Figure 4a. Unsaturated hydraulic conductivity measured by the one-step outflow procedure. Sample 6-D; Depth 45 cm.

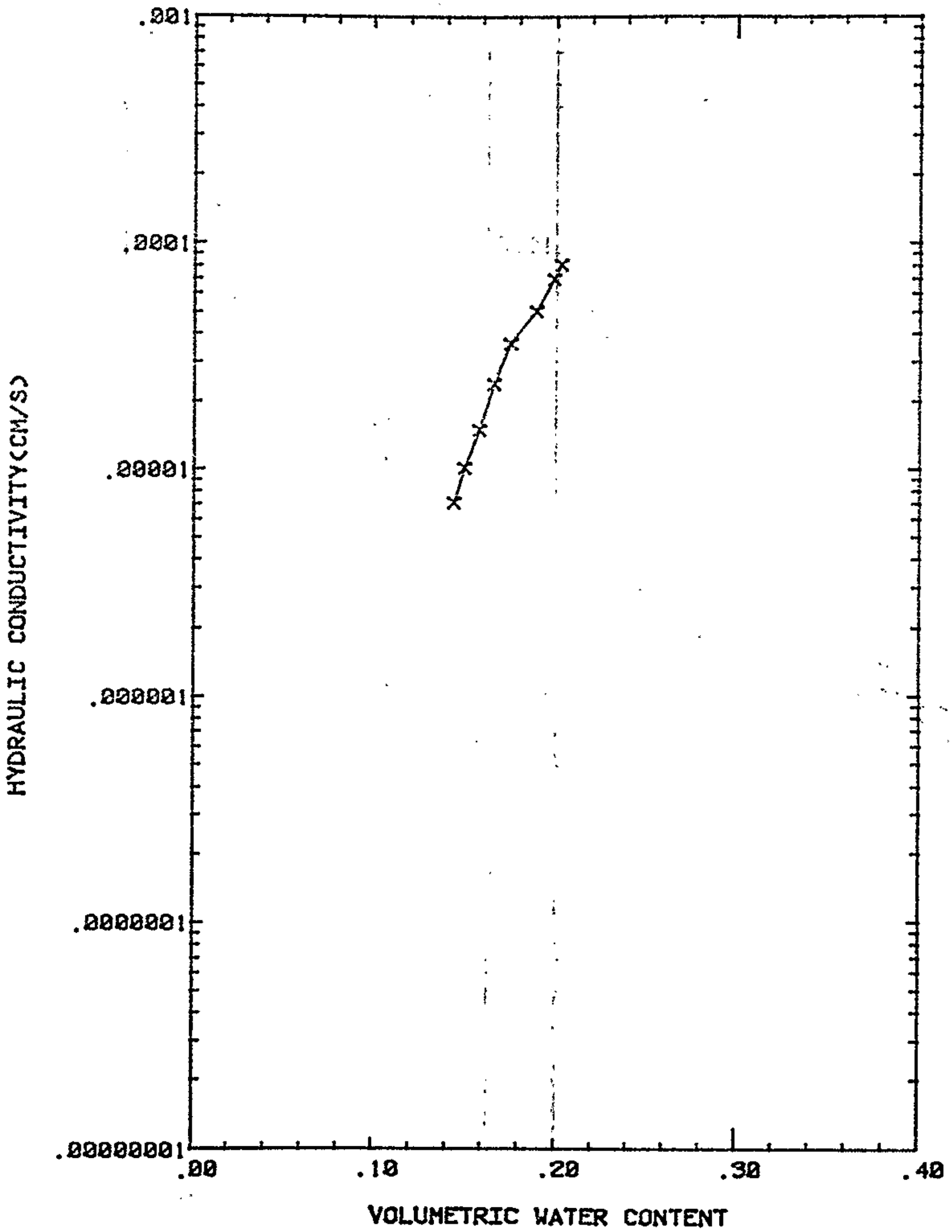

Figure 4b. Unsaturated hydraulic conductivity measured by the one-step outflow procedure. Sample 33-D; Depth 122 cm.

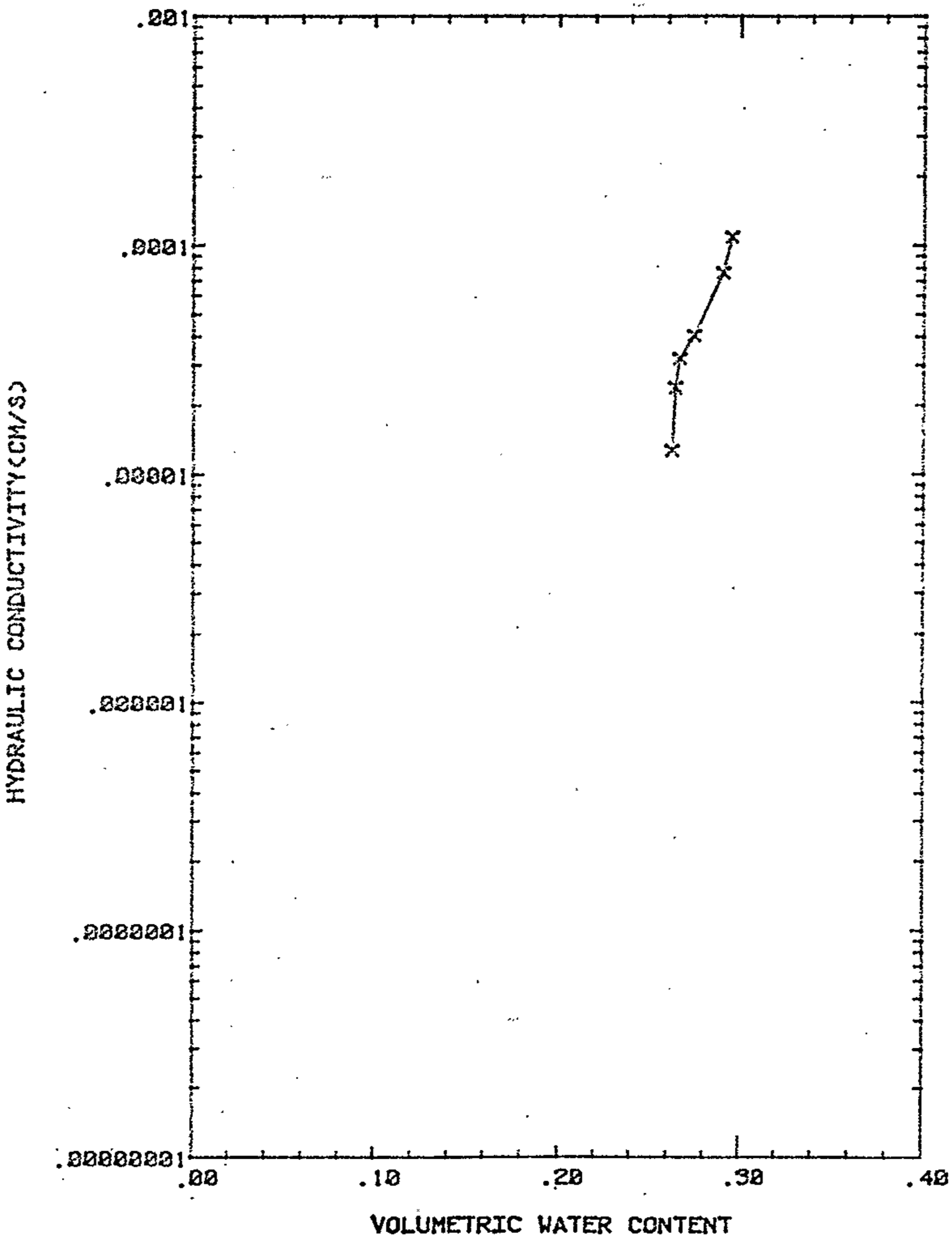

Figure 4c. Unsaturated hydraulic conductivity measured by the one-step outflow procedure. Sample 3-D; Depth 122 cm.

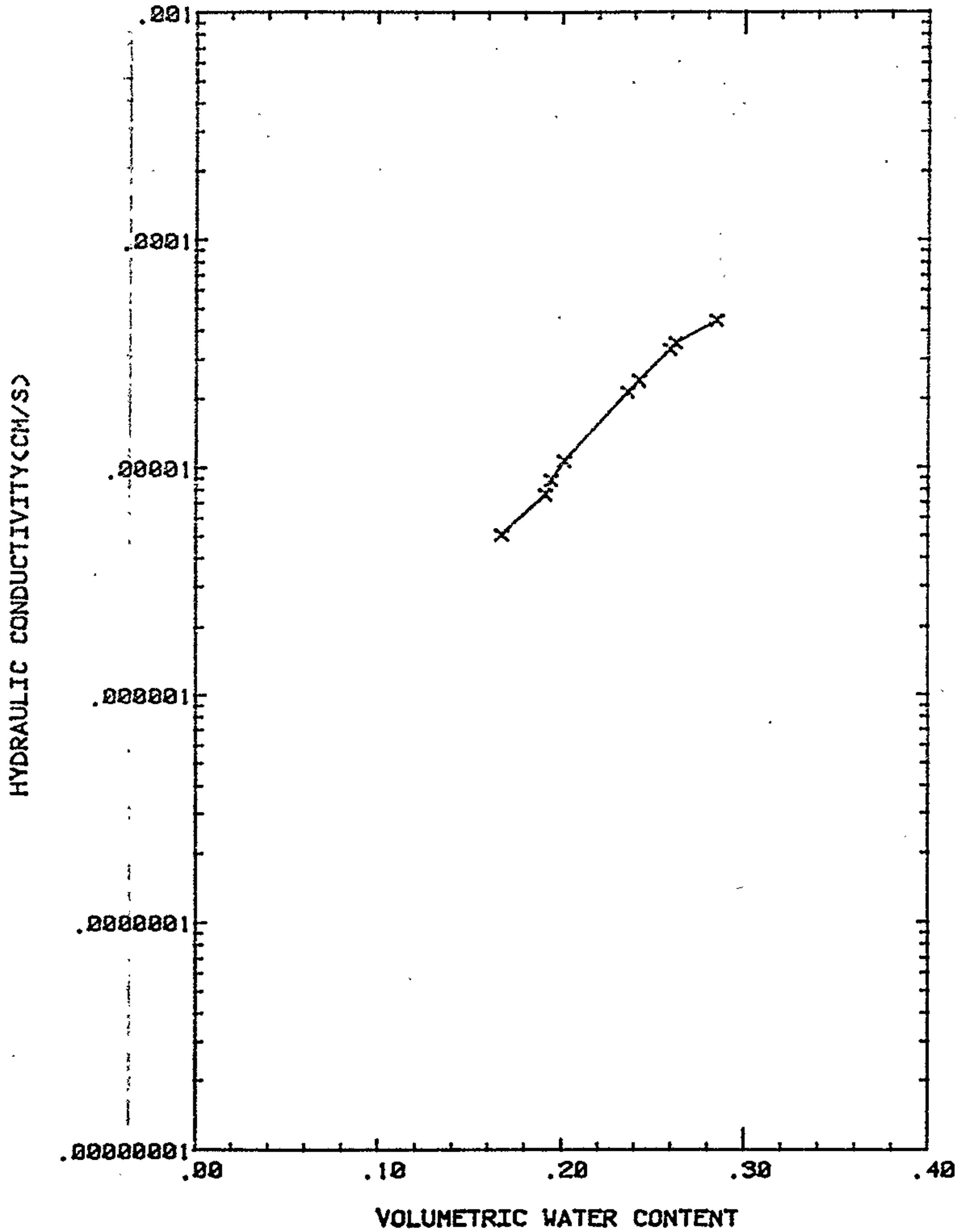

Figure 4d. Unsaturated hydraulic conductivity measured by the one-step outflow procedure. Sample 40-D; Depth 244 cm.

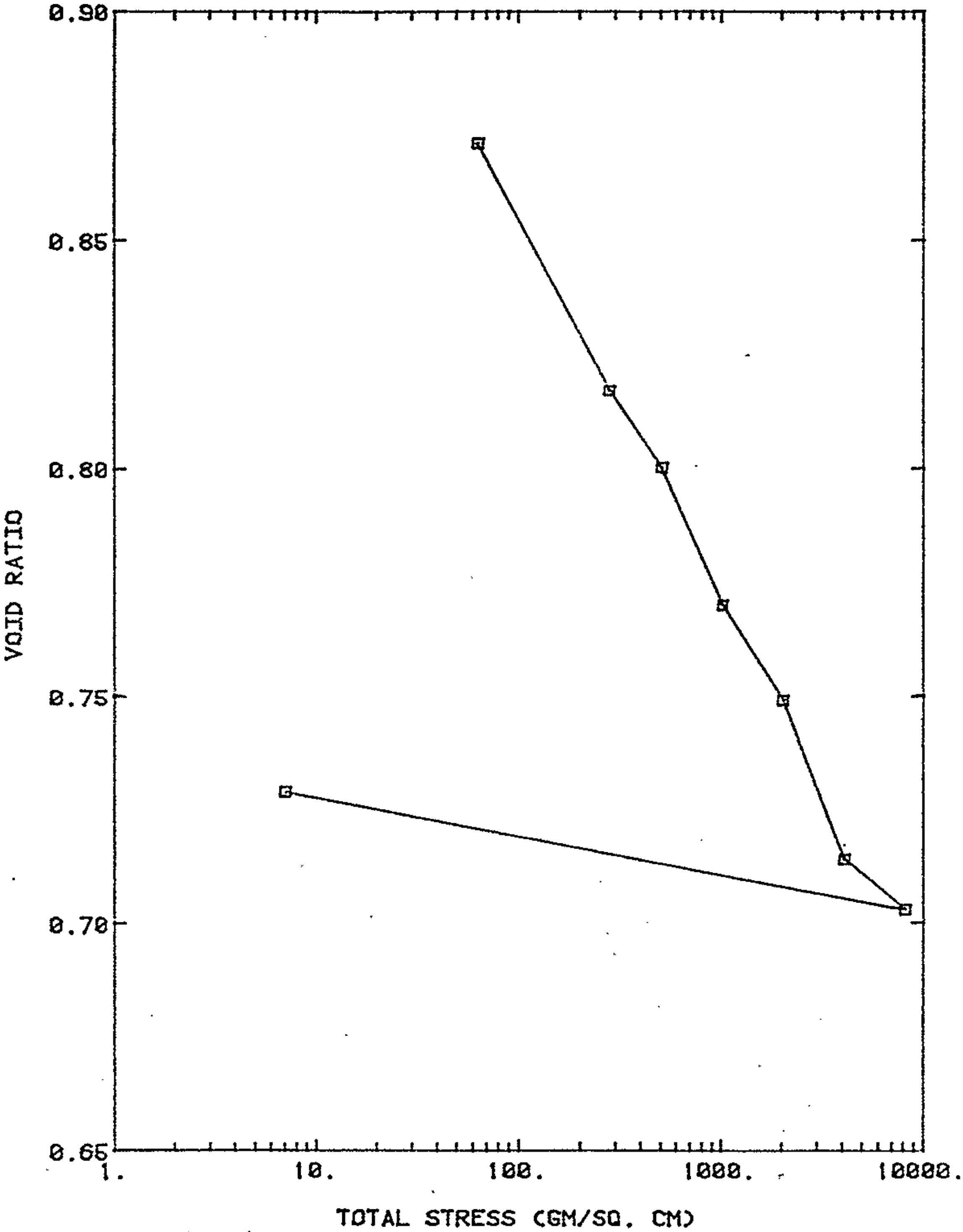

Figure 5a. Void ratio versus applied stress at background moisture content.

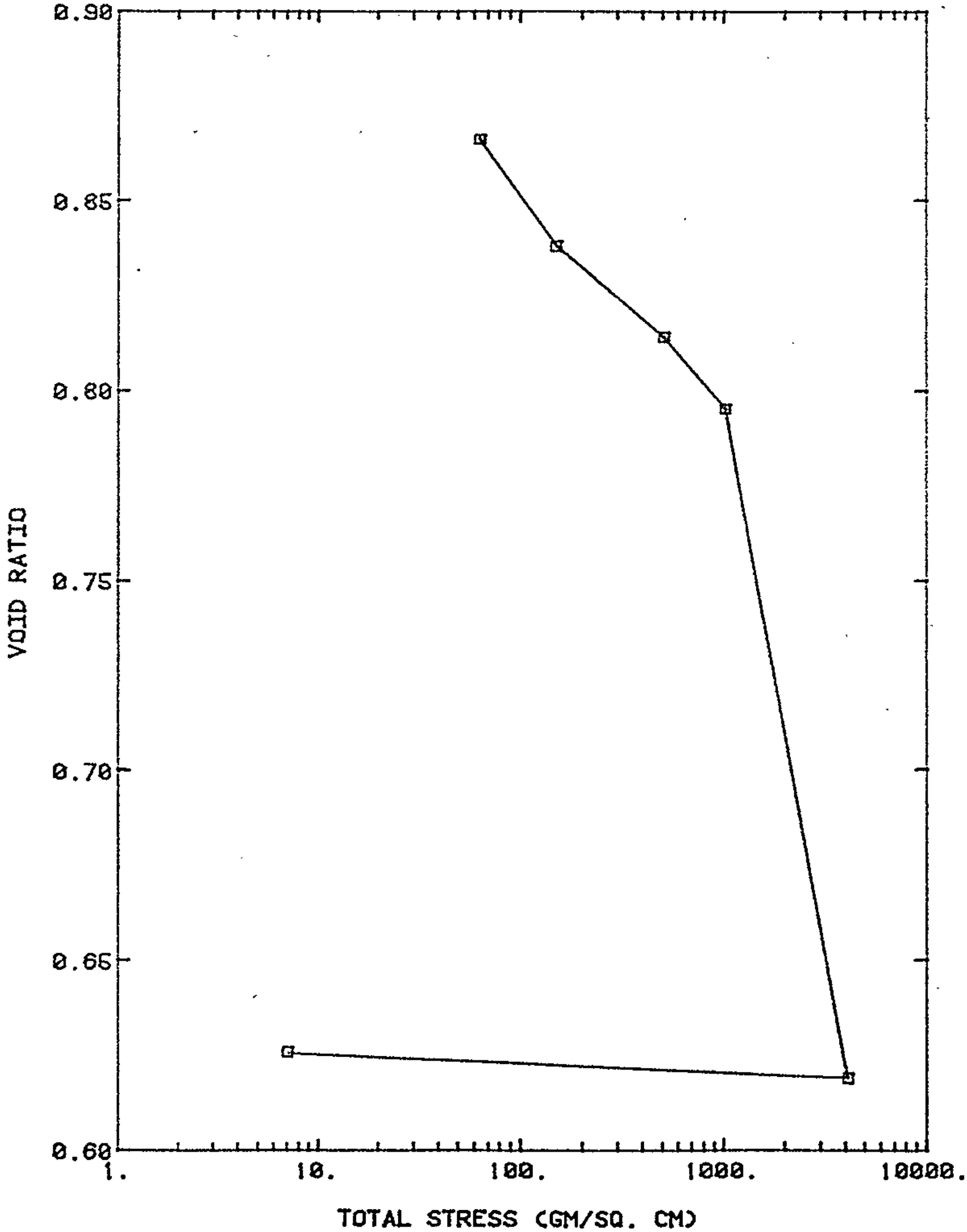

Figure 5b. Void ratio versus applied stress at saturation.

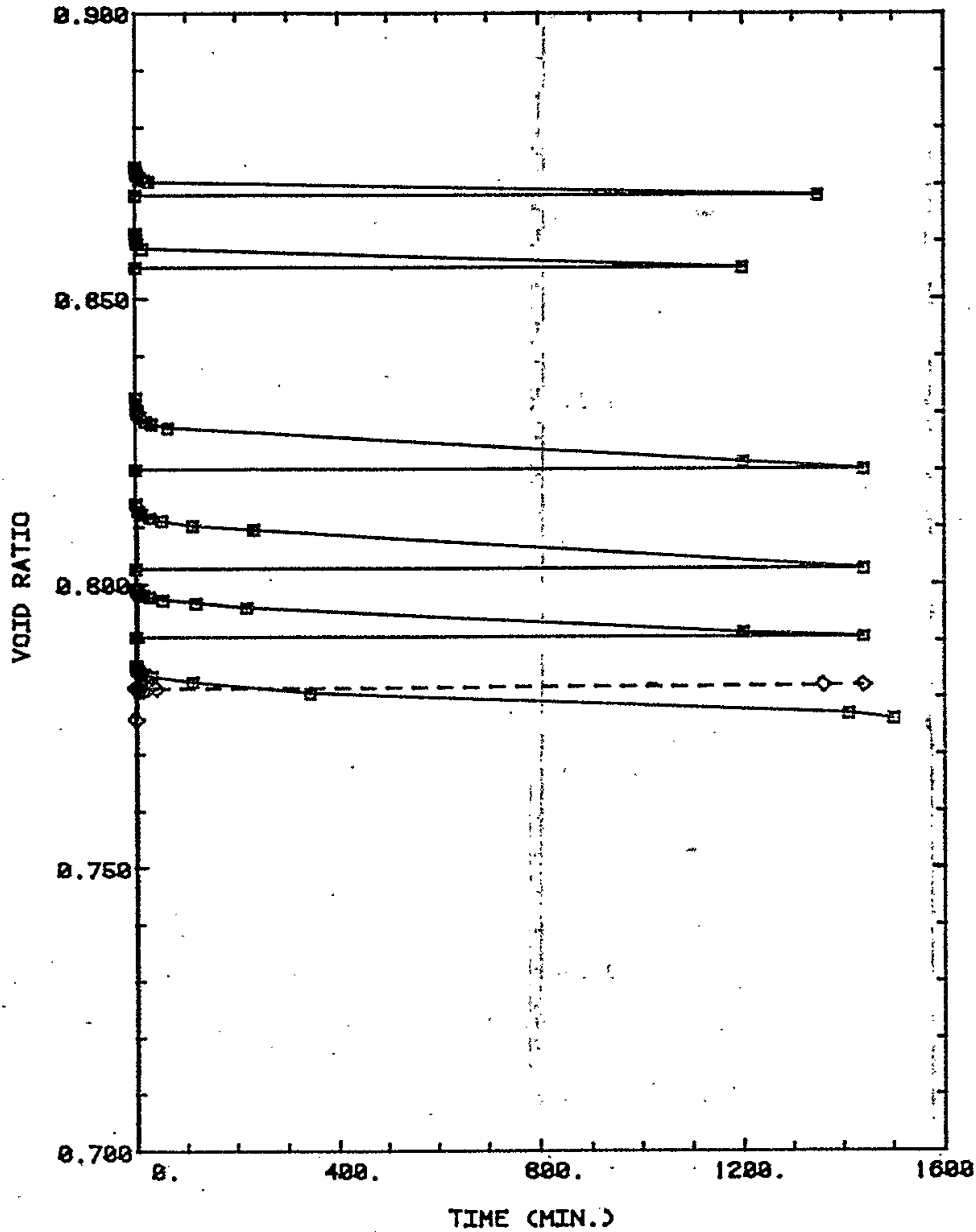

Figure 6a. Collapse observed during loading in consolidation cell at background moisture content. Dashed line shows rebound.

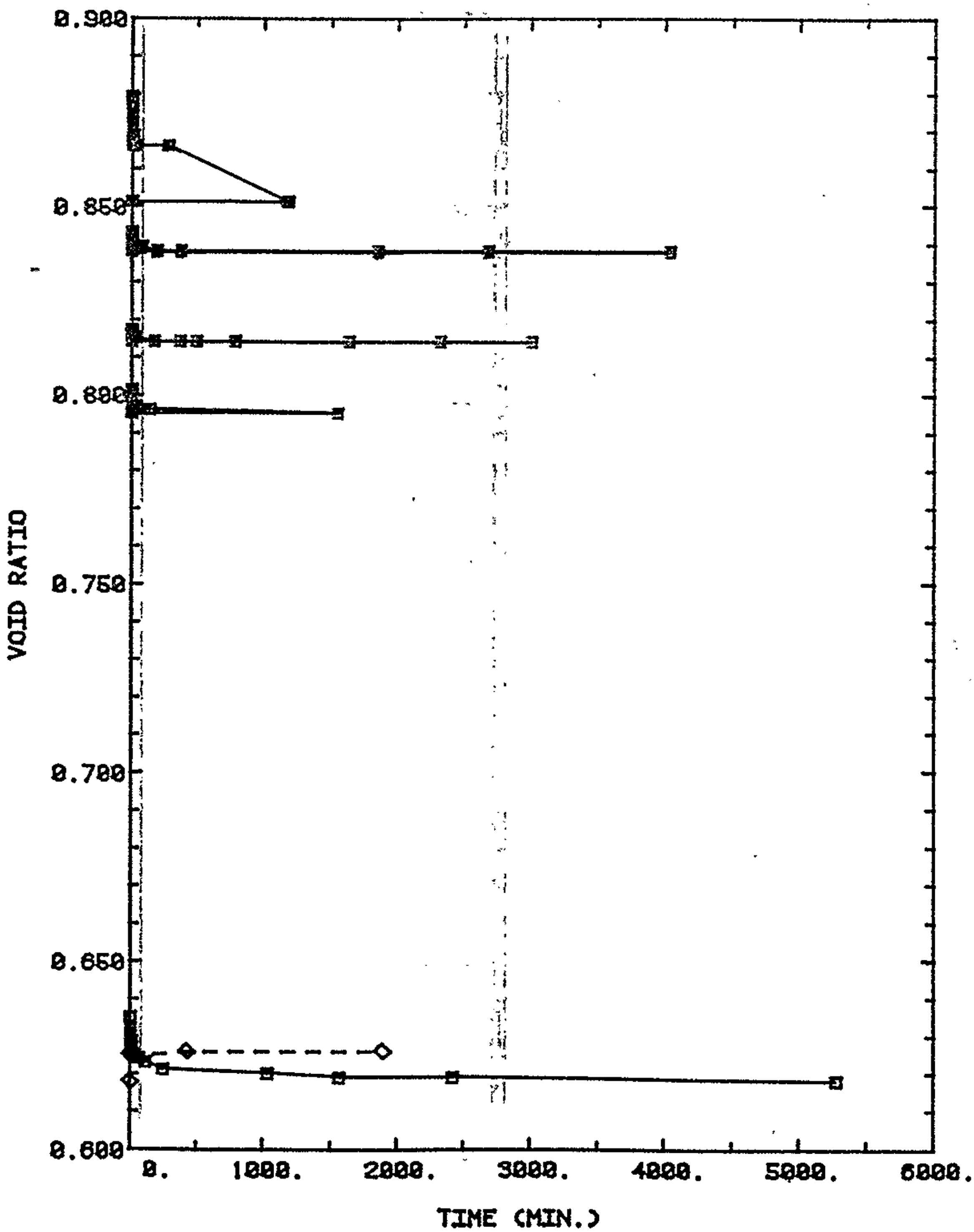

Figure 6b. Collapse observed during loading in consolidation cell at saturation. Dashed line shows rebound.

retention characteristics. The median particle size shows that the profile is comprised of fine to medium sand (Table 1).

Numerical Simulation

We previously pointed out that existing numerical models of variably saturated flow in deforming porous media utilize the effective stress concept. This approach is inappropriate for predicting soil collapse. In order to approximately predict collapse a two-step method was employed. First, a finite element numerical model, UNSAT-2 (Neuman et al., 1974), was selected to predict the distribution of moisture surrounding the borehole. The increase in moisture predicted by the model was used to estimate collapse on the basis of the laboratory relationship between moisture content increase and collapse which was obtained in the odeometer. The model does not take into account flow through fissured media, unless the fissures are so dense that the soil can be considered an equivalent porous media.

Data input to the numerical model were obtained mostly from the average properties from laboratory analyses. The tabulated moisture content versus pressure head input data were obtained by fitting a curve through a composite of data points from the hanging column analyses (Figure 7) using the regression procedure of van Genuchten (1980). The parameters of fit from the regression were then used in the model by Mualem (1976) to determine unsaturated hydraulic conductivity (Figure 8).

Two model runs were made using different values of saturated hydraulic conductivity. In the first run, saturated hydraulic conductivity, K_s, was set equal to 2.0 x 10^{-4} cm/s, which is nearly equal to the conductivity calculated from the field experiment according to:

$$K_s = \frac{Q}{2\pi H^2}[\sinh^{-1}(H/r) - 1] \quad (3)$$

Table 1. Summary of Particle Size Characteristics

Sample Number	Depth (cm)	d_{10} (mm)	d_{50} (mm)	Uniformity Coefficient
6-D	45	0.06	0.26	5.5
5-D	61	0.07	0.40	12.9
3-D	122	0.06	0.26	9.1
33-D	122	0.08	0.40	10.6
34-D	183	0.05	0.11	3.4
40-D	244	0.06	0.14	3.3

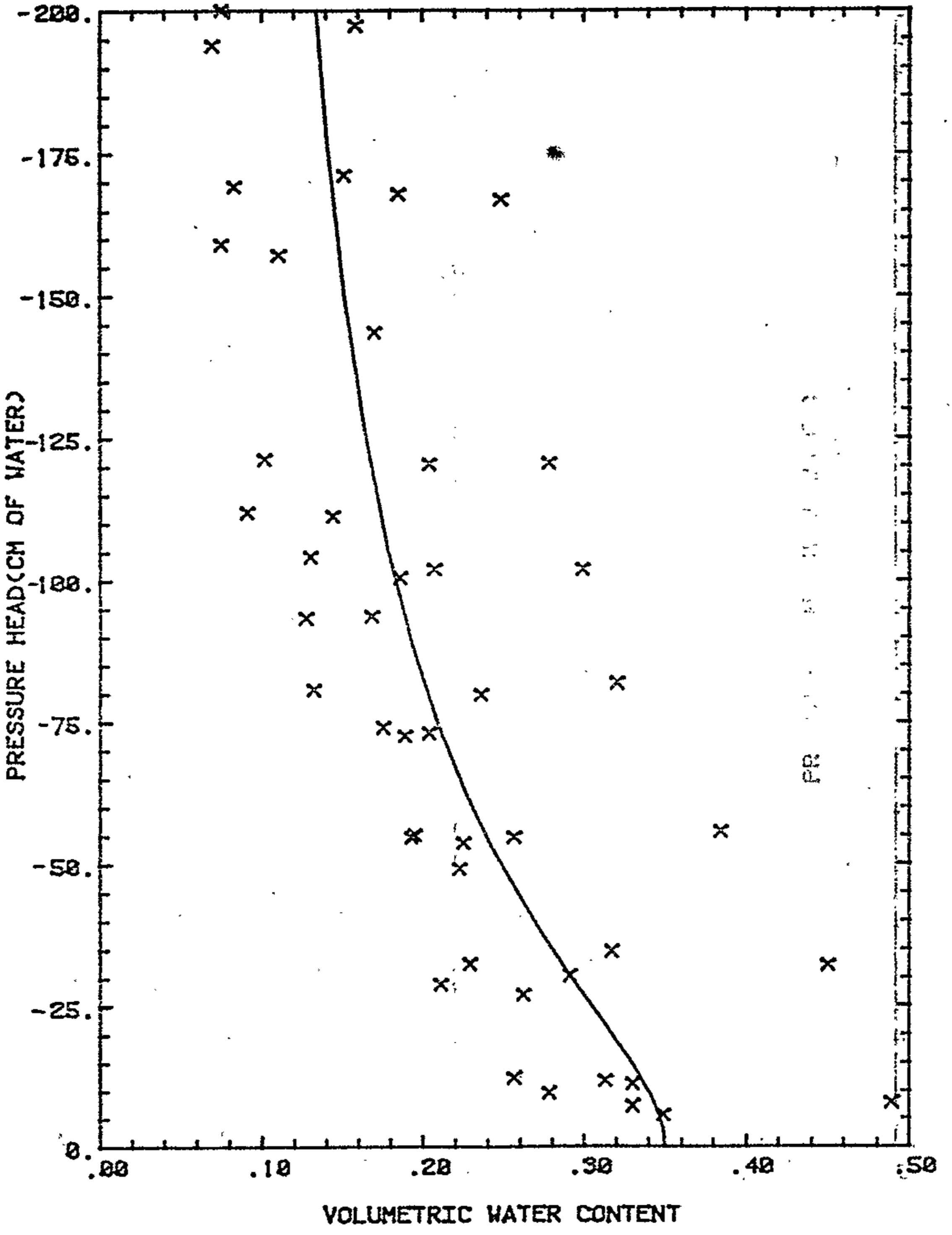

Figure 7. Composite moisture retention data and best fit through data using a procedure by van Genuchten (1980).

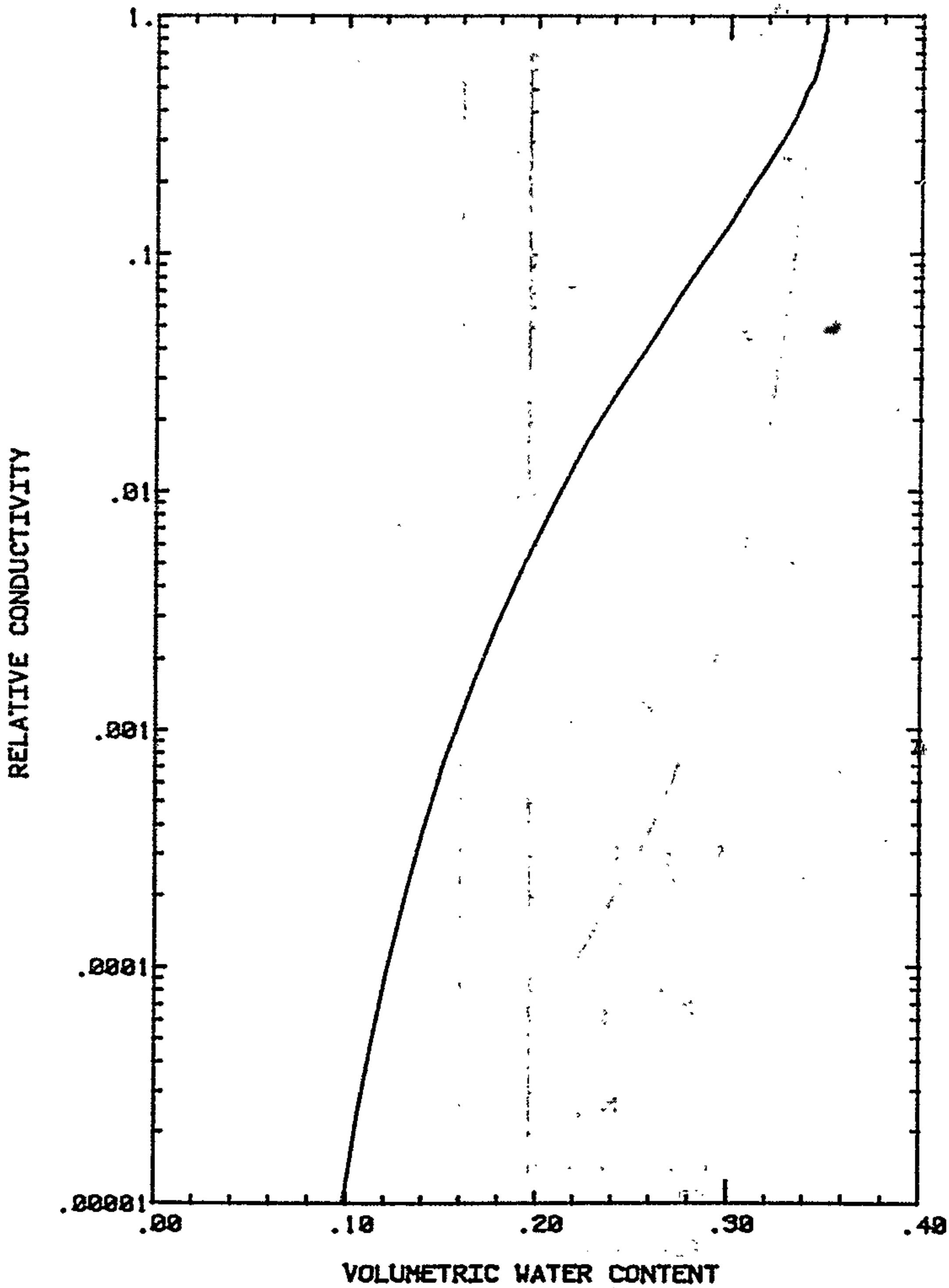

Figure 8. Calculated conductivity from composite soil moisture retention measurements.

where Q is the observed steady flow rate from the borehole, H is the depth of water in the borehole, and r is the borehole radius (Glover, 1960). Actually, flow from a borehole above the water table under a constant head boundary condition, which we are using to induce collapse, is a well-recognized method to calculate K_s in the field. In fact, the senior author has extensive experience with the method, and using his improved solutions which account for capillarity (Stephens et al., 1985), K_s is about 5.8 x 10^{-4} cm/s. Unfortunately, when this value is used in the numerical model, the calculated infiltration is less than observed. Therefore, in the second run, K_s was 2.0 x 10^{-3} cm/sec. This value, when used in the model, gives a good match of observed and predicted infiltration rates. Both K_s values in runs 1 and 2 are approximately within the range of those calculated from the shelby tube samples.

The grid for the finite element model consisted of 550 nodes and 490 elements within an area about 475 cm wide by 1515 cm (Figure 9). A quasi-three-dimensional, axisymmetrical flow field was considered. The upper 305 cm on the symmetry axis was a constant head boundary to simulate the water level in the borehole near land surface. The lower boundary of the mesh was assumed to represent a water table; other boundaries were impermeable. The initial condition was assigned as a uniform pressure head of -158 cm; this value corresponds to the average moisture content of 0.147 cm^3/cm^3 observed below the upper meter of the profile.

The numerical model was run to simulate the distribution of moisture during the 15 days of the field experiment. To calculate collapse, only the wetted zone above about 10 m depth was considered. Within this zone and along the columns formed by the finite element grid, the total stress was calculated, assuming a background wet density of 1.55 g/cc and accounting for the predicted increases in moisture content during infiltration. The total

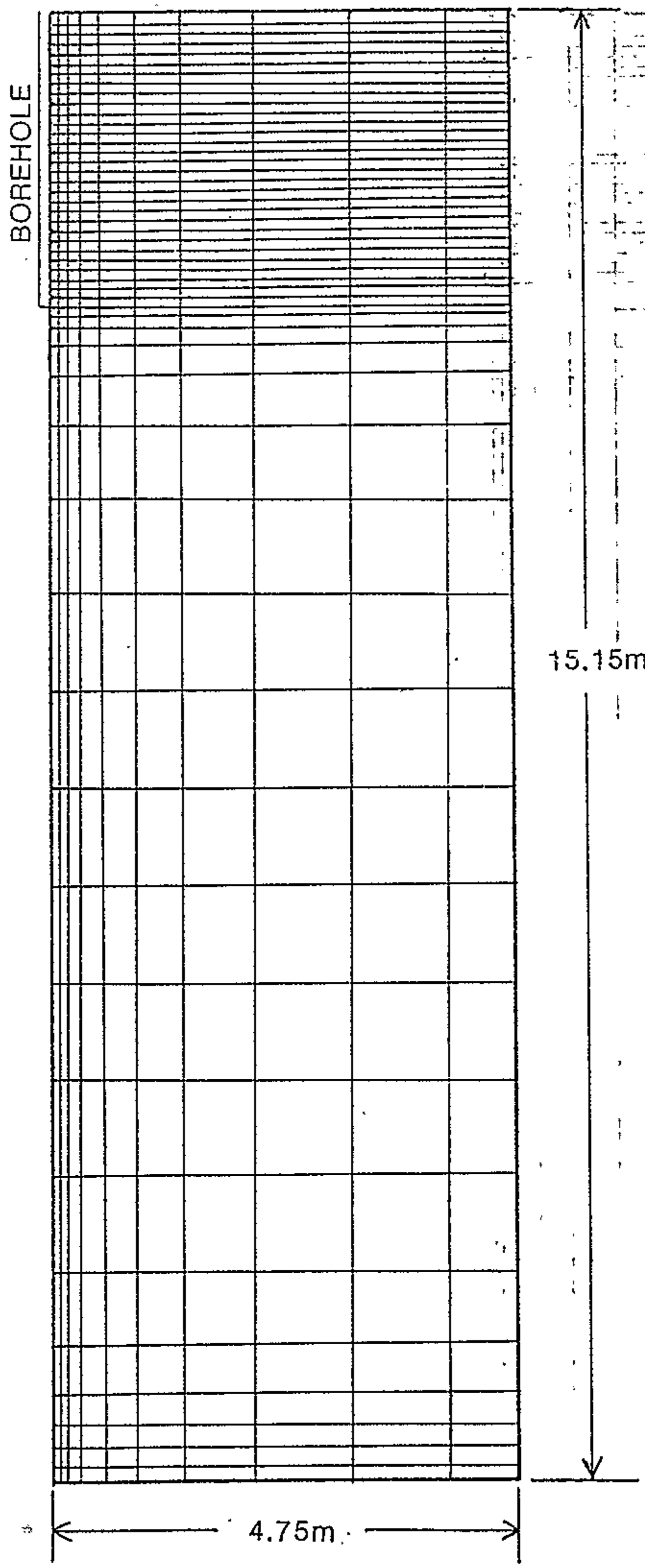

Figure 9. Finite element mesh.

stress was then used to determine the void ratio on each of the two curves in Figure 5, for background moisture content and saturated conditions. The data for background moisture conditions were approximated as:

$$e = 1.022 - 0.036 \ln \sigma_T \quad (4)$$

and for the near saturated case:

$$e = 1.083 - 0.056 \ln \sigma_T \quad (5)$$

To obtain the void ratio at intermediate moisture content values predicted by the model, a linear interpolation procedure was applied to the laboratory measurements. The decrease in void ratio between the predicted value and that void ratio which would exist without wetting is an index of the amount of collapse when summed over the vertical columns.

One problem with this simplified approach is that the same total stress, that at the wetted condition, was used to calculate the void ratio on both curves in Figure 5. Actually, the total stress at field water content should be used to obtain the void ratio for deformation at background moisture conditions; however, this introduces an additional calculation. This error would tend to underestimate collapse. Another source of error is that the collapse is assumed to occur instantly with wetting. In our approach the time delay in the predicted collapse is due only to the time delay of wetting the profile from the borehole. Owing to the absence of good measurements of collapse from the Sondex wells and infrequent measurements of the moisture distribution, the time delay between wetting and collapse cannot be reliably assessed from field data.

RESULTS

Field Experiment

During the 15 day field experiment, a total of 6.66 x 10^4 liters (17,592 gallons) of water were injected. The infiltration rate versus time plot (Figure 10) shows a rapid decrease in infiltration rate at early time. When the head in the borehole is constant, it is expected that the infiltration rate will decrease, as capillary effects diminish during wetting. After a few hours, the infiltration rate was relatively steady at about 43 cm^3/s (0.7 gallons per minute). The reason for the decrease in infiltration rate after about 4 days was due to a problem with maintaining a constant head in the borehole; at times the level dropped at least 0.44 m. The increase in flow rate after about 11 days is apparently due to water ponded on the surface; however, the opening of channels and fissures by flowing water may also be a contributing factor.

The observed distribution of moisture surrounding the borehole is illustrated in Figures 11a-c. After the wetting front reached a particular distance and the soil collapsed, the elevation of the top of the neutron probe decreased; this makes comparisons of moisture at the same depth at different times only approximate. As Figures 11a-c indicate, the wetting front did not penetrate below the 8 m depth at the 1.5 m radius until after about one week of infiltration. At this same time, the wetting front had not yet reached the 3.0 m depth. As expected from other numerical model studies of infiltration from a borehole (Stephens and Neuman, 1982), the wetted region is elongated downward in response to gravity.

During the second week of infiltration, the wetting front advanced to a radial distance of 4.5 m. The irregular nature of the wetting front is shown in Figure 11c at 4/8/85 (two days after infiltration stopped); behind this

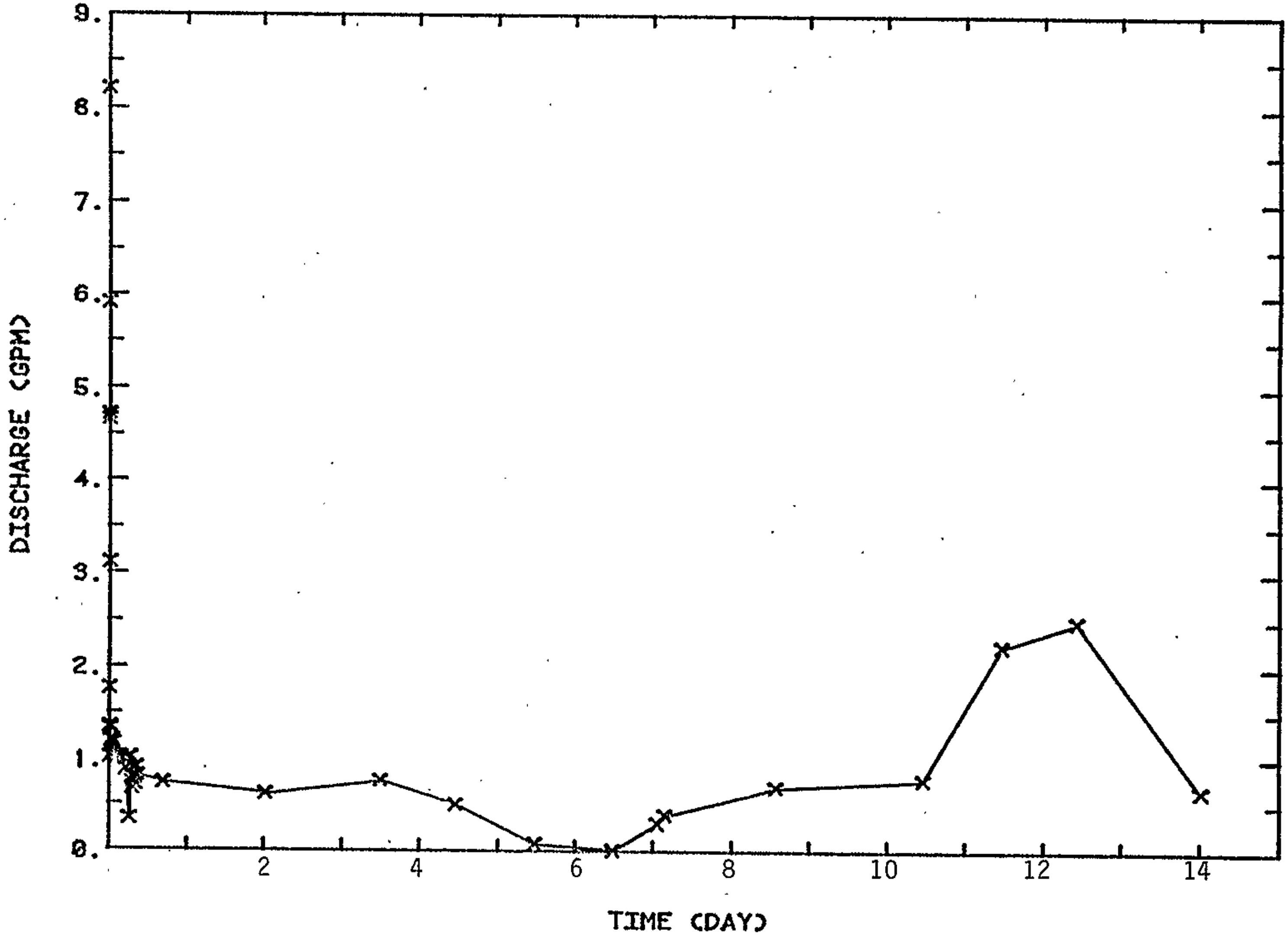

Figure 10. Observed infiltration rate versus time during field test.

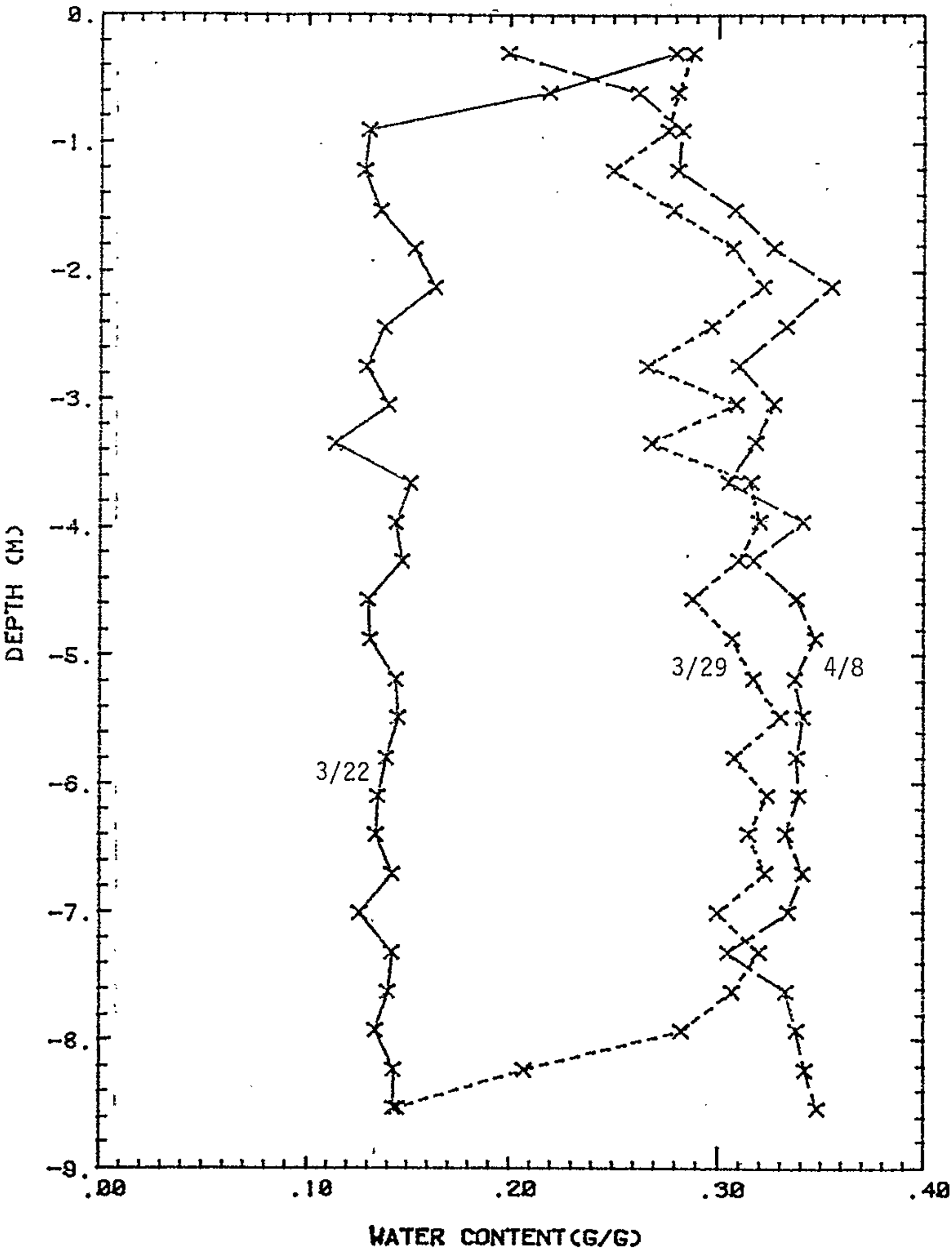

Figure 11a. Moisture content distribution at 1.5 m distance from borehole.

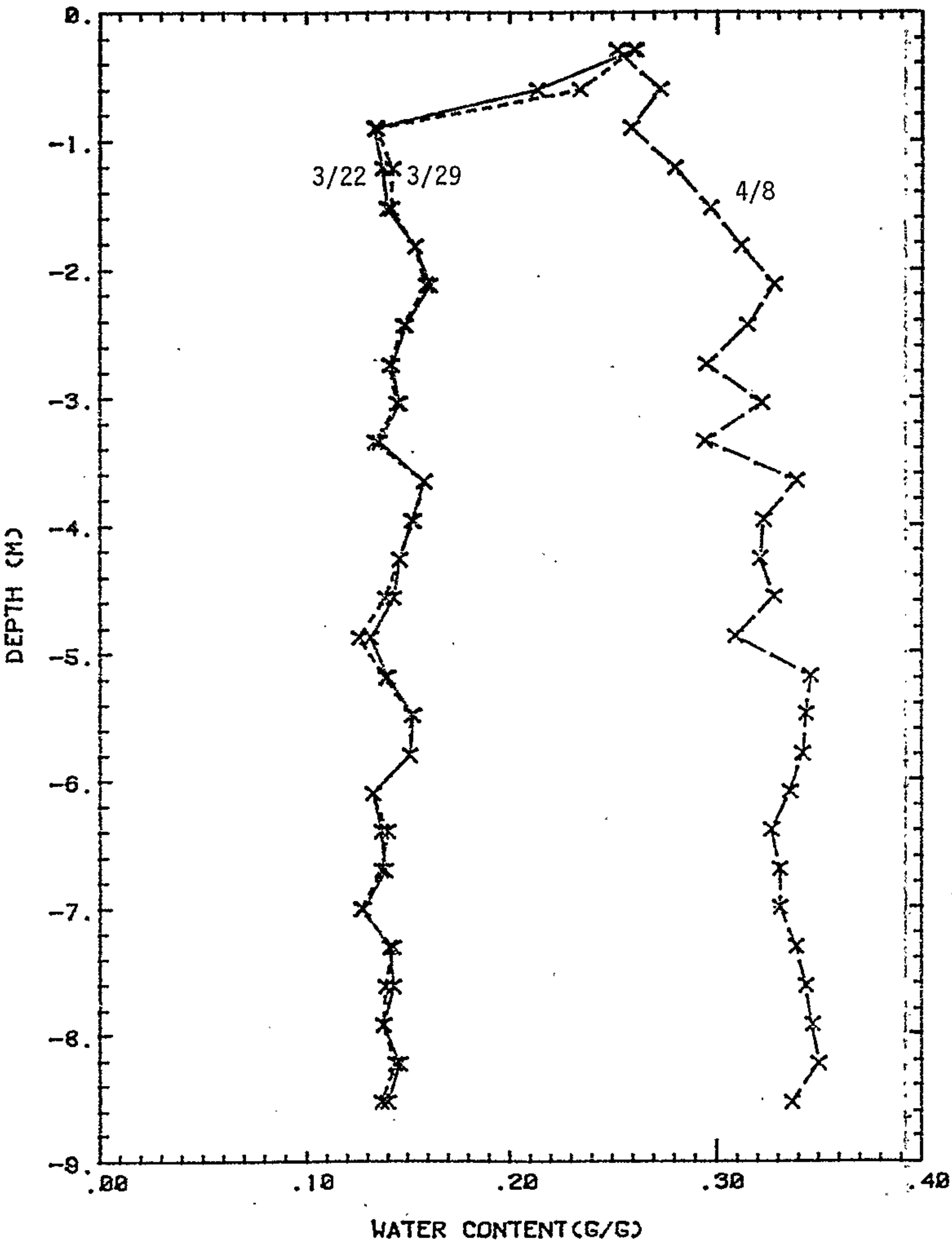

Figure 11b. Moisture content distribution at 3.0 m distance from borehole.

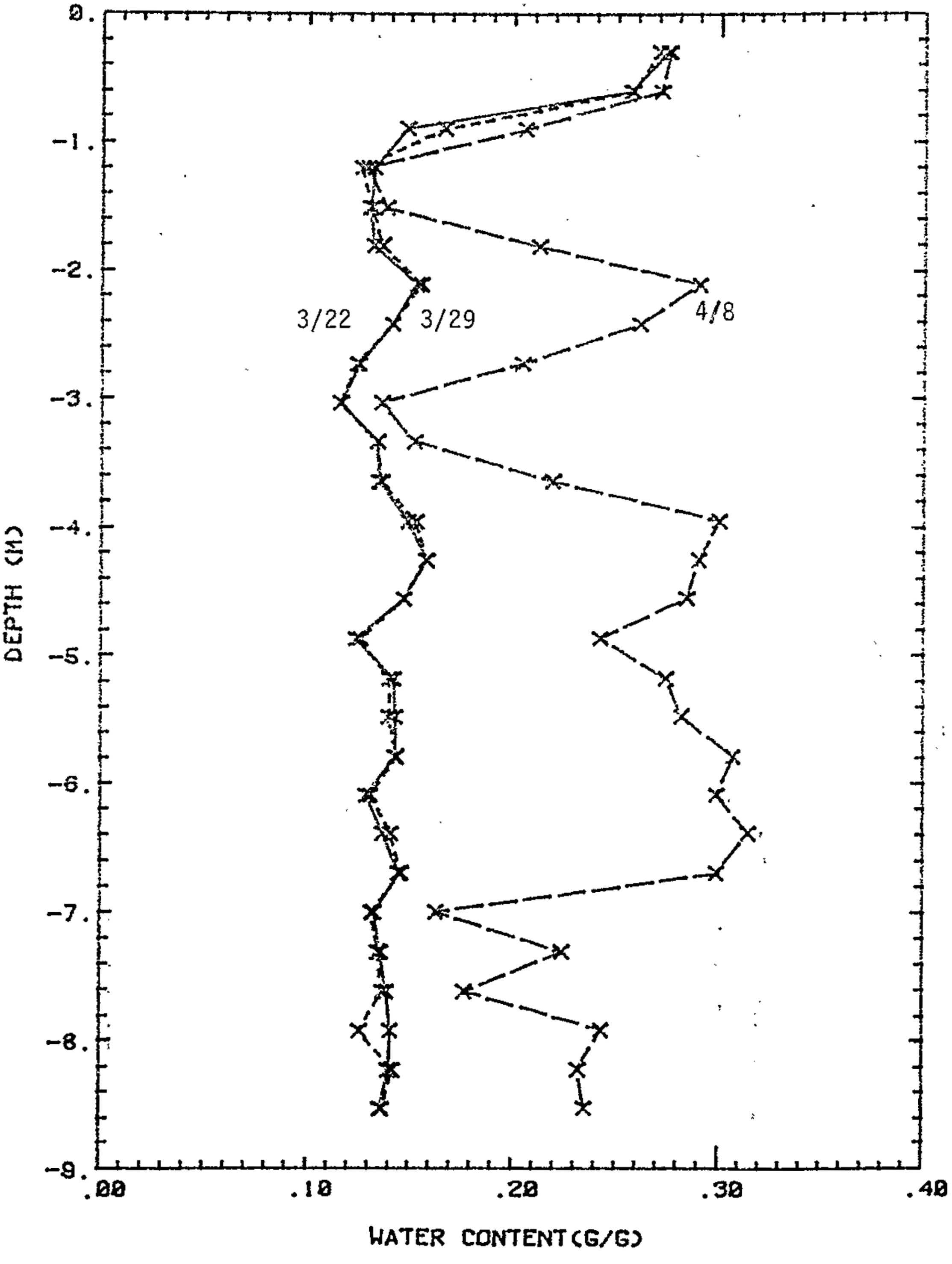

Figure 11c. Moisture content distribution at 4.5 m distance from borehole.

front, where the sediments are nearly saturated, the moisture profile is more uniform. The irregular shape of the wetting front clearly reflects the heterogeneous nature of the unsaturated hydraulic characteristics. This type of variability in stratified sediments may be expected to lead to anisotropy in the flow field; that is, there is a greater tendency for lateral flow as moisture content decreases (Yeh, 1983; Mualem, 1984). Anisotropy is neglected in the numerical model.

According to Stephens and Neuman (1982), when the flow field reaches steady state, only the region near the borehole should be nearly saturated, whereas moisture content will gradually decrease along a flow path with increasing distance from the borehole. Thus, the reason the moisture content at a radius of 4.5 m on 4/8/85 is lower than that closer to the borehole is not necessarily because the wetting front has not yet reached this distance; on the contrary, the moisture distribution at 4.5 m on 4/8/85 may be very close to the steady-state condition, even though the soil is not fully saturated. The amount of collapse will therefore be expected to decrease with increasing distance from the borehole, inasmuch as the moisture content will decrease with increasing distance from the borehole.

The values of the field-measured neutron probe data in Figures 11a-c reflect an inconsistency with average laboratory-measured moisture retention data in Figure 7. The average saturated moisture content on a volumetric basis used in the model is about 0.35 cm^3/cm^3 (Figure 7), based on the laboratory data. In contrast, the neutron probe measurements near the borehole exceed about 0.45 cm^3/cm^3 (0.30 g/g water content on a mass basis, as shown in Figure 11). One source of this apparent inconsistency could be due to spatial variability in unsaturated hydraulic properties; as shown in Figure 7 and Figure 2e, one sample did in fact exhibit a near saturated water content of about 0.50 cm^3/cm^3. A more representative mean retention curve could lie to the right of the one shown in Figure 7. Another possible explanation could be due to errors in calibration of the neutron probe. The calibration was performed using background moisture contents, and therefore the range of measured values was limited to about 0.04 to 0.18 g/g. The low correlation coefficient on the neutron probe calibration also reflects the large uncertainty in the estimated field moisture content. Still another reason for the discrepancy could be attributed to differences in the amount entrapped air during infiltration in the field compared with samples wetted in the hanging column. Owing to the relatively long period of wetting in the field when entrapped air may redissolve, the near saturated field water content could be significantly greater than the laboratory value.

The collapse potential is 5%, as defined in equation 1 and calculated from our laboratory results with equations 4 and 5. According to Jennings and Knight (1975) moderate trouble to trouble with collapsing soil is to be expected. The collapse indicated by daily measurements in the Sondex wells did not produce results which were consistent with observations in the field. Reasons for this failure may include slippage between the Sondex tubing and surrounding gravel. The only data available to us from the NMBMMR were measurements at the end of the field infiltration test using vertical distances between a horizontal grid and land surface (Figure 12).

The observed collapse decreased almost linearly from the borehole to a distance of more than 3.5 m. The collapse at about 1.5 m reflects the step-wise nature of the collapse due to fissuring. Photographs and maps by the NMBMMR in the Final Report of the El Llano Geotechnical Investigation clearly show concentric fissures surrounding the borehole. Because the onset of collapse and its progression were not recorded in the field we do not know whether there is a time delay between the arrival of the wetting front and the

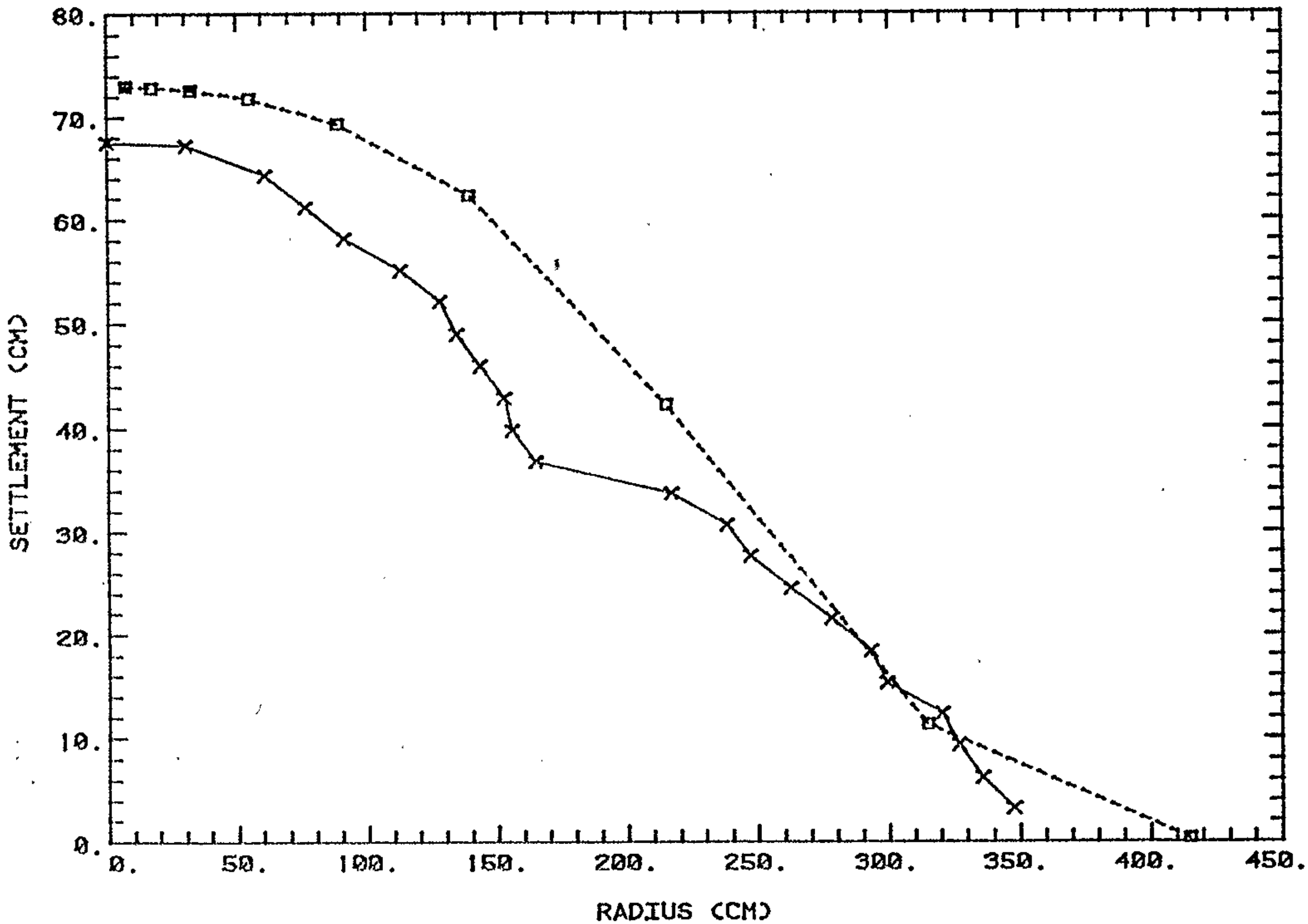

Figure 12. Observed and calculated collapse after 15 days, assuming $K_s = 2.0 \times 10^{-4}$ cm/s.

initiation of collapse or whether there is a critical value of moisture content at which collapse begins. Nevertheless, the field results appear to be consistent with the concept that the amount of collapse increases with increasing water content. Figures 11a-c show that the profile at 4.5 m from the borehole is not as wet as at locations closer to the borehole. It is not clear from field measurements at the 4.5 m distance whether additional wetting and collapse would occur if the experiment were run longer, or whether the moisture content and collapse are in an equilibrium condition. However, the rather slight increase in moisture content at the 1.5 m distance between 3/29 and 4/8/85 (Figure 11a) suggests that the moisture distribution, at least near the borehole, is nearly at equilibrium.

Numerical Simulation

The model predicted moisture content distributions for run #1 ($K_s = 2.0 \times 10^{-4}$ cm/s) is shown in Figure 13 for 11 and 15 days of infiltration. The wetting front has just reached the 3.0 m distance within about 11 days; predicted pressure head in Figure 14 also shows this. The predicted wetting front has not reached the 4.5 m radial distance during the 15 days of simulation in this run. This is in contrast to wetting observed at the 4.5 m radius, as shown in Figure 11c. Comparisons of field and predicted values of moisture content are not considered useful, owing to the problems discussed earlier, such as the poor calibration of the moisture probe.

The steady infiltration rate predicted by the model is about 4.5 cm^3/s (0.07 gpm), in contrast to an observed value of about 43 cm^3/s (0.7 gpm) (Figure 10). The fact that the model predicts a wetting front which is moving too slowly and an infiltration rate which is too low suggests that the value of K_s in run #1 is too low. The value of K_s for run #2 was increased ten fold so that the steady infiltration rate in the model would agree almost

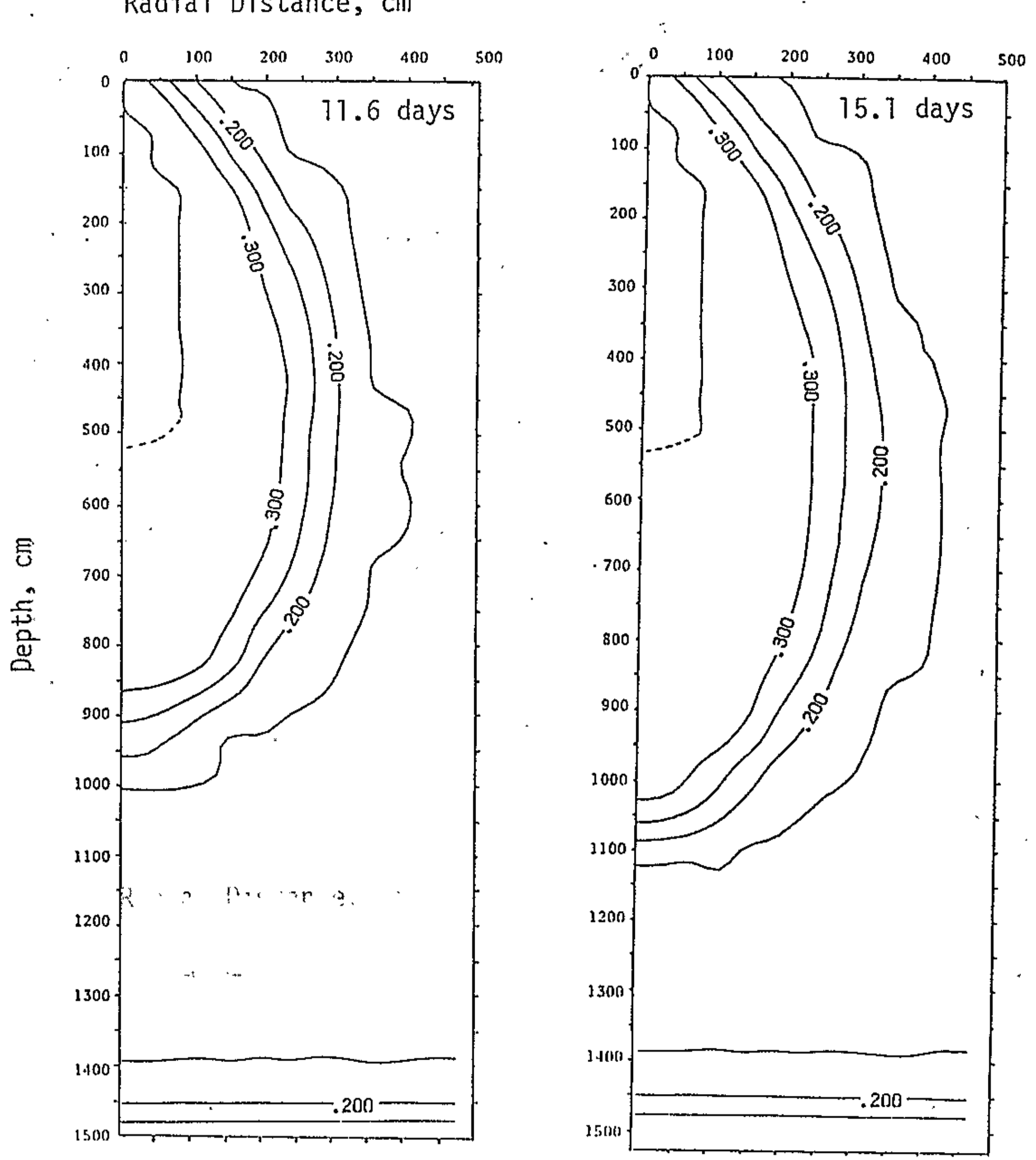

Figure 13. Model predicted moisutre content (cm^3/cm^3) distribution for $K_s = 2.0 \times 10^{-4}$ cm/s. (Dashed where hand drawn.)

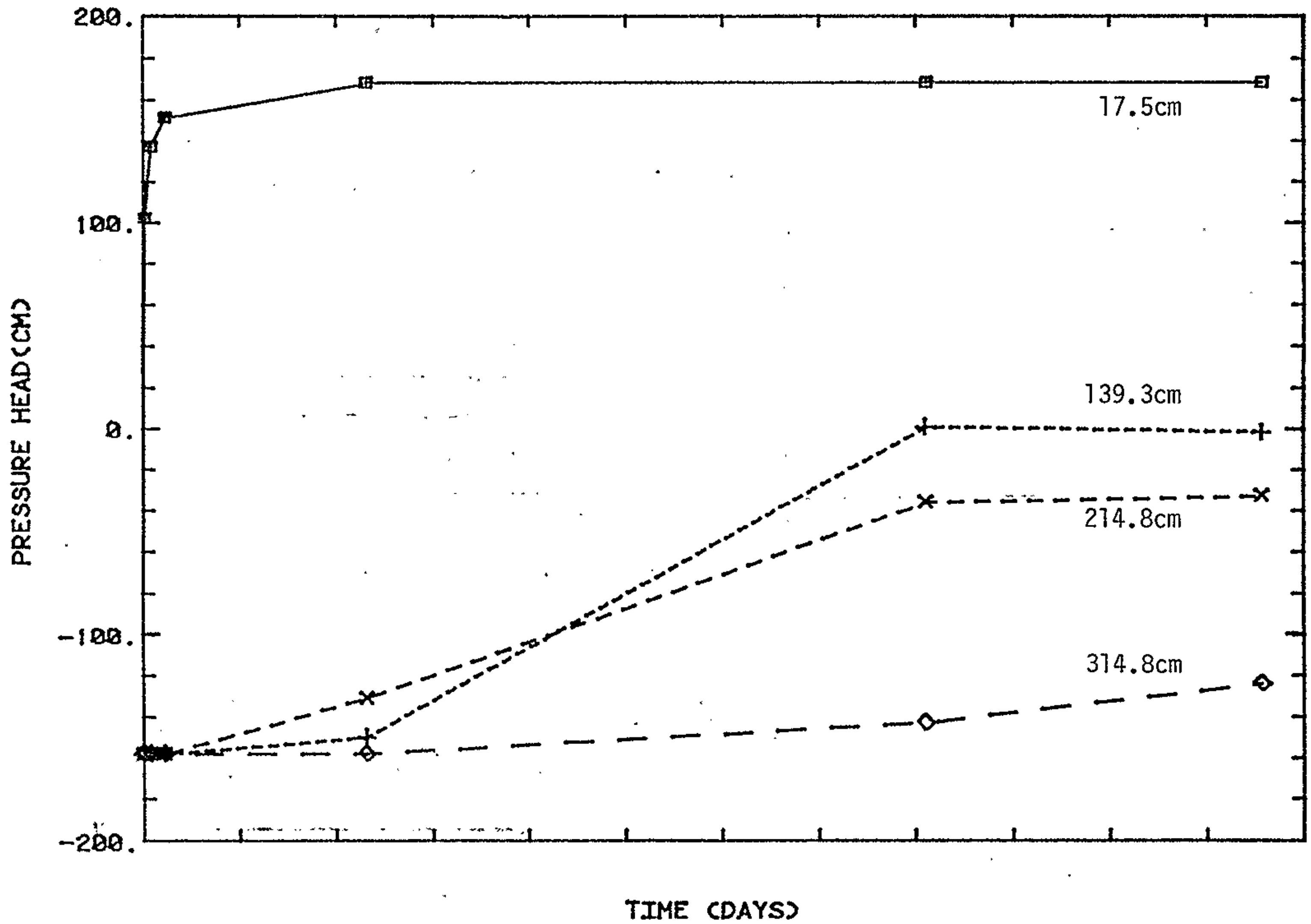

Figure 14. Model predicted pressure head at the 3.0 m depth at different radial distances from the borehole when $K_s = 1.0 \times 10^{-4}$ cm/s.

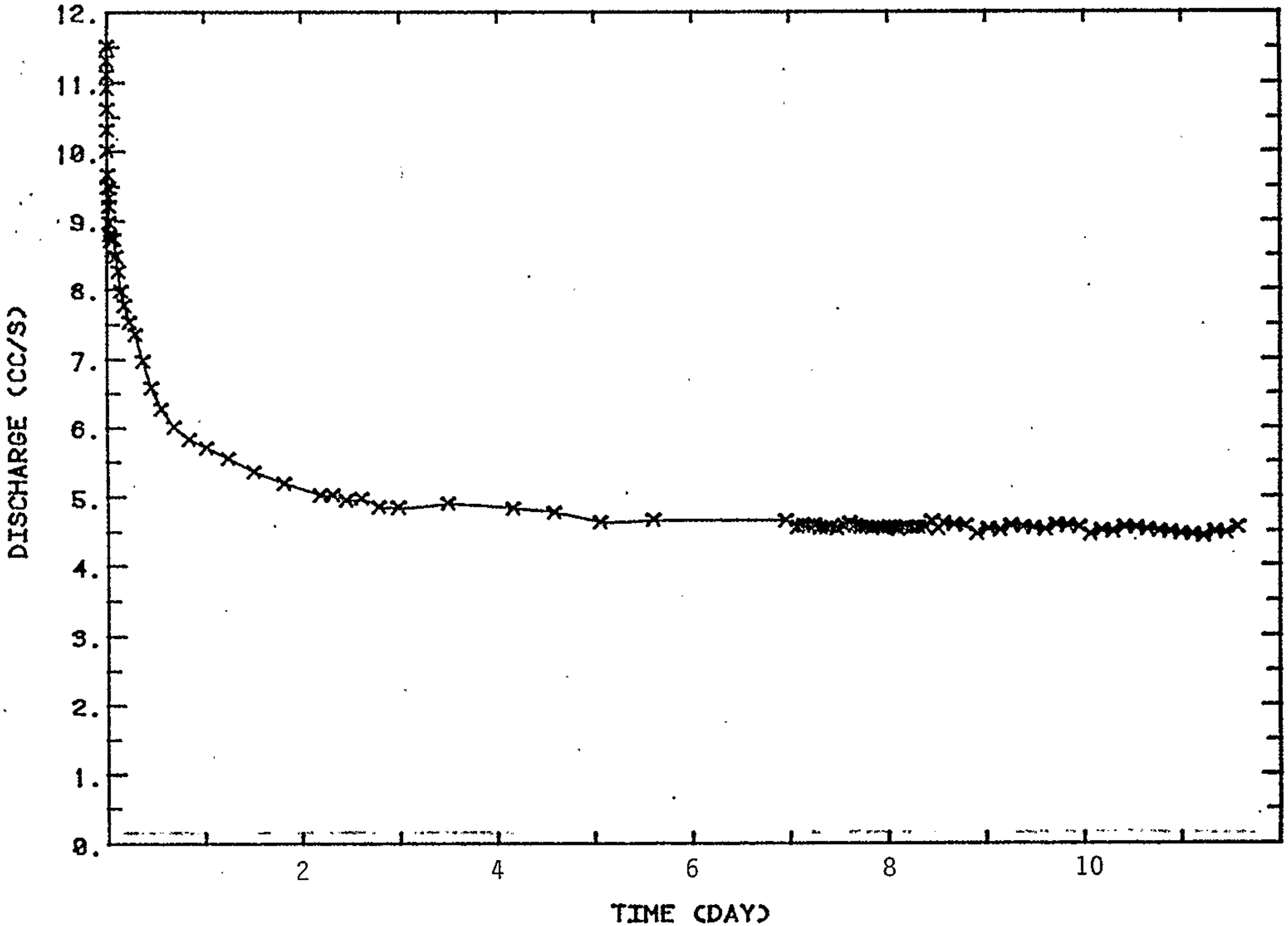

Figure 15. Model predicted infiltration rate when $K_s = 2.0 \times 10^{-4}$ cm/s.

exactly with the observed infiltration rate.

The moisture content distribution for run #2 ($K_s = 2.0 \times 10^{-3}$ cm/s) is shown in Figure 16. For this case we would predict that the wetting front should reach 3.0 m within one day. In contrast, the observed increase in water content at this distance (Figure 11b) did not occur until after at least seven days. Therefore, the value of K_s used in run #2 seems to be too large even though the predicted infiltration rate agreed with field results. We now have the dilemma of how to achieve a steady infiltration in the model which agrees with observed results while at the same time accurately predicting the rate of wetting. One possibility is the importance of fissures on the flow of water from the borehole. One or more small fissures may have a significant influence on infiltration rate, but only a small influence on the wetting of the soil matrix by water moving from the borehole. A representative value of K_s, for the entire profile probably lies between our two selections. Recall from a previous discussion that recently developed solutions to compute K_s from water infiltrating from a borehole suggest that K_s may, in fact, be on the order of 5.8×10^{-4} cm/s. Undoubtedly, adjustments to unsaturated hydraulic properties input to the model are also necessary. Nevertheless, the two runs shown here appear to bracket observed field behavior. Time constraints and limited computer funds precluded a thorough model calibration.

An interesting and useful observation is that the moisture content distribution at 11.6 days (Figure 13) for run #1 is practically identical with the results at 1.2 days (Figure 16) for run #2. This is due to the fact that K_s was increased by one order of magnitude from 2.0×10^{-4} cm/s in run #1 to 2.0×10^{-3} cm/s in run #2. By analogy, the results of run #2 at 2.43 and 3.01 days would be exactly the same as the results of run #1 if it were extended to 24.3 and 30.1 days. It is also important to realize that K_s does not affect the distribution of moisture surrounding the borehole under

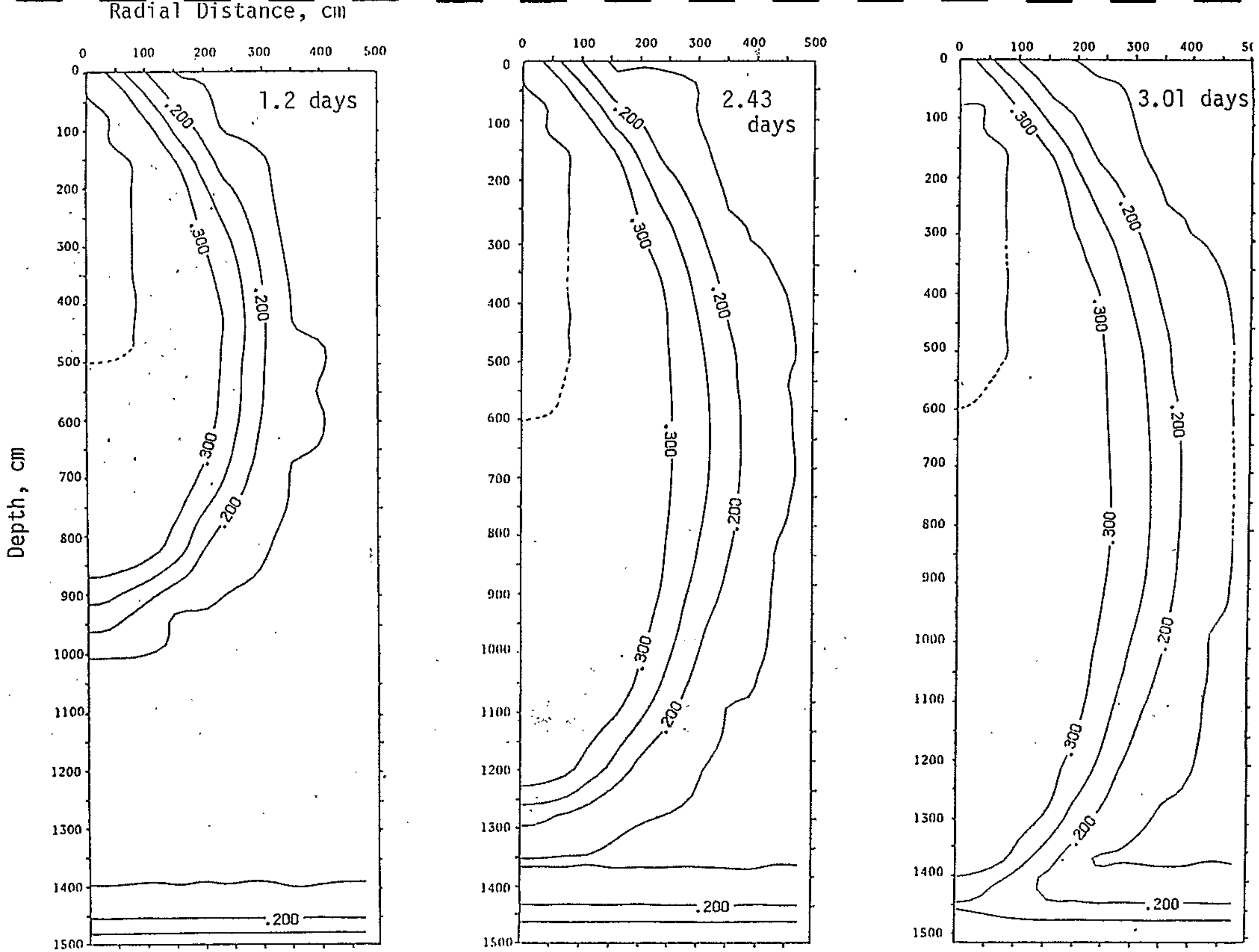

Figure 16. Model predicted moisture content (cm^3/cm^3) distribution for $K_s = 2.0 \times 10^{-3}$ cm/s. (Dashed where hand drawn.)

state conditions; K_s only affects the transient behavior of wetting and the magnitude of the predicted infiltration rate. As a result, regardless of our choice of K_s, the final wetting profile would probably resemble the pattern shown for late time in Figure 16. Note that wetting has progressed to nearly the 4.5 m radius, as observed. This is significant to establish the expected radial limit of collapse.

The calculated collapse is shown in Figure 12 using model predicted moisture content from run #1 at 15.1 days. Even at this time, the calculated collapse is greater than that observed by less than about 20 cm. The collapse calculated for run #2 at 3.01 days is shown in Figure 17; recall that this collapse would be the same as run #1 at 30.1 days. The similarity in model predicted results in Figures 12 and 17 indicate that the flow field is nearly steady at the end of both runs. These differences in observed and predicted collapse may be attributed to many factors: a time lag between wetting and collapse; unrepresentative laboratory measurements of collapse and hydraulic properties; or over simplifications in the empirical approach, such as the assumption of a linear increase in collapse with increasing moisture. Nevertheless, our errors are reasonably consistent with the experience summarized by Dudley (1970) who indicated that the collapse calculated from laboratory tests similar to ours could be divided by a factor of two in some cases.

The profile above a depth of about 10 m (the vertical extent of collapsible soil) may continue to increase in moisture content beyond the state shown in Figure 13, although the increase would be small based on our numerical simulations. Therefore, differences between calculated and observed collapse may actually decrease if there is a time delay factor present. The observed radial limit of collapse is predicted reasonably well by the model as shown in Figures 12 and 17.

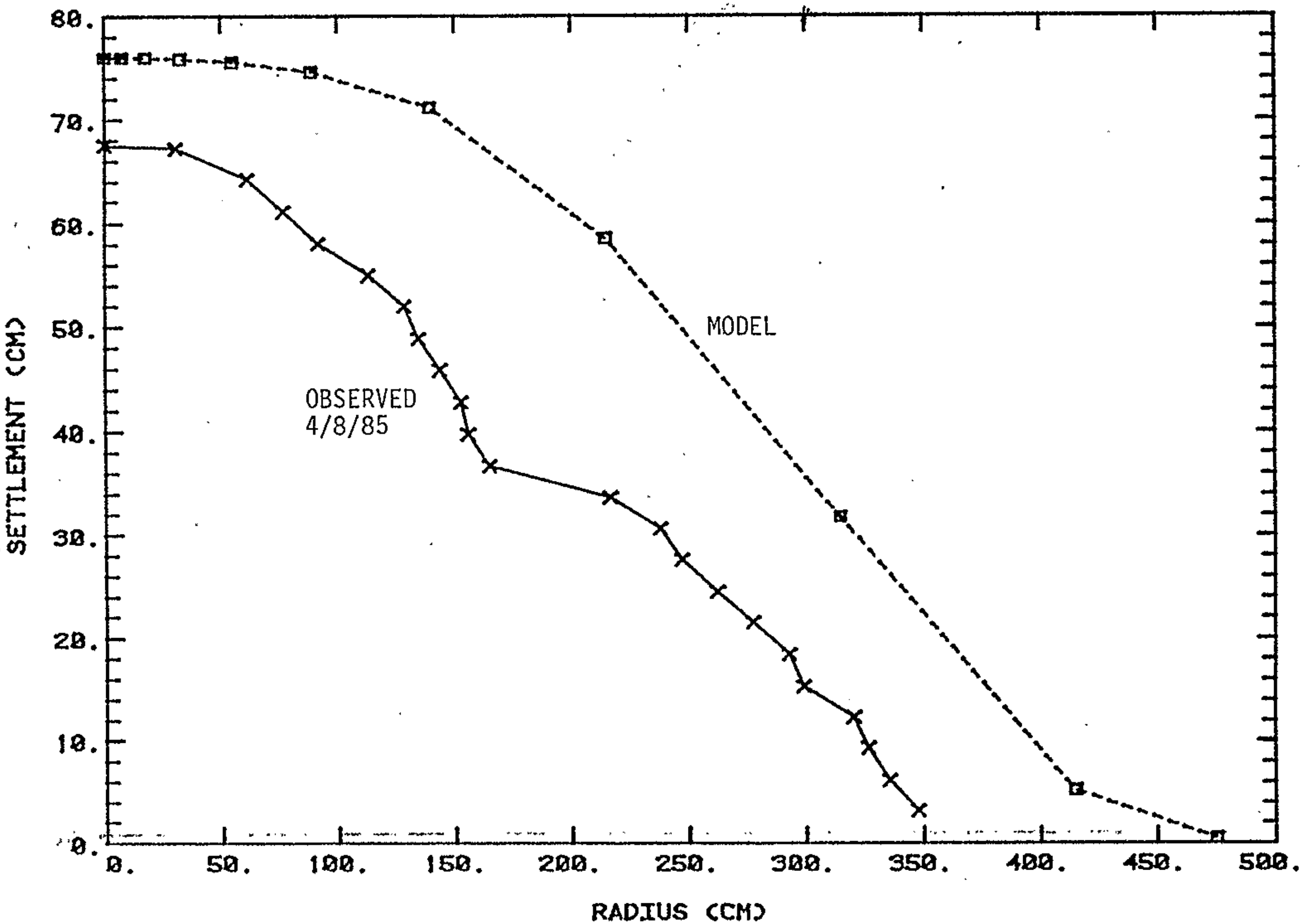

Figure 17. Observed collapse after 15 days and calculated collapse after 3.01 days assuming $K_s = 2.0 \times 10^{-3}$ cm/s.

CONCLUSIONS

1. Numerical models to simulate the collapse of soil upon wetting cannot be based upon the effective stress concept. An approximate method to predict collapse was developed. This approach combines laboratory measured collapse at background moisture content and at saturation with numerical simulations of water flow.
2. A field experiment was conducted to demonstrate collapse during wetting by infiltration from a shallow borehole. The moisture content profile was nearly steady after about 15 days and partially saturated conditions extended beyond 4.5 meters radial distance from the borehole. Maximum collapse was about 68 cm near the borehole, and collapse diminished almost linearly to a distance of about 3.6 m.
3. Model results from two runs appear to bracket the field distribution of moisture content. The maximum predicted collapse is within 15% of observed collapse. The model predicted radial extent of collapse is in good agreement with field observations.
4. Spatial variability in hydraulic properties and collapse characteristics, the effect of collapse on hydraulic properties, and the significance of flow in fissures should be studied in greater detail in order to apply the approach to designing remedial action alternatives.

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APPENDIX XXII

Groundwater Analyses Report - EID

A technical report on ground-water quality in the El Llano area was prepared by Mr. Douglas Earp of the New Mexico Environmental Division (Earp, 1985)* for the Office of Military Affairs, Civil Emergency Preparedness Division. The major findings are that there are a number of sources of ground water contamination. Among these are seepage from an irrigation ditch and septic tank leach fields. Animal wastes and agricultural fertilizers may also be contributing factors.

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* Earp, D., 1985, Ground-water quality in the El Llano area of the Española Valley: Environmental Improvement Division, Ground Water/Hazardous Waste Bureau, 22 pp.

GROUND-WATER QUALITY IN THE EL LLANO AREA OF THE ESPANOLA VALLEY

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13 June 1985

APPENDIX XXIII

Weekly Reports - ESP Project

El Llano Geotechnical Investigation
Weekly Report 1
December 17-21

This weeks activities consisted of drilling, seismic refraction surveys, a seismic reflection survey, and ground vibration monitoring.

A total of six drill holes were completed. Holes ranged in depth from 41 to 70 feet. The first three were sampled with a split-spoon sampler at 2.5-to-5 foot intervals. The remaining three were sampled primarily with a thin-wall (Shelby tube) sampler but some split-spoon samples were also retrieved. Shelby tube samples were generally obtained at 5-foot intervals. A total of 102 samples were obtained consisting of 73 split-spoon samples and 29 Shelby tube samples.

A total of 2,700 feet of seismic refraction data were obtained in three lines near the Moya residence. The first line trends roughly N-S across the subsidence pit west of the Moya residence and is 300 feet in length. The second line trends roughly E-W down the driveway between the Airport road and the Voight residence and is 750 feet in length. The third line trends roughly N-S just east of the Airport road and is 1,650 feet in length. Data from the seismic refraction survey are presently being anayzed by Charles B. Reynolds and Associates of Belen.

One mile-long seismic reflection survey was completed in an approximately E-W direction through El Llano. The survey consisted of 160 drops of a 400-pound weight falling 6.5 feet and recording of the signal with a digital recorder. The data from the seismic reflection survey are being analyzed by Charles B. Reynolds and Associates of Belen.

A ST-4 seismic-triggered seismograph (hereafter referred to as a ground vibration monitor) was installed in the living room of the Moya residence. The instrument has been in continuous operation since December 17 at approximately 1:00 p.m. The instrument is being monitored on a regular basis and some events have been noted. A second instrument of this type has been ordered for installation elsewhere in the community.

Two persons were hired by the Bureau to assist with the project. Their names, titles, and dates of hire are as follows: Felipe Valdez, Field Technician, December 18, 1984; and Mark Hemingway, Geologist, December 19, 1984. Other Bureau personnel engaged in the project are Gary Johnpeer, Dave Love, John Hawley, and George Austin.

The following consultants visited the site during the week to conduct contracted work:

1. Fox and Associates of New Mexico, Inc. (drilling)
2. Dr. Charles B. Reynolds and Associates (geophysics)
3. Dr. Catherine T. Aimone (ground vibration monitor)
4. Dr. Robert L. McNeill, Inc. (geotechnical engineering consultant)

Problems

Snow and rain hampered progress on drilling, seismic reflection and the aerial photo acquisition.

Due to weather conditions, the split-spoon sampling procedure (and blow counts) was curtailed and replaced by Shelby tube sampling.

Removal of snow beneath drop points along the seismic reflection line showed progress. As a result, 300 feet of the contracted seismic refraction line were not obtained.

Due to snow cover in the El Llano area, acquisition of vertical stereo photographs has been delayed. It is anticipated that warmer weather will allow the photos flights to be flown shortly.

Gary Johnpeer
December 23, 1984

El Llano Geotechnical Investigation
Weekly Report 2
December 26-28

This week's activities consisted of drilling and also planning for the flooding study.

A total of five drill holes were completed. Holes ranged in depth from 40 to 124 feet. All were sampled with a thin-wall (Shelby tube) sampler and, in addition, selected split-spoon samples were retrieved. Shelby tube samples were obtained at 5-foot intervals and split-spoon samples were taken in places too coarse-grained or too hard to sample with a Shelby tube. A total of 28 Shelby tube samples and 29 split-spoon samples were obtained from the five drill holes.

Analysis of data from the seismic reflection and seismic refraction lines was continued. Preliminary results of one of the three seismic refraction lines are available and will be reviewed January 2.

The ST-4 seismic-triggered seismograph continued in operation in the Moya residence. Several events have been recorded with the instrument set at its most sensitive level of detection. A second instrument of this type is scheduled to be installed in another residence next week.

A meeting was held in Santa Fe at the New Mexico State Highway Department to plan the flooding and soaking study. In attendance were Warren Bennett (New Mexico State Highway Department), Robert McNeill (consultant), and Gary Johnpeer (NMBM&MR). McNeill will develop the study plan further and present a cost estimate to include site preparation, materials, and labor. The preliminary site selected for the flooding and soaking study is in El Llano approximately 1,200 feet southwest of the southern end of the airport runway (just west of the Valdez residence).

Fred Nevarez (New Mexico General Construction Bureau) and Frank Murray (Attorney General's Office) were also present to discuss a re-evaluation of the nine condemned houses. It was decided that Robert McNeill would meet with Nevarez and Dr. Randy Holt next week to conduct a house-by-house study of each condemned house. The study would be to determine if the houses may be re-occupied following minimal short-term upgrading. It was decided that the houses should be photo documented. Neil Hollander of the New Mexico Corrections Department was identified as a photographer highly capable to conduct the photo documentation.

Additional work to be completed during the structural re-evaluation will be billed to the NMBM&MR emergency geologic study. However, it is to be made clear that these additional funds are in support of the General Construction Bureau's needs.

Problems

Weather continued to hamper progress on drilling and aerial photo acquisition. In particular, mud and rain made working conditions poor. A mechanical breakdown in the drilling equipment occurred the last day of the week.

Due to remaining snow cover in the El Llano area, acquisition of vertical stereo photographs continues to be delayed. It is anticipated that warmer weather shortly will allow the photo flights to be flown.

El Llano Geotechnical Investigation
Weekly Report 3
January 2-4, 1985

This weeks activities included drilling, ground vibration monitoring, surveying, and planning for the flooding study.

A total of seven drill holes were completed. Holes ranged in depth from 34 to 100 feet. All were sampled with a thin-wall (Shelby tube) sampler and, in addition, selected split-spoon samples were retrieved. Undisturbed samples (Shelby tube and continuous core) were obtained at 5-to-10-foot intervals and split-spoon samples were taken in places too coarse grained or too hard to sample with a Shelby tube.. A total of 70 samples were obtained consisting of 59 undisturbed samples (Shelby and continuous core) and 11 split-spoon samples.

Preliminary results of the seismic reflection and seismic refraction lines obtained by Reynolds were reviewed by Robert McNeill and Gary Johnpeer.

The ST-4 ground vibration monitor continued to operate in the Moya residence. A second instrument of this type is scheduled to be installed in another residence next week.

A television news crew from channel 7 (Albuquerque) was at site filming the drillers; in addition, the news crew interviewed Gary Johnpeer. A surveying crew, consisting of Dave Love, Fritz Reimers, and Felipe Valdez, surveyed in detail the area that may undergo the flooding experiment. They also are surveying to help construct a detailed topographic map and profile of El Llano subsidence area.

Neil Hollander, New Mexico Corrections Department, took oblique aerial photographs of the site. John Hawley also was aboard and directed the operation. Hollander also photographed the topography of El Llano and the machinery being used in the project from the ground.

On Friday (January 4th) Robert McNeill and R. Leyba and Fred Nevarez (Construction Industries Division) examined buildings that have been damaged and condemned to determine if families can move back into them. Neil Hollander went with them to photograph the interiors and exteriors of the buildings.

One person was hired by the Bureau on January 2nd to assist with the project, Danny Bobrow, geologist. Other Bureau personnel presently engaged in the project are: Gary Johnpeer, John Hawley, David Love, Mark Hemingway, George Austin, Jeanette Chavez; and Felipe Valdez. Fritz Reimers, a graduate student at NMIMT and engaged in sample analysis, also visited the site during week 3.

The following consultants and others visited the site during the week to conduct various contracted work and investigations:

1. H. Brown, Koogle and Pouls
2. Robert McNeill, Robert L. McNeill, Inc.
3. Randy Holt, Randy Holt & Associates, Inc.
4. Fox & Associates of New Mexico, Inc.
5. Fred Nevarez and R. Leyba of the Construction Industries Division, Regulation & Licensing Department, State of New Mexico
6. Neel Hollander, (New Mexico Correction Dept.) photographer for the Governor's Office.

Problems

1. Some mechanical problems hampered progress on drilling.
2. Cold weather interferred with water flow necessary for drilling and flooding.

Danny J. Bobrow
January 6, 1985

El Llano Geotechnical Investigation
Weekly Report 4
January 7-11, 1985

This week's activities included drilling, ground vibration monitoring, reconnaissance geologic mapping, meetings, and preliminary review of aerial and ground photographs of El Llano area.

A total of 15 drill holes were completed. Holes ranged in depth from 30 to 102 feet. All were sampled with a thin-wall sampler and, in addition, selected split-spoon samples were retrieved. Undisturbed samples (Shelby tube and continuous core) were obtained at 5-to-10-foot intervals and split-spoon samples were taken in places too coarse grained or too hard to sample with a Shelby tube or continuous core sampler. A total of 143 samples were obtained consisting of 113 undisturbed samples. Sondex settlement casing was installed in four of the wells, water monitors were installed in three of the wells, settlement monuments were installed in three of the wells, and the remaining five wells drilled this week were backfilled.

A total of seventeen wells were drilled prior to this week. One well has a water monitor installed in it, three wells have settlement monuments installed in them, and the remaining thirteen wells were backfilled.

An ST-4 ground vibration monitor continued to operate in the Moya residence. A second instrument of this type was installed in the Valdez residence at 5:00 p.m. on Thursday, January 11.

Dave Love did reconnaissance geologic mapping east of the highway in El Llano area. While mapping, he found five charcoal sites suitable for C14 dating.

On Monday, January 7, Gary Johnpeer met with the residents of

El Llano area at their request to discuss preliminary data of El Llano subsidence project. On Tuesday, January 8, Gary met with P. Mondragon who suggested that Gary attend a meeting on Wednesday with the consultants hired by the Bureau for this project and the General Construction Bureau of the state of New Mexico. Later on Tuesday Gary met with Martin Vinyard of Fox & Associates to review the status of the drilling program, evaluate the sampling procedure, and set up a meeting for Wednesday with Olivas and Lueck of the State Highway Department.

On Wednesday Gary attended a meeting with R. Holt and Associates, F. Nevarez, R. McNeill, F. Murray, and N. Hollander. Discussed at the meeting were the petition of El Llano residents relating to the emergency and how the state agencies should respond to the petition. A meeting in Espanola of El Llano residents is scheduled on February 4, 1985. The Bureau of Mines and Mineral Resources will have minimal input into this meeting because it will not be concerned specifically with geologic problems. Also during the Wednesday meeting (January 9), R. McNeill and R. Holt reviewed the findings of the reevaluation of condemned homes, recommendations for stabilization, and the cost of stabilization of the homes. Their report will be submitted to Nevarez on February 18. Later on Wednesday Gary attended a meeting of Vinyard, Olivas, and Lueck. They discussed the testing procedures in general and the duplicate testing program between the Highway Department and Fox.

John Hawley, Dave Love, Danny Bobrow, and Gary Johnpeer did preliminary reviews of the aerial and ground photographs taken by N. Hollander, January 2-4. On Friday, January 11, Dave Love picked up 1934 aerial photographs of El Llano area at the remote sensing office of the Technical Application Center in Albuquerque.

Bureau personnel engaged in the project this week were: Gary Johnpeer, John Hawley, Dave Love, Mark Hemingway, Danny Bobrow, George Austin, Jeanette Chavez, and Felipe Valdez.

The following consultants and others visited the site during the week to conduct various contracted work and investigations:

1. W. Bennett, D. Lueck, and R. Olivas, State Highway Department.
2. R. Leyba, Construction Industries Division, Regulation and Licensing Department, State of New Mexico.
3. H. Agoyo, Tribal Governor of the San Juan Pueblo.
4. Fox & Associates of New Mexico, Inc.

Problems

1. Mechanical problems hampered progress on drilling.
2. Melting snow caused vehicles to bog down in the mud.
3. Cloud cover delayed the taking of aerial photographs by Koogle and Pouls.

Danny J. Bobrow
January 13, 1985

El Llano Geotechnical Investigation
Weekly Report 5
January 14-18, 1985

This week's activities included the completion of the first phase of the drilling program, seismic refraction surveys, aerial photography, ground vibration monitoring, surveying, reconnaissance geologic mapping, information gathering for a future article in New Mexico Geology, and an interview by Joselyn Lieu of the Rio Grande Sun.

A total of 12 drill holes were completed. The holes ranged in depth from 29.5 to 110 feet. All were sampled with a thin-wall sampler and, in addition, selected split-spoon samples were retrieved. Undisturbed samples (Shelby tube and continuous core) were obtained at 5-to-10-foot intervals and split-spoon samples were taken in places too coarse grained or too hard to sample with a Shelby tube or continuous core sampler. A total of 124 samples were obtained consisting of 83 undisturbed samples and 41 split-spoon samples. Sondex settlement casing was installed in four of the drill holes; water monitors were installed in four of the drill holes; water monitors were installed in two of the drill holes; and the remaining six holes drilled this week were backfilled. The drilling for geotechnical samples was completed on Friday, January 18, and the drill rigs returned to Denver and Albuquerque.

A total of 1,800 feet of seismic refraction data were obtained from two survey lines run through the El Llano area. The survey lines consisted of 74 drops of a 450-pound weight falling 6.5 feet and recording of the signal with a digital recorder that was operated by H. Sylvester of Reynolds and Associates, Inc. of Belen, New Mexico.

The first line was located approximately ¼ mile south of Espanola High School and trends roughly NE-SW across State Road 291. The line is 750 feet in length. The second line also trends roughly NE-SW and follows the road between Moya's and Felipe Valdez's residences. This latter line is 1,050 feet in length. Data from the seismic refraction survey are presently being analyzed by Charles B. Reynolds and Associates of Belen.

Koogle and Pouls took aerial photographs of El Llano area on Tuesday, January 15. The aerial photographs were picked up on Friday, January 18, at Koogle and Pouls office in Albuquerque.

The two ST-4 ground vibration monitors continued to operate in the Moya and Valdez residences. Several events have been recorded with the instruments set at their most sensitive level of detection.

A surveying crew consisting of Dave Love, Fritz Reimers, and Deborah Shaw or Felipe Valdez worked on a detailed cultural survey to determine the locations and the elevations of houses in El Llano. These data will be used to monitor changes in the elevations of houses in El Llano subsidence area.

Dave Love continued to do reconnaissance geologic mapping on the east side of State Road 291 in the El Llano area. He also collected four charcoal samples from three sites that are suitable for C14 dating.

Deborah Shaw, editor of New Mexico Geology (a NMBM&MR publication), was at the site from Wednesday to Friday, January 16 to 18. She was gathering information and taking photographs about the work being done and the damage to the homes. The information will be used for a feature article that will appear in New Mexico Geology (May 1985).

Joselyn Lieu of the Rio Grande Sun interviewed Gary Johnpeer and John Hawley at the Chamisa Inn on Friday morning, January 18. The interview will be published in the Wednesday, January 23 edition of the Rio Grande Sun.

Bureau personnel engaged in the project this week were: Gary Johnpeer, John Hawley, Dave Love, Mark Hemingway, Danny Bobrow, Fritz Reimers, Deborah Shaw, George Austin, Jeanette Chavez, and Felipe Valdez.

The following consultants and others visited the site during the week to conduct various contracted work and investigations:

1. D. Lueck, State Highway Department;
2. R. Leyba, Construction Industries Division;
3. N. Hollander, New Mexico Corrections Department;
4. Fox and Associates of New Mexico, Inc.
5. H. Sylvester and T. Weeks, Reynolds and Associates of Belen;
6. Aerial photography, Koogle and Pouls.
7. J. Lieu, Rio Grande Sun.

Problems

1. Mechanical problems slowed progress on drilling
2. Minor vandalism destroyed a previously installed settlement monument; therefore, protective covers have been ordered for the water monitoring wells.

El Llano Geotechnical Investigation
Weekly Report 6
January 21-25, 1985

This week's activities included backhoe exploration trenching, ground-vibration monitoring, Sondex well monitoring, meetings, planning for the Geotechnical Ground Stabilization study, an inventory of drilling samples stored at the New Mexico Bureau of Mines and Mineral Resources, studying aerial photographs of El Llano, and ordering additional photographs.

A total of five backhoe exploration trenches were excavated this week. The trenches were up to 2 feet wide, 12 feet deep, and 35 feet long. Two were dug near the subsidence feature in Moya's backyard, one trench was dug south of the Yelvington residence, and the remaining two were dug on the Valdez property west of the acequia. The exploration trenches were dug to investigate features such as cracks, "sotanos", and subsidence pits.

The walls of the trenches revealed subsurface geologic relationships and were logged by John Hawley, Gary Johnpeer, Dave Love, Mark Hemingway, and Danny Bobrow. Mark Roybal, who is mapping soils of the Espanola Basin for the Soil Conservation Service, stopped by on Thursday, January 24th, to examine the soils exposed in the walls of the trenches and to discuss the soil types in the El Llano area. Samples of the subsurface soils were collected and the exploration trenches were then backfilled.

The two ST-4 ground-vibration monitors continued to operate in the Moya and Valdez residences. Several events were recorded with the instruments set at the most sensitive level of detection.

The Sondex settlement casings that were installed in seven drill holes were monitored this week by Felipe Valdez and Gary Johnpeer. It is expected that monitoring the Sondex casings will help document further subsidence in the El Llano area.

On Monday, January 21st, Gary Johnpeer, John Hawley, and George Austin attended a meeting with R. McNeill and W. Bennett to plan the next phase of the El Llano project, the Geotechnical Ground-Stabilization Study (G.G.S.S.). It was decided that the Bureau personnel would obtain legal permission for the use of private land and proceed with the installation of drill holes. Later that day Gary met with staff of Koogle and Pouls to discuss the further processing of aerial photographs of the El Llano area.

On Tuesday, January 22nd, all Bureau personnel working on the project met with George Austin and Frank Kottlowski to discuss the status of the study and to plan the G.G.S.S.

On Wednesday, January 23rd, John Hawley met with D. MacQuillan, O. Simpson, and G. Silva of the E.I.D. Their discussions centered on investigative techniques that may be used to analyze soil moisture and ground water quality in the study area.

On Thursday, January 24th, Danny Bobrow met with F. Murray, Assistant Attorney General. F. Murray wrote a legal permission form for private land owners to sign allowing the G.G.S.S. to be conducted on their land (see attached form). Later that day Danny met with Neil Hollander to examine photographic contact sheets and to select the photos Neil will print in an 8 x 10 inch size.

An inventory of the undisturbed (Shelby tube and continuous core) and split-spoon samples stored at the Bureau was conducted by Mark Hemingway and Danny Bobrow.

The Bureau personnel examined aerial and ground photographs of the El Llano area. On Wednesday, January 23rd, Dave Love ordered the 1973 color aerial photographs of El Llano from the Technical Application Center (TAC). On Friday Dave picked up the enlargements of the 1985 aerial photographs that were shot by Koogle and Pouls last week.

Bureau personnel engaged in the project this week were: Gary Johnpeer, John Hawley, Dave Love, Mark Hemingway, Danny Bobrow, George Austin, Jeanette Chavez, and Felipe Valdez.

Problems

1. Unstable trench walls at some of the exploration trenches precluded shoring and detailed logging.
2. The owners of two potential sites for the G.G.S.S. would not sign the legal permission form (see attached). An alternative site east of State Road 291 (Airport Road), on Indian land, will be pursued.

Danny J. Bobrow
January 27, 1985

RELEASE AND AUTHORIZATION FOR TESTING
AND GRANT OF LICENSE FOR USE OF PROPERTY

The owner(s) of that certain real estate situated in Rio Arriba County, New Mexico within what is commonly described as the El Llano subdivision and more particularly described as:

Do hereby release the state of New Mexico, the Bureau of Mines, and the officers, agents and employees of the State of New Mexico and its agencies, and any person on contract with the State or its agencies from any and all claims or damages which may arise from testing and investigation of the soil subsidence or damage to buildings and property real o personal on the above described real property.

We further authorize the State of New Mexico, Bureau of Mines, and contract personnel and the officers, agents and employees of such agencies or persons to perform testing including but not limited to the boring of holes and flooding

They are further authorized to build structures for a geotechnical stabilization study and install monitoring equipment.

We specifically recognize that the testing may result in damage to this property which damage will be permanent, and recognize no compensation will be paid for such damage by the State of New Mexico, its agencies, contractors, officers agents and employees.

This release is granted of our free and voluntary will to help determine the causes of the settlement problems and damages to buildings, roads, and structures in the area and possible methods of alleviating or understanding the problem.

We represent that we are the owners of the property described herein and have authority to grant this permission.

____
Owner

____
Owner

On this ____________________, 1985, there personally appeared before me __________________ and __________________ __________ who signed this document in my presence and acknowledged the same as their free and voluntary act.

____
Notary Public

My Commission Expires:

____

El Llano Geotechnical Investigation
Weekly Report 7
January 28-February 1, 1985

This week's activities included backhoe exploration trenching, ground-vibration monitoring, Sondex well monitoring, bailing-out of water monitoring wells, meetings, planning for the Geotechnical Ground Stabilization Study (G.G.S.S.), an inventory of drilling samples stored at Fox and Associates, and preparations for the February 4th El Llano meeting.

Two backhoe exploration trenches were excavated this week. The trenches were up to 2 feet wide, 12 feet deep, and 35 feet long. One was dug south of the Valdez residence and is parallel to a seismic refraction line run by Reynolds and Associates. The second trench was dug east of the Voight residence (behind the A. Trujillo residence). This trench crossed a north-south and also ran parallel to an east-west seismic reflection line.

The walls of the trenches revealed subsurface geologic relationships and were logged by Gary Johnpeer, Mark Hemingway, and Danny Bobrow. Samples of the subsurface soils were collected and the exploration trenches were then backfilled.

The two ST-4 ground-vibration monitors continued to operate in the Moya and Valdez residences. Several events were recorded with the instruments set at the most sensitive level of detection.

The Sondex settlement casings were monitored this week by Danny Bobrow, Gary Johnpeer, and Mark Hemingway.

The water-monitoring wells had accumulated sediment; therefore, John Hawley bailed-out the sediment from the bottom of the wells.

On Wednesday, January 30th, Gary Johnpeer showed Charles Carrillo

(Historical Archeologist) and Joel Burstein (Assistant Attorney General) the El Llano subsidence area. On the same day John Hawley met with Ed Smith (geologist with Eight Northern Pueblos). They discussed what has been done on the El Llano project and the possibility of doing a G.G.S.S. on San Juan Pueblo land.

On Thursday, January 31st, Danny Bobrow met with F. Murray to draft a revised legal permission form for the G.G.S.S. (see attached form). While in Santa Fe Danny also met with N. Hollander to pick up 8 x 10 inch photographs of the El Llano area. Later Danny and Gary met with Richard Cook in Espanola. Mr. Cook signed the legal permission form that allows the G.G.S.S. to be done on his land east of NM 291. Drilling relating to the G.G.S.S. is planned to begin on Tuesday, February 5th.

An inventory of the undisturbed (Shelby tube and continuous core) and split-spoon samples stored at Fox and Associates was conducted by Mark Hemingway and Danny Bobrow. A Shelby tube and continuous core sample extruder and consolidation apparatus arrived and was assembled at the NMBM&MR. Dan Stevens of NMIMT has agreed to do hydrologic modelling on the El Llano data.

Danny Bobrow and Gary Johnpeer completed a chart of geotechnical work performed in the El Llano area to be used at the February 4th meeting. NMBM&MR and other state agencies will be present at the February 4th meeting in Espanola.

Bureau personnel engaged in the project this week were: Gary Johnpeer, John Hawley, Dave Love, Mark Hemingway, Danny Bobrow, George Austin, Jeanette Chavez, James Brannan, and Felipe Valdez.

Problems

1. Unstable trench walls at an exploration trench precluded shoring and detailed logging.
2. The bitter cold weather slowed work progress.

Danny J. Bobrow
February 3, 1985

RELEASE AN AUTHORIZATION FOR TESTING
AND GRANT OF LICENSE FOR USE OF PROPERTY

The owner(s) of that certain real estate situation in Rio Arriba County, New Mexico within what is commonly described as the El Llano Subdivision and more particularly described as:

as shown on exhibit A attached

Do hereby release the state of New Mexico, the Bureau of Mines, and the officers, agents and employees of the State of New Mexico and its agencies, and any person on contract with the State or its agencies from any and all claims or damages present or future which may arise from testing and investigation of the soil subsidence or damage to buildings and property real or personal on the above described real property.

We further authorize the State of New Mexico, Bureau of Mines, and contract personnel and the officers, agents and employees of such agencies or persons to perform testing

Office of the

COUNTY CLERK

RIO ARRIBA COUNTY

Tierra Amarilla, N.M., Feb. 14, 1985

RECEIVED OF Espanola Abstract Co.

Seven and no/100 Dollars

For recording Rel. of Authorization & Grant of License

Amount 7.00

☐ CASH

☑ CHECK

☐ OTHER

Nº 10504

Jose E. Atencio

CLERK.

Rosalia R. Atencio

DEPUTY.

THE VALLIANT CO., ALBUQUERQUE

including but not limited to the boring of holes and flooding. They are furthe. authorized to build structures for a geo-technical stabilization study and install monitoring equipment

Testing may be performed through August 31, 1985.

We specifically recognize that the testing may result in damage to this property which damage will be permanent, and recognize no compensation will be paid for such damage by the State of New Mexico, its agencies, contractors, officers agents and employees.

Damage to fences or utilities if they occur, will be paid for by the Bureau of Mines.

If a hole is created or ground settlement occurs due to testing the Agency will back fill the hole created on a one time basis, to the original ground contour.. No further continuing fill will be provided and the State, its officers, agents, employees, and contract personnel shall not be in any way responsible for damage due to settling ground.

In return for this grant of permission to use this property for testing, the owner of the property will be provided free of charge, a copy of any report generated by this testing. The owner will further receive $200 for the use of the land.

Only Bureau of Mines personnel or persons authorized by them shall be permitted on the site during site preparation and testing.

This permission may be terminated on 7 day days written notice by the landowner and testing may be halted at any time by the Bureau of Mines.

This release is granted of our free and voluntary will to help determine the causes of the settlement problems and damages to buildings, roads, and structures in the area and possible methods of alleviating or understanding the problem.

We represent that we are the owners of the property described herein and have authority to grant this permission.

Piedra Inc.
Richard P. Cook – President
Owner

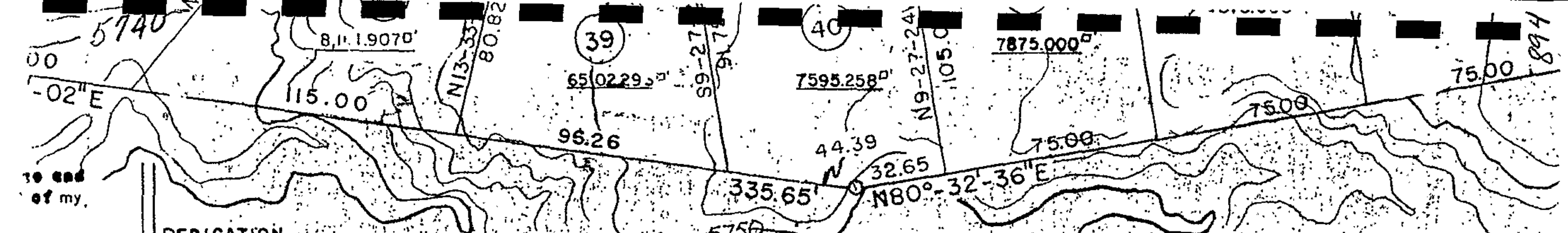
____
Owner

On this 31st day of January, 1985, there personally appeared before me Richard P. Cook and N/A ____________ who signed this document in my presence and acknowledged the same as their free and voluntary act.

Nancy M. Miller
Notary Public

NOTARY PUBLIC STATE OF NEW MEXICO

My Commission Expires:
02-24-85



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...or the purpose of drainage of surface waters including the effects of saturation, perculation, and erosion resulting therefrom.
...uch lot or tract free from any structure, planting, or other material which may change the direction of flow or obstruct or...

DEDICATION

Know All By these Presents that Richard R Cook has made a subdivision of herein described lands lying, situated and being in the County of Santa Fe and the County of Rio Arriba, State of New Mexico as shown on this plat thereof; that said subdivision is named and shall be known as "LA VISTA DEL RIO" UNIT 2.

That the above and foregoing subdivision of the following described lands to wit: Beginning at a point which bears N71-50-30W a distance of 1254.85 feet from a Brass Cap Monument designating the Southeast corner of Sec. 36, T21N, R8E, N.M.P.M; said point of beginning also being on the Easterly right-of-way line of El Llano Road, thence bearing S0-55-20W a distance of 52.88 feet to a point, then bearing S4-41-00E a distance of 186.40 feet to a point, thence bearing S9-27-24E a distance of 528.87 feet to a point, all along said Easterly right-of-way line of El Llano Road, thence bearing N76-24-26E a distance of 229.18 feet to a point, thence bearing N56-07-37E a distance of 149.22 feet to a point, thence bearing S33-52-23E a distance of 35.00 feet to a point, thence bearing S56-07-37W a distance of 149.21 feet to a point, thence bearing S9-27-24E a distance of 44.89 feet to a point, thence bearing S82-08-02E a distance of 335.65 feet to a point, thence bearing N80-32-36E a distance of 428.89 feet to a point, thence bearing N55-42-28E a distance of 139.36 feet to a point, thence bearing S77-42-24E a distance of 76.27 feet to a point, thence along a curve to the right having a radius of 25.00 and an arc length of 39.27 feet to a point; thence bearing S12-17-36 a distance of 56.70 feet to a point, thence bearing S77-42-24E a distance of 30.00 feet to a point, thence bearing S12-17-36W a distai of 80.00 feet to a point, thence bearing S77-42-24E a distance of 110.00 feet to a point, thence bearing N12-17-36E a distance of 144.02 feet to a point, thence bearing S60-09-39E a distance of 90.13 feet to a point, thence bearing N27-25-12E a distance of 100.0 feet to a point, thence bearing N1-42-00E a distance of 232.00 feet to a point, thence bearing N29-37-35W a distance of 216.62 feet to a point, thence bearing N48-35-14E a distance of 352.78 feet to a point, thence bearing N88-18-00W a distance of 1762.00 feet to the point of beginning and containing 26.697 acres more or less as it appears on this plat; that the same is made with free consent and in accordance with the desires of the undersigned owner and proprietor thereof; that the streets, public thorough fares and drainage areas shown hereon are hereby dedicated to the public use subject to the easements granted and specifie hereon.

OWNER

33769

FILED IN THE COUNTY CLERK'S OFFICE
8:10 O'CLOCK A. M
Book 151-A Page 890-894
FEB 1 5 1985
JOSE E. ATENCIO
County Clerk Rio Arriba County
New Mexico
By Lori Cordova Deputy

exhibit A

141

El Llano Geotechnical Investigation
Weekly Report 8
February 4-8, 1985

This week's activities included drilling related to the Geotechnical Ground Stabilization Study (G.G.S.S.), ground-vibration monitoring, Sondex well monitoring, surveying, reconnaissance geology, and meetings.

Fifteen drill holes relating to the G.G.S.S. were completed at two sites. This completes the drilling program for the initial G.G.S.S. The holes ranged in depth from approximately 35 to 50 feet. Eight of the holes were drilled at the site east of NM-291; the other seven holes were drilled at the second site west of the acequia in El Llano. All the holes were sampled with a thin-wall, Shelby tube sampler and, in addition, split-spoon samples were retrieved.

Undisturbed Shelby tube samples were obtained at 10-foot intervals and split-spoon samples were taken between Shelby tube samples or in places too coarse grained or too hard to sample with a Shelby tube. Mark Hemingway logged the subsurface geology of the samples retrieved.

A total of 147 samples were obtained consisting of 62 undisturbed Shelby tube samples and 85 split-spoon samples. Sondex settlement casing was installed in 12 of the drill holes, one hole was backfilled, and perforated PVC pipe were installed in the remaining two holes drilled this week. These two holes (one at each site) will be the water injection wells during the G.G.S.S.

The two ST-4 ground-vibration monitors continued to operate in the Moya and Valdez residences. Several events were recorded with the instruments set at the most sensitive level of detection.

The Sondex settlement casings were monitored this week by Dave Love, Gary Johnpeer, and Danny Bobrow.

A surveying crew consisting of Dave Love, Gary Johnpeer, Danny Bobrow, and Felipe Valdez completed a detailed survey to determine the elevations of the G.G.S.S. related drill holes. These data will be used to monitor changes in the elevations of the drill holes.

Gary Johnpeer, Dave Love, and Danny Bobrow did reconnaissance geology east of NM-291.

On Monday, February 4th, Gary Johnpeer and Dave Love attended a hearing in Espanola; also present were some Bureau subcontractors, representatives of other state agencies, and the El Llano residents. Gary explained the geotechnical work that has been completed in the El Llano area. Also testifying at the hearing were: R. McNeill, R. Holt, representatives of the C.I.D. and O.C.E.P., and the El Llano residents.

On Thursday, February 7th, Gary Johnpeer, Dave Love, and Danny Bobrow met with Martin Vinyard of Fox & Associates to discuss data acquisition and laboratory procedures.

Bureau personnel engaged in the project this week were: Gary Johnpeer, John Hawley, Dave Love, Mark Hemingway, Danny Bobrow, George Austin, Jeanette Chavez, and Felipe Valdez.

Problems

1. Mechanical problems slowed progress in drilling.
2. Cold weather also slowed work progress.

El Llano Geotechnical Investigation
Weekly Report 9
February 11-15, 1985

This week's activities included injecting water into the injection wells, hand augering three additional shallow-injection wells, bailing out water-monitoring wells, collecting water samples, ground-vibration monitoring, Sondex well monitoring, surveying, collecting sample data, and meetings.

Approximately a total of 3,000 gallons of water were injected into the injection wells at G.G.S.S. site 1 (east of NM-291) and 1,500 gallons of water were injected into the injection wells at G.G.S.S. site 2 (west of the acequia). During the experiment it became apparent that the upper 15 feet of soil were not being thoroughly wetted; therefore, three shallow (less than 15 feet deep) injection wells were hand augered by Mark Hemingway. Perforated PVC pipe was placed in these wells and water (included in the totals above) was successfully injected into the upper 15 feet of soil.

John Hawley bailed out the accumulated sediments from the bottom of the water-monitoring wells; then he monitored the water levels in these wells. On Tuesday and Thursday, February 12th and 14th, John and representatives of E.I.D. collected water samples in El Llano. These samples will undergo water quality testing at the E.I.D. laboratories.

The two St-4 ground vibration monitors continued to operate in the Moya and Valdez residences. Several events were recorded with the instruments set at the most sensitive level of detection.

The Sondex settlement casings were monitored this week by Felipe Valdez, Dave Love, Gary Johnpeer, and Danny Bobrow.

A surveying crew consisting of Dave Love, Gary Johnpeer, and Danny Bobrow completed a detailed survey to determine the initial elevation of the ground at the two G.G.S.S. sites. These data will be used to monitor subsequent changes in the elevation of the ground.

Mark Hemingway ran tests on El Llano soil samples at the soil testing laboratory of the New Mexico Bureau of Mines.

On Monday, February 11th, Gary Johnpeer, Dave Love, and George Austin attended a meeting in the offices of the Civil Emergency Preparedness Division; also attending were C. Reynolds, J. Burstein, and representatives of Shell Oil (Shell Western E&P Inc.) Technical geophysical information was presented by Scott Jones and John Rice, Jr., of Shell regarding the seismic exploration that Shell Western E&P did in the El Llano area on November 10th and 11th, 1984.

Bureau personnel engaged in the project this week were: Gary Johnpeer, John Hawley, Dave Love, Mark Hemingway, Danny Bobrow, George Austin, Jeanette Chavez, Fritz Reimers, and Felipe Valdez.

<u>Problems</u>

1. The water meters clogged periodically slowing the injection of water.

Danny J. Bobrow
February 17, 1985

EL LLANO GEOTECHNICAL INVESTIGATION
Weekly Report 10
February 16-22, 1985

This week's activities included drilling related to the Geotechnical Ground Stabilization Study (G.G.S.S.), injecting water into the injection wells, bailing out the water-monitoring wells, ground-vibration monitoring, Sondex well monitoring, surveying, collecting sample data, sending samples for carbon 14 age dating, and meetings.

Six moisture-monitoring drill holes relating to the G.G.S.S. were completed this week. The holes ranged in depth from 33 to 40 feet. Four of the holes were drilled at G.G.S.S. site 1 (east of NM-291); the other two holes were drilled at G.G.S.S. site 2 (west of the acequia). Continuous split-spoon samples were collected at two of the wells; at the other four wells split-spoon samples were obtained at 2 1/2-5-foot intervals. A total of 84 split-spoon samples were obtained.

Sondex settlement casing was installed in one of the drill holes and the remaining five holes were backfilled. In addition, the three shallow injection wells (Weekly Report 9) were reamed out this week using the drill rig. Mark Hemingway logged all the samples retrieved.

A total of 4,066 gallons of water were injected into the injection wells at G.G.S.S. site 1 and 754 gallons of water were injected into the injection wells at G.G.S.S. site 2. On Friday, February 22, the 32 foot deep injection well at G.G.S.S. site 1 was backfilled to approximately 22 feet; this is expected to facilitate soil wetting in the upper 20 feet of the injection well.

John Hawley continued to bail out the accumulated sediments from the bottom of the water-monitoring wells. He also monitored the water levels in these wells.

The two ST-4 ground-vibration monitors continued to operate in the Moya and Valdez residences. Several events were recorded with the instruments set at the most sensitive levels of detection. On Thursday, February 21, the ground-vibration monitor was removed from the Valdez residence and the level of sensitivity on the monitor in the Moya residence was raised to 0.05 ips.

The Sondex settlement casings were monitored this week by Danny Bobrow, Felipe Valdez, and Gary Johnpeer.

A surveying crew consisting of Gary Johnpeer, Dave Love, and Danny Bobrow did detailed surveys to monitor changes in ground elevation at the G.G.S.S. site west of the acequia and at the subsidence feature west of the Moya residence.

Gary Johnpeer, Danny Bobrow, Mark Hemingway, Fritz Reimers, and Rick Lozinsky conducted density and moisture tests on El Llano soil samples at the soil testing laboratory of the New Mexico Bureau of Mines.

Dave Love submitted five samples for carbon 14 age dating. Two of the samples were sent to the Radioisotope Laboratory at the University of Arizona-Tucson and three samples were sent to the Dicarb Radioisotope Laboratory in Norman, Oklahoma.

On Wednesday, February 20, Robert McNeill visited the G.G.S.S. sites in El Llano. He checked the progress and installation of wells at the two G.G.S.S. sites.

On Friday, February 22, Dave Love picked up the rectified photo-topographic (5-foot contour intervals) maps from Koogle and

Pouls.

Bureau personnel engaged in the project this week were: Gary Johnpeer, John Hawley, Dave Love, Mark Hemingway, Danny Bobrow, George Austin, Jeanette Chavez, Felipe Valdez, Fritz Reimers, and Rick Lozinsky.

Danny J. Bobrow
February 24, 1985

El Llano Geotechnical Investigation
Weekly Report 11
February 25-March 1, 1985

This week's activities included injecting water into the injection wells, hand augering a moisture-monitoring well, ground-vibration monitoring, Sondex well monitoring, laboratory testing, research on acequias of the El Llano area, and meetings.

A total of 4,379 gallons of water were injected into the injection wells at G.G.S.S. site 1 (east of NM-291) and 540 gallons of water were injected into the injection wells at G.G.S.S. site 2 (west of the acequia). On Friday, March 1, a 200-gallon low-flow G.G.S.S. hydrologic reservoir was installed at each site; these reservoirs are expected to facilitate wetting of the upper 15 feet of soil.

One moisture-monitoring well (13 feet deep) was hand augered at G.G.S.S. site 1 by Gary Johnpeer and Danny Bobrow. The moisture content of the soil increased with depth.

The ST-4 ground-vibration monitor continued to operate in the Moya residence. Two events were recorded with the instrument set at a sensitivity level of 0.05 ips.

The Sondex settlement casings were monitored this week by Gary Johnpeer, Danny Bobrow, and Felipe Valdez.

Mark Hemingway, Danny Bobrow, Gary Johnpeer, and Fritz Reimers conducted density and moisture tests on El Llano soil samples at the soil testing laboratory, New Mexico Bureau of Mines. On Tuesday, February 26, Catherine Aimone assisted Gary Johnpeer and Fritz Reimers in setting up the consolidometer apparatus in the soil testing laboratory. On Friday, March 1, Fritz Reimers met with Martin Vinyard of Fox and Associates to observe laboratory procedures for using the consolidometer.

On Thursday, February 28, Charles Carrillo (Historical Archeologist) met with Gary Johnpeer to discuss the technical history of acequias in the El Llano area. Charles is also interviewing residents concerning the historical locations of acequias in the El Llano area.

On Monday, February 25, ESP Bureau personnel met with Robert McNeil and Charles Reynolds to discuss the El Llano Study and the April 15th interim report. Also present at the meeting were Bob Knowlton (hydrologist), Deborah Shaw (editor of NM Geology) and Jeanette Chavez who took minutes of the meeting (see attachment 1).

Bureau personnel engaged in the project this week were: Gary Johnpeer, John Hawley, Dave Love, Mark Hemingway, Danny Bobrow, George Austin, Jeanette Chavez, Felipe Valdez, and Fritz Reimers.

The February 25 meeting began at 9:55 a.m. Present were Robert Knowlton, Robert McNeill, Charles Reynolds, Danny Bobrow, Fritz Reimers, Gary Johnpeer, John Hawley, Mark Hemingway, and Dave Love.

An aerial photo of El Llano area was displayed. Orange (reflection) and red (refraction) lines were pointed out. One line was not put in because of the line not fitting in the photo but the location was pointed out by Johnpeer.

John Hawley, Gary Johnpeer, Robert McNeill, and Charles Reynolds discussed drilling in El Llano area and the locations of residences with subsidence problems.

Gary Johnpeer explained the plotting of two wells east of the highway and a discussion ensued. Total water put in the wells is being recorded but it was suggested that all water be monitored in case some water is leaking. Topographic maps were examined and locations of the wells were pointed out.

A regional investigation of the area is being done instead of on individual homes. It seems more work was done than originally intended.

Robert McNeill brought up the following questions:
1) how to identify collapsible soil; 2) how to mitigate the effects of collapsible soil, existing and new.

El Llano Geotechnical Investigation
Weekly Report 12
March 4-8, 1985

This week's activities included drilling related to the Geotechnical Ground Stabilization Study (G.G.S.S.) and the Geotechnical Hydrologic Calibration Study (G.H.C.S.), injecting water into the low-flow hydrologic reservoirs, bailing out the water-monitoring wells, collecting water samples, geologic mapping, ground-vibration monitoring, Sondex well monitoring, surveying, laboratory testing, and meetings.

Twenty-one moisture-monitoring wells relating to the G.G.S.S. and seven drill holes relating to the G.H.C.S. were completed this week. The holes ranged in depth from 10 to 45 feet. Eight of the holes were drilled at G.G.S.S. site 1; six of the holes were drilled at G.G.S.S. site 2; and the remaining seven holes were drilled at the G.H.C.S. site. Two-inch PVC pipe was installed in 15 of the drill holes (6 at G.G.S.S. site 1, 6 at G.G.C.S. site 2, and three at the G.H.C.S site); these will be the neutron moisture-density probe holes. Three drill holes (at the G.H.C.S. site) had Sondex casing installed, two drill holes were backfilled, and the remaining hole had slotted PVC pipe installed and will serve as the injection well for the G.H.C.S. In addition, a 100-foot-deep geotechnical water-monitoring well was drilled west of the acequia; on Friday, March 8; the water level in the well was 72.5 feet.

A total of 115 split-spoon samples were retrieved this week. Continuous split-spoon samples were collected at 2 of the wells, at 18 other wells split-spoon samples were obtained at 2 1/2 - 10 foot intervals, and at the G.H.C.S. injection well five continuous undisturbed Shelby tube samples were obtained. Mark Hemingway logged all the samples retrieved.

A total of 4,581 gallons of water was injected into the low-flow hydrologic reservoir at G.G.S.S. site 1 and 2,417 gallons of water were injected into the low-flow hydrologic reservoir at G.G.S.S. site 2.

John Hawley bailed out the accumulated sediment from the bottom of the water-monitoring wells, then he monitored the water levels in these wells. On Monday, March 4, John Hawley and Dave Love met with representatives of E.I.D. to discuss completed El Llano water quality analyses. On Wednesday, March 6, John Hawley and Pat Langmire (E.I.D.) collected water samples in El Llano. These samples will undergo water quality analyses at the E.I.D. laboratories.

Dave Love did geologic mapping east of NM-291. He will continue mapping next week.

The ST-4 ground-vibration monitor continued to operate in the Moya residence. Three events were recorded with the instrument set at a sensitivity level of 0.05 i.p.s.

The Sondex settlement casing were monitored this week by Danny Bobrow, Dave Love, Gary Johnpeer, and Felipe Valdez.

A surveying crew consisting of Dave Love, Gary Johnpeer, Danny Bobrow, and Bob Knowlton (hydrologist) did a detailed survey to monitor changes in ground elevation at the two G.G.S.S. sites.

Mark Hemingway and Danny Bobrow conducted density and moisture tests on El Llano soil samples at the soil testing laboratory, New Mexico Bureau of Mines.

On Monday, March 4, Dave Love picked up 1962 aerial photographs of El Llano from T.A.C. in Albuquerque. Also on Monday, John Hawley met with Jim Aldrich of Los Alamos Laboratories to discuss geophysical data relating to the El Llano area.

On Friday, March 8, Dan Stephens (hydrologist) inspected the G.H.C.S. site. He outlined procedures and locations for the installation of the wells at the site.

Bureau personnel engaged in the project this week were: Gary Johnpeer, John Hawley, Dave Love, Mark Hemingway, Danny Bobrow, George Austin, Jeanette Chavez, and Felipe Valdez.

Danny J. Bobrow
March 10, 1985

El Llano Geotechnical Investigation
Weekly Report 13
March 11-15, 1985

This week's activities included injecting water into the low-flow hydrologic reservoirs, laboratory testing, and office work relating to the El Llano interim report.

A total of 3,000 gallons of water was injected into the low-flow hydrologic reservoir at G.G.S.S. site 1 (east of NM-291) and 1,420 gallons of water were injected into the low-flow hydrologic reservoir at G.G.S.S. site 2 (west of the acequia).

Gary Johnpeer and Fritz Reimers conducted consolidometer tests, and Mark Hemingway and Danny Bobrow conducted moisture tests on El Llano soil samples at the soil testing laboratory, New Mexico Bureau of Mines.

This week, the ESP Bureau personnel worked on the El Llano interim report. The work consisted of writing, graphics, and data reduction. Dave Love and Kevin Cook (New Mexico Bureau of Mines) reduced the El Llano survey data.

On Thursday, March 14, Bill Arnold (New Mexico Bureau of Mines) picked-up the 1949, 1951, and 1976 El Llano air photographs from T.A.C. in Albuquerque. On Friday, March 15, Dave Love spoke with Dan Cash (Los Alamos Laboratories) about the El Llano seismic and geophysical data.

Bureau personnel engaged in the project this week were: Gary Johnpeer, Dave Love, Mark Hemingway, Danny Bobrow, George Austin, Jeanette Chavez, Felipe Valdez, Fritz Reimers, and Kevin Cook.

Problems

1. Rain and mud hampered the injection of water.

2. Need to modify computer programs slowed data reduction.

Danny J. Bobrow
March 18, 1985
Geologist

El Llano Geotechnical Investigation
Weekly Report 14
March 18-22, 1985

This week's activities included injecting water into the low-flow hydrologic reservoirs, density and moisture monitoring of the Geotechnical Ground Stabilization Study Neutron Probe (G.G.S.S.N.P.) drill holes, surveying, ground-vibration monitoring, Sondex well monitoring, geologic mapping, office work related to the El Llano interim report, and laboratory testing.

A total of 2,120 gallons of water was injected into the low-flow hydrologic reservoir at G.G.S.S. site 1 (east of NM-291) and 1,246 gallons of water were injected into the low-flow hydrologic reservoir at G.G.S.S. site 2 (west of the acequia). On Thursday, March 21, Felipe Valdez, Gary Johnpeer, and Bob Knowlton (hydrologist) excavated an 800-foot-long by 6-inch-deep trench and buried flexible PVC pipe in the trench. The PVC pipe extends from the water source to G.G.S.S. site 1 and to the Geotechnical Hydrologic Calibration Study (G.H.C.S.) site. Later, Gary and Bob constructed a subsurface reservoir system at the G.H.C.S. site to monitor the amount of water being injected into the injection well.

On Friday, March 22, Gary Johnpeer and Danny Bobrow used the neutron depth probe to monitor the changes in moisture and density of the subsurface soils in the G.G.S.S.N.P. drill holes at G.G.S.S. sites 1 and 2. A total of 79 moisture readings and 79 density readings were taken.

On Thursday, March 21, the ST-4 ground-vibration monitor was removed from the Moya residence. Preliminary data recorded by ST-4 ground-vibration monitors will be included in the interim report.

The Sondex settlement casings were monitored this week by Gary Johnpeer and Danny Bobrow.

Dave Love, Danny Bobrow, Gary Johnpeer, and Fritz Reimers completed detailed surveys to monitor changes in ground elevation at G.G.S.S. sites 1 and 2, the G.H.C.S. site, and at the subsidence feature west of the Moya residence.

Dave Love mapped pre-Holocene geologic units east of NM-291. On Thursday, March 21, Dave Love and Danny Bobrow investigated ground depressions east of NM-291 in El Llano.

All Bureau project personnel worked on the El Llano interim report. On Tuesday, March 19, a carbon 14 age date of 2,330 years was received from the Radioisotope Laboratory at the University of Arizona (Tucson). The sample giving this age was collected in the trench excavated west of the Moya residence. Charles Carrillo (Historical Archeologist) submitted his final report on the technical history of acequias in the El Llano area. The report will be included in the interim report.

Bureau personnel engaged in the project this week were: Gary Johnpeer, John Hawley, Dave Love, Danny Bobrow, Mark Hemingway, George Austin, Jeanette Chavez, Felipe Valdez, Fritz Reimers, and Kevin Cook.

Danny J. Bobrow
Geologist
March 25, 1985

El Llano Geotechnical Investigation
Weekly Report 15
March 25-29, 1985

This week's activities included injecting water into the low-flow hydrologic reservoirs, moisture and density monitoring of the Geotechnical Ground Stabilization Study Neutron Probe (G.G.S.S.N.P.) drill holes, Sondex well monitoring, bailing out the water-monitoring wells, collecting water samples, office work related to the interim report, laboratory testing, and meetings.

A total of 5,010 gallons of water was injected into the low-flow hydrologic reservoir at G.G.S.S. area 1 (east of NM-291), 3,690 gallons of water were injected into the subsurface low-flow hydrologic reservoir at G.G.S.S. area 3 (previously referred to as the G.H.C.S. site) 75 feet south of G.G.S.S. area 1, and 4,060 gallons of water were injected into the low-flow hydrologic reservoir at G.G.S.S. area 2 (west of the acequia). A second low-flow hydrologic reservoir was installed at G.G.S.S. area 2. This is expected to facilitate injection of water at G.G.S.S. area 2.

On Tuesday, March 19, all ESP Bureau personnel attended a short course about using depth probes for measuring moisture and density of subsurface soils. Also discussed was radiation protection. On Friday, March 29, ESP Bureau personnel were licensed by the Environmental Improvement Division (E.I.D.) to use the depth probe. Also on Friday, Mark Hemingway monitored changes in moisture and density of subsurface soils in the G.G.S.S.N.P. drill holes using the depth probe. He took 46 moisture readings and 46 density readings.

The Sondex settlement casings were monitored by Felipe Valdez.

John Hawley bailed out the accumulated sediment from the bottom of the water-monitoring wells, and he monitored the water levels in these wells. On Tuesday, March 26, John and Doug Earp (E.I.D.) collected water samples in El Llano. These samples will undergo water-quality analyses at the E.I.D. laboratories. On Wednesday and Thursday, March 27 and 28, John Hawley met with the State Engineer's staff in Santa Fe to collect data on water wells in El Llano.

All ESP Bureau personnl worked on the interim report. The work consisted of acquiring and reducing data, writing, and designing graphics.

George Austin completed clay-size fraction analyses on El Llano soil samples at the NMBM&MR x-ray diffraction laboratory. These data will be included in the interim report.

Bureau personnel engaged in the project this week were: Gary Johnpeer, John Hawley, Dave Love, Danny Bobrow, Mark Hemingway, George Austin, Jeanette Chavez, Felipe Valdez, Fritz Reimers, and Kevin Cook.

Problems

1. Rain and snow hampered the monitoring of Sondex wells and neutron-probe drill holes.

Danny J. Bobrow
Geologist
April 1, 1985

El Llano Geotechnical Investigation
Weekly Report 16
April 1-5, 1985

This week's activities included injecting water into the low-flow hydrologic reservoirs, monitoring moisture and density changes in the Geotechnical Ground Stabilization Study Neutron Probe (G.G.S.S.N.P.) drill holes, monitoring the Sondex wells, office work related to the interim report, and meetings.

A total of 16,840 gallons of water was injected into the low-flow hydrologic reservoir at G.G.S.S. area 1 (east of NM-291), 8,190 gallons of water were injected into the subsurface low-flow hydrologic reservoir at G.G.S.S. area 3 (75 feet south of G.G.S.S. area 1; see weekly report 15), and 6,370 gallons of water were injected into the low-flow hydrologic reservoirs at G.G.S.S. area 2 (west of the acequia).

On Wednesday, April 3, Gary Johnpeer and Dave Love monitored changes in moisture and density of subsurface soils in the G.G.S.S.N.P. drill holes using the depth probe. They took 50 moisture and 50 density readings. Gary and Dave also examined and documented with photographs subsidence features (induced by subsurface wetting) at G.G.S.S. areas 1 and 3.

The Sondex settlement casings were monitored by Felipe Valdez. The Sondex data will compose Appendix VII of the interim report.

All ESP Bureau personnel worked on the interim report. The work consisted of reducing data, writing, designing graphics, and proofreading. On Thursday, April 4, preliminary copies of the interim report were given to the following people for review: Robert McNeill, Frank Kottlowski, Deborah Shaw, and ESP Bureau personnel.

On Wednesday, April 3, Joe Guillen (Deputy Director of the Council of Local Governments) spoke with George Austin and Danny Bobrow about the El Llano project. The agency he represents has $50,000-$100,000 in funds that can be made available to the El Llano residents for repair of structures damaged by subsiding soils.

Bureau personnel engaged in the project this week were: Gary Johnpeer, Dave Love, Danny Bobrow, Mark Hemingway, John Hawley, George Austin, Jeanette Chavez, Felipe Valdez, Fritz Reimers, Kevin Cook, Lynne McNeil, Judy Vaiza, and the drafting department.

Danny J. Bobrow
Geologist
April 7, 1985

EL LLANO GEOTECHNICAL INVESTIGATION
Weekly Report 17
April 8-12, 1985

This week's activities included finalizing the interim report, injecting water into the low-flow reservoirs, documenting the subsidence features at G.G.S.S. areas 1 and 3, monitoring the Geotechnical Ground Stabilization Study areas, surveying, infra-red aerial photography of the El Llano area, and meetings.

All ESP Bureau personnel worked on the interim report. The report was completed on Saturday, April 13, and will be delivered this week. In addition, a copy will be available as an open-file report from the NMBM&MR.

A total of 2,520 gallons of water was injected into the low-flow reservoirs at G.G.S.S. area 2. On Monday, April 8, the flow of water was terminated to G.G.S.S. areas 1 and 3. Also on Monday, ESP Bureau personnel and Neil Hollander (New Mexico Corrections Department) examined and photographed significant subsidence features (induced by subsurface wetting) at G.G.S.S. areas 1 and 3. During the experiment, a total of 42,996 gallons of water was injected into G.G.S.S. area 1 and 11,880 gallons of water were injected into G.G.S.S. area 3. Water is still being injected into G.G.S.S. area 2.

Mark Hemingway, Danny Bobrow, and Bob Knowlton (hydrologist) monitored changes in moisture and density of subsurface soils in the G.G.S.S.N.P. drill holes using the depth probe. The Sondex settlement casings were monitored by Felipe Valdez, Danny Bobrow, and Mark Hemingway.

Dave Love, Gary Johnpeer, Felipe Valdez, and Danny Bobrow completed detailed topographic surveys at G.G.S.S. areas 1, 2, and

3 to monitor changes in ground elevation.

On April 2, Koogle and Pouls took infra-red aerial photographs of the El Llano area.

On Monday, April 8, Gary Johnpeer and Dave Love met with Pete Mondragon (Civil Emergency Preparedness Division) to discuss the status of the project.

Bureau personnel engaged in the project this week were: Gary Johnpeer, Dave Love, John Hawley, Mark Hemingway, Danny Bobrow, Felipe Valdez, Kevin Cook, and the clerical and drafting departments of NMBM&MR.

Danny J. Bobrow
Geologist
April 14, 1985

EL LLANO GEOTECHNICAL INVESTIGATION
Weekly Report 18
April 15-19, 1985

This week's activities included interim report delivery, injecting water into GGSS area 2, monitoring the Geotechnical Ground Stabilization Study (G.G.S.S.) areas, surveying, seismic refraction surveys, and planning for the G.G.S.S. slab study and the April 25 meeting.

On Monday, April 15, Danny Bobrow and Mark Hemingway delivered copies of the interim report to the Civil Preparedness Division of the Office of Military Affairs, Robert McNeill, Construction Industries Division, Attorney General (Burstein), New Mexico Highway Department (W. Bennett), and the Espanola public library. In addition, a copy is available as Open-File Report 225 at the NMBM&MR. Other copies of the report were mailed to the Environmental Improvement Division, San Juan Pueblo, John Ramming, and State Engineer.

A total of 4,630 gallons of water was injected into G.G.S.S. area 2. Mark Hemingway and Danny Bobrow monitored changes in moisture and density of subsurface soils in the G.G.S.S.N.P. drill holes using the depth probe. The Sondex settlement casings were monitored by Danny Bobrow, Mark Hemingway, and Felipe Valdez.

Gary Johnpeer, Mark Hemingway, and Danny Bobrow completed detailed topographic surveys at G.G.S.S. areas 1, 2, and 3 to monitor changes in ground elevation.

The aquisition of 3,000 linear feet of shallow seismic refraction data was planned. There will be four survey lines: two lines trend NE-SW across G.G.S.S. areas 1 and 3, the third line trends E-W across the Valdez property, and the fourth trends E-W across G.G.S.S. area 2.

On Wednesday, April 17, Gary Johnpeer met with Robert McNeill to plan the construction procedures to be used at G.G.S.S. area 4 (slab study).

ESP Bureau personnel conducted office work related to the project; the work consisted of data reduction, planning for the G.G.S.S. slab study, and preparations for the April 25 meeting in Santa Fe.

Bureau personnel engaged in the project this week were: Gary Johnpeer, Mark Hemingway, Danny Bobrow, Felipe Valdez, and the clerical and drafting departments of NMBM&MR.

Problems

1. Rain and mud hampered the seismic surveys and the injection of water.

Danny J. Bobrow
Geologist
April 22, 1985

EL LLANO GEOTECHNICAL INVESTIGATION
Weekly Report 19
April 22-26, 1985

This week's activities included the April 25 meeting, injecting water (G.G.S.S. area 2), excavation of footings for the G.G.S.S. slab study, seismic refraction surveys, laboratory testing, office work related to the project, and the receipt of infra-red aerial photographs and two radiocarbon age dates.

On Thursday, April 25, Gary Johnpeer, John Hawley, Dave Love, Danny Bobrow, and George Austin attended a meeting in Santa Fe. Gary presented a summary of the objectives and preliminary recommendations of the El Llano study. Other speakers at the meeting included: R. McNeill, J. Guillen (Deputy Director of the Council of Local Governments), David Steel and Fred Nevarez (C.I.D.). Other agencies present included E.I.D., O.C.E.P., State Engineer, Highway Department, Attorney General's Office, and El Llano residents. The meeting was chaired by Brigadier Genereral Harry Taylor (Office of Military Affairs, Civil Emergency Preparedness Division).

A total of 1,270 gallons of water was injected into G.G.S.S. area 2. On Wednesday, April 24, Gary Johnpeer and Danny Bobrow mapped the ground cracks in the subsidence feature at G.G.S.S. area 3. Also on Wednesday, Felipe Valdez, Gary Johnpeer, and Danny Bobrow excavated and leveled the ground and dug footings for the slab study (G.G.S.S. area 4). On Friday, April 26, Felipe poured cement slab at G.G.S.S. area 4.

H. Sylvester (Reynolds and Associates) acquired seismic refraction data E-W across the Valdez property. Mark Hemingway conducted Atterberg limit and hydrometer tests on El Llano soil samples.

ESP Bureau personnel conducted office work related to the project; the work consisted of data reduction, proofreading, and further planning for the G.G.S.S. slab study. On Friday, April 26, carbon 14 age dates were received from the Dicarb Radioisotope Co., Norman, Oklahoma. Also on Friday, Deborah Shaw (NMBM&MR) picked-up the color infra-red aerial photographs of El Llano from Koogle and Pouls.

Bureau personnel engaged in the project this week were: Gary Johnpeer, Dave Love, John Hawley, Danny Bobrow, Mark Hemingway, Felipe Valdez, George Austin, and the clerical and drafting departments of the NMBM&MR.

Problems

1. Rain and mud hampered the seismic surveys and the slab study. Equipment failure of Reynolds and Assoc. slowed progress on seismic refraction surveys.

Danny J. Bobrow
Geologist
April 28, 1985

DJB/jc

EL LLANO GEOTECHNICAL INVESTIGATION
WEEKLY REPORT 20
April 29-May 3, 1985

This week's activities included excavation of footings and pouring a concrete BRAB slab at G.G.S.S. area 4, terminating the injection of water at G.G.S.S. area 2, detailed mapping of the subsidence features at G.G.S.S. areas 1 and 3, office work related to the project, and meetings.

On Monday and Tuesday, April 29 and 30, Felipe Valdez, Gary Johnpeer, Mark Hemingway, and Danny Bobrow dug footings and installed rebar supports for the BRAB slab at G.G.S.S. area 4. On Wednesday, May 1, the above ESP workers poured and finished the BRAB slab.

On Friday, April 26, the flow of water was terminated to G.G.S.S. area 2. During the experiment a total of 24,567 gallons of water was injected into G.G.S.S. area 2. No measureable settlement was produced.

Fritz Reimers, Gary Johnpeer, Mark Hemingway, Danny Bobrow, and Felipe Valdez mapped in detail the ground cracks and completed detailed elevation surveys of the subsidence features at G.G.S.S. areas 1 and 3.

The ESP Bureau personnel conducted office work related to the project; the work consisted of planning the drilling program for G.G.S.S. area 4 with Warren Bennett (State Highway Dept.), contouring the detailed topographic maps of the subsidence features at G.G.S.S. areas 1 and 3, and meetings.

On Monday, April 29, R. McNeill and R. Holt visited the G.G.S.S. 4 site and discussed the procedures to be used in preparing the BRAB slab. On Wednesday, May 1, R. Holt inspected the rebar supports and footings for the BRAB slab. He also collected two cylinders of the concrete used for the slab. The concrete in the cylinders will undergo stress tests at Holt and Associates laboratory.

Bureau personnel engaged in the project this week were: Gary Johnpeer, Danny Bobrow, Mark Hemingway, Felipe Valdez, George Austin, Jeanette Chavez, and Fritz Reimers.

Danny J. Bobrow
Geologist
May 4, 1985

EL LLANO GEOTECHNICAL INVESTIGATION
Weekly Report 21
May 6-10, 1985

This week's activities included drilling and the installation of the water injection system at G.G.S.S. area 4; density, moisture, and Sondex well monitoring; seismic refraction surveys; office work related to the project, laboratory testing, and meetings.

Fifteen drill holes at G.G.S.S. area 4 (slab study) were completed this week by the New Mexico Highway Department. The holes ranged in depth from 11 to 41 feet. A total of 27 split-spoon and 15 undisturbed (Shelby tube) samples were obtained. Mark Hemingway logged the retrieved samples.

Sondex settlement casing was installed in five of the drill holes; two-inch PVC pipe was installed in five drill holes, which will be depth probe monitoring holes (for moisture and density monitoring); and perforated PVC pipe was installed in the remaining five drill holes, which will serve as the water injection wells for G.G.S.S. area 4.

On Wednesday and Thursday, May 8 and 9, Gary Johnpeer, Danny Bobrow, and Mark Hemingway installed the multi-well water-injection system at G.G.S.S. area 4. They also monitored the Sondex settlement casings and changes in moisture and density of subsurface soils in the depth probe drill holes at the G.G.S.S. areas.

H. Sylvester (Reynolds and Associates) acquired seismic refraction data E-W across the Valdez property, NW-SE across G.G.S.S. areas 1 and 3, and E-W across G.G.S.S. area 2. A total of 2900 feet of seismic refraction survey was acquired.

The ESP Bureau personnel conducted office work related to the project including data reduction and proofreading. Fritz Reimers (NMBM&MR) conducted moisture, density, and Atterberg limit tests on El Llano soil samples at the soil testing laboratory, New Mexico Bureau of Mines.

The following New Mexico State Highway Department personnel visited the G.G.S.S. sites this week: Dick Lueck, Robert Olivas, Dan Sowle, and Warren Bennett. They checked on drilling progress and inspected the water-induced subsidence features at G.G.S.S. areas 1 and 3. On Thursday, May 9, John Hawley spoke with Doug Earp (E.I.D.) about El Llano water quality analyses.

Bureau personnel engaged in the project this week were: Gary Johnpeer, Mark Hemingway, Danny Bobrow, Fritz Reimers, George Austin, John Hawley, Jeanette Chavez, and Felipe Valdez.

EL LLANO GEOTECHNICAL INVESTIGATION
WEEKLY REPORT 22
May 13-17, 1985

This week's activities included injecting water and loading the concrete slabs at G.G.S.S. area 4, density and moisture monitoring, backfilling and densifying exploration trench ESBH-11, collecting information for an article in New Mexico Geology, reviewing the water quality analyses, laboratory testing, office work related to the project, and meetings.

A total of 5,856 gallons of water was injected into G.G.S.S. area 4 (slab study). On Monday and Tuesday, May 13 and 17, Mark Hemingway, Gary Johnpeer, Danny Bobrow, and Deborah Shaw (NMBM&MR) loaded the concrete slabs with sandbags to simulate the weight of an above ground structure. Gary, Mark, and Danny also adjusted the water injection system to increase and stabilize the rate of flow.

Gary Johnpeer and Danny Bobrow monitored the changes in moisture and density of subsurface soils in the depth probe holes at G.G.S.S. areas 3 and 4. On Tuesday, May 14, Amigo Construction, Mark Hemingway, and Danny Bobrow excavated the upper five feet of the exploration trench west of the A. Trujillo residence. They then emplaced a layer of bentonite, backfilled, and compacted the trench, and graded the ground surface.

Deborah Shaw (NMBM&MR) collected information about the G.G.S.S. areas for an article in New Mexico Geology. On Thursday and Friday, May 16 and 17, John Hawley discussed with El Llano residents the results of water quality analyses completed at the E.I.D. laboratories.

Mark Hemingway, Fritz Reimers, Kevin Cook, and Denny Lang (NMBM&MR) conducted consolidation, Atterberg limits, moisture, and density tests on El Llano soil samples at the soil testing laboratory, New Mexico Bureau of Mines. Mark Hemingway and Danny Bobrow also did Scanning Electron Microscopy (S.E.M.) on El Llano soil samples at the S.E.M. laboratory, New Mexico Tech.

The ESP Bureau personnel conducted office work related to the project including data reduction, interpretation, and proofreading.

On Thursday, May 16, Gary Johnpeer attended a meeting in Santa Fe. Also present were: L. Vespigani (C.E.P.D.) and other representatives from state and federal agencies involved in the El Llano project. After the meeting Gary and the representatives inspected damaged structures in El Llano and examined the G.G.S.S. areas. On Friday, May 17, Herman Agoyo (San Juan Pueblo) toured the G.G.S.S. areas.

Bureau personnel engaged in the project this week were: Gary Johnpeer, Mark Hemingway, Danny Bobrow, John Hawley, George Austin, Deborah Shaw, Fritz Reimers, Kevin Cook, Denny Lang, and the clerical department of the NMBM&MR.

Danny J. Bobrow
Geologist
May 19, 1985

EL LLANO GEOTECHNICAL INVESTIGATION
Weekly Report 23
May 20-25, 1985

This week's activities included injecting water into G.G.S.S. area 4; density, moisture, and Sondex settlement monitoring; laboratory testing; office work related to the project; and meetings.

A total of 12,630 gallons of water was injected into G.G.S.S. area 4 wells (concrete foundation study). On Monday, May 20, Gary Johnpeer and Danny Bobrow regulated the water injection system, and on Thursday, May 23, Gary and Danny installed higher sensitivity regulating valves at each of the five wells. These procedures are expected to maximize water flow and minimize over-flow at the wells. Danny and Gary also made a detailed map of the drill holes at G.G.S.S. area 4.

Mark Hemingway and Fritz Reimers monitored the changes in density and moisture of subsurface soils in the depth probe holes and Danny Bobrow and Fritz Reimers monitored the Sondex settlement casings at G.G.S.S. area 4. Changes in the density, moisture, and Sondex casings indicate plumes of water are moving outward from the water injection wells.

Mark Hemingway, Fritz Reimers, and Kevin Cook conducted consolidation, Atterberg limits, moisture, density tests, and sieve analyses on El Llano soil samples at the soil testing laboratory, New Mexico Bureau of Mines. Mark also conducted Scanning Electron Microscopy (S.E.M.) at the S.E.M. laboratory, New Mexico Tech.

The ESP Bureau personnel conducted office work related to the project including: graphics, data reduction and interpretation, and proofreading. On Friday, May 24, George Austin delivered ESP project budgetary data to Bill Rives (C.E.P.D.) in Santa Fe.

Bureau personnel engaged in the project this week were: Gary Johnpeer, Danny Bobrow, Mark Hemingway, Fritz Reimers, George Austin, Felipe Valdez, Kevin Cook, and the clerical staff of the NMBM&MR.

Danny J. Bobrow
Geologist
May 25, 1985

EL LLANO GEOTECHNICAL INVESTIGATION
WEEKLY REPORT 24
May 26-31, 1985

This week's activities included injecting water and documenting the subsidence features at G.G.S.S. area 4; density, moisture, and Sondex settlement monitoring; geologic mapping; reviewing water quality analyses; laboratory testing; office work related to the project; and meetings.

On Sunday, May 26, Felipe Valdez notified Gary Johnpeer that G.G.S.S. area 4 had incipient cracking. At the time of initial cracking a total of 20,180 gallons had been injected. On Tuesday and Friday, May 28 and 31, Gary Johnpeer, Danny Bobrow, Dave Love, Mark Hemingway, and Fritz Reimers examined and documented with photographs the subsidence features (induced by subsurface wetting) at G.G.S.S. area 4. On Friday, May 31, the subsidence feature was eight inches deep and 36 feet across and was surrounded by cracks. Dave, Danny, Gary, and Fritz mapped in detail the ground cracks and completed detailed elevation surveys of the subsidence feature. The map and elevation survey were updated as the subsidence feature grew. This week a total of 36,417 gallons of water was injected into G.G.S.S. area 4 wells (concrete-foundation study).

Gary Johnpeer and Mark Hemingway monitored the changes in density and moisture of subsurface soils in the depth probe holes and Danny Bobrow monitored the Sondex settlement casings at G.G.S.S. area 4.

Dave Love mapped the geology east of NM-291 in El Llano. He recovered three vertebrate fossils while mapping. On Tuesday, May 28, John Hawley discussed the results of El Llano water quality analyses with E.I.D. personnel.

Mark Hemingway, Fritz Reimers, and Kevin Cook conducted sieve analyses, Atterberg limits, consolidation, moisture, and density tests on El Llano soil samples at the soil testing laboratory, New Mexico Bureau of Mines. Mark also conducted Scanning Electron Microscopy (S.E.M.) at the S.E.M. laboratory, New Mexico Tech.

The ESP Bureau personnel conducted office work related to the project including: graphics, data reduction and proofreading, and planning the final report. On Friday, R. McNeill visited G.G.S.S. area 4. He examined the subsidence feature and discussed the Sondex and neutron probe data. His time for this effort was not charged to the project.

Bureau personnel engaged in the project this week were: Gary Johnpeer, Danny Bobrow, Dave Love, Mark Hemingway, Fritz Reimers, John Hawley, George Austin, Felipe Valdez, Kevin Cook, and the clerical staff of the NMBM&MR.

Problems

1. The backhoe operator for Amigo construction stopped working on the project and we are seeking another backhoe and operator to continue ground restoration in El Llano.

Danny J. Bobrow
Geologist
June 2, 1985

EL LLANO GEOTECHNICAL INVESTIGATION
WEEKLY REPORT 25
June 3-7, 1985

This week's activities included monitoring the subsidence feature and injecting water at G.G.S.S. area 4; density, moisture, and Sondex settlement monitoring; backfilling and densifying exploration trench ESBH-9 and G.G.S.S. areas 1 and 2; compiling a geologic map and cross sections of the El Llano area; laboratory testing; and office work related to the project.

A total of 33,856 gallons of water was injected into G.G.S.S. area 4 wells (concrete foundation study). On Monday and Tuesday, June 3 and 4, Danny Bobrow, Mark Hemingway, and Fritz Reimers monitored changes in density and moisture of subsurface soils in the depth probe holes and the Sondex settlement casings at G.G.S.S. areas 1, 2, 3, and 4. They also monitored the growth of the subsidence feature at G.G.S.S. area 4; on Tuesday, June 4, the subsidence feature was 1.1 feet deep and 40 feet across.

On Monday and Tuesday Rudy Trujillo Construction, Danny, Mark, and Fritz backfilled and densifyied exploration trench ESBH-9 and G.G.S.S. areas 1 and 2 (see attached memo for backfilling procedure).

Dave Love worked on a geologic map of El Llano. The work consisted of compiling geologic field maps and photographic-interpretation. John Hawley compiled geologic cross sections of El Llano area.

Kevin Cook conducted Atterberg limits and sieve analyses on El Llano soil samples at the soil testing laboratory, New Mexico Bureau of Mines. Mark Hemingway conducted Scanning Electron Microscopy (S.E.M.) at the S.E.M. laboratory, New Mexico Tech.

The ESP Bureau personnel conducted office work related to the project including: graphics, data reduction and interpretation, proofreading, and planning the final report. Deb Shaw (NMBM&MR) and Gary Johnpeer worked on an article about the G.G.S.S. areas and recommendations for construction and collapsible soils. The article will appear in the August issue of New Mexico Geology.

Bureau personnel engaged in the project this week were Danny Bobrow, Mark Hemingway, Dave Love, Fritz Reimers, Gary Johnpeer, Deb Shaw John Hawley, Kevin Cook, Felipe Valdez, and the clerical and graphics departments of the NMBM&MR.

Danny J. Bobrow
Geologist
June 9, 1985

New Mexico Bureau of Mines & Mineral Resources
Socorro, NM 87801

A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

rmation: 505/835-5420
lications: 505/835-5410

June 6, 1985

MEMO

TO: Gary Johnpeer

FROM: Danny Bobrow

SUBJECT: Backfilling and densifying trenches and subsidence features

The procedure used for backfilling and densifying the Trujillo (ESBH-11) and Valdez (ESBH-9) trenches was as follows: Each trench was overexcavated to a depth of 5 feet and a width and length greater than the original trench. A two-to-three inch layer of bentonite was emplaced in the bottom of the trench. Then the trench was backfilled, compacted with a vibro-compactor and the backhoe, and graded to the original ground contours. The restoration of the Trujillo trench was completed on May 14, 1985 and the Valdez trench on June 3, 1985; both homeowners are aware of the restoration procedure.

The procedure used for backfilling and densifying the subsidence features (G.G.S.S. areas 1 & 2) was as follows: The drill holes and PVC pipes were backfilled with native material and one bag of bentonite per drill hole. The PVC and Sondex casing were extracted with the backhoe from the subsurface soils. In cases where this was not possible, the PVC and Sondex casing were sheared off at approximately a three-foot depth. Then bentonite was emplaced in all ground depressions, the ground surface compacted with the backhoe, and the areas graded to the original ground contours.

DJB/jc

EL LLANO GEOTECHNICAL INVESTIGATION
WEEKLY REPORT 26
June 10-14, 1985

This week's activities included monitoring the subsidence feature and terminating the flow of water at G.G.S.S. area 4, office work related to the project, and planning the final report.

On Monday, June 10, Gary Johnpeer, Danny Bobrow, Mark Hemingway, and Fritz Reimers documented with photographs and updated the crack location map and topographic map the subsidence feature at G.G.S.S. area 4 (concrete foundation study). The subsidence feature was 1.3 feet deep and 52 feet across. They also monitored the changes in density and moisture in the depth probe holes and monitored the Sondex settlement casings at G.G.S.S. area 4.

On Monday, at 1:00 p.m., the injection of water into G.G.S.S. area 4 was terminated (total water injected was 107,691 gallons). This completes the four geotechnical ground stabilization studies.

The ESP Bureau personnel conducted office work related to the project including: graphics, data reduction and interpretation, proofreading, and planning the removal of the concrete foundations from G.G.S.S. area 4. Deb Shaw (NMBM&MR) and Gary Johnpeer worked on the article about the G.G.S.S. areas and recommendations for construction on collapsible soils.

On Wednesday, June 12, ESP Bureau personnel met with R. McNeill and C. Reynolds. Discussed at the meeting were the 3,000 feet of seismic refraction data, generated during May 1985, and the format for the El Llano Geotechnical Study final report.

On Monday, George Griswold and a mining engineering class (New Mexico Tech) visited El Llano and the G.G.S.S. areas to observe geotechnical monitoring procedures. Fritz Reimers demonstrated the geotechnical procedures used at the sites.

Bureau personnel engaged in the project this week were: Gary Johnpeer, Mark Hemingway, Danny Bobrow, Fritz Reimers, Deb Shaw, Dave Love, John Hawley, George Austin, and the graphics and clerical staff of the NMBM&MR.

Danny J. Bobrow
Geologist
June 17, 1985

EL LLANO GEOTECHNICAL INVESTIGATION
FINAL WEEKLY REPORT 27
June 17-28, 1985

This week's activities included removing the concrete foundations at G.G.S.S. Area 4, backfilling wells and grading G.G.S.S. Areas 3 and 4, and working on the final report.

On Wednesday, June 19, a 5 yard front end loader (rented from Cook's Transit Mix) removed the concrete foundations from G.G.S.S. Area 4. The conventional foundation cracked while being removed and loaded on a flat bed truck whereas the reinforced foundation (BRAB slab) did not crack. However, due to the BRAB slab's great weight it could only be dragged to the edge of the field.

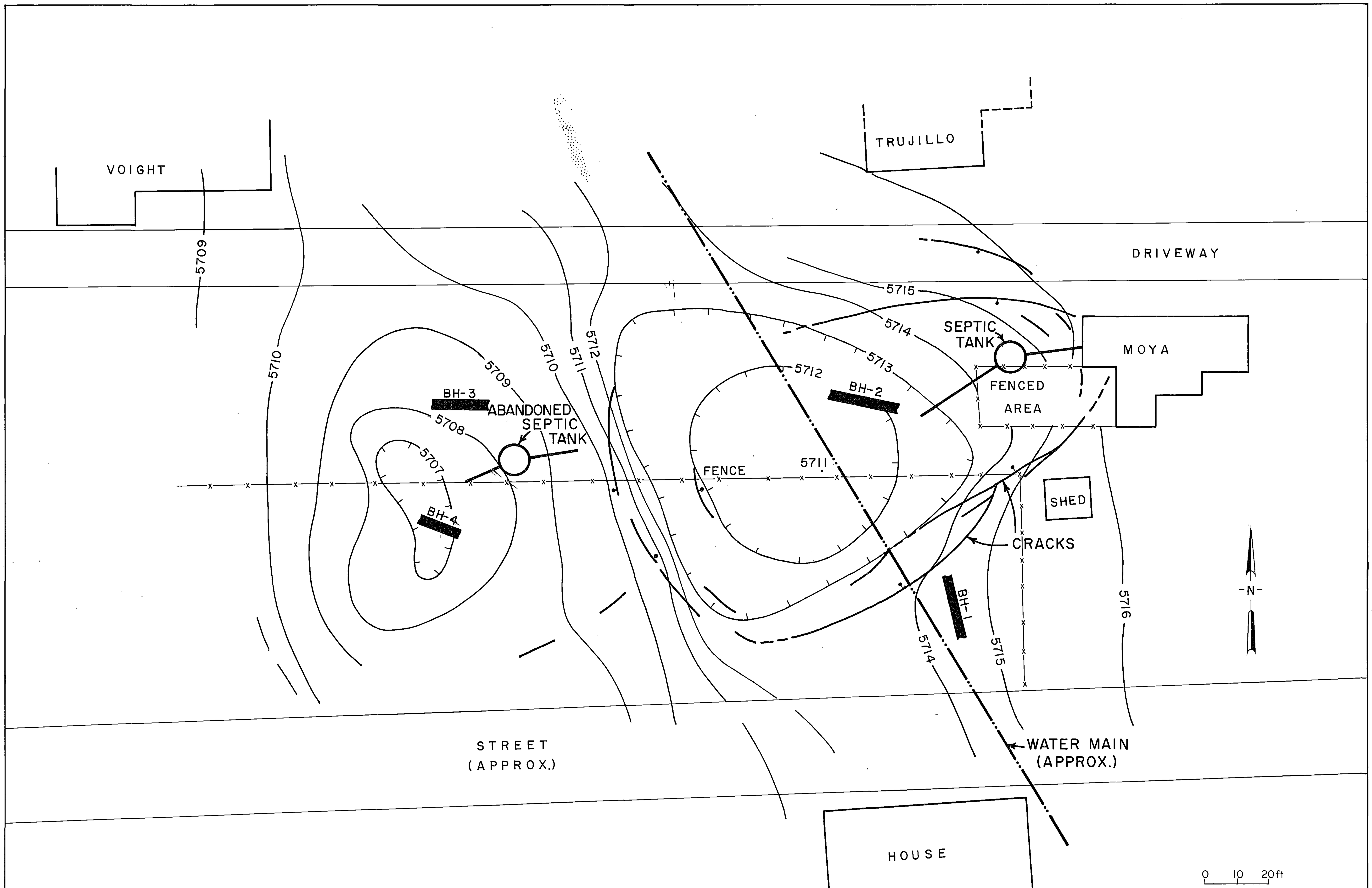
On Wednesday and Thursday, Danny Bobrow, Mark Hemingway, Gary Johnpeer, and Leroy Roybal (D&A Backhoe Enterprises) backfilled and graded G.G.S.S. Areas 3 and 4 and the following wells in El Llano: ESPDH 11, 14, 18, 20, 22, 24, 25, 36, 38, 40, and 41. The remaining wells are being left open with the written permission of the property owner.

The ESP Bureau personnel worked all weekend and the last week on the final report. The work consisted of: graphics, data reduction, proofreading, writing, xeroxing, and binding the copies. The Bureau graphics, clerical, and reproduction staffs assisted. On Friday, June 28, the completed final report was delivered to the agencies and individuals on the distribution list.

Bureau personnel engaged in the project this week were: Gary Johnpeer, Danny Bobrow, Mark Hemingway, Dave Love, John Hawley, Fritz Reimers, Deb Shaw, George Austin, and the graphics, clerical, and copy staff of the NMBM&MR.

Danny J. Bobrow
Geologist
June 28, 1985

APPENDIX XVII TOPOGRAPHIC MAP OF MOYA SUBSIDENCE AREA 12/4/84



SURVEYED BY D. LOVE, F. REIMERS, G. JOHNPEER 12/4/84

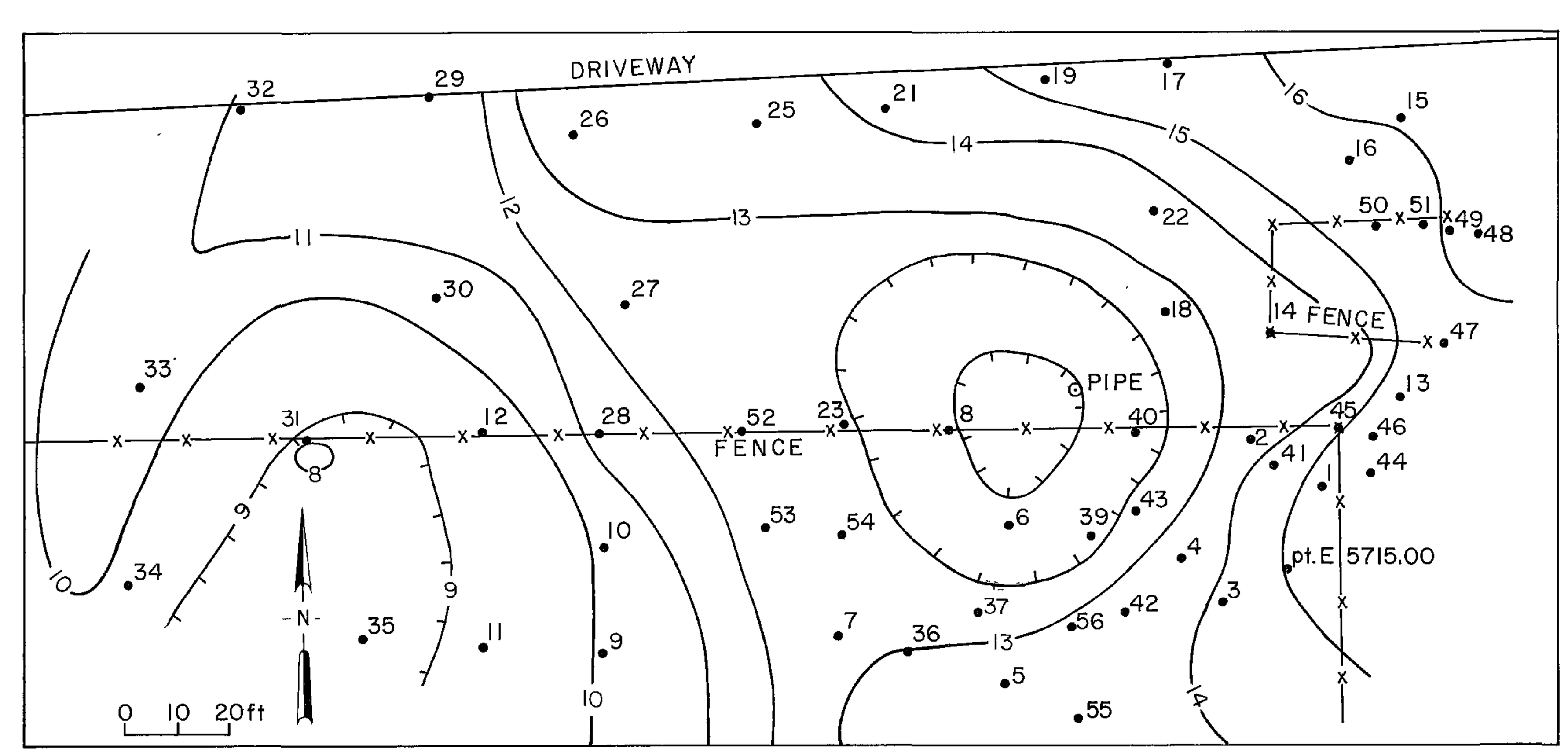
NOTES

1) ADDITIONAL ACTIVITIES FOR THIS AREA SHOWN ON SECTION 25 APPENDIX XII

2) CONTOUR ELEVATIONS ARE APPROXIMATE

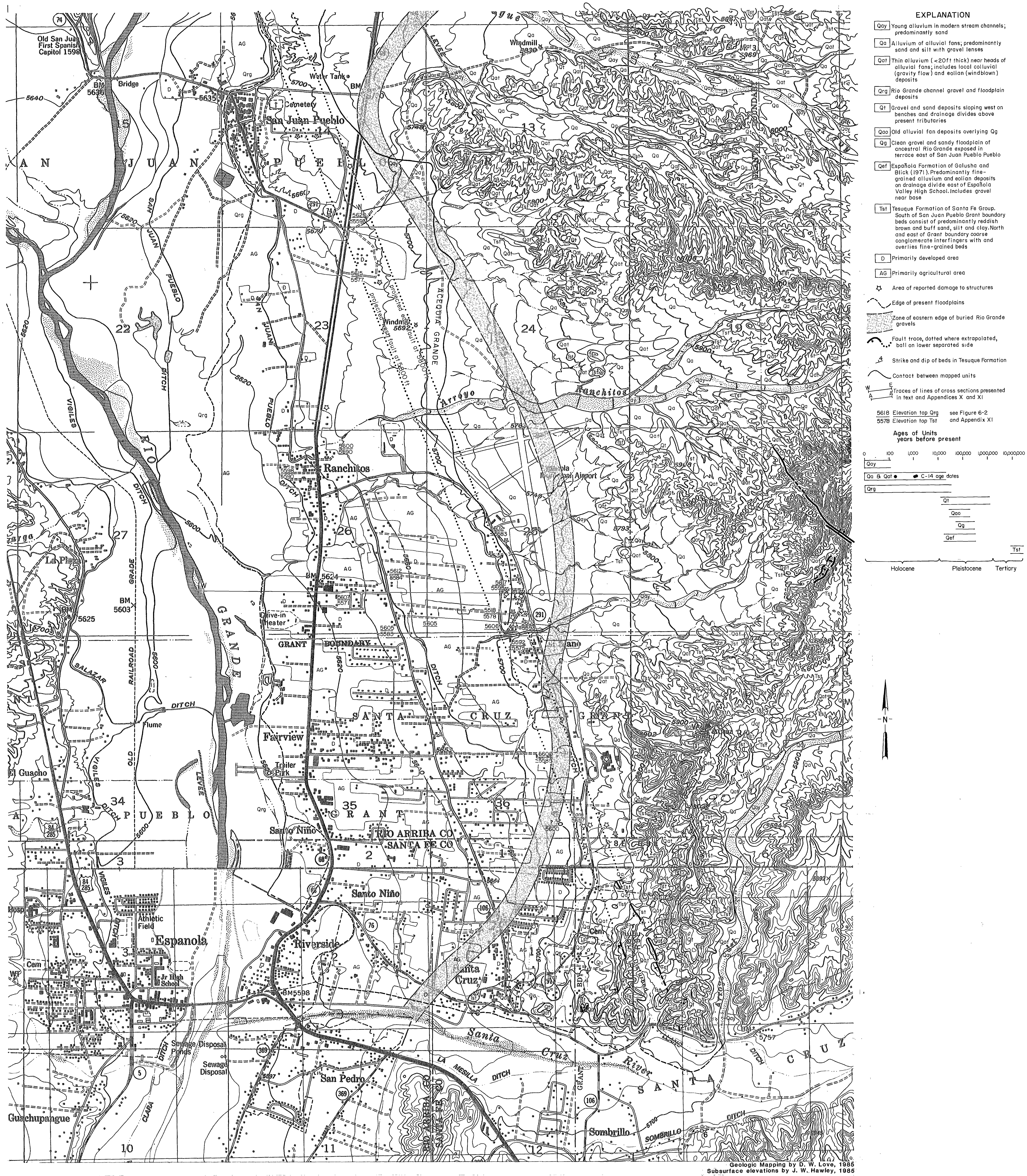
3) ONLY MAJOR CRACKS SHOWN

BH-4 BACKHOE TRENCH



SURVEY STATIONS (DRIVEN REBAR) USED FOR SUBSIDENCE MONITORING OF THIS AREA

SEE APPENDIX XVII TABLE A-1



APPENDIX V GEOLOGIC MAP OF A PORTION OF SOUTHERN RIO ARRIBA AND NORTHERN SANTA FE COUNTIES, NEW MEXICO

0 .5 1mi

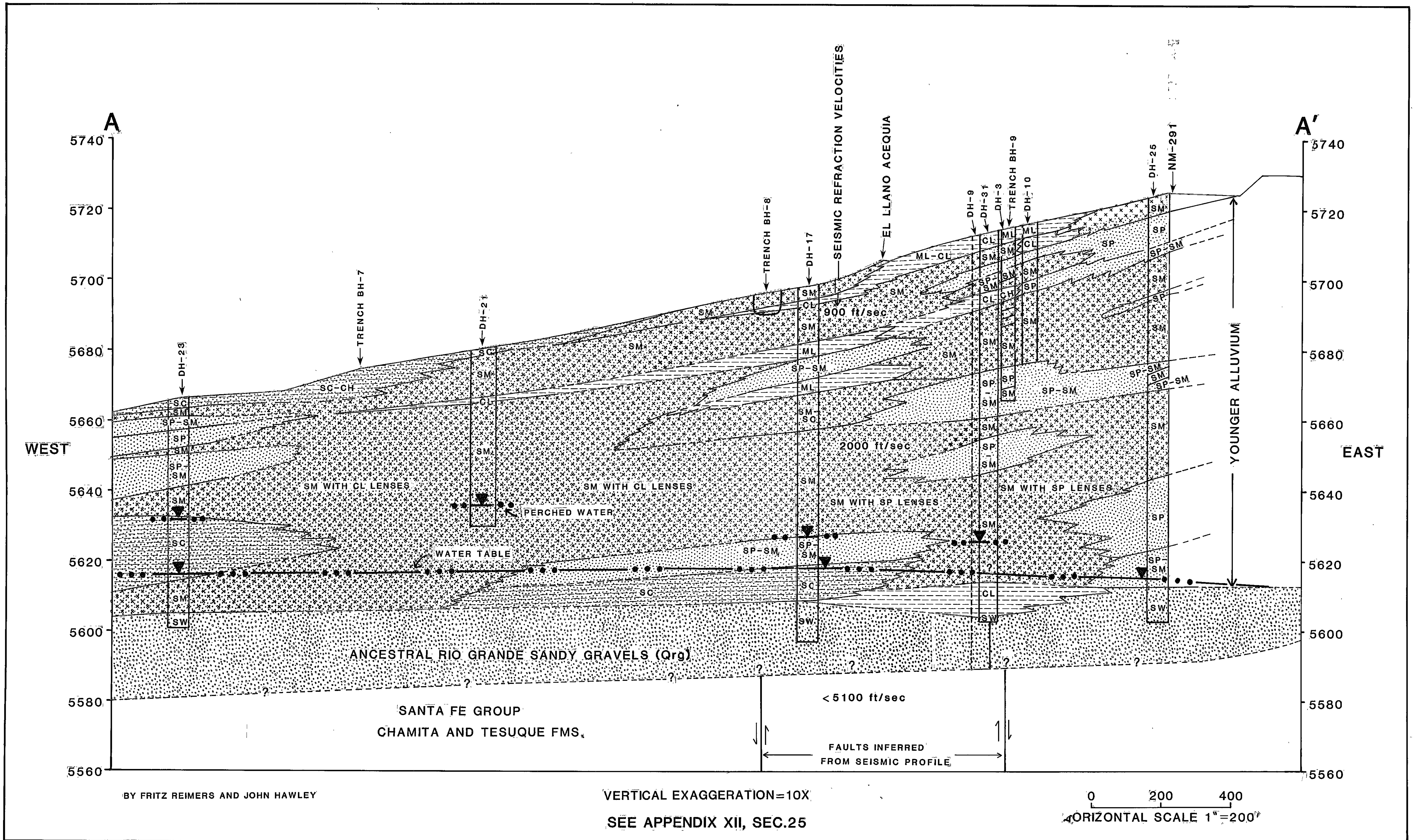


Figure A-2. East-West geologic cross section through El Llano.

28 JUNE 1985

OF 226

28 JUNE 1985

NO ACTIVITIES ON THIS MAP

GEOTECHNICAL ACTIVITY LOCATION MAP

Scale: 1" = 200'

LEGEND

- 1000' NEW MEXICO STATE PLANE GRID COORDINATE, CENTRAL ZONE
- FIELD CONTROL POINT
- RECOVERED SECTION CORNER
- GRAPHICALLY PROJECTED SECTION CORNER
- 5675 INDEX CONTOUR
- INTERMEDIATE CONTOUR
- DEPRESSION CONTOUR
- X27.5 SPOT ELEVATION

SHEET INDEX

		R8E R9E
23	24	19
26	25	30
35	36	31
2	1	T21N T20N

CONTOUR INTERVAL 5 FEET

COMPILED BY PHOTOGRAMMETRIC METHODS
DATE OF PHOTOGRAPHY JANUARY 15, 1985

ELEVATIONS ARE BASED ON
CITY OF ESPANOLA BM 5625.95

NEW MEXICO STATE PLANE GRID BASED ON
U.S.C.& G.S. STATIONS JOSE AND JOSE AZ. MK.

THIS MAP COMPLIES WITH THE
NATIONAL MAP ACCURACY STANDARDS.

MAP 1 OF 9

RECTIFIED PHOTO - TOPOGRAPHIC MAP
OF
ESPANOLA, NEW MEXICO & VICINITY
FOR
NEW MEXICO BUREAU OF MINES
FEBRUARY 1985

SECTION 24, T. 21 N., R. 8 E.

KOOGLE & POULS ENGINEERING

OF 226

28 JUNE 1985

EXPLANATION

- o DRILL HOLE
- s SETTLEMENT MONITORING WELL
- w WATER MONITORING WELL
- g GEOTECHNICAL WELL
- EXPLORATION TRENCHES
- SEISMIC REFRACTION LINE
- SEISMIC REFLECTION LINE
- GROUND VIBRATION MONITOR

LEGEND

- 1000' NEW MEXICO STATE PLANE GRID COORDINATE, CENTRAL ZONE
- FIELD CONTROL POINT
- RECOVERED SECTION CORNER
- GRAPHICALLY PROJECTED SECTION CORNER
- 5675 INDEX CONTOUR
- INTERMEDIATE CONTOUR
- DEPRESSION CONTOUR
- X27.5 SPOT ELEVATION

SHEET INDEX

		R8E R9E
23	24	19
26	25	30
35	36	31
2	1	T21N T20N

200 100 0 200 400 600 800

Scale: 1" = 200'

CONTOUR INTERVAL 5 FEET

COMPILED BY PHOTOGRAMMETRIC METHODS
DATE OF PHOTOGRAPHY JANUARY 15, 1985

ELEVATIONS ARE BASED ON
CITY OF ESPANOLA BM 5625.95

NEW MEXICO STATE PLANE GRID BASED ON
U.S.C.& G.S. STATIONS JOSE AND JOSE AZ. MK.

THIS MAP COMPLIES WITH THE
NATIONAL MAP ACCURACY STANDARDS.

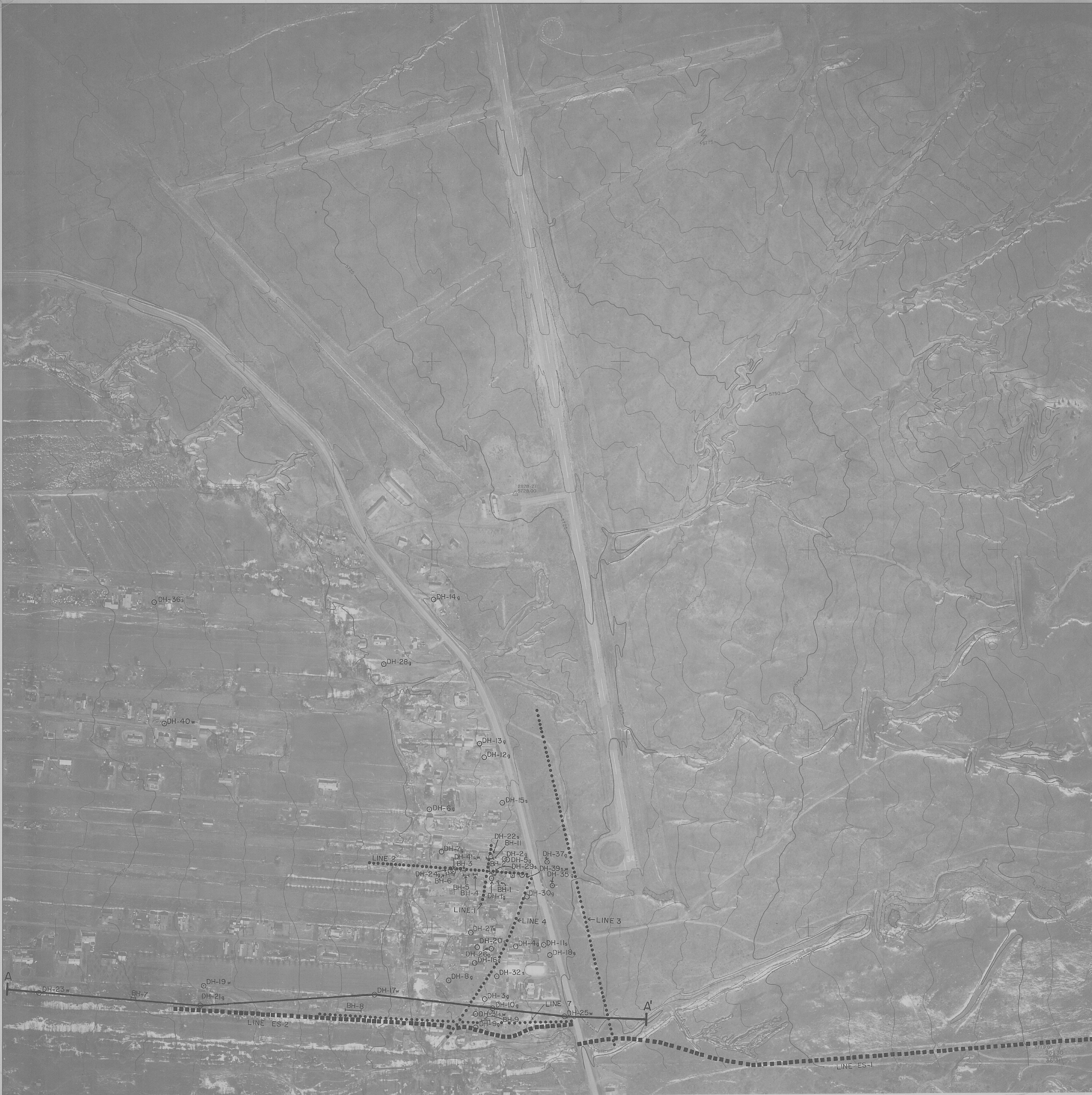
MAP 2 OF 9

GEOTECHNICAL ACTIVITY LOCATION MAP

RECTIFIED PHOTO - TOPOGRAPHIC MAP
OF
ESPANOLA, NEW MEXICO & VICINITY
FOR
NEW MEXICO BUREAU OF MINES
FEBRUARY 1985

SECTION 23, T. 21 N., R. 8 E.

KOOGLE & POULS ENGINEERING
8338A COMANCHE N.E., ALBUQUERQUE, N.M. 87110



28 JUNE 1985

GEOTECHNICAL ACTIVITY LOCATION MAP

EXPLANATION

- o DRILL HOLE
- s SETTLEMENT MONITORING WELL
- w WATER MONITORING WELL
- g GEOTECHNICAL WELL
- EXPLORATION TRENCHES
- SEISMIC REFRACTION LINE
- SEISMIC REFLECTION LINE
- GROUND VIBRATION MONITOR
- A A' GEOLOGIC CROSS SECTION SEE APPENDIX X

KOOGLE & POULS ENGINEERING
8338A COMANCHE N.E., ALBUQUERQUE, N.M. 87110

LEGEND

- 1000' NEW MEXICO STATE PLANE GRID COORDINATE, CENTRAL ZONE
- FIELD CONTROL POINT
- RECOVERED SECTION CORNER
- GRAPHICALLY PROJECTED SECTION CORNER
- 5675 INDEX CONTOUR
- INTERMEDIATE CONTOUR
- DEPRESSION CONTOUR
- X27.5 SPOT ELEVATION

SHEET INDEX

		R8E R9E
23	24	19
26	25	30
35	36	31
2	1	T21N T20N

200 100 0 200 400 600 800

Scale: 1" = 200'

CONTOUR INTERVAL 5 FEET

COMPILED BY PHOTOGRAMMETRIC METHODS
DATE OF PHOTOGRAPHY JANUARY 15, 1985

ELEVATIONS ARE BASED ON
CITY OF ESPANOLA BM 5625.95

NEW MEXICO STATE PLANE GRID BASED ON
U.S.C.& G.S. STATIONS JOSE AND JOSE AZ. MK.

THIS MAP COMPLIES WITH THE
NATIONAL MAP ACCURACY STANDARDS.

MAP 3 OF 9

RECTIFIED PHOTO - TOPOGRAPHIC MAP
OF
ESPANOLA, NEW MEXICO & VICINITY
FOR
NEW MEXICO BUREAU OF MINES
FEBRUARY 1985

SECTION 25, T. 21 N., R. 8 E.

28 JUNE 1985

GEOTECHNICAL ACTIVITY LOCATION MAP

EXPLANATION

- o DRILL HOLE
- s SETTLEMENT MONITORING WELL
- w WATER MONITORING WELL
- g GEOTECHNICAL WELL
- EXPLORATION TRENCHES
- SEISMIC REFRACTION LINE
- SEISMIC REFLECTION LINE
- GROUND VIBRATION MONITOR

LEGEND

- 1000' NEW MEXICO STATE PLANE GRID COORDINATE, CENTRAL ZONE
- FIELD CONTROL POINT
- RECOVERED SECTION CORNER
- GRAPHICALLY PROJECTED SECTION CORNER
- 5675 INDEX CONTOUR
- INTERMEDIATE CONTOUR
- DEPRESSION CONTOUR
- X27.5 SPOT ELEVATION

SHEET INDEX

		R8E / R9E
23	24	19
26	25	30
35	36	31
2	1	T21N / T20N

200 100 0 200 400 600 800

Scale: 1" = 200'

CONTOUR INTERVAL 5 FEET

COMPILED BY PHOTOGRAMMETRIC METHODS
DATE OF PHOTOGRAPHY JANUARY 15, 1985

ELEVATIONS ARE BASED ON
CITY OF ESPANOLA BM 5625.95

NEW MEXICO STATE PLANE GRID BASED ON
U.S.C.& G.S. STATIONS JOSE AND JOSE AZ. MK.

THIS MAP COMPLIES WITH THE
NATIONAL MAP ACCURACY STANDARDS.

MAP 4 OF 9

RECTIFIED PHOTO - TOPOGRAPHIC MAP
OF
ESPANOLA, NEW MEXICO & VICINITY
FOR
NEW MEXICO BUREAU OF MINES
FEBRUARY 1985

SECTION 26, T. 21 N., R. 8 E.

KOOGLE & POULS ENGINEERING
8338A COMANCHE N.E., ALBUQUERQUE, N.M. 87110

OF 226

28 JUNE 1985

EXPLANATION

- ○ DRILL HOLE
- s SETTLEMENT MONITORING WELL
- w WATER MONITORING WELL
- g GEOTECHNICAL WELL
- ├─┤ EXPLORATION TRENCHES
- •••• SEISMIC REFRACTION LINE
- ■■■ SEISMIC REFLECTION LINE
- ⊡ GROUND VIBRATION MONITOR

NOTE: DETAILS OF GGSS-AREA 2 SHOWN IN APPENDIX XX.

GEOTECHNICAL ACTIVITY LOCATION MAP

LEGEND

- 1000' NEW MEXICO STATE PLANE GRID COORDINATE, CENTRAL ZONE
- FIELD CONTROL POINT
- RECOVERED SECTION CORNER
- GRAPHICALLY PROJECTED SECTION CORNER
- 5675 INDEX CONTOUR
- INTERMEDIATE CONTOUR
- DEPRESSION CONTOUR
- X27.5 SPOT ELEVATION

SHEET INDEX

		R8E / R9E
23	24	19
26	25	30
35	36	31
2	1	

T 21N / T 20N

200 100 0 200 400 600 800

Scale: 1" = 200'

CONTOUR INTERVAL 5 FEET

COMPILED BY PHOTOGRAMMETRIC METHODS
DATE OF PHOTOGRAPHY JANUARY 15, 1985

ELEVATIONS ARE BASED ON
CITY OF ESPANOLA BM 5625.95

NEW MEXICO STATE PLANE GRID BASED ON
U.S.C.& G.S. STATIONS JOSE AND JOSE AZ. MK.

THIS MAP COMPLIES WITH THE
NATIONAL MAP ACCURACY STANDARDS.

MAP 5 OF 9

RECTIFIED PHOTO - TOPOGRAPHIC MAP
OF
ESPANOLA, NEW MEXICO & VICINITY
FOR
NEW MEXICO BUREAU OF MINES
FEBRUARY 1985

SECTION 36, T. 21 N., R. 8 E.

KOOGLE & POULS ENGINEERING
8338A COMANCHE N.E., ALBUQUERQUE, N.M. 87110

28 JUNE 1985

NO ACTIVITIES ON THIS MAP

GEOTECHNICAL ACTIVITY LOCATION MAP

LEGEND

- 1000' NEW MEXICO STATE PLANE GRID COORDINATE, CENTRAL ZONE
- FIELD CONTROL POINT
- RECOVERED SECTION CORNER
- GRAPHICALLY PROJECTED SECTION CORNER
- 5675 INDEX CONTOUR
- INTERMEDIATE CONTOUR
- DEPRESSION CONTOUR
- X27.5 SPOT ELEVATION

SHEET INDEX

	R8E	R9E
23	24	19
26	25	30
35	36	31
2	1	T21N T20N

N

200 100 0 200 400 600 800

Scale: 1" = 200'

CONTOUR INTERVAL 5 FEET

COMPILED BY PHOTOGRAMMETRIC METHODS
DATE OF PHOTOGRAPHY JANUARY 15, 1985

ELEVATIONS ARE BASED ON
CITY OF ESPANOLA BM 5625.95

NEW MEXICO STATE PLANE GRID BASED ON
U.S.C.& G.S. STATIONS JOSE AND JOSE AZ. MK.

THIS MAP COMPLIES WITH THE
NATIONAL MAP ACCURACY STANDARDS.

MAP 6 OF 9

RECTIFIED PHOTO - TOPOGRAPHIC MAP
OF
ESPANOLA, NEW MEXICO & VICINITY
FOR
NEW MEXICO BUREAU OF MINES
FEBRUARY 1985

SECTION 35, T. 21 N., R. 8 E.

KOOGLE & POULS ENGINEERING
8338A COMANCHE N.E., ALBUQUERQUE, N.M. 87110

OF 226

28 JUNE 1985

EXPLANATION

- o DRILL HOLE
- s SETTLEMENT MONITORING WELL
- w WATER MONITORING WELL
- g GEOTECHNICAL WELL
- EXPLORATION TRENCHES
- SEISMIC REFRACTION LINE
- SEISMIC REFLECTION LINE
- GROUND VIBRATION MONITOR

NOTE: DETAILS OF GGSS-AREA 1 GGSS-AREA 2 AND GGSS-AREA 3 SHOWN IN APPENDIX XX.

GEOTECHNICAL ACTIVITY LOCATION MAP

LEGEND

- 1000' NEW MEXICO STATE PLANE GRID COORDINATE, CENTRAL ZONE
- FIELD CONTROL POINT
- RECOVERED SECTION CORNER
- GRAPHICALLY PROJECTED SECTION CORNER
- 5675 INDEX CONTOUR
- INTERMEDIATE CONTOUR
- DEPRESSION CONTOUR
- X27.5 SPOT ELEVATION

SHEET INDEX

R8E R9E

23	24	19
26	25	30
35	36	31
2	1	

T21N T20N

200 100 0 200 400 600 800

Scale: 1" = 200'

CONTOUR INTERVAL 5 FEET

COMPILED BY PHOTOGRAMMETRIC METHODS
DATE OF PHOTOGRAPHY JANUARY 15, 1985

ELEVATIONS ARE BASED ON
CITY OF ESPANOLA BM 5625.95

NEW MEXICO STATE PLANE GRID BASED ON
U.S.C.& G.S. STATIONS JOSE AND JOSE AZ. MK.

THIS MAP COMPLIES WITH THE
NATIONAL MAP ACCURACY STANDARDS.

MAP 7 OF 9

RECTIFIED PHOTO - TOPOGRAPHIC MAP
OF
ESPANOLA, NEW MEXICO & VICINITY
FOR
NEW MEXICO BUREAU OF MINES
FEBRUARY 1985

SECTION 1, T. 20 N., R. 8 E.

KOOGLE & POULS ENGINEERING
8338A COMANCHE N.E., ALBUQUERQUE, N.M. 87110

OF 226

OF 226

28 JUNE 1985

NO ACTIVITIES ON THIS MAP

GEOTECHNICAL ACTIVITY LOCATION MAP

LEGEND

- 1000' NEW MEXICO STATE PLANE GRID COORDINATE, CENTRAL ZONE
- FIELD CONTROL POINT
- RECOVERED SECTION CORNER
- GRAPHICALLY PROJECTED SECTION CORNER
- 5675 INDEX CONTOUR
- INTERMEDIATE CONTOUR
- DEPRESSION CONTOUR
- X27.5 SPOT ELEVATION

SHEET INDEX

		R8E R9E
23	24	19
26	25	30
35	36	31
2	1	T21N T20N

200 100 0 200 400 600 800

Scale: 1" = 200'

CONTOUR INTERVAL 5 FEET

COMPILED BY PHOTOGRAMMETRIC METHODS
DATE OF PHOTOGRAPHY JANUARY 15, 1985

ELEVATIONS ARE BASED ON
CITY OF ESPANOLA BM 5625.95

NEW MEXICO STATE PLANE GRID BASED ON
U.S.C.& G.S. STATIONS JOSE AND JOSE AZ. MK.

THIS MAP COMPLIES WITH THE
NATIONAL MAP ACCURACY STANDARDS.

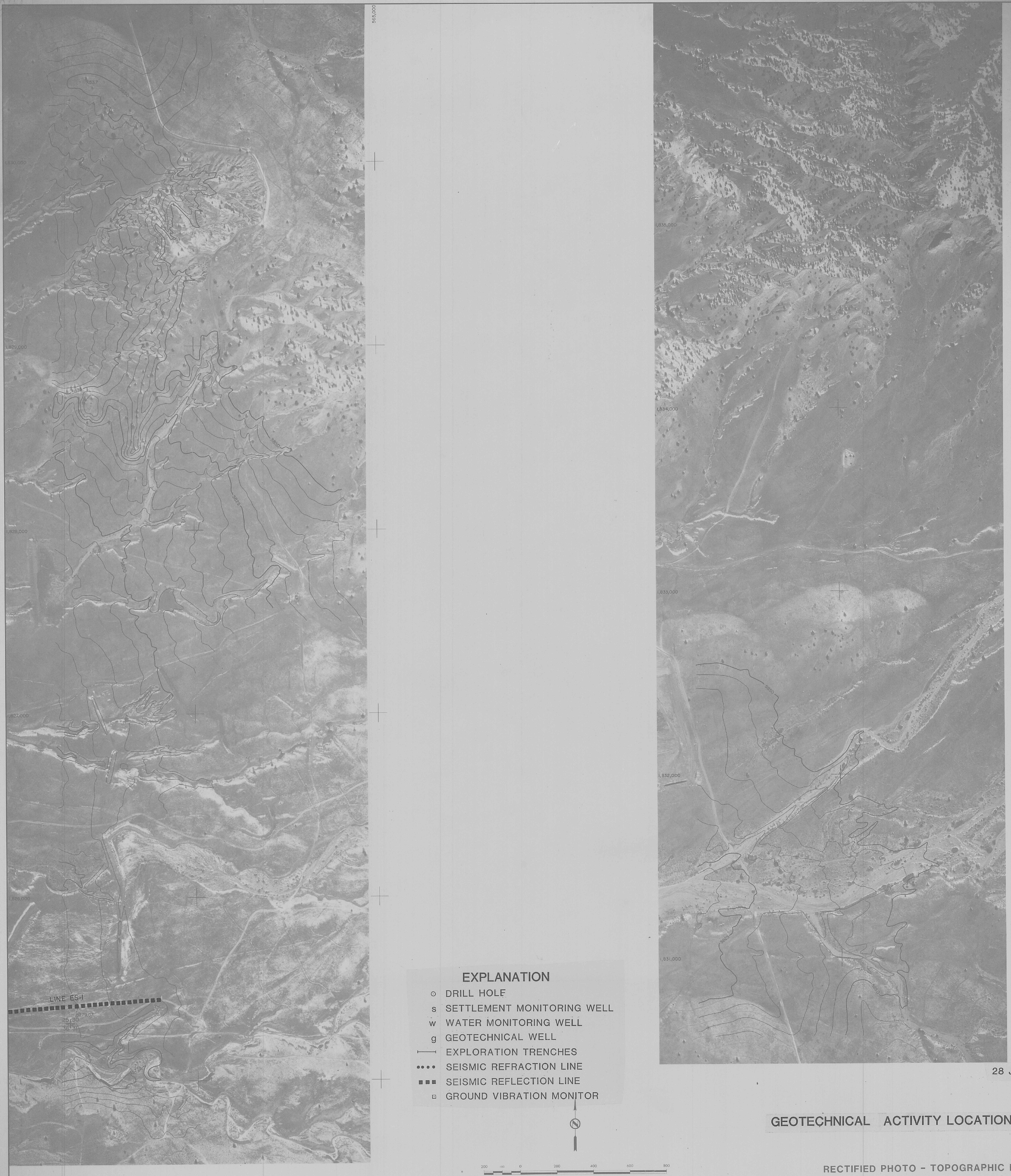
MAP 8 OF 9

RECTIFIED PHOTO - TOPOGRAPHIC MAP
OF
ESPANOLA, NEW MEXICO & VICINITY
FOR
NEW MEXICO BUREAU OF MINES
FEBRUARY 1985

SECTION 2, T. 20 N., R. 8 E.

KOOGLE & POULS ENGINEERING
8338A COMANCHE N.E., ALBUQUERQUE, N.M. 87110

OF 226



EXPLANATION

- o DRILL HOLE
- s SETTLEMENT MONITORING WELL
- w WATER MONITORING WELL
- g GEOTECHNICAL WELL
- EXPLORATION TRENCHES
- SEISMIC REFRACTION LINE
- SEISMIC REFLECTION LINE
- GROUND VIBRATION MONITOR

28 JUNE 1985

GEOTECHNICAL ACTIVITY LOCATION MAP

RECTIFIED PHOTO - TOPOGRAPHIC MAP
OF
ESPANOLA, NEW MEXICO & VICINITY
FOR
NEW MEXICO BUREAU OF MINES
FEBRUARY 1985

PORTIONS OF SECTIONS 19, 30, & 31,
T. 21 N., R. 9 E.

MAP 9 OF 9

200 100 0 200 400 600 800

Scale: 1" = 200'

CONTOUR INTERVAL 5 FEET

COMPILED BY PHOTOGRAMMETRIC METHODS
DATE OF PHOTOGRAPHY JANUARY 15, 1985

ELEVATIONS ARE BASED ON
CITY OF ESPANOLA BM 5625.95

NEW MEXICO STATE PLANE GRID BASED ON
U.S.C.& G.S. STATIONS JOSE AND JOSE AZ. MK.

THIS MAP COMPLIES WITH THE
NATIONAL MAP ACCURACY STANDARDS.

SHEET INDEX

		R8E R9E
23	24	19
26	25	30
35	36	31
2	1	T21N T20N

LEGEND

- 1000' NEW MEXICO STATE PLANE GRID COORDINATE, CENTRAL ZONE
- FIELD CONTROL POINT
- RECOVERED SECTION CORNER
- GRAPHICALLY PROJECTED SECTION CORNER
- 5675 INDEX CONTOUR
- INTERMEDIATE CONTOUR
- DEPRESSION CONTOUR
- X27.5 SPOT ELEVATION

KOOGLE & POULS ENGINEERING
8338A COMANCHE N.E., ALBUQUERQUE, N.M. 87110