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U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN REGION
SANPETE RANGER DISTRICT
MANTI, UTAH

INTERIM GEOTECHNICAL REPORT

- MANTI CANYON NORTH SLIDE STABILITY STUDIES
- DEBRIS DAM FOUNDATION INVESTIGATIONS

SEPTEMBER 1976

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EXECUTIVE VICE PRESIDENT

September 2, 1976

U.S. Department of Agriculture
Forest Service
Intermountain Region
324 25th Street
Ogden, Utah 34401

Attention: Mr. John K. Campbell, Contracting Officer

SUBJECT: Interim Geotechnical Report
Manti Canyon North Slide Stability Studies
Forest Service - Intermountain Region

Gentlemen:

The joint venture team of Caldwell, Richards and Sorensen, Inc. (CRS) and International Engineering Company, Inc. (IECO) is pleased to submit this Interim Geotechnical Report for the Manti Canyon, North Slide stability studies as per terms of the contract between the Forest Service and CRS/IECO.

The primary purpose of this interim report is to present preliminary conclusions regarding the stability of the North Slide and consequent feasibility of constructing a by-pass pipeline across the slide mass. Opinions regarding the foundation of a site in Manti Canyon proposed for an 80-foot high debris dam are also presented.

Findings of the study show that construction of a by-pass pipeline across the North Slide is undesirable, due to the incipient instability of the slide mass. Construction of an 80-foot-high debris-retention dam was also found to be undesirable, due to geologic conditions at the site that was investigated. Construction of smaller dam at the site investigated or at other locations in Manti Canyon would be geologically feasible.

The conclusions presented in this report are preliminary, pending the completion of additional field surveys, to be followed by a final report at the end of this year. We do not anticipate changes in the basic conclusions with new field data. However, modification of conclusions and more positive recommendations regarding possible remedial measures for mitigating erosion and sedimentation problems related to the landslides in Manti Canyon may be forthcoming in the final report.

The close cooperation of the Forest Service during the study period has been greatly appreciated.

Very truly yours,

G. Bryce Bennett

G. Bryce Bennett
Executive Vice President

ERRATA

INTERIM REPORT

- Page 2-5, first line.

  "All tests were performed by CRS in "should read "All tests were performed by CRS and Pittsburg Testing Laboratory in"

- Page 2-17, third from last line.

  "North Horn Formations" should read "North Horn Formation"

- Page 2-29, second from last line.

  "direction, The North Slide" should read "movement direction of the North Slide"

* * *

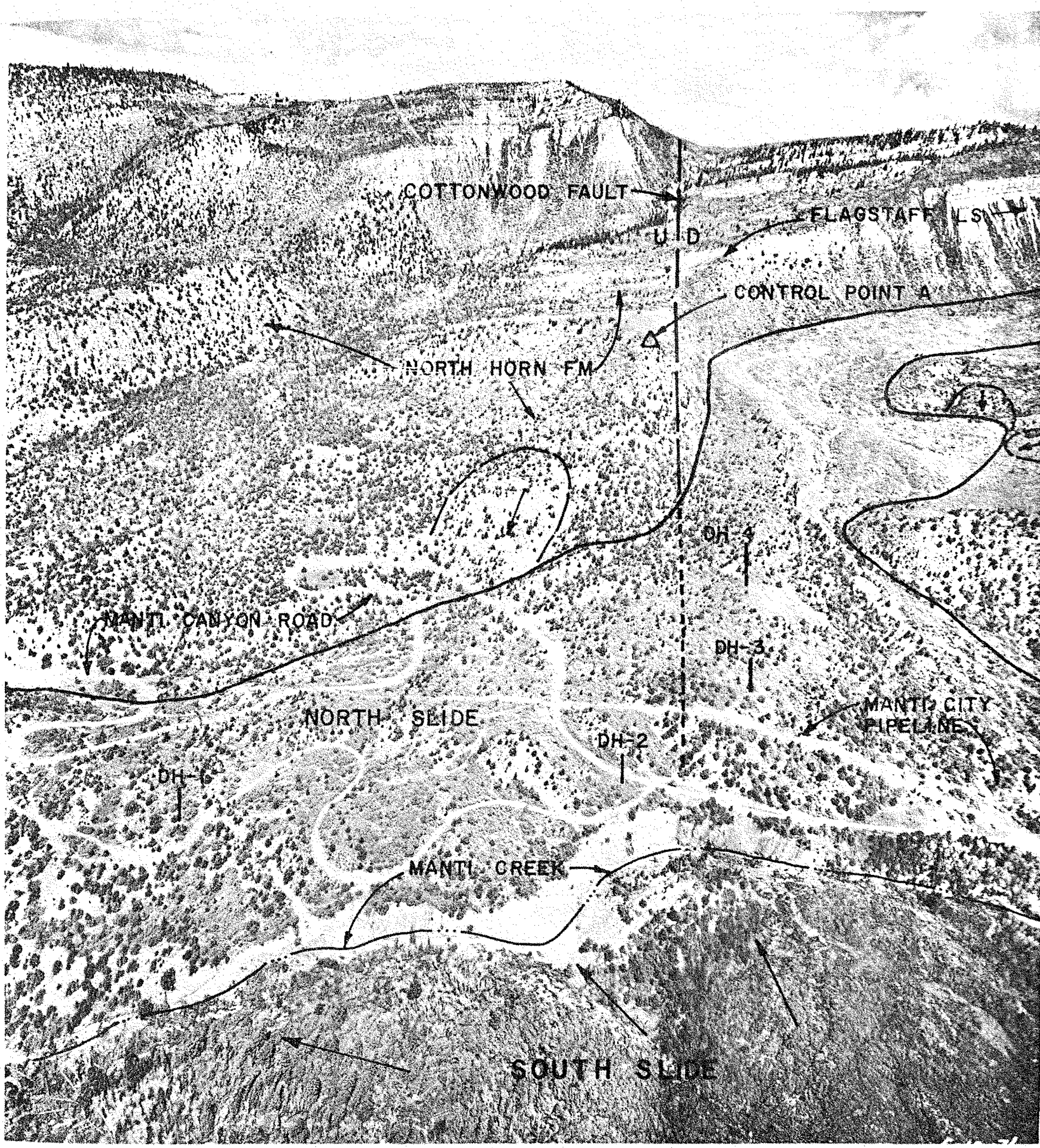

PHOTO I - PORTION OF NORTH SLIDE

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S.1 SUMMARY

Investigations of the slide included a subsurface exploratory program, seismic surveys, laboratory testing and field instrumentation.

- Exploration consisted of four borings from 150 to 350 feet deep, drilled on the North Slide and one 70-foot deep boring at the debris damsite providing a total of 1131 linear feet of exploratory drilling. Samples were obtained by Shelby tubes, split spoon samplers and Nc-wireline coring.

- A total of 14,065 linear feet of seismic survey lines were run on the North Slide and debris-retention damsite.

- Laboratory testing included gradation, Atterberg limits, moisture content, triaxial and direct shear tests. X-Ray diffraction tests were also made to determine specific clay mineralogy.

- Inclinometer casing was installed in the four boreholes on the North Slide. A total of 1008 feet of casing was installed in the holes which were between 150 and 327 feet deep. Purpose of the casing installation was to provide a means for detection of movement within the North Slide. A special downhole instrument known as the Miniprobe, which is designed for precise detection of direction, amount of movement and depth, was used.

- Surface survey monuments were located at each inclinometer site and were monitored periodically by precise survey methods.

- Surface survey points and the inclinometer holes were monitored every two weeks between June and August, 1976.

- The monitoring program will continue at monthly intervals through December, 1976.

- The Bishop's modification of the Swedish Circular Arc and the planar method were used for stability analyses of the North Slide.

- Settlement analyses were made of the debris-retention dam foundation.

S.2 CONCLUSIONS

- The North Slide mass is composed of glacial till which extends to a depth of 350 feet.

- The till is underlain by sandstone shale and siltstone beds of the North Horn Formation. (The North Horn Formation contains montmorillonite shale beds and is associated with numerous landslides in Utah.)

- Till of the North Slide is divided into at least two layers: an upper layer from 10 to 80 feet deep composed of loose silty gravel and a lower layer of dense, overconsolidated gravel in a matrix of stiff montmorillonite clay. The till matrix is primarily glacial rock flour which contributes the "milky" turbidity to several streams flowing into Manti Creek.

- Numerous tension cracks, springs, ponds and irregular hummocky topographic features provide visual evidence of soil creep or land flow in the upper layer of the North Slide above elevation 7500 feet.

- Shear zones were observed in core samples of the dense glacial till. Shear zones are caused by: 1) deformations in the till resulting from ice action during the glacial periods; 2) plastic deformation by slow, deep seated, mass soil creep, and 3) possibly shearing by movement on the Cottonwood Fault.

- The groundwater table within the North Slide mass was temporarily influenced by drilling operations and has not returned to its natural conditions (August 31, 1976). Therefore the influence of groundwater on the slide is not known. Water under artesian pressures was encountered in boring DH-2, either in the upper bedrock layers or in gravelly alluvium which was penetrated immediately above bedrock.

- The study area is in a region which has a record of moderate seismic activity in historic times. Geologic evidence found during the study indicates that high magnitude earthquakes and active faulting can also be expected in or close to the study area.

- Factors of safety of the North Slide mass are close to unity without earthquake. Analyses of the North Slide area, assuming continued erosion of the streambed by Manti Creek, indicate that the factor of safety will be less than 1.0. Analyses also show that a rock lining of the streambed to prevent erosion, will eliminate further reduction of the already low factor of safety of the North Slide and will provide some degree of buttressing against local failure.

- Inclinometer and surface surveys support the results of stability analyses. These data show small downslope movements, which can be expected with marginal factors of safety.

- Investigations at the proposed site of an 80-foot high debris retention dam revealed poor geologic conditions for dam construction and operation. The dam foundation is underlain by up to 58 feet of rock slopewash, gravelly alluvium or glacial till all of which appear to be in a loose condition. In addition, the left abutment of the proposed dam will have marginal stability after saturation by the proposed reservoir.

S.3 RECOMMENDATIONS

- The existing condition of incipient creep can be transformed into a slope failure by changes in hillside geometry resulting from the erosion in Manti Creek and/or increased loading due to snow, seismic or groundwater changes. Therefore, a by-pass pipeline should not be considered a permanent solution for mitigating sedimentation and flooding problems on Manti Creek.

- Because of stability problems on the left abutment of the debris-retention damsite the selected site is not considered to be geologically feasible for a 80-foot high debris dam. Smaller structures at the selected site and possibly other locations in Manti Canyon will provide alternatives which are geologically feasible.

CHAPTER 1

INTRODUCTION

1.1 PURPOSE

This interim report presents the results of exploration and surveys, engineering geologic studies and stability analyses performed between May and August 1976 to determine the geotechnical feasibility of: 1) constructing a by-pass pipeline to carry the flow of Manti Creek across the toe of a possible landslide on the north side of the creek, referred to herein as the North Slide, (see Figure 1-1 and Photo 1); and 2) constructing a debris-retention dam near the mouth of Manti Canyon. The report has also been prepared to assist the U.S. Forest Service in deciding what measures can be taken to reduce the possibility that debris and sediment, from a landslide in Manti Creek , will cause excessive flooding or interfere with the water supply to the town of Manti, Utah.

A final report to be based on continued monitoring of inclinometers in the North Slide and associated survey points installed during this study, will be submitted to the Forest Service on or before January 1, 1977.

1.2 AUTHORITY

The engineering services were authorized by the U.S. Forest Service Intermountain Region, Ogden, Utah, and performed by Caldwell, Richards and Sorensen, Inc. (CRS) of Salt Lake City, Utah, and International Engineering Company, Inc. (IECO) of San Francisco, California, under a contract dated May 6, 1976. CRS/IECO subcontracted the exploration drilling and sampling to Boyles Brothers Drilling Company of Salt Lake City, Utah, and some of the laboratory testing to Chen and Associates of Denver, Colorado.

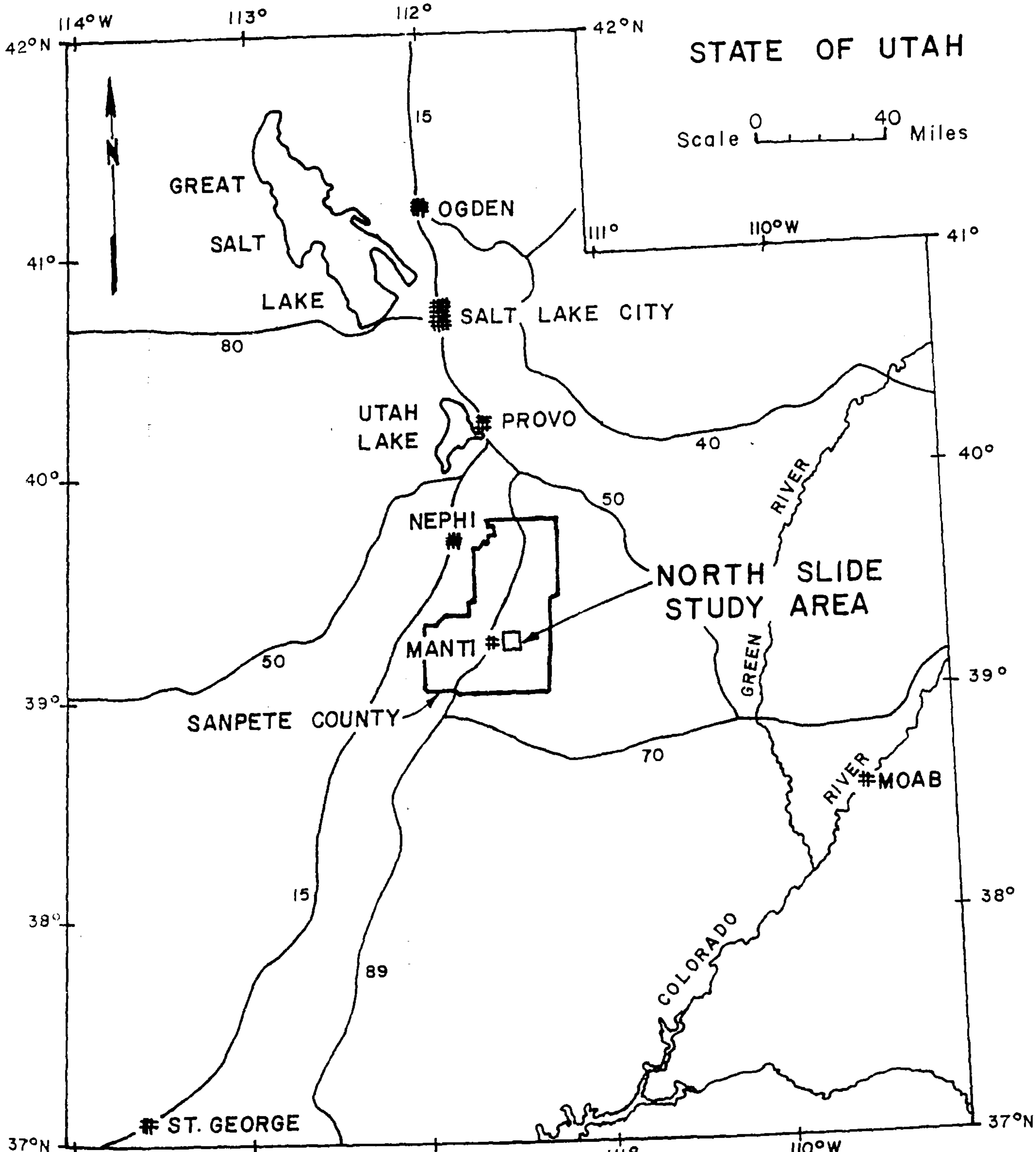

FIGURE 1-1—LOCATION OF THE NORTH SLIDE STUDY AREA

1.3 SCOPE OF WORK

The scope of work, as outlined in the contract with the Forest Service, includes the following services:

- Stability analyses of the North Slide.
- Foundation analysis of the debris-retention damsite for an 80-foot-high dam.
- Seismic survey of the North Slide and proposed debris-retention dam.
- Drilling and sampling at the North Slide and the debris-retention damsite.
- Soil testing.
- Geologic mapping of the North Slide and the debris-retention damsite.
- Installation of inclinometer casing in four drill holes and periodic monitoring of landslide deformation, if any.
- Surface survey controls to monitor ground movement, if any.

1.4 BACKGROUND

The town of Manti receives much of its water supply for irrigation, power generation and domestic use from Manti Creek and from mountain springs via a pipeline. In May 1974 this pipeline was severed by movement of a landslide on the south side of Manti Canyon (known as the Cottonwood Landflow and referred to herein as the South Slide). Subsequent movement of the ground hampered repair of the pipeline and led to its being rerouted along a new alignment on the north side of the Manti Canyon. However, this new alignment, along with the alignment of the proposed Manti Creek by-pass pipeline, crosses the toe of the North Slide, the stability of which was unknown prior to the CRS/IECO studies.

Drilling for the CRS/IECO studies began on May 19, 1976, to obtain the required data and prepare an interim geotechnical report for the Forest Service to be submitted by September 3, 1976.

1.5 ACKNOWLEDGMENTS

The CRS/IECO team appreciates the assistance received from the U.S. Forest Service Intermountain Region personnel, particularly Mr. Eugene D. Hansen, Regional Materials Engineer and Messrs. Darius Coker, Ted Wood and John Riley who worked under his direction. Also, the assistance given by Mr. Dick Allred, District Ranger of the Sanpete Ranger District, Manti-LaSal National Forest, is greatly appreciated.

The extra efforts provided by Mr. Ray Fraser of Boyles Bros. Drilling Co., and his drill crews also greatly aided in completing drilling, sampling and installation of inclinometers under difficult drilling conditions.

CHAPTER 2

NORTH SLIDE AND BY-PASS PIPELINE ALIGNMENT

2.1 EXPLORATION AND SURVEYS

Exploration and surveys conducted for the Forest Service during stability studies for the North Slide consisted of: establishment of survey ground control points and precise measurement of ground surface movement at various locations on the North Slide; drilling of deep boreholes for delineation of depth of the slide mass; soil sampling; and seismic surveys for determination of depth to bedrock and physical characteristics within the slide mass.

A. Drilling, Casing Installation and Sampling

The original plan envisioned the drilling of four exploratory holes on the North Slide and the installation of inclinometer casing in each of these holes. However, because extremely difficult conditions were encountered in the drilling and casing installation, inclinometer casing was installed in only one of the exploratory holes (DH-2), and three additional holes (DH-1A, DH-3A and DH-4A) were drilled adjacent to exploratory holes DH-1, DH-3 and DH-4, for installation of inclinometer casing (see Exhibit 2).

The first hole to be drilled was DH-2. The drilling contractor used a Joy 44 core drill and advanced the hole with 4-inch casing, using either a diamond casing bit alone or a diamond casing bit together with a rock bit. The rock bit was specially designed so that it could either be lowered into the casing to assist in hole advancement by drilling slightly ahead of the casing or be removed to permit drilling with the diamond casing bit only. Inclinometer casing was placed inside the 4-inch casing in DH-2 when the target depth was reached. The Joy 44 was also used to drill exploratory holes DH-1, DH-3 and DH-4, but a Failing 1500, a much larger drill was used to expedite drilling and casing installation in inclinometer holes DH-1A, DH-3A and DH-4A.

The inclinometer casing used consists of aluminum pipe with a nominal outside diameter of 3.4 inches and slots on four sides. It is manufactured in 10-foot-long segments, which are connected with 12-inch aluminum couplers. During installation, the casing is positioned so that opposite slots are in the north-south and east-west directions, respectively. The casing is seated by washing fine sand down the hole with water until the space between it and the soil is completely filled and it is held firmly in position.

Table 2-1 shows the depth of inclinometer casing in drill holes on the North Slide.

Table 2-1
INCLINOMETER CASING DEPTH

Inclinometer Drill Hole	Inclinometer Casing Depth (feet)
DH-1A	231.7
DH-2*	325.0
DH-3A	301.5
DH-4A	150.5
Total	1008.7

Soil samples were taken in each exploratory hole with a 2-1/2 inch-diameter Shelby tube and a 2-inch-diameter split spoon sampler, which is used to obtain samples for standard penetration tests. The original plan was to obtain a Shelby tube or split spoon sample every 5 feet. However, due to the bouldery nature and stiffness of the deposits encountered in the exploratory holes, the Shelby tube and split spoon sampling program was only partially successful. Fortunately, the drilling contractor found it advantageous to core continuously with an Nc wire-line core barrel and diamond bit. Thus, sufficient samples were obtained for laboratory testing,

* DH-2 was utilized for both installation of inclinometer casing and geologic exploration.

and the core provided excellent information regarding the materials within the North SLide mass. Table 2-2 shows the depth and number of samples taken in each of the exploratory holes.

Table 2-2
EXPLORATORY DRILL HOLE DEPTHS
AND NUMBER OF SAMPLES TAKEN

Exploratory Drill Hole	Depth (feet)	Number of Samples Taken	
		Shelby Tube	Split Spoon
DH-1	232.9	-	18
DH-2*	328.0	4	35
DH-3	350.0	2	18
DH-4	150.5	-	5
Total	1061.4		

Each of the exploratory drill holes was logged by an engineering geologist. Summaries of the drill logs are included in Appendix A.

B. Laboratory Testing

Forty-five samples were selected for laboratory testing from the Shelby tube, split spoon and drill core (see Table 2-3). The following tests were performed to determine soil properties and strength parameters:

- Sieve Analysis
- Hydrometer
- Liquid Limit
- Plastic Limit
- Plastic Index
- Moisture Content
- Specific Gravity
- Clay Mineralogy
- Triaxial Compression
- Direct Shear
- Unit Weight
- Consolidation

* DH-2 was utilized for both geologic exploration and installation of inclinometer casing.

Table 2-3

SOILS SAMPLES FOR LABORATORY TESTING

Exploratory Drill Hole	Sample Number	Sample Type	Depth (feet)	Length (feet)
DH-1	2	Nc Core	36.5 to 37.8	1.3
	4	2" Split Spoon	50.8 to 52.2	1.4
	5	Nc Core	53.9 to 55.7	1.8
	6	Nc Core	57.2 to 58.7	1.5
	12	Nc Core	83.5 to 84.7	1.2
	13	2" Split Spoon	90.8 to 92.1	1.1
	17	Nc Core	131.4 to 132.4	1.0
	20	Nc Core	147.2 to 149.0	1.8
	24	Nc Core	203.8 to 205.4	1.6
	25	Nc Core	210.7 to 212.1	1.4
DH-2	1	1-7/8" Split Spoon	21.5 to 22.5	1.0
	2	Shelby Tube	29.5 to 30.0	1.0
	3	1-7/8" Split Spoon	36.1 to 37.4	1.3
	7	1-7/8" Split Spoon	58.0 to 58.5	0.5
	11	Nc Core	76.8 to 78.1	1.5
	14	Nc Core	88.0 to 89.0	1.0
	17	Nc Core	102.5 to 103.8	1.3
	20	Nc COre	113.2 to 114.3	1.1
	23	Nc Core	126.2 to 127.2	1.0
	25	Nc Core	134.1 to 135.0	0.9
	29	Nc Core	153.0 to 154.2	1.2
	32	Nc Core	164.7 to 165.7	1.0
	38	Nc Core	187.0 to 187.9	0.9
	42	Nc Core	218.6 to 219.3	0.7
	44	Nc Core	232.0 to 233.0	1.0
	45	Nc Core	248.4 to 249.4	1.0
DH-3	5	2" Split Spoon	55.5 to 56.5	1.0
	6	Nc Core	76.5 to 78.0	1.5
	11	Nc Core	139.0 to 140.0	1.0
	13	Nc Core	184.5 to 185.6	1.1
	18	Nc Core	205.0 to 206.3	1.3
	19	Nc Core	224.7 to 226.6	1.9
	21	Nc Core	245.5 to 246.8	1.4
	23	Nc Core	279.2 to 280.4	1.2
	24	Nc Core	286.3 to 286.8	0.5
	27	Nc Core	324.0 to 325.2	1.2
	28	Nc Core	322.7 to 232.5	0.8
DH-4	3	Nc Core	48.9 to 49.5	1.0
	4	Nc Core	60.4 to 61.6	1.2
	5	Nc Core	88.5 to 91.0	2.5
	7	Nc Core	107.5 to 108.5	1.0
	8	Nc Core	122.5 to 123.7	1.2
	9	Nc Core	136.2 to 137.1	0.9
	10	Nc Core	145.3 to 147.2	1.9
	11	2" Split Spoon	148.5 to 149.4	0.9

All soil tests were performed by CRS in Salt Lake City, except for the triaxial compression, direct shear and unit weight tests, which were performed by Chen and Associates in Denver, Colorado.

Values of material properties used in the different stability analyses, including angle of internal friction, density and cohesion, were selected on the basis of engineering-geologic judgment and the soil test results. Details regarding selection of material property values are discussed in Section 2.3A.

C. Seismic Surveys

Seismic surveys were conducted with sixteen lines which were shot on and near the North Slide, and one which was located near the downstream end of the by-pass pipeline alignment. An RS-4, 12 channel, SIE engineering seismograph was used by IECO for the seismic surveys.

The locations of the seismic lines are shown on Exhibit 2. As shown on Table 2-5, 13,415 linear feet of seismic lines were run in North Slide study area.

The seismic velocities obtained by the geophysical survey provided information regarding the bulk properties of the North Slide mass and depth to bedrock. Results of the surveys are shown on Exhibits 3, 4 and 5.

D. Surface Control Survey

To accurately determine the location and the elevation of the top of the four inclinometer drill holes on the North Slide, the CRS/IECO field investigation team selected two survey control points (A and B) on stable ground (see Exhibit 2). Permanent concrete monuments were constructed at these two points. The survey control was tied into U.S. Forest Service control points T-8 and T-9.

Initial readings of the location and elevation of the control points and the inclinometer holes (to the nearest 0.001 foot) were made on June 30, 1976. These readings are shown in Table 2-4.

Table 2-4
SURFACE SURVEY DATA - INITIAL READINGS (June 30, 1976)

Site	Coordinates		Elevation (feet)
Point A	N 339,280.800	E 1,983,961.671	7,866.597
Point B	N 338,087.429	E 1,985,335.999	7,651.375
DH-1A	N 336,817.278	E 1,982,552.845	7,005.558
DH-2	N 336,986.210	E 1,983,521.800	7,166.407
DH-3A	N 337,242.076	E 1,984,014.991	7,272.657
DH-4A	N 337,774.585	E 1,984,184.431	7,361.282

After the initial readings in June, the inclinometer holes were surveyed about every 2 weeks, using a surveying method that conformed to the specifications for Second Order Class II horizontal control.

E. Inclinometer Surveys

Inclinometer surveys are being made to determine whether the North Slide mass is moving and, if so, at what depth, rate and in what direction. A biaxial Mini Probe Inclinometer, manufactured by Terra Technology Corporation, Seattle, Washington, is being used for this purpose. This inclinometer consists of a 1-inch-diameter, 2-foot-long probe and a digital readout unit capable of recording horizontal deflections in the inclinometer casing to the nearest thousandth of an inch. The probe has wheels that fit into the slots in the inclinometer casing, and its axes (A and B) are perpendicular to each other in the horizontal plane.

Two sets of readings are taken at 2-foot intervals from the top to the bottom of each hole each time the holes are surveyed. In both sets of readings, the A axis of the probe is lined up with the north-south slots in the inclinometer casing, but before the second set of readings is taken, the probe is rotated 180^{0}. Data from the two sets of readings are then averaged, by computer, to provide the amount of deflection and the direction of movement at each measurement point.

The inclinometer holes were surveyed every 2 weeks between June and August, 1976. The results of the surveys are discussed in Section 2.3. Additional inclinometer and surface surveys will be made once a month from September through December, 1976. The results of the readings to be made between September and December will be included in the final report.

2.2 GEOLOGY

The regional geology, geohydrology and seismicity of the Manti Canyon area have been studied to help in evaluating the stability of the North Slide and the bypass pipeline alignment. Observations have also been made of the South Slide to obtain a better understanding of possible modes of instability in the Manti Canyon area.

A. Regional Geology and Seismicity

Manti Canyon is located near the western margin of the Wasatch Plateau, in an area known as the Wasatch Monocline (see Figure 2-1). Tertiary formations in Manti Canyon dip west into Sanpete Valley, an elongated trough filled with Quaternary sediments; there, the Tertiary formations disappear beneath the valley fill, which is more than 500 feet deep.

The oldest exposed bedrock in the Manti Canyon area, and also throughout most of the Wasatch Monocline, is the Late Cretaceous or Early Tertiary North Horn Formation. Deposition of the interbedded siltstones and sandstones of the North Horn Formation occurred continuously from the Cretaceous period into Paleocene time. The formation is comprised primarily of interbedded sandstone, shale and siltstone and ranges from 300-400 feet thick. In Manti Canyon the North Horn Formation dips northwest 10^{0} to 20^{0} and crops out on the canyon walls.

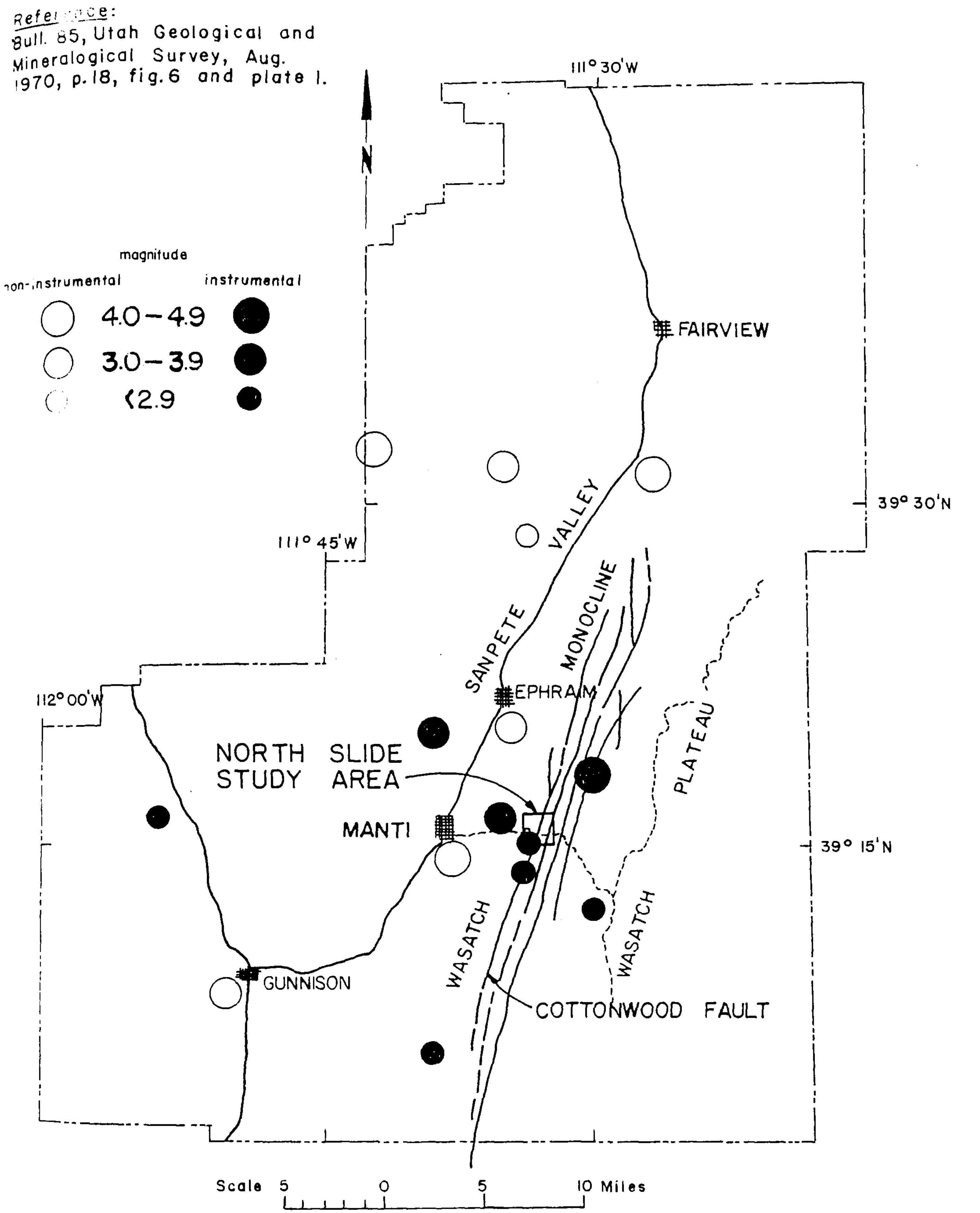

FIGURE 2-1 — EARTHQUAKE EPICENTERS IN SANPETE COUNTY, 1850-1964 AND MAJOR FAULTS ON AND ADJACENT TO STUDY AREA

Many of the massive landslides in Utah are on slopes underlain by North Horn Formation materials which contain numerous montmorillonite beds to make the formation prone to sliding.

The north rim of Manti Canyon is a near-vertical outcrop of Flagstaff Limestone. The Flagstaff Limestone was deposited in Upper Paleocene time in freshwater lakes that formed in the Manti area, and lies conformably on the North Horn Formation.

During the ice age many of the valleys in Utah, including Manti Canyon, contained glaciers. Much of the valley floor and slopes of Manti Canyon are covered by glacial till. Terminal moraines have been identified in Manti Canyon (see Exhibit 1).

The Wasatch Monocline was broken by major north-south trending, near-vertical, normal faults before and during the ice age (see Figure 2-1 and Exhibit 1). These faults strike from north-south to N20^{o}E and appear to cut some of the glacial till in Manti Canyon. The longitudinal blocks formed by the faulting have been variably uplifted and depressed, leading to the present sawtooth-like configuration on the canyon rims.

Faults that disturb deposits as geologically youthful as glacial till are considered active or potentially active since movement on them can rupture the ground surface and produce high-magnitude earthquakes.

Movement on the faults in the Manti Canyon area appears to have continued into Recent time, and some of them are probably still active. Six earthquakes have occurred in the Manti Canyon area between 1850 and 1964. Two of these earthquakes had magnitudes of between 4.0 and 5.0 on the Richter scale, and several others had magnitudes of 3.0 or less. Two of the earthquakes with magnitudes of 3.0 or less occurred on the Cottonwood Fault, which passes directly through the study area (see Figure 2-1).

There is geologic evidence of numerous landslides in Manti Canyon. Some are deep-seated, and others exhibit the characteristics of shallow soil creep. Factors that have led to landslide activity in the canyon include: the glaciation of the canyon, local seismicity, active faulting, annual precipitation, ground water introduced into glacial till through faults, strength of saturated materials, mineralogy and specific sliding planes. Some of the landslides in Manti Canyon are still active. The most striking example of present-day landslide activity is the massive South Slide.

To understand the mechanism and modes of landslide activity in Manti Canyon, which led to failure of the South Slide and others, it is necessary to understand the glacial history of the canyon. The canyon was extensively glaciated during Pleistocene and Recent time. The glaciation ended about 8000 to 10,000 years ago, leaving remnants (till) covering most of the canyon slopes to depths of up to 300 to 400 feet.

The South Slide mass is composed of glacial till. Initial movement of the slide mass was probably caused by deep erosion of a terminal moraine that once filled the channel of Manti Creek near the toe area of the slide.

Erosion led to breaching of the natural dam formed by this moraine and ultimately to removal of toe support of the south slope, which was probably already incipiently unstable, due to high pore pressures and low shear strength of saturated glacial till. In addition, a potential failure plane probably exists on montmorillonite shale beds of the North Horn Formation immediately under the glacial till. The shale beds dip toward the canyon in the direction of slide movement. Earthquake activity also may have been one of the triggering mechanisms of movement of the massive South Slide.

The South Slide has been reactivated numerous times in the geologic past. The reasons for initial movement and reactivation are related to the very delicate natural balance between all of the geologic factors mentioned above. More detailed discussion regarding landslide failure modes and mechanisms is presented in Sections 2.2.B and 2.3.

B. North Slide Geology

The portion of the study area designated as the North Slide is shown on Exhibits 1 and 2. The North Slide is comprised of glacial till which is up to 334 feet thick in DH-3. Seismic data show that the till may be as deep as 350 feet in the area around DH-4. The till material overlies clay shale and sandstone beds of the North Horn Formation which dip 10 to 12 degrees to the northwest and strike between N 40 to 50^{o}E. Cross sections of the North Slide are shown on Exhibits 3, 4 and 5.

Seismic surveys across the North Slide have delineated two and in places three layers or zones in the glacial till (see Exhibits 3, 4 and 5). The upper layer is from 10 to 80 feet deep and has a seismic velocity between 1300 to 2500 feet per second. Between the upper layer and bedrock of the North Horn Formation the glacial till has a seismic velocity of between 4800 and 8800 feet per second. The seismic velocity of the North Horn Formation is between 9500 to 14,300 feet per second. (See Table 2-5).

The material in the upper 10 to 80 feet is loose silty gravel with some sand and clay. Drilling conditions were poor in the upper layer with considerable caving of the drill holes and loss of drilling fluids. Low seismic velocities confirm the looseness of this upper layer.

The glacial till between the upper layer and bedrock which was encountered in each of the four exploratory drill holes consists of dense clayey sandy gravels. These gravels are primarily subangular to subrounded fragments of sandstone and limestone with some fragments of shale (see Photo 2). The rock fragments are hard, and most are fresh, but some of them are slightly iron stained. They are contained in a matrix of very stiff slightly moist sandy clay, most of which is either brown or gray. The difference in color of the different parts of the till matrix may be due to changes in height in the groundwater table during periods of glaciation in the geologic past. The brown color resulted from oxidation of the till above the groundwater table and the gray till may have been predominantly below the groundwater table where reduction took place.

Table 2-5
NORTH SLIDE REFRACTION SURVEY
Glacial Till

Line No.	Length	1st Layer Velocity	2nd Layer Depth	2nd Layer Velocity	3rd Layer Depth	3rd Layer Velocity	Bedrock (North Horn Formation) Depth	Bedrock (North Horn Formation) Velocity
SL-1	600	1,300	11	3,500	61	7,200		
SL-2	650	1,800	29	4,500	74	6,900		
SL-3	650	1,300	23	6,000				
SL-03	900	1,300	20	6,400				
SL-4	1,650	2,500	31	6,300			215	9,500
SL-5	325	2,700	44	5,200				
SL-6	740	1,800	18	4,800	90	8,400		
SL-7	650	1,600	21	5,000			120	11,300
SL-8	375	1,100	10	2,500	54	7,500	120	**
SL-9	1,300	2,400	78	7,400			325	12,000
SL-10	1,300	2,400	30	5,100	111	7,600	350	12,000
SL-11	1,300	2,500	31	5,600	90	8,400	300	**
SL-12	325	1,000	10	4,300	42	7,900		
SL-13*								
SL-14*								
SL-15	325	1,500	10	3,000			80	14,300
SL-16	650	1,800	15	5,500			110	10,200
SL-17	1,300	2,400	48	6,100			198	9,900
SL-18	375	1,800	18	2,900	70	6,700		
Total	13,415							

NOTE: Length and depths in feet, velocities in feet per second.

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* Seismic lines at the proposed retention damsite.
** Sufficient data not available for velocity calculations

Glacial till beneath the upper layer appears to be overconsolidated in relation to the amount of load on the material at the present time. The weight of ice has consolidated the till to its present density, which averages 129.0 per cubic foot. The average range of blow counts per foot in the sandy clay was 80 to 100 blows per foot which also indicates high density.

The fine-grained materials in the glacial till are stiff at the natural moisture content but become plastic and weak with the addition of a small amount of water. Most of the fine-grained matrix is probably glacial rock flour.

Two samples of fine-grained matrix materials from each drill hole were selected for clay mineralogy studies. The results of these studies are shown on Tables 2-6, 2-7 and 2-8. The major minerals found in the samples, as shown on Table 2-6, are calcite, dolomite, quartz and montmorillonite. Small amounts of mica and kaolinite are also present.

Table 2-6
X-RAY DIFFRACTION
(Minerals in Bulk Material)

Sample		Major Minerals	Minor Minerals
DH-1	37.8 ft	calcite dolomite quartz	mica
DH-1	92 ft	calcite dolomite quartz montmorillonite	
DH-2	58 ft	calcite dolomite quartz	mica
DH-2	155 ft	calcite dolomite quartz	montmorillonite
DH-3	56.5 ft	calcite dolomite quartz	mica
DH-3	206 ft	calcite dolomite quartz montmorillonite	
DH-4	49 ft	calcite dolomite quartz	mica
DH-4	149 ft	calcite dolomite quartz montmorillonite	

Below the upper layer the minus two micron fraction of the silicate clay minerals are composed of up to 93% montmorillonite (see Table 2-7). Silicate clay minerals in the upper layer contain no montmorillonite (see Table 2-7). The reason for the lack of montmorillonite in the upper layer is not clear but might be related to the various stages of glaciation in Manti Canyon. Glacial till in the upper layer may have been deposited by the last stage of glaciation when the till under the last glacier was reworked by glacial processes. The very fine-grained minus two micron materials may have been removed by melt waters from the receding glacier at the end of the ice age. The removal of glacial flour; which contains very fine-grained colloidal materials, from glacial deposits is a well known process and is taking place today on Milk Creek and Cottonwood Creek.

Table 2-7
X-RAY DIFFRACTION
(Minus 2 Micron Size Silicate Clays)

Sample		Silicate Clay Minerals			Others
		Montmorillonite	Mica	Kaolinite	Minerals
DH-1	37.8 ft	0	Trace	0	quartz calcite dolomite
DH-1	92.0 ft	93%	1%	6%	quartz
DH-2	58.0 ft	0	Trace	0	quartz calcite dolomite
DH-2	155.0 ft	86%	0	14%	quartz calcite dolomite
DH-3	56.5 ft	0	Trace	Trace	quartz calcite dolomite
DH-3	206.0 ft	66%	15%	19%	quartz
DH-4	49.0 ft	0	Trace	0	quartz calcite dolomite
DH-4	149.0 ft	93%	0	7%	quartz

The exchangeable cations in the fine-grained glacial flour matrix of the till, are presented on Table 2-8. As shown, the predominant minerals are calcium and magnesium and result from the grinding of dolomitic limestone fragments, which are abundant in the till, to fine-grained rock flour. These minerals probably provide the milky color to the water in Cottonwood Creek and Milk Creek (see Photos 3 and 4).

Table 2-8

Exchangeable Cations (Milliequivalents Per 100 Grams Sample)

Sample	Sodium	Potassium	Calcium	Magnesium
DH-1 37.8 ft	1.2	1.3	10.7	9.8
DH-1 92 ft	5.4	1.2	30.0	24.9
DH-2 58 ft	0.9	2.7	20.5	9.4
DH-2 155 ft	3.4	1.0	21.2	9.9
DH-3 56.5 ft	1.0	2.4	24.1	9.7
DH-3 206 ft	1.0	3.1	21.6	15.2
DH-4 49 ft	1.0	1.8	21.1	11.3
DH-4 149 ft	6.2	1.6	18.4	18.0

The average natural moisture content of the glacial till is 10.0%. No groundwater was found in the till during drilling of the exploratory holes. Drilling water losses in the upper loose layer in DH-2 and DH-3 were high, however.

Water level measurements made in the four inclinometer holes over the past two months show that very little water has drained away from the holes. Due to the impervious nature of the dense glacial till the water table may take a considerable amount of time to stabilize at its natural level. The depth to water in each hole is shown in Table 2-9 and is presented on Exhibits 3, 4 and 5.

Table 2-9

WATER LEVELS IN INCLINOMETER HOLES

Drill Hole	Depth - Feet June 25, 1976	Depth - Feet August 23, 1976
DH-1A	171.5	184.0
DH-2*	154.0	154.0
DH-3A	127,0	132.0
DH-4A	69.0	108.0

* Note that the water level in DH-2 has not changed. The sound of running water can be heard coming from the inclinometer casing in DH-2. Sandstone beds penetrated at a depth of 306 feet in DH-2 appear to be carrying groundwater under pressure possibly from the nearby Cottonwood Fault. When the sandstone layers were penetrated, the groundwater flowed up into the drill holes under artesian pressure.

Several springs have been found above elevation 7500 feet on the North Slide. These springs are shown in Exhibit 1. Small ponds are associated with some of the springs. Springs indicate that the glacial till on the North Slide above the 7500 foot elevation has a much higher permeability and moisture content than lower on the slope. Sources of the water include melting snow and artesian flow from fault zones beneath the glacial till. The water is probably stored in the upper layer of the North Slide mass which drilling and seismic information indicates is loose and contains numerous voids.

The effects of water in the upper part of the slide are apparent. Much of the ground surface above elevation 7500 feet shows visual evidence of soil creep or landflow. A small active landslide 400 feet east of DH-4 is the result of spring water seeping into the upper layer of till on the North Slide.

Several small shear zones and shear planes were noted in the drill core obtained from exploratory holes (see Drill Logs and Exhibits 3, 4 and 5). Photo 5 shows two shear planes at the depth of 75.0 feet in DH-2. The shear zones are characterized by dark gray and bluish gray sandy clay with natural moisture up to 23%, and numerous irregular discontinuous slickensided surfaces. Dip of the shear planes range from 16^{0} to 80^{0}. The shear zones result from local differential settlement and slumping during glaciation or slow plastic deformation similar to soil creep. Several dark gray clay shear zones can be seen in the bank of Manti Creek near DH-2. These zones are approximately 1 foot thick, irregular and discontinuous.

The bedrock penetrated in both DH-2 and 3 consists of interbedded sandstones, siltstones and some clay shale. In DH-2 the sandstone is stained light brown, is moderately hard and is cross bedded. Open joints which are iron stained indicate the presence of groundwater. The inferred bedrock profile which is based on drill hole and seismic data, is shown on geologic cross sections on Exhibits 3, 4 and 5.

Two major north-south trending faults have been mapped in the study area. The faults are shown on Exhibit 1 and are designated the Cottonwood and the North Slide Faults. The Cottonwood Fault passes under and possibly through the glacial till between DH-2 and DH-3 as shown on Exhibits 4 and 5. The North Fault passes through the slide at its upper limits. Periodic movment along the Cottonwood Fault may also have caused some of the movement within the glacial till which is represented by the shear zones found in the drill holes.

In summary, geologic studies of the North Slide have led to the following preliminary conclusions:

- Material comprising the North Slide mass is glacial till up to 350 feet deep.

- The till is underlain by sandstone shale and siltstone beds of the North Horn Formations. (The North Horn Formation contains montmorillonite shale beds and is associated with numerous landslides in Utah).

- Till of the North Slide is divided into at least two layers: an upper layer from 10 to 78 feet deep composed of loose silty gravelly till and a lower layer of dense, overconsolidated gravelly till in a matrix of stiff montmorillonite clay. The till matrix is primarily glacial rock flour which contributes the "milky" color turbidity to several streams that flow into Manti Creek.

- Visual evidence of soil creep or land flow in the upper layer is present above elevation 7500 feet on the North Slide surface where numerous tension cracks, springs, ponds and irregular hummocky topographic features were observed.

- Core samples of shear zones in the dense glacial till were obtained from exploratory holes drilled on the North Slide. Shear zones are the result of deformation of the till by ice action during the glacial period, plastic deformation by slow, deep seated, mass soil creep, and possibly shearing by fault movement on the Cottonwood Fault which extends under the North Slide.

- The study area is in a region which has a record of moderate seismic activity in historic times. Geologic evidence found during the study indicates that faults in the study area may be active and that high magnitude earthquakes can be expected in or close to the study area.

- The groundwater table within the North Slide mass has not stabilized at the time of this report. Water under artesian pressures were encountered in DH-2 from bedrock layers or gravelly alluvium immediately above bedrock.

- Inclinometer and surface surveys of the North Slide made between June and August, 1976 show the slide to be moving. Movement rate, direction and engineering significance is discussed in Section 2.3.D.

C. By-Pass Pipeline Alignment

A "by-pass" pipeline to divert Manti Creek from the present streambed around the toe of the South Slide is one alternative for mitigating the affect of the South Slide on Manti Creek. Length of the line would be about 7200 feet. The proposed alignment is shown on Exhibit 2.

The first 2000 feet of the pipeline from the intake structure, will be excavated in loose alluvial sandy gravel. Seismic data indicate the sandy gravel is approximately 10 feet thick with an average velocity of 1300 feet per second. Below 10 feet, the material is probably dense glacial till composed of clayey-sandy gravel. Seismic velocity of the lower zone is 3500 feet per second (fps).

Between 2000 feet downstream from the intake and the outlet end of the pipeline, excavation along the pipeline would be almost entirely in the glacial till. Most of the section would be within the boundaries of the North Slide which is described in the previous section. As shown in the previous section the pipeline would be excavated in the "upper layer" which is composed of loose silty gravel till containing some boulder size material. Geological evidence which is supported by instrumentation data from inclinometer surveys indicates the materials in which the pipeline would be excavated, are unstable.

Materials in the area of both the intake and outlet structures provide acceptable foundations for these relatively small structures. Excavation along the entire alignment can be accomplished by common excavation methods. A small amount of blasting might be required to remove local boulders.

2.3 STABILITY ANALYSES

Stability analyses were performed on four sections taken through the North Slide (see Figure 2-2). The selection of these sections was based on their

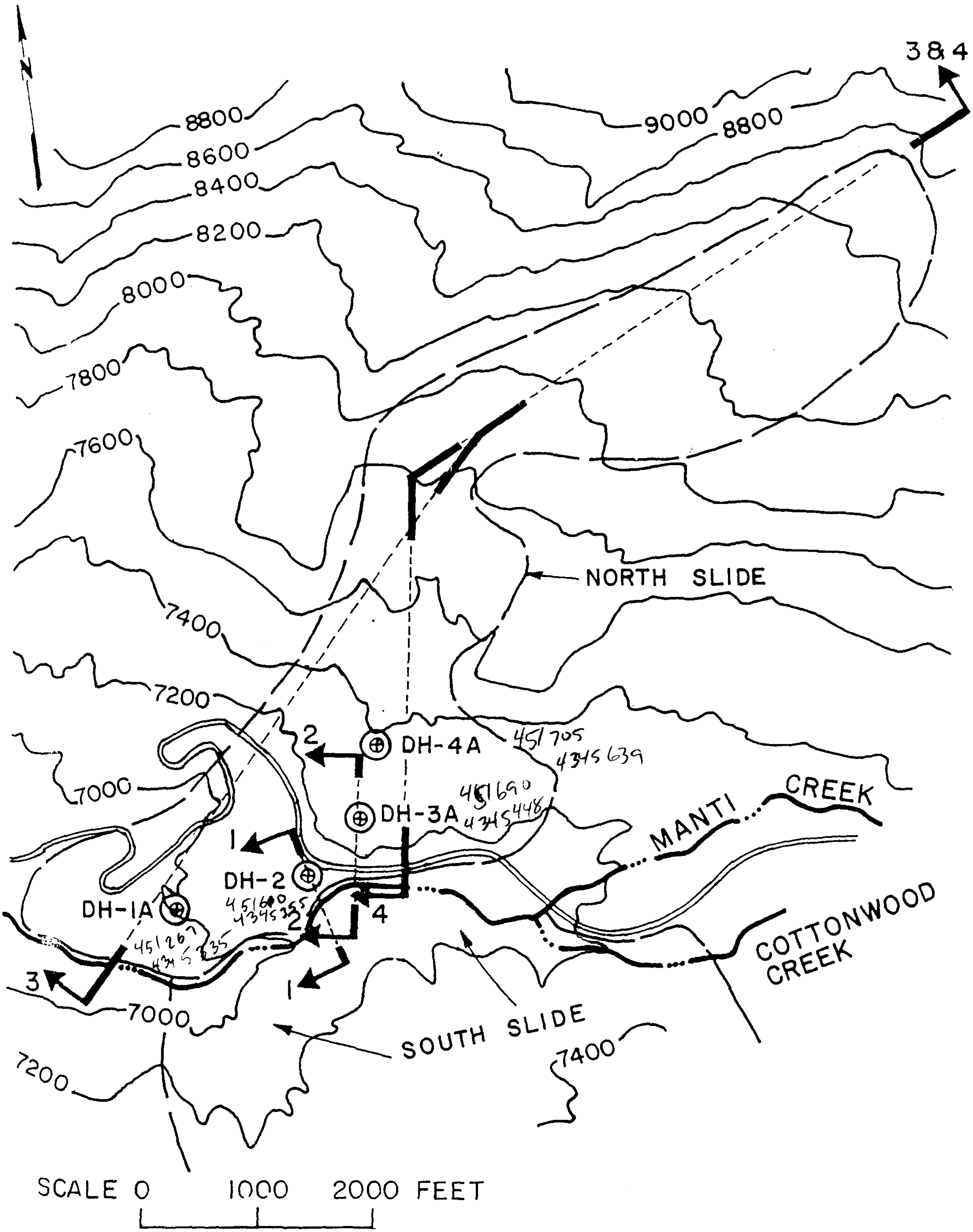


FIGURE 2-2 — LOCATION OF STABILITY ANALYSIS SECTIONS impact on the proposed by-pass pipeline if failure should occur. Two of the sections were analyzed by Bishop's method of slices for slip circle failure and two sections were analyzed by the planar slide stability method.

A. Selection of Soil Parameters for Stability Analyses

1. General - The soil strength parameters used for the stability analysis are the unit weight in pounds per cubic foot, the angle of internal friction of the soil in degrees and the cohesion of the soil in pounds per square foot. The influence of earthquakes was not considered in the analysis.

Because of the great variation in the materials that make up the soil strata within the North Slide, it was difficult to obtain individual soil samples from the drilling operations that were accurately representative of the in-situ condition. Slickensides on shear planes, large boulders and rocks intermixed with clay and sand contributed to the difficulty in selecting soil strength parameters directly from laboratory test results.

The selection of the soil parameters to be used in the stability analyses was based on visual observation of the materials, results of the test data and engineering judgment in which the total geologic framework was considered.

The accuracy of these values will be re-examined in the final report, by back analysis of the slope, using the more complete inclinometer data and final surface survey results.

2. Materials - Values for the in-place densities of the materials used in the analysis varied from 100 pcf to 135 pcf. Values for Section 1 ranged from 110 pcf to 120 pcf. In-place densities of materials in Section 2 vary from 130 pcf to 135 pcf.

3. <u>Strength Parameters</u> - Consolidated undrained triaxial compression and direct shear tests were run on selected samples. The specimens had diameters of from 2.2 to 2.4 inches. They were consolidated to pressures varying from 4.0 ksf to 14.4 ksf depending on the location and depth of sampling. The estimated values of the total strength parameters used in the analysis for each soil layer are shown on Exhibits 11, 12, 13 and 14. The test results are shown in Tables 2-10 and 2-11.

Table 2-10

SOIL CLASSIFICATION TEST DATA

Drill Hole	Sample No.	Depth Ft.	Liquid Limit	Plastic Limit	Plasticity Index	Natural Moisture %	Specific Gravity	Color	Unified Soil Classification
1	2	37.8	18.4	13.2	5.2	7.1	2.63	Brown	Silty Sandy Gravel (GM)
1	4	52.0	27.2	14.4	12.8	-	2.64	Gray	Gravelly Sandy Clay (GC)
1	13	92.0	42.9	24.0	18.9	19.9	2.45	Gray	Sandy Clay (CL)
1	25	212.0	23.1	13.8	9.3	9.3	2.69	Gray	Clayey Sandy Gravel (GC)
2	1	29.0	24.1	10.8	13.3			Gray	Gravelly Silty Sand (SM)
2	2	30.0				-		Gray	Clayey Sandy Gravel (GC)
2	3	37.0	31.0	12.9	18.1	-	2.74	Gray	Clayey Sandy Gravel (GC)
2	7	58.0	27.3	15.2	12.1	-	2.72	Lt.Brown	Gravelly Sandy Clay (CL)
2	11	78.0	22.0	13.9	8.1	6.1	2.67	Brown	Gravelly Sandy Clay (CL)
2	29	155.0	36.2	16.4	19.8	10.6	2.57	Brown	Gravelly Sandy Clay (CL)
3	5	56.5	18.7	12.8	5.9	8.3	2.67	Gray	Gravelly Sandy Silt (ML)
3	11	140.0	23.8	13.4	10.4	12.6	2.63	Brown	Clayey Sandy Gravel (GC)
3	19	226.6	22.0	13.3	8.7	7.1	2.55	Brown	Gravelly Sandy Clay (CL)
3	23	280.0	28.2	16.4	11.8	-	2.51	Gray	Gravelly Sandy Clay (CL)
4	3	49.0	29.2	16.7	12.5	8.4	2.62	Lt.Brown	Clayey Sandy Gravel (GC)
4	7	108.0	17.6	11.7	5.9	7.1	2.63	Brown	Gravelly Sandy Silt (ML)
4	11	149.0	49.2	25.8	23.4	22.9	2.38	Dk.Gray	Gravelly Sandy Clay (CL)

Table 2-11

STRENGTH PARAMETER TEST DATA

Drill Hole	Sample No.	Depth Ft.	Dry Density pcf	Water Content %	TRIAXIAL SHEAR TEST				DIRECT SHEAR TEST			
					σ_1 - ksf	σ_3-ksf	ø°	c-ksf	σ_n-ksf	τ-ksf	ø°	c-ksf
1	6	58.0	126.1	17.6					7.2	4.3		
1	6	58.0	126.1	17.6					10.8	4.9	13.0	1.5
1	6	58.0	126.1	17.6					3.6	2.5		
1	17	131.5	144.0	7.1	60.0	13.0						
1	20	148.0	122.3	12.3	21.9	13.0	5.0	3.2				
1	20	148.0	124.2	12.3	16.7	8.6						
1	24	204.0	119.5	17.8	43.0	13.0	22.0	1.2				
1	24	204.0	105.6	17.8	18.8	8.6						
2	2	29.0	107.0	12.5	1.0	0.53	18.0	0.5				
2	2	30.0	93.0	11.0	3.37	0.26						
2	3	75.0	135.3	5.3					12.0	13.4		
2	3	75.0	135.3	5.3					8.0	11.2	34.0	7.5
2	3	75.0	135.3	5.3					4.0	10.0		
2	32	164.7	106.2	19.0	19.9	14.4	4.0	1.70				
2	32	164.7	106.2	19.0	8.9	7.2						
2	25	135.0	125.7	13.2	52.0	14.4						
2	14	88.0	142.2	5.2	40.8	20.8	35.0	0.0				
2	14	89.0	148.6	5.2	24.7	7.0						
2	23	126.2	116.9	17.6	28.1	14.1						
2	20	113.2	143.9	6.5	20.8	10.3	12.5	2.2				
2	17	102.5	132.6	14.4	17.5	6.9						
2	44	232.0	137.1	9.5	25.7	14.4						
2	42	218.6	144.8	7.0	15.9	10.8	12.0	0.8				
2	45	248.4	133.3	9.6	11.7	7.2						
3	6	76.5	126.1	17.6					6.5	3.2		
3	6	76.5	126.1	17.6					14.0	6.4	15.0	1.7
3	6	76.5	126.1	17.6					17.2	5.7		
3	13	184.5	132.3	11.6	30.0	13.8						
3	28	322.7	120.3	14.4	25.6	12.8						
3	27	324.0	126.3	9.3	23.4	9.2	10.0	4.1				
3	27	324.0	132.8	9.3	20.[illegible]	4.5						
3	21	246.0	132.5	8.3	33.0	13.0	26.0	0.0				
4	4	60.4	135.0	7.5	47.4	8.6						
4	8	122.5	142.2	7.8	54.4	13.0						
4	9	136.2	138.8	7.9	36.6	8.6	32.0	2.2				
4	10	145.3	145.4	4.2	60.0	13.0						

B. Bishop Method for Slip Circle Analysis

1. Discussion of Method - This method of slope stability analysis was first described by Bishop in 1955 and is very similar to the Swedish Circle Method. The failure surface is assumed to be a circular section. The surface is actually a log-spiral curve but closely approximates a circular section. Two sets of forces are involved along the circular section; the driving forces and the resisting forces. The factor of safety against sliding is the ratio of the resisting forces to the sliding forces. The resisting forces are the cohesion of the soil along the failure surface and the normal component of the weight of the soil at the failure surface times the tangent of the angle of internal friction. The driving forces are the components of the weight of the soil that are tangential to the failure plane. Earthquake forces were not considered in the analyses for this interim report.

The analyses of the sections on the North Slide were done using an HP9830 computer. The cross-sections were drawn on a coordinate grid system using coordinate points and straight lines to define ground lines, soil lines and water tables. Using coordinate geometry the sections can be analyzed faster, with more accuracy and in greater detail than would be possible manually.

Two separate sections were chosen where localized slip circle failure might critically affect the foundation of the proposed by-pass pipeline. The two sections are presented as Sections 1 and 2, (see Exhibits 11 and 12).

The stability analyses of the sections were based on three separate conditions. First, the sections were analyzed as the slopes now exist. The sections were then analyzed assuming that the toe of the slope was undercut 20 feet by erosion of Manti Creek. This is highly probable because the streambed was reported to have been uplifted 80 feet by the recent activity of the South Slide and the stream will attempt to regain its original gradient by eroding back into the channel. Third, the sections were analyzed assuming the existing channel was filled to a depth of 20 feet with rockfill and gabions.

2. <u>Stability of Section 1</u> - Section 1 was chosen because of its steep bank slope and its high susceptibility to erosion and undercutting by Manti Creek (see Figure 2-2). A failure of this section would induce progressive failure up the slope and that would endanger the Forest Service access road and the proposed by-pass pipeline by erosion of toe support of the steep bank of Manti Creek (see Photo 6).

The critical factors of safety for the three assumed conditions of analyses are shown on Figure 2-3. The computed critical or minimum factor of safety for the existing condition (F.S. of 1.07) is very close to 1.0 and could be slightly below 1.0 since there is evidence of movement on the North Slide. It would be very desirable to have a higher factor of safety due to the numerous unknowns such as the in situ materials properties, earthquake possibilities and hydrologic conditions.

The factor of safety (F.S.) for the eroded condition is 0.87. This lower value is an indication that if the stream is eroded further, the rate of movement of the North Slide might accelerate to a critical rate at which destructive slope failure will take place.

The F.S. with the rockfill placed in the creek channel will improve the stability of the slope and stop further stream erosion. The critical factor of safety for this condition is 1.52 as the rockfill provides buttressing against local bank failure.

3. <u>Stability of Section 2</u> - Section 2 was chosen because the toe of the slope is being eroded by Manti Creek (see Photo 7). A failure in this section would remove the Forest Service road and the proposed by-pass pipeline and the City of Manti's water pipeline (see Exhibit 12).

The critical factors of safety for the three conditions of analyses are shown on Figure 2-4. The computed critical or minimum factor of safety for the existing condition (F.S. of 1.06) is very close to 1.0 and again, as in Section 1, the factor of safety could be slightly below 1.0.

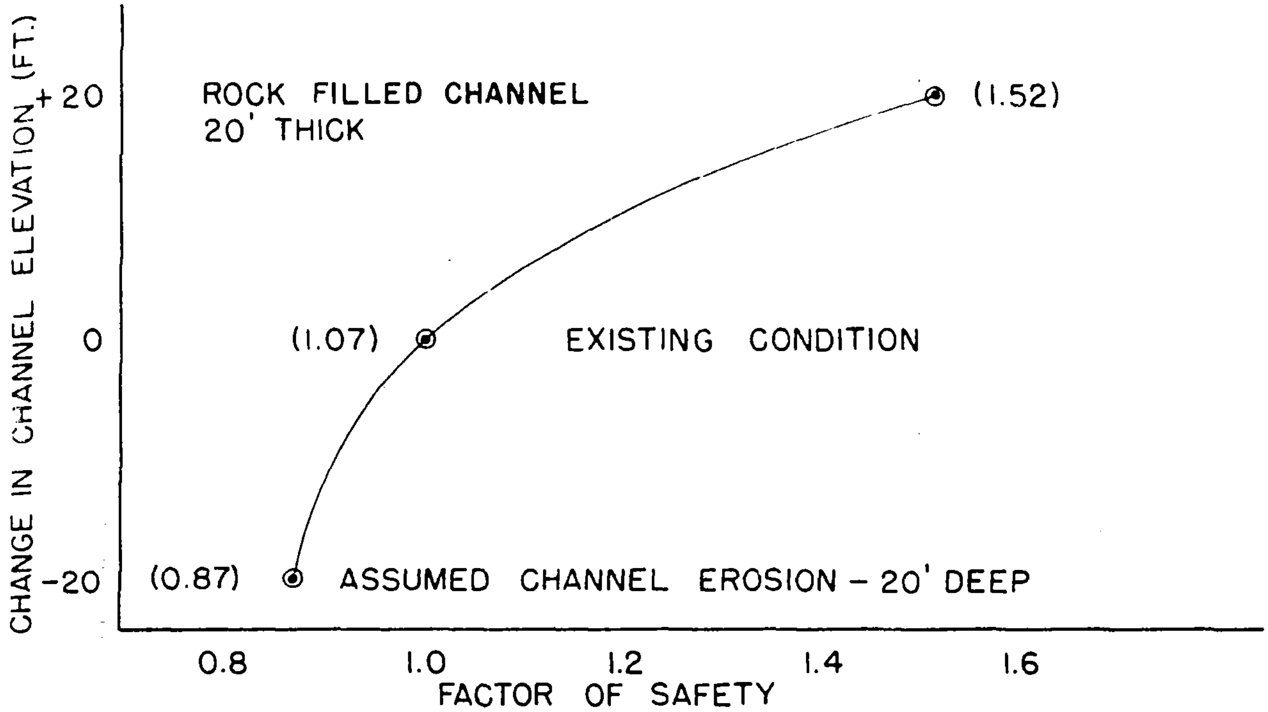


FIGURE 2-3 — FACTOR OF SAFETY OF NORTH SLIDE
BISHOP STABILITY ANALYSIS - SEC. 1

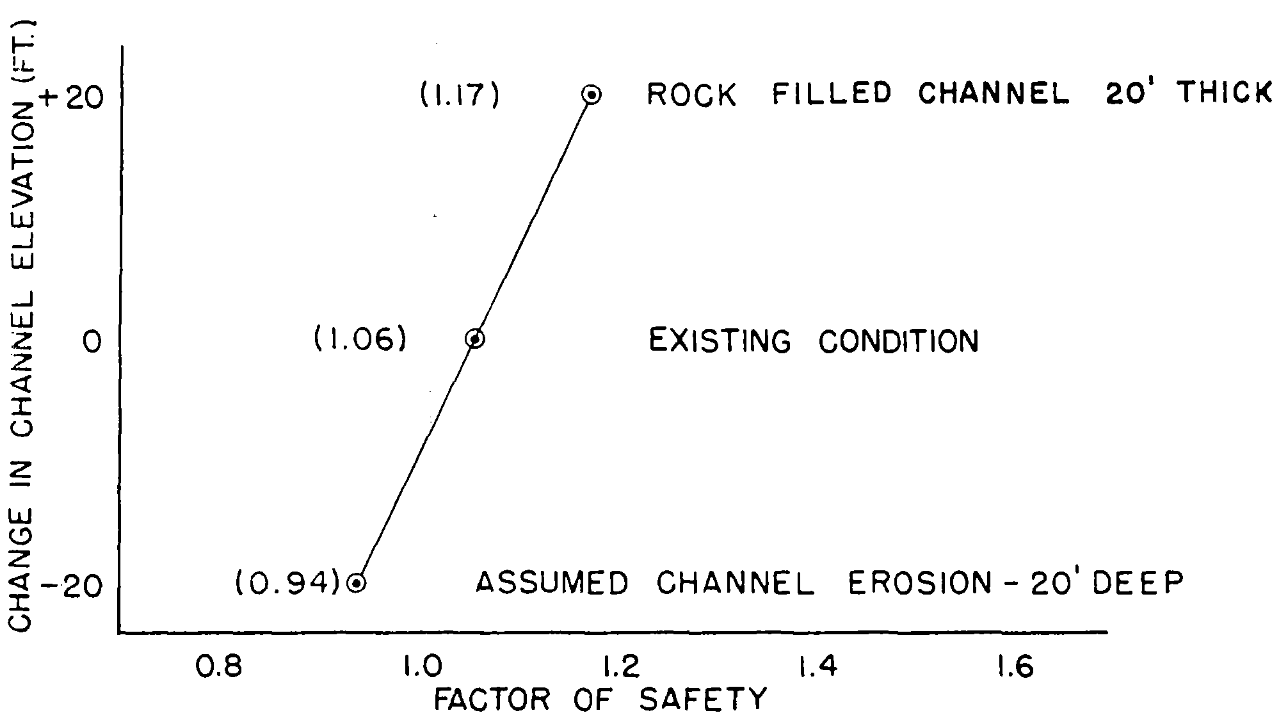


FIGURE 2-4 — FACTOR OF SAFETY OF NORTH SLIDE
BISHOP STABILITY ANALYSIS - SEC. 2

The factor of safety for the eroded channel in Section 2 is 0.94. This value indicates that further erosion of the channel would induce slip circle failure.

The filling of the channel to a depth of 20 feet with rockfill yields a factor of safety of 1.17. The rock lining does not affect the stability as greatly for this section as it did for Section 1 because the critical slip circle on Section 1 is very localized and shallow, while the slip circle for Section 2 extends much deeper and further upslope (see Exhibit 12). In addition the rockfill at the toe of the slope is a relatively small part of the total mass of material.

C. Planar Slide Stability Analysis

1. Discussion of Method - This method of stability analysis is very similar to the Bishop method of slices for slip circle analysis except that the failure surface is an irregular, planar surface rather than a circular surface. The driving forces and resisting forces discussed earlier remain the same as only the shape of the failure surface has changed.

Two sections were chosen to evaluate the overall stability of the North Slide mass (see Figure 2-2). These are Sections 3 and 4 (see Exhibits 13 and 14.)

2. Stability of Section 3 - Section 3 was chosen as it extends from the lower most point of the North Slide to the top of the slide. The failure plane is an approximation of a shear plane that was noted in DH-3 during field exploration.

The critical factor of safety against sliding for this section is 1.06 (see Exhibit 13). Any major shift in the stability equilibrium of the slide, created by an earthquake or rising water table, could cause a major failure in the North Slide.

3. <u>Stability of Section 4</u> - Section 4 begins at the base of the North Slide, but is located further upstream than Section 3 (see Figure 2-2). As with Section 3 the failure plane was approximated from shear zones observed during field exploration. This assumed failure plane extends from the toe of the slope in Manti Creek to the top of the slide.

The factor of safety against sliding for Section 4 is 1.14 (see Exhibit 14). Again this is quite low and as with Section 3 a small amount of additional loading by an earthquake would cause excessive movement if the basic assumptions are valid.

D. Discussion of Stability Analysis

The stability analyses made on the four sections show the North Slide has an existing factor of safety very close to one. Changes in the existing geologic hydrologic factors such as earthquake, erosion and elevation of the water table could cause a critical reduction in the safety factor.

An example of these geologic - hydrologic factors would be a year of heavy snow fall where the snow melt would cause the ground water table in the north slope to rise. The rise in the groundwater table would increase the pore water pressure in the materials and thus decrease the stability of the slope and increase the present rate of movement. Seismic loading on the slope would also tend to increase the pore pressures within the slide materials and could cause a further reduction in the factor of safety of the slope.

X-Ray diffraction analyses of the North Slide materials have shown that there is a very large percentage of montmorillonite clay in the fine portion of the materials. When the water content of the montmorillonite clays is increased, dispersion may decrease the soil strength and stability of the slope.

Since the existing channel is presently being eroded to lower levels, the rate of erosion could be increased by a series of high water periods. Erosion also would cause a decrease in the slope stability.

Placement of rockfill in the creek channel has been indicated as a possible means of improving stability (see Photos 8 and 9). This method has been successfully used by IECO for another project somewhat similar to Manti Creek. Numerous other methods for stabilization such as surface and subsurface drainage may also be appropriate.

E. Inclinometer and Survey Surface Data

Inclinometer and surface surveys of inclinometer hole casings show ground deformation at all four installations. The results of surface survey points and deep inclinometer readings are shown on Exhibits 7, 8, 9 and 10 for the period between June and August, 1976. Surface survey results are shown on Table 2-12.

Table 2-12
RESULTS OF SURFACE SURVEYS
June 30 - August 10, 1976

Inclinometer Hole	Vertical Movement (inches)	Vertical Rate (in/yr.)	Horizontal Movement (inches)	Horizontal Rate (in/yr.)	Horizontal Direction (degrees)
1A	-1.080	-9.612	1.464	13.034	232.7
2	0.312	2.778	0.499	4.446	215.2
3A	0.528	4.700	0.475	4.226	196.1
4A	0.648	5.769	0.414	3.690	157.9

Surface surveys show horizontal movement in a southwest or downslope direction on the North Slide. The direction of the vertical movement is positive or up, at inclinometer holes DH-2, 3A, and 4A. The vertical component of surface movement at DH-1A is down. Magnitude of movement ranges from 0.3 to 1.1 inches.

Deflections measured in inclinometer holes, at depth, are in the same order of magnitude (see Exhibits 7, 8, 9 and 10). However, conclusions regarding the direction, the North Slide, must await additional information from surveys to be made between September and December, 1976.

A review of the initial readings of the data indicates that no well defined shear planes exist in the inclinometer holes except for possible planes at depths of 198 feet and 213 feet in DH-1A. Therefore, the North Slide may be experiencing slow plastic deformation due to downslope gravity movement.

The deformation may also result from pressure exerted by the massive South Slide against the toe of the North Slide on a deep seated plane of movement. The upward and generally southward movement of the surface survey points on the North Slide resembles the displacement which would be expected for bulging of the toe of a landslide with an active, deep seated slide plane moving from south to north.

CHAPTER 3

DEBRIS-RETENTION DAMSITE

3.1 EXPLORATION AND SURVEYS

The CRS/IECO contract with the Forest Service included foundation analysis for an 80-foot high earthen dam on Manti Creek to serve as a debris and settling basin. The site was selected by the Forest Service and is located approximately 1.5 miles upstream from the mouth of Manti Creek (Exhibit 1).

Originally another site, 750 feet downstream, was to be investigated for a 40-foot high earthfill dam. The site discussed in this report was selected during the field investigation. Geophysical surveys were made at both sites. Geologic mapping, drilling, sampling and testing were all done at the upstream location.

A. Drilling and Sampling

Two drill holes were originally planned at the downstream site. Each hole was limited by the contract to a depth of 40 feet. Forest Service and IECO personnel agreed during field investigations that one hole would be drilled on the right abutment of the upstream site to a maximum depth of 100 feet. The purpose of one hole to a greater depth was to ensure that bedrock would be penetrated by at least one hole in order to develop a bedrock profile together with surface geology and geophysical information.

Bedrock was encountered at a depth of 57.5 feet. The materials penetrated above bedrock consisted of rocky slopewash. Six attempts were made to obtain penetration test and Shelby tube samples in the rocky slopeswash. Attempts at soil sampling were only partially successful. The hole was completed in bedrock at a depth of 70 feet.

Drill water circulation was lost at 30 feet. After the hole was cased it was still difficult to maintain water circulation below 30 feet. Permeability tests were performed according to USBR Earth Manual Standard Specifications E-18; Field Permeability Tests in Bore Holes. Open end gravity tests were made in slopewash. A pressure test was made in bedrock. The permeability measured at various depths in the bore holes are as follows:

Table 3-1

DEBRIS-RETENTION DAM SITE FOUNDATION PERMEABILITY

Depth (ft)	Material Type	Permeability (cm/sec)
34	Sandy gravel slope wash	3.48×10^{-2}
57	Sandy gravel slope wash	1.46×10^{-4}
57-70	Fractured sandstone bedrock	5.16×10^{-5}

B. Laboratory Testing

Modified consolidation tests were made on two samples for analysis of dam settlement. Samples from DH-5 were screened through a No. 4 sieve and consolidated to pressures corresponding to a 40-foot and 80-foot high dam. The samples were then saturated and allowed to consolidate before completing the settlement curve.

C. Seismic Surveys

Two seismic lines (650 ft. of line) were made by IECO at the downstream site (see Exhibit 6). These lines were run prior to selection of the damsite which is discussed in this report. Following selection of the upper damsite for investigation, Forest Service personnel made a seismic survey (110 feet of line) at the site utilizing a single geophone Bison seismograph (see Exhibit 6). Results of both seismic surveys were used in interpretation of geologic features at the site.

3.2 GEOLOGY

The results of geologic mapping, drilling and seismic surveys in the area of the debris detention damsite are presented on Exhibits 5 and 6.

A. Right Abutment

The right abutment of the debris detention damsite is underlain by unconsolidated rocky slopewash and alluvium which ranges from 10 to 57.7 thick. The slopewash and alluvium is underlain by weak siltstone and shale of the North Horn Formation. The siltstone is gray to bluish gray and the shale is light brown. The siltstone and shale is interbedded with light reddish brown, medium to coarse-grained, cross-bedded sandstone which crops out on the right abutment, approximately 100 feet in elevation above the proposed dam crest. Surface outcrops of sandstone and siltstone above the dam crest and presumably beds under the damsite strike N. 50^{o} E and dip 15^{o} NW or into the abutment.

Two major joint sets were observed on outcrops. One set strikes N 5^{o} E and dips 70^{o} southeast. The other strikes N 80^{o} W and dips 80^{o} southwest. The joints are spaced from two to eight feet apart. One major joint set is parallel to the major north-south faults that have been mapped in Manti Canyon. However, no evidence of faulting was found in the damsite area. Also no springs were noted on the right abutment.

B. Channel Section

Geophysical surveys show alluvial deposits in the channel section to be at least 25 feet deep. The alluvium is comprised of unconsolidated silty gravels with a high percentage of gravel and rounded cobble sized materials. Due to the bouldery nature of the material a seismic velocity of 8,000 feet per second was obtained above the groundwater table. Geologic projections from DH-5 indicate that the alluvium is underlain by sandstone beds of the North Horn Formation. Seismic velocity of the sandstone is 14,000 feet per second (see Exhibit 5).

C. Left Abutment

No outcrops of bedrock were found on the left abutment. It is estimated that at least 50 feet of loose slopewash or glacial till which contains some limestone boulders up to 20 feet in diameter, covers bedrock on the left abutment. No springs or evidence of faulting was found in the abutment area. Natural slope of the left abutment is steep, probably in the order of 1:1.

3.3 FOUNDATION EVALUATION

A. Stability

Instability can be expected on the left abutment after saturation of the abutments during reservoir filling. Weak siltstone and mudstone beds, which underlie the slopewash, dip toward Manti Creek at 17 to 19 degrees and are potentially unstable. Glacial till and slopewash on the steep left abutment probably contain montmorillonite clays and will be susceptible to slope failure after saturation.

B. Settlement

As stated in the previous section on Laboratory Testing, two consolidation tests were performed on the minus #4 sieve size material from split spoon samples taken in DH-5. It was necessary to use disturbed samples for consolidation as undisturbed samples could not be obtained from the coarse sandy and gravelly slopewash materials encountered. Therefore the consolidation tests did not represent true field conditions.

Past experience in similar materials indicates that foundation settlement of three inches may be expected under an 80-foot high embankment at the site which was studied. Most foundation consolidation would take place during construction followed by limited long-term settlement.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 NORTH SLIDE AND BY-PASS PIPELINE ALIGNMENT

One main objective of the interim geotechnical report was to determine the stability of the North Slide mass and the geotechnical feasibility of constructing a by-pass pipeline across the slide for diversion of Manti Creek around the toe of both the North and South Slides. A concentrated field exploration and office analysis effort has permitted the CRS/IECO team to make preliminary conclusions regarding stability of the North Slide and offer possible recommendations for mitigating landslide and erosion hazard on Manti Creek.

It is expected that additional data to be collected between September and the end of 1976 will modify but not materially change the conclusions.

A. Conclusions

It is concluded that sufficient geological, surface survey and instrumentation data have been obtained in the interim study period, to show the North Slide is incipiently unstable. The slope appears to be in a state of delicate equilibrium with the natural geologic phenomena such as groundwater level, soil strength and natural slopes. Stability analyses and indication of slope deformation from surface and inclinometer surveys show that other geologic-hydrologic factors such as earthquake and erosion or rising of the groundwater table, alone or combined, could upset the delicate natural equilibrium and trigger large scale movement of the North Slide.

B. Recommendations

It is recommended that a by-pass pipeline not be considered as a viable permanent solution for mitigating sedimentation erosion and landslide problems on Manti Creek. One possible alternative, of several, is control of Manti Creek streambed erosion in the critical toe areas of the North and South Slides. Erosion control might be implemented by rockfill-gabion structures as shown on Photos 8 and 9.

4.2 DEBRIS-RETENTION DAMSITE

The second objective of the report was to study the foundations of an 80-foot high debris damsite selected by the Forest Service. Limited field data were obtained from the investigation but the data obtained are sufficient for a reconnaissance geologic evaluation of the site.

A. Conclusions

Construction of an 80-foot high debris dam at the selected site is not recommended. Foundation stability problems on the left abutment, which could be detrimental to the safety of the structure, are indicated by geologic conditions observed in the field.

B. Recommendations

A series of small sedimentation ponds at appropriate locations might be a more advisable solution to accomplish the objectives in Manti Canyon which are desired by the Forest Service. Additional information regarding specific properties and quantities of Manti Creek sediments are required before workable concepts can be evaluated.

DRILL LOG

PROJECT: Manti Slide Study		JOB NO. 614-02	HOLE NO. DH-1
SITE: near toe north Manti Slide	BEGUN: 6/15/76	COMPLETED: 6/19/76	HOLE SIZE: NC
ANGLE FROM HORIZ.&BEARING: Vertical			
COORDINATES: N.336,817 E.1.982,553	DEPTH/EL GROUND WATER: none	GROUND EL.: 7005.0	DEPTH/EL. TOP OF ROCK: None
DRILLING CONTRACTOR: Boyles Bros. Drilling Co.	CORE RECOV. LENGTH/%: 207.0 ft./99%	SAMPLES: 18	CORE BOXES: 20
DEPTH/EL. BOTTOM OF HOLE: 232.9/6772.1			
DRILL MAKE AND MODEL: Longyear 44	LOGGED BY: C.C. Payton & J. A. Cercone		

Type tool and dia.	Method N- Blow count	Advance	Recovery %	Remarks (Water levels, Water return, Drilling fluid, Casing depth)	Elevation	Depth	Box/Sample No.	Material Classification / Physical Description
tricone 5 5/8"				first 20ft. drilled with rock-bit- 100% water return.	7005	0		GLACIAL DEBRIS, consolidated, primarily made up of subrounded to subangular rock fragments, gravel to boulder sized. In a brown clayey sandy, slightly moist, not plastic at natural moisture, becomes plastic with addition of water, stiff.
				4" casing set at 20°ft.		10		
NC	50			SPT-0.6ft.penetration No recovery. Began drilling with NC-wire line, regular core barrel.		20	#1	
			82	SPT-(Standard Penetration Test) 2"dia. split spoon sampler driven with 140 lb. hammer.		30		Similar to above but denser, very stiff, very slow dilatancy, medium clay strength, medium toughness. A few isolated large boulders, in brown clayey sandy gravels.
	50			SPT- 0.3ft.penetration 0.1ft. recovery		40	#2	Sample No.2 Natural moisture content 7.1% Liquid limit 18.4% - PI = 5.2% Specific gravity 2.63. 41% gravel sizes 17% sand 42% plastic fines (ML)
			100					
	50			SPT-almost no penetration			#3	
			100					
	13/44/50			SPT- 1.4ft.penetration 1.2ft.recovered		50	#4	57.6to 58.2ft. shear zone with slickensides a gray clay dipping approximately 25° moisture content 13%
			94					Sample No. 4 Gravelly sand clay 17% gravel sized rock frags. 19% sand 64.0% plastic fines (CL)
	45/50			SPT- 0.7ft.penetration 0.7ft. recovered		60	#5	
			92			70		

Graphic log:

INTERNATIONAL ENGINEERING CO., INC.

DRILL LOG

PROJECT	JOB NO	HOLE NO.
Manti Slide Study	614-02	DH-1

SAMPLE DATA: TYPE TOOL AND DIA	METHOD N- BLOW COUNT	ADVANCE	RECOVERY %	REMARKS (WATER LEVELS, WATER RETURN, DRILLING FLUID, CASING DEPTH)	ELEVATION	DEPTH	GRAPHIC LOG	BOX/SAMPLE NO	MATERIAL CLASSIFICATION – PHYSICAL DESCRIPTION
NC	50		92	Drilled with NC wire-line, 100% water return.		70		#7	GLACIAL DEBRIS, consolidated, primarily subangular to subrounded rock fragments in a clayey sand matrix.
	50			SPT-0.4ft.penetration		80		#8	
	24/50		100	SPT- 0.9ft.penetration recovered 0.9ft.				#9	83.0 to 84.0 shear zone with slickensides. Ø = 13° cohesion 1.5 ksf Dry density 126.0 lb./ft.^{3}
	24/40/50		100	SPT-1.3ft.penetration 1.3ft.recovered		90		#10	Changed in color at 91.0ft. with a possible shear plane. Gradational contact between the above consolidated brown clayey sandy glacial debris and a multicolored glacial debris including some black shales. Fines are stiff, moist, medium to high toughness, slow dilatancy, medium to high dry strength, not plastic at natural moisture but with added water becomes plastic. Increase in moisture at 92 ft. to 20% matrix is sandy clay, gray, with liquid limit of 43% - PI = 19%
						100			
						110			
	28/50		99	SPT-1.0ft.penetration 0.9ft. recovered 80% drill fluid return		120		#11	
	19/50		100	SPT-0.9ft.penetration No sample recovered		130		#12	134.7 to 135.3 - shear zone, dark gray clay, abundant slickensides, core breaks easily with hand pressure on smooth surfaces.
	50		100	SPT-0.4ft.penetration 0.4ft.recovered		140		#13	shear plane at 148.0 dips 25° Ø = 5° cohesion = 32 ksf
						150			

[INT]ERNATIONAL ENGINEERING CO., INC.

[D]RILL LOG

PROJECT: Manti Slide Study | JOB NO: 614-02 | HOLE NO.: DH-1

[SAMP]LE DATA: METHOD N- BLOW COUNT	ADVANCE	RECOVERY %	REMARKS (WATER LEVELS, WATER RETURN, DRILLING FLUID, CASING DEPTH)	ELEVATION	DEPTH	BOX/SAMPLE NO.	MATERIAL CLASSIFICATION – PHYSICAL DESCRIPTION
35	50		SPT- 0.9ft.penetration		150	#14	GLACIAL DEBRIS, consolidated, multi-colored, rock fragment average is 0.5ft. Fines are a mixture of fine sand, silt and clay, brown to dark gray, moist very stiff, non-plastic at natural moisture but becomes plastic with added water.
		100	Drilling with NC wire line, regular core barrel and mud. 75% drilling fluid return.		160		
50			SPT-0.1ft.penetration 0.1ft. recovered		170	#15	Sandstone boulder
		100	Lost drilling fluid at 180.0 ft.		180		
30	50		SPT-0.8ft.penetration 0.8ft. recovered			#16	
		93	No drilling fluid return		190		Consolidated glacial debris primarily sandstone and limestone boulders in a sandy clay
50			SPT -0.4ft.penetration no sample recovered		200	#17	Shear zone between 203-208.5ft, dark gray clay, shear planes, slickensides, dip 35 degrees. Ø = 22° cohesion 1.2 ksf.
		100			210		Sample No. 18 Gray clayey sandy gravel (GC) 30% gravel sizes 20% sand 50% plastic fines (CL) liquid limit 23.1% PI = 9.3% natural moisture 9.3%
50			SPT-0.3ft.penetration 0.3ft.recovered			#18	
		96	Inclinometer casing installed in drill hole to a depth of 231.7 ft.		220 / 230 / 232		Brown weathered sandstone boulder in matrix of brown soft clayey sand.
							Bottom of Hole 232.9ft. Elevation 6772.1

HOLE NO. DH-1

...RILL LOG

PROJECT	JOB NO.	HOLE NO.
Manti Slide Study	614-02	DH-2

...	BEGUN	COMPLETED	HOLE SIZE	ANGLE FROM HORIZ.&BEARING
Bottom of canyon near Manti Creek	5/19/76	6/1/76	4"	Vertical

...NATES	DEPTH/EL GROUND WATER	GROUND EL.	DEPTH/EL. TOP OF ROCK
N.336,986 E.1.983,522	-	7166.0	306.0/6860.0

...NG CONTRACTOR	CORE RECOV. LENGTH/%	SAMPLES	CORE BOXES	DEPTH/EL. BOTTOM OF HOLE
Boyles Bros. Drilling Co.	176 ft/67%	39	22	328.0ft/6838.0

...MAKE AND MODEL	LOGGED BY:
Longyear 44	C.C. Payton & J.A. Cercone

...MPLE DATA	METHOD N / BLOW COUNT	ADVANCE	RECOVERY	REMARKS: WATER LEVELS, WATER RETURN, DRILLING FLUID, CASING DEPTH	ELEVATION	DEPTH	BOX/SAMPLE NO.	MATERIAL CLASSIFICATION — PHYSICAL DESCRIPTION
...one ...and ...asing				3 7/8" tricone bit inside 4" casing. 17.5 lost water return. SPT(Standard Penetration Test) 2" dia. split spoon sampler driven with 140 lb. hammer.	7166.0	10		GLACIAL DEBRIS - angular to subrounded sandstone boulders in a light brown silty sand matrix, dense, dry, non-plastic.
	8/1	4/	14	SPT 1.5ft.penetration		20	#1	Light gray,silty sandy gravels, dense, slightly plastic, very little fines, mostly medium size sands.
	Sh			2.5"Shelby tube		30	#2	Sample No. 2 32.5% gravel 31.8% sand 35.7% plastic fines (CL) Liquid limit 24.1 PI = 13.3 Specific gravity 2.74 Increase in plastic fines
	11/2	4/	14	SPT-1.5ft.penetration			#3	Sample from 58.0 ft. 16% gravel 22.0% sand
	Sh			0.2ft.penetration		40	#4	62.0% plastic fines (CL) Liquid limit 27.3% PI = 12.1% Gradational change from silty sandy fines to sandy clayey plastic fines
	50			SPT-0.2ft.penetration			#5	
	Sh			No recovery 4"casing set at 59.0ft,		50	#6	GLACIAL material with boulder sized rock fragments in a light brown to light gray sandy clayey matrix, moist, dense, cohesive, plastic
	60			SPT-0.5ft.penetration		60	#7	
	Sh						#8	
NC				Started drilling w/NC-wire line, reg. core barrel				
	41/	50		SPT-1ft penetration		70	#9	

INTERNATIONAL ENGINEERING CO., INC.

DRILL LOG

PROJECT: Manti Slide Study | JOB NO. 614-02 | HOLE NO. DH-2

Type Tool and Dia.	Method N- Blow Count	Advance	Recovery %	Remarks (Water Levels, Water Return, Drilling Fluid, Casing Depth)	Elevation	Depth	Box/Sample No	Material Classification – Physical Description
NC			50	Drilling with NC-wire line reg.core barrel		70		GLACIAL DEBRIS, Consolidated, abundant boulders in a matrix of fine sandy clays. Shear planes with slickensides dip 70°-75°, Ø = 34°, cohesion =7.5ksf Natural moisture 6.1% Gravels are subangular to subrounded fine gravel to boulder sizes, hard.
	50/			SPT - 0.7ft.penetration			#10	
			100	0.7ft recovered				
	50			SPT-1.0ft.penetration		80	#11	
			100					
	45/50			SPT-1 .0ft.penetration			#12	
			100	0.3ft.recovered				
	50			SPT-0.2ft.penetration No recovery		90	#13	
	32/50			SPT-0.8ft.penetration			#14	Shear zone indicated by a dark gray clay with abundant slickensides damp, very stiff, plastic, dips 70°-75°
	50			SPT-0.1ft.penetration No recovery		100	#15	
			90					
	31/50			SPT-0.7ft.penetration 0.7ft.recovered			#16	
			85					
	34/50			SPT-0.7ft.penetration 0.4ft.recovered		110	#17	clayey sandy gravels, very stiff, slightly moist, medium dry strength, medium toughness, plastic
			100					
	45/50			SPT-0.9ft.penetration			#18	
			100					
			17			120		
	29/30/50			SPT-1.4ft.penetration 0.5ft.recovered			#19	Change in Color — GLACIAL DEBRIS
			80					
	20/50			SPT-0.7ft.penetration No recovery		130	#20	Gray clayey sandy gravels, dense, slightly moist, several shear planes with slickensides dip 35° dark gray clay on shear surfaces, clay moist, stiff, plastic with a medium dry strength.
			80					
	50			SPT-0.1ft.penetration No recovery.			#21	
			45					
	20/50			SPT-0.8ft.penetration 0.5ft.recovered		140	#22	
			28					
	33/50			SPT-0.9ft.penetration. 0.5ft.recovered			#23	
			36			150		

HOLE NO. DH-2

INTERNATIONAL ENGINEERING CO., INC.

DRILL LOG

PROJECT	JOB NO	HOLE NO.
Manti Slide Study	614-02	DH-2

Sample Data: Method N-Blow Count	Advance / % Recovery	Remarks (Water Levels, Water Return, Drilling Fluid, Casing Depth)	Elevation	Depth	Graphic Log	Box/Sample No
28/50		SPT-1.0ft.penetration		150		#24
	80	No recovery				
50		SPT-0.4ft.penetration				#25
		0.2ft.recovered				
	88					
				160		
17/50		SPT-1.0ft.penetration				#26
		No recovery				
	94					
19/41/50		SPT-1.4ft.penetration				#27
		1.3ft.recovered				
				170		
13/28/50		SPT-1.0ft.penetration				#28
		No recovery				
	100					
20/50		SPT-0.8ft.penetration				#29
		No recovery				
	43					
				180		
50		SPT-0.3ft.penetration				#30
	60	0.3ft.recovered				
50		SPT-0.1ft.penetraiton				#31
		No recovery.				
	90					
				190		
	50					
26/40/50		SPT-1.1ft.penetration				#32
		0.4ft.recovered				
	66					
				200		
	50					
	100					
	100					
50		SPT-0.5ft.penetration		210		#33
		0.2ft.recovered				
	80					
	100					
50		SPT-0.3ft.penetration		220		#34
		0.1ft.recovered				
	100					
50		SPT-0.1ft.penetration				#35
		No recovery.				
	100			230		

MATERIAL CLASSIFICATION — PHYSICAL DESCRIPTION

GLACIAL DEBRIS, consolidated gray, clayey sandy gravels, dense, fines are very stiff, slightly moist, non-plastic at natural moisture, add moisture, material becomes plastic with medium toughness, very slow dilatancy and medium dry strength.

Sample from 155.0 ft.
18.0% gravel sized rock fragments
20.0% sand
62.0% plastic fines (CL)
Natural moisture 10.6%
Liquid limit 36.2%
Plasticity Index 19.8%
Specific gravity 2.57

Change in Color

GLACIAL DEBRIS, consolidated brown, clayey sandy gravels, slightly moist, non-plastic at natural moisture but becomes plastic with small amount of additional moisture, with medium toughness, very slow to no dilatancy and medium dry strength.

[IN]TERNATIONAL ENGINEERING CO., INC.

DRILL LOG

PROJECT	JOB NO	HOLE NO
Manti Slide Study	614-02	DH-2

SAMPLE DATA: TYPE AND DIA	METHOD N- BLOW COUNT	ADVANCE	RECOVERY %	REMARKS: WATER LEVELS, WATER RETURN, DRILLING FLUID, CASING DEPTH	ELEVATION	DEPTH	BOX/SAMPLE NO	MATERIAL CLASSIFICATION: PHYSICAL DESCRIPTION
NC			100			230		GLACIAL DEBRIS, consolidated brown clayey sandy gravels, dense - fines are very stiff, slightly moist, non plastic at natural moisture.
	50			SPT-0.3ft.penetration 0.1ft.recovered			#36	
			100			240		
			100	No drilling fluid return				— 243.5- dark gray clay, moist, plastic stiff.
			89					— 248.2- shear plane, dip 35° slicken sides in dark gray clay, stiff, plastic, Ø=12° C= 0.8 ksf
			66			250		Change in Color
			100					Gray clayey sandy gravels dense, slightly moist, fines with added moisture are plastic, stiff, medium dry strength. Gravels are gray, hard, fresh, some stained light brown on surface.
	50			SPT-0.5ft.penetration 0.2ft.recovered		260	#37	
			80					
			20			270		
			100					scattered dark gray clay irregular thin layers mixed with gray clay.
	50			SPT-0.1ft.recovered			#38	
			82			280		core can be broken with hand pressure but it is difficult.
			100					
			100	Drilling rate average 8 ft/hr with NC wire line diamond core barrel				Gradual increase in large gravel and cobbled sized rock fragments. Hard, gray and light gray, fresh, sandstones, limestones and occasional quartzite rock fragments.
			74			290		
			74			300		
			66	4" casing reamed to 305° ft.				TOP OF BEDROCK
			78	Drilling fluid return	6860.0	306		SANDSTONE, light reddish brown, fine to medium grained
						310		

HOLE NO. DH-2

INTERNATIONAL ENGINEERING CO., INC. SHEET 5 OF 5

DRILL LOG

PROJECT	JOB NO.	HOLE NO.
Manti Slide Study	614-02	DH-2

SAMPLE DATA: TYPE AND DIA	METHOD N-BLOW COUNT	ADVANCE	% RECOVERY	REMARKS: WATER LEVELS, WATER RETURN, DRILLING FLUID, CASING DEPTH	ELEVATION	DEPTH	GRAPHIC LOG	BOX/SAMPLE NO.	MATERIAL CLASSIFICATION: PHYSICAL DESCRIPTION
			100	lost drilling fluid return at 310.0 ft.		310			SANDSTONE, light brown, moderately hard, bedded, cross-bedded, dip range 15 - 20 degrees
			100						
			19			320			
			100					39	SILTSTONE, dark gray, soft, bedded, bedding plane dip 15 - 20 degrees.
	50		9	SPT-0.3ft.penetration 0.3ft. recovered					
				Inclinometer casing installed to a depth of 325 ft.					BOTTOM OF HOLE Depth 328.0 Elevation 6838.0

HOLE NO. DH-2

…RILL LOG

PROJECT: Manti Slide Study			JOB NO. 614-02	HOLE NO. DH-3
…center of study area	BEGUN: 6/7/76	COMPLETED: 6/26/76	HOLE SIZE: NC	ANGLE FROM HORIZ. & BEARING: vertical
…NATES: …337,242 E.1,984,015	DEPTH/EL. GROUND WATER: none		GROUND EL.: 7272.0	DEPTH/EL. TOP OF ROCK: 334.0/6938.0
…ING CONTRACTOR: Boyles Bros. Drilling Co.	CORE RECOV. LENGTH/%: 248.5ft./75%	SAMPLES: 30	CORE BOXES: 23	DEPTH/EL. BOTTOM OF HOLE: 350.0/6922.0
…MAKE AND MODEL: Mobil Drill B-56 and Longyear 44	LOGGED BY: C.C. Payton & J.A. Cercone			

SAMPLE DATA	METHOD / BLOW COUNT / ADVANCE	% RECOVERY	REMARKS (WATER LEVELS, WATER RETURN, DRILLING FLUID, CASING DEPTH)	ELEVATION	DEPTH	BOX/SAMPLE NO.	MATERIAL CLASSIFICATION – PHYSICAL DESCRIPTION
casing			Started hole with a combination of 4" casing and a 3 7/8" dia. tricone rock bit.	7272.0			GLACIAL DEBRIS, loose to dense, light gray and light brown silty sandy gravels, fines are stiff, slightly moist but are not plastic at natural moisture. Mtl. becomes plastic with addition of a small amount of moisture, low to medium dry strength.
			SPT (Standard Penetration Test) 2" dia. split spoon sampler driven 18" with a 140 lb. hammer		10		
	13/20/31		SPT-1.5ft.penetration		20	#1	
	sh		25.0ft. lost all drilling fluid return. Took a shelby tube sample at 25.0.			#2	
	4/3/4		SPT-0.8ft.recovered 1.5ft.penetration		30	#3	
	sh		4" casing placed in hole to 40 ft.			#4	
NC wire-line diamond core bit and 5.0 ft regular core bbl.		17	Started drilling w/NC-wire line regular core barrel 5 ft. long.		40		Gradational change in mtl and color
		66					GLACIAL DEBRIS, consolidated brown, clayey sandy gravels, slightly moist, stiff, fines become plastic with additional moisture, medium toughness, very slow to no dilatancy, and medium dry strength
		38			50		
	43/19/36		SPT-1.0ft.recovered 1.5ft.penetration			#5	Sample No. 5 20.0% gravel sized rock fragments 20.0% sand 60.0% fines (ML) liquid limit = 18.7% PI = 5.9% natural moisture 8.3% specific gravity 2.67
		45	No drilling fluid return		60		
		90			70		

HOLE NO. DH-3

INTERNATIONAL ENGINEERING CO., INC.

DRILL LOG

PROJECT: Manti Slide Study | JOB NO.: 614-02 | HOLE NO.: DH-3

TYPE TOOL AND DIA.	METHOD N-BLOW COUNT	ADVANCE	% RECOVERY	REMARKS (WATER LEVELS, WATER RETURN, DRILLING FLUID, CASING DEPTH)	ELEVATION	DEPTH	BOX/SAMPLE NO.	MATERIAL CLASSIFICATION / PHYSICAL DESCRIPTION
						70		
NC			80	No drilling fluid return				GLACIAL DEBRIS, consolidated brown clayey sandy gravels, dense, slightly moist, fines are not plastic at natural moisture with added moisture they become plastic with medium toughness, and medium dry strenght.
			100			80		
	15/41	17/	50	SPT-1.2ft.penetration 0.7ft.recovered			#6	Sample No. 6 - Direct Shear Test $\emptyset = 15^{\circ}$ cohesion 1.7 ksf Dry density 126.0 lb/ft^3
			100					
	46	50		SPT-0.7ft.penetration			#7	
			60			90		
			60					
	50			SPT-0.2ft.penetration No recovery		100	#8	
			65					Rock fragments are hard, fresh sandstones and limestones, subangular to subrounded, gravel to boulder sizes. Rock fragments are in a matrix of very stiff, brown, slightly moist sand clay.
			57	Average drilling rate W/NC diamond bit - 10 ft/hr				
			56			110		
			60					
			54			120		
	50			SPT- 0.2ft.penetration			#9	
			64	0.2ft. recovered				
			96			130		
			52					natural moisture 12.6% specific gravity 2.63 30% gravel sized rock fragments 16% sand 54% plastic fines (CL) liquid limit 23.8%
			96			140		
	17	50		SPT - ft. of penetration ft. recovered			#10	PI = 10.4%
			79			150		

HOLE NO. DH-3

INTERNATIONAL ENGINEERING CO., INC. SHEET 3 OF 5

DRILL LOG

PROJECT Manti Slide Study | JOB NO 614-02 | HOLE NO DH-3

SAMPLE DATA: TYPE AND DIA.	METHOD N-BLOW COUNT	ADVANCE	% RECOVERY	REMARKS: WATER LEVELS, WATER RETURN, DRILLING FLUID, CASING DEPTH	ELEVATION	DEPTH	GRAPHIC LOG	BOX/SAMPLE NO	MATERIAL CLASSIFICATION / PHYSICAL DESCRIPTION
NC			100	No drilling fluid return		150			GLACIAL DEBRIS, consolidated brown clayey sandy gravels, dense slightly moist. Brown plastic fines are very stiff, not plastic at natural moisture, but become plastic w/small amount of additional moisture, with medium toughness, medium dry strength.
			74						
			100			160			
			100						
			60						
			100			170			
			42						
			76						
			62			180			
	25	50		SPT- 0.9ft. penetration 0.9ft. recovered				#11	
			33			190			
			78						
	28	50		SPT-0.7ft. penetration				#12	Dark gray clay, shear plane dip 50 degrees
			38			200			
	20	48 50		SPT- 1.2ft. penetration 1.2ft. recovered.				#13	
			68						Dark blue-gray sandy clay-very stiff, shear plane at 206.0 dip 70 degrees.
	21	50		SPT-0.6ft. penetration 0.2ft. recovered				#14	
			40			210			Brown clayey sandy gravels, dense, slightly moist, as above.
			15						
			40						27% gravel sized rock fragments 16.0% sand 57.0% plastic fines (CL) liquid limit 22.0% PI = 8.7% natural moisture 7.1%
			64			220			
			100			230			

HOLE NO. DH-3

INTERNATIONAL ENGINEERING CO., INC.

DRILL LOG

PROJECT	JOB NO.	HOLE NO.
Manti Slide Study	614-02	DH-3

SAMPLE DATA: TYPE AND DIA	METHOD N-BLOW COUNT	ADVANCE	RECOVERY %	REMARKS: WATER LEVELS, WATER RETURN, DRILLING FLUID, CASING DEPTH	ELEVATION	DEPTH	BOX/SAMPLE NO.
NC			72			230	
			62				
	50			SPT- 0.4ft. penetration 0.4ft. recovered		240	#15
			88				
			100				
			96			250	
			48				
			48			260	
			74				
	24	50		SPT-0.9 ft. penetration 0.9 ft. recovered		270	#16
			25				
			100			280	
	60		84	SPT- 0.5ft. penetration 0.4ft. recovered			#17
			100			290	
	50			SPT- 0.4ft. penetration 0.4ft. recovered			#18
			100			300	
	25/50			SPT-0.9 ft. penetration 0.9ft. recovered			#19
			94			310	

MATERIAL CLASSIFICATION — PHYSICAL DESCRIPTION

GLACIAL DEBRIS, consolidated brown, clayey sandy gravels, dense. Rock fragments are hard, gray subangular. Fines are very stiff, brown, slightly moist not plastic at natural moisture, become plastic with additional moisture with medium toughness and medium dry strength.

Color change - dark gray clayey sandy

246.0 - shear plane dip 30 degrees.

$\phi = 32.0^{\circ}$ cohesion = 0.0 ksf.

Brown clayey sandy gravels as above.

Color change

Grayish brown to gray clayey sandy gravels, dense, slightly moist, decrease in the size and amount of gravels.
Fines are not plastic at natural moisture, become plastic w/slight amount of additional moisture, with medium toughness and medium dry strength.

286.5-wood-old buried tree limb.

Sample from 280.0 ft.
7.0% gravel sized rock fragments
30.0% sand
63.0% plastic fines (CL)
Liquid limit 28.2% PI = 11.8%
specific gravity 2.51

INTERNATIONAL ENGINEERING CO., INC.

DRILL LOG

PROJECT	JOB NO.	HOLE NO
Manti Slide Study	614-02	DH-3

SAMPLE DATA: AND DIA	METHOD N-BLOW COUNT	ADVANCE	% RECOVERY	REMARKS: WATER LEVELS, WATER RETURN, DRILLING FLUID, CASING DEPTH	ELEVATION	DEPTH	BOX/SAMPLE NO	MATERIAL CLASSIFICATION: PHYSICAL DESCRIPTION
HC			94	No drilling fluid return but fluid stays in bottom of hole while drilling		310		GLACIAL DEBRIS, consolidated gray clayey, sandy gravel, dense as above.
			100					Dry density 132 lb/ft^3
						320		Color change
			100					shear zone - marbled dark gray and brown clayey sandy gravels, average dip of zone 25^0, slickensides on shear planes dip shown at left. Ø = 10^0 cohesion 4.1 ksf
			80					
						330		Color change - light brown, increase in gravels.
			100		6938	334		TOP OF BEDROCK
			85					
	50			SPT- 0.5ft. penetration 0.5ft. recovered			#20	SILTSTONE, dark bluish gray, massive bedded, soft, molds w/hand pressure to gravelly sandy silt.
			90			340		
			58	No ground water				Increasing hardness with depth. occasional thin (1mm thick) white mineral healed fractures.
			100					
						350		
				301.5ft of inclinometer casing installed in drill hole 3.				BOTTOM OF HOLE - Depth 350.0ft. Elevation - 6922.0

[illegible]ERNATIONAL ENGINEERING CO., INC. SHEET 1 OF 2

[illegible]RILL LOG

PROJECT: Manti Slide Study		JOB NO. 614-02	HOLE NO. DH-4
upper most site in study area	BEGUN: 6/20/76	COMPLETED: 6/23/76	HOLE SIZE: NC
ANGLE FROM HORIZ. & BEARING: Vertical			
[illegible]DINATES: [illegible]337.794 N.1.984.184	DEPTH/EL GROUND WATER: none	GROUND EL.: 7361.0	DEPTH/EL. TOP OF ROCK: None
[illegible]ING CONTRACTOR: [illegible]yles Bros. Drilling Co.	CORE RECOV LENGTH/%: 115[8] / 89	SAMPLES: 5	CORE BOXES: 13
DEPTH/EL. BOTTOM OF HOLE: 150.5/7210.5			
[illegible] MAKE AND MODEL: [illegible]ngyear 44	LOGGED BY: C.C. Payton & J.A. Cercone		

[illegible]PLE DATA: [illegible] AND DIA	METHOD N-BLOW COUNT	ADVANCE	% RECOVERY	REMARKS: WATER LEVELS, WATER RETURN, DRILLING FLUID, CASING DEPTH	ELEVATION	DEPTH	BOX/SAMPLE NO	MATERIAL CLASSIFICATION — PHYSICAL DESCRIPTION
[illegible]8" [illegible]cone				Started hole with a 5 5/8" tricone bit	7361.0	0		GLACIAL DEBRIS, consolidated Brown dense, clayey sandy gravels; fines very stiff, non plastic at natural moisture, slightly moist. Add small amount of moisture fines become plastic, with medium toughness, very slow dilatancy, and medium dry strength.
				SPT-(Standard Penetration Test) 2" dia. split spoon sampler driven with a 140 lb. hammer		10		
[illegible]C	11	50	79	0[9]ft.penetration 4" dia. casing placed to a depth of 20[0] ft.		20	#1	
	50		67	SPT- 0.3ft.penetration 0.3 ft. recovered		30	#2	
			95	Started drilling at 20.0 ft. with NC-wire line core bbl and diamond bit.				
			66			40		Sample from 49.0 ft. Natural moisture 8.4% Specific gravity 2.62 40% gravel sized rock frags. 13% sand 47% plastic fines (CL) Liquid limit 29.2% PI = 12.5%
			50	Average drilling rate with NC-wire line regular core barrel is 10 ft/hr				
			73					
			95			50		
			96					slight color change, mixed brown and light gray, very stiff clayey sand matrix around fresh, hard light gray rock fragments.
			80					
			100	100% return of drilling fluid light brown		60		
			40					
			100			70		

HOLE NO. DH-4

INTERNATIONAL ENGINEERING CO., INC.

DRILL LOG

PROJECT	JOB NO.	HOLE NO.
Manti Slide Study	614-02	DH-4

SAMPLE DATA: TYPE TOOL AND DIA.	METHOD N-BLOW COUNT	ADVANCE	RECOVERY %	REMARKS: WATER LEVELS, WATER RETURN, DRILLING FLUID, CASING DEPTH	ELEVATION	DEPTH	BOX/SAMPLE NO.
		1	00				
			45				
			53			80	
			83				
		1	00				
			60			90	
		1	00				
	50			SPT-0.4 ft. penetration 0.4 ft. recovered			#3
			78			100	
		1	00				
		1	00				
			85			110	
		1	00				
			98			120	
	50			SPT-0.3 ft. penetration 0.3 ft. recovered			#4
		1	00			130	
			96				
			55	Hole bottomed at 150.0ft. as designated by the U.S. Forest Service		140	
			60				
		1	00				
	32	50		SPT-0.9ft.penetration		150	#5

GRAPHIC LOG

MATERIAL CLASSIFICATION — PHYSICAL DESCRIPTION

GLACIAL DEBRIS, consolidated Brown, dense, slightly moist, clayey sandy gravels. Fines are very stiff, not plastic at natural moisture but becomes plastic with slight addition of moisture, medium toughness, medium dry strength, very slow to no dilatancy.

change in color, mixed reddish and yellowish brown, brown and gray mottled dense clayey sandy gravels.

Sample from 108 ft.
22% gravel sized rock frags
20% sand
58% plastic fines (CL)
Liquid limit = 17.6% PI 5.9%
natural moisture 7.1%
specific gravity 2.63
Decrease in hard gravels

Mottled yellowish brown, gray and dark gray, clayey sandy gravels very stiff, slightly moist, fines plastic with added moisture, low toughness, low to medium dry strength.

Increase in subangular gravels clayey sandy gravels, glacial debris, mottled yellowish brown, brown and gray fines.
Dry density = 140 lb/ft.^{3}
$\emptyset$ = 32° cohesion = 2.2 ksf

148.0- dark gray clay with some sand and gravels, very stiff, slightly damp - possible zone of deformation beginning at 148.0ft.

HOLE NO. DH-4

No recovery below 149.9 Bottom of Hole depth 150.0, elevation 7210.5 ft.
Inclinometer casing installed in drill hole to a depth of 150.0 ft.

...ERNATIONAL ENGINEERING CO., INC.

SHEET 1 OF 1

...RILL LOG

PROJECT	JOB NO.	HOLE NO.
Manti Slide Study	614-02	DH-5

...	BEGUN	COMPLETED	HOLE SIZE	ANGLE FROM HORIZ. & BEARING
...am Site Right Abutment	6/15/76	6/16/76	NC	Vertical

...NATES	DEPTH/EL. GROUND WATER	GROUND EL.	DEPTH/EL. TOP OF ROCK
None determined	none	6140.0	57.5 ft./6082.5

... CONTRACTOR	CORE RECOV. LENGTH/%	SAMPLES	CORE BOXES	DEPTH/EL. BOTTOM OF HOLE
...oyles Bros. Drilling Company	13.6ft. 59%	6	2	70 ft./6070

...MAKE AND MODEL	LOGGED BY:
...obil Drill B-56	J. Cercone and F.D. Nielson

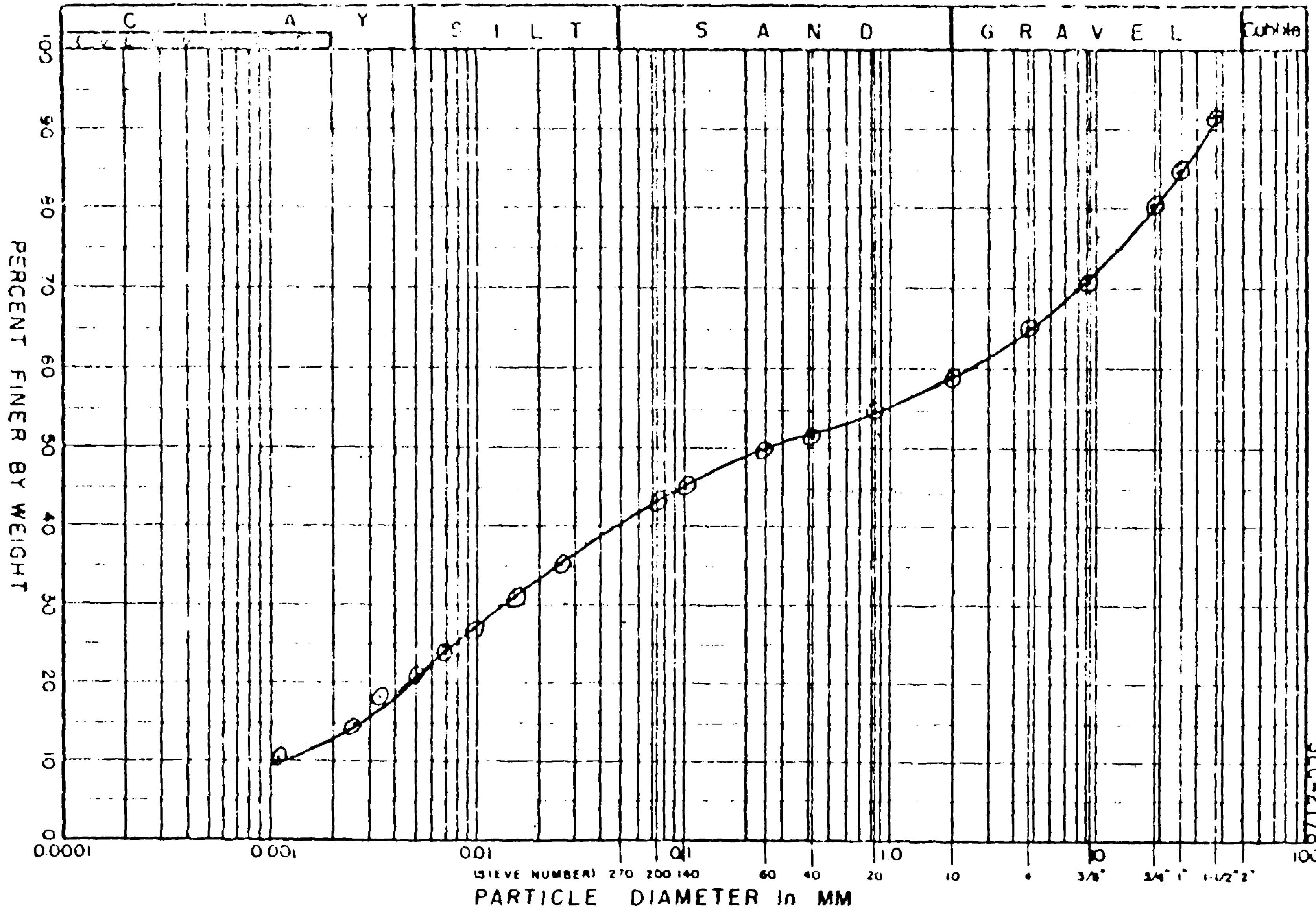
...PLE DATA (METHOD / N-BLOW COUNT / ADVANCE)	RECOVERY	REMARKS (WATER LEVELS, WATER RETURN, DRILLING FLUID, CASING DEPTH)	ELEVATION	DEPTH	BOX/SAMPLE NO.	MATERIAL CLASSIFICATION — PHYSICAL DESCRIPTION
...e		Drilled with tricone rock bit	6140.0	0		Slope Wash Material - consists primarily of a heterogeneous mixture of rock fragments and blocks of all sizes up to several feet in a matrix of brownish to tan sandy silt.
Sh		0.7 ft recovery		10	#1	Rock fragments are hard to mod. hard, subangular, gray and light brown, sandstones and limestones.
2/9/9		SPT (Standard Penetration Test) Driven with "2" split spoon and 140 lb hammer.			#2	
				20		
11/9/9		SPT-1.5ft. penetration 0.9 ft. recovered			#3	
Sh		0.5 ft. recovered		30	#4	
		Lost water circulation at 30.0				
		At 37ft. open end permeability test. k= 3.48×10^{-2} cm/sec				
				40		
11/12/32		SPT - 1.5ft. penetration			#5	
NC		Started drilling with NC-wire line regular core barrel.		50		Alluvium - some rounded rock fragments gravel to cobble sized, a few larger boulders in a matrix of sandy silt.
		At 57ft. open end permeability test. k= 1.46×10^{-4} cm/sec				TOP OF BEDROCK
NC-CS 50		SPT - 0.1 ft. penetration no recovery			#6	SANDSTONE - greenish-gray, fine grained, sugary texture. Open horizontal to 20° joints. Bedding not well defined but contacts between fine & medium grained sandstones shows 17° - 19° dip.
				60		
		Permeability test between 57-70 ft k= 5.16×10^{-5} cm/sec		70		

HOLE NO. DH-5

Bottom of Hole - Depth 70ft - El. 6070.0ft (estimated)

GRAIN SIZE DISTRIBUTION CURVES

Sample No	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
DH1-2		Specific Gravity (-#10) 2.635	DP	7-21-76	DP	7-22-76

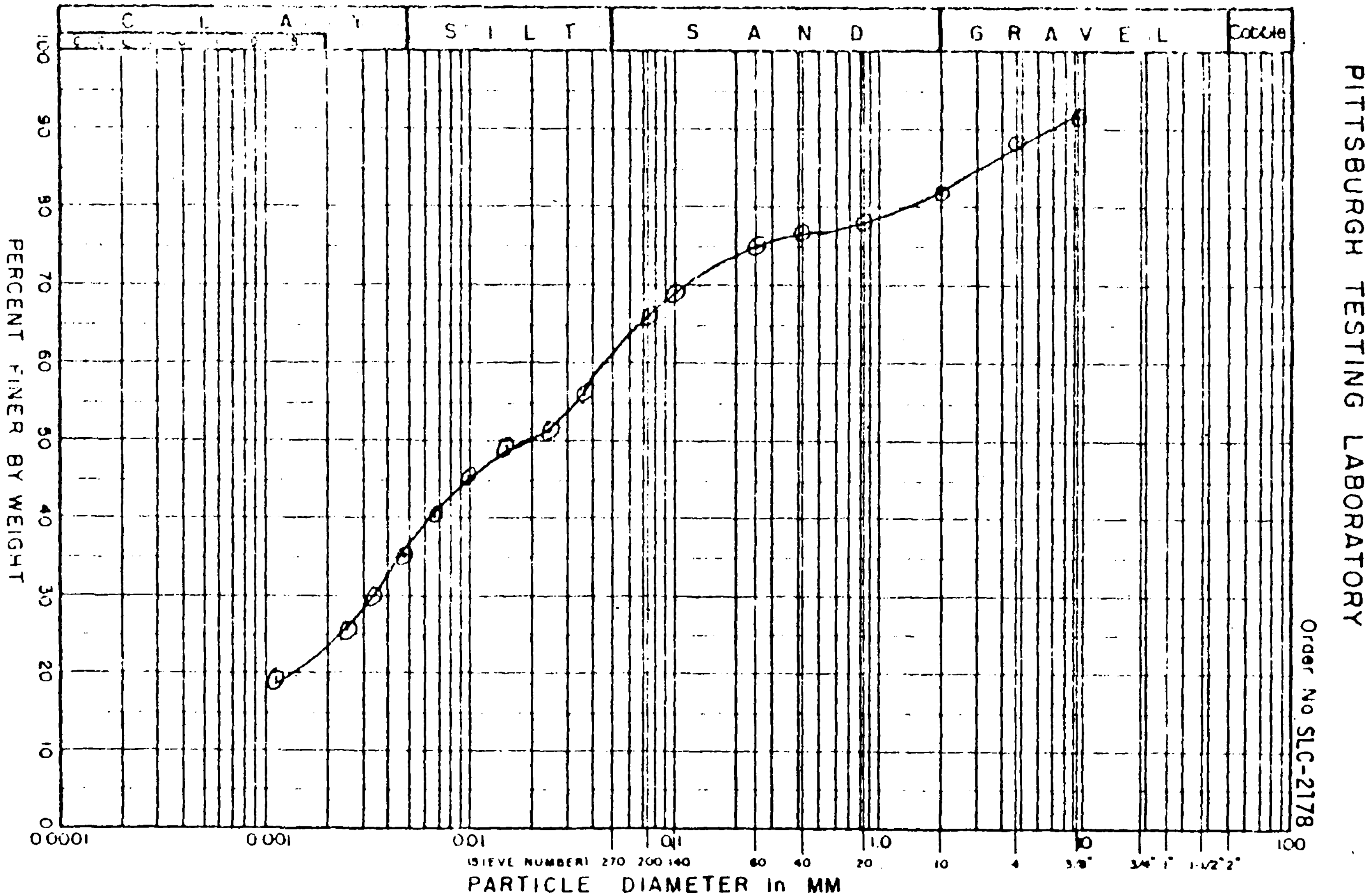


Order No SLC-2178

PITTSBURGH TESTING LABORATORY

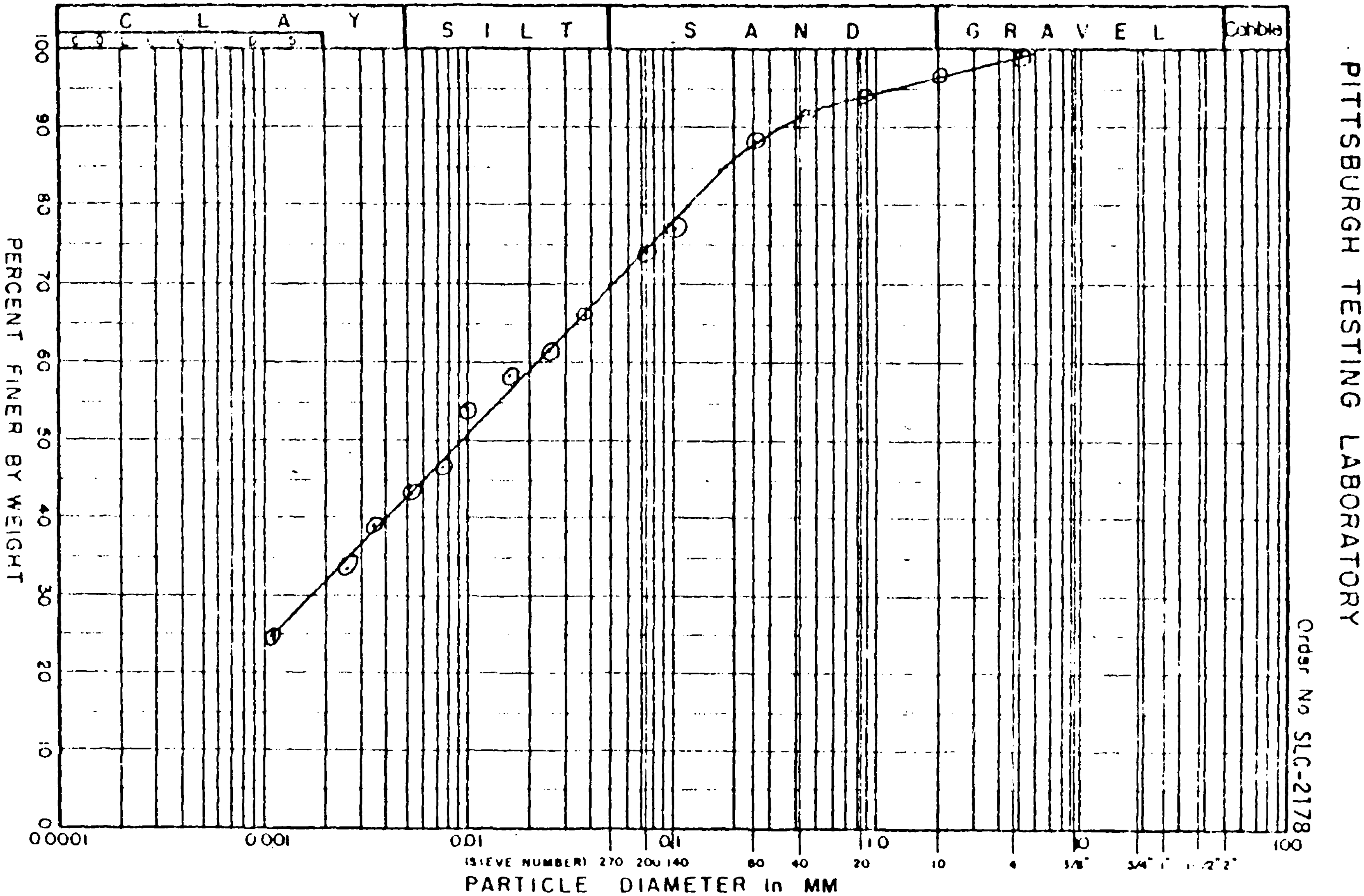
GRAIN SIZE DISTRIBUTION CURVES

Sample No	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
DHT-4		specific gravity (-#10) 2.64	DP	7-21-76	DP	7-22-76



GRAIN SIZE DISTRIBUTION CURVES

Sample No	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
DH1-13		Specific Gravity (-#10) 2.452	DP	7-21-76	DP	7-22-76



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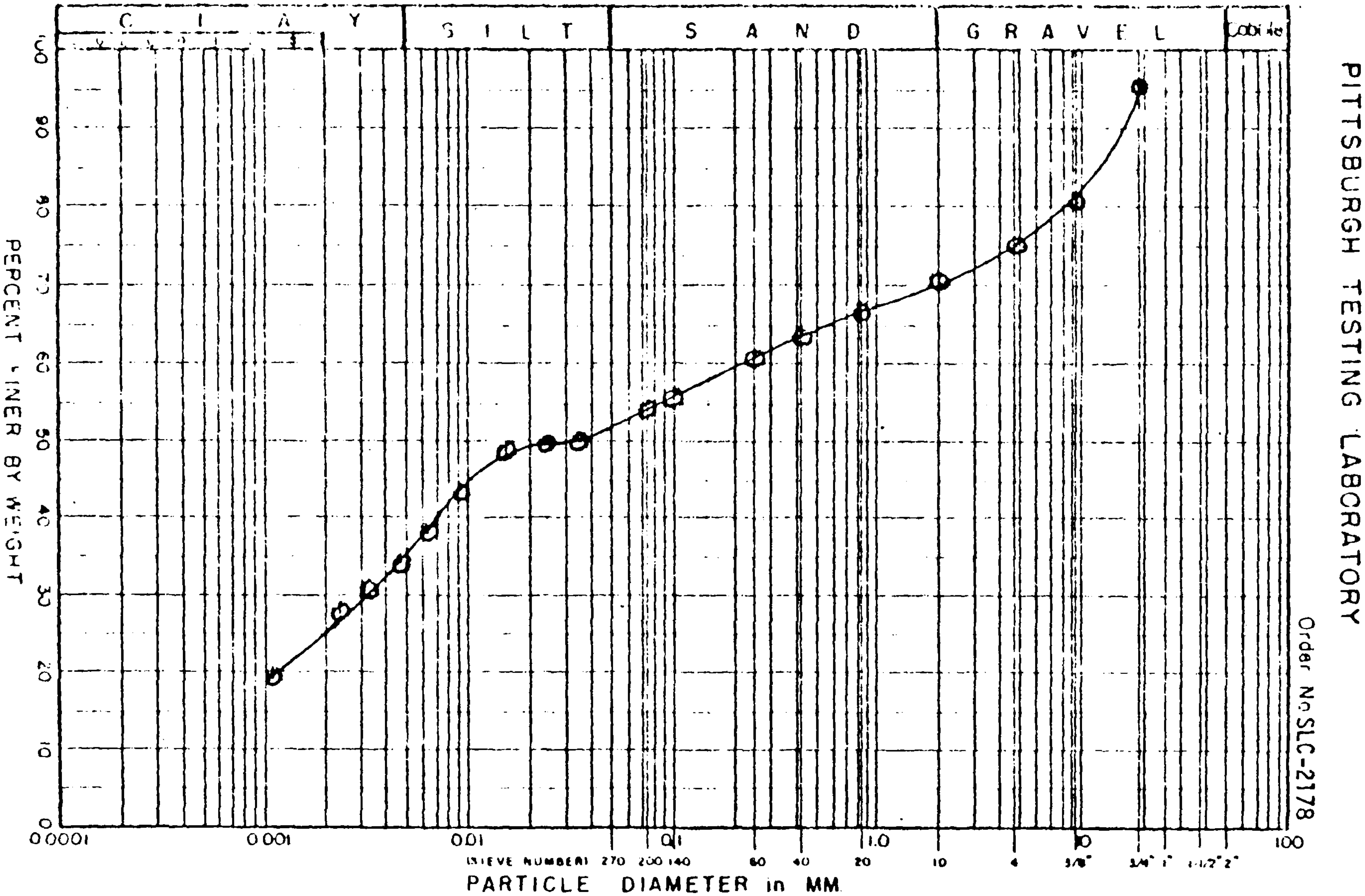
GRAIN SIZE DISTRIBUTION CURVES

Sample No	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
DH1-25	————	Specific Gravity (-#10) 2.69	DP	7-21-76	DP	7-22-76



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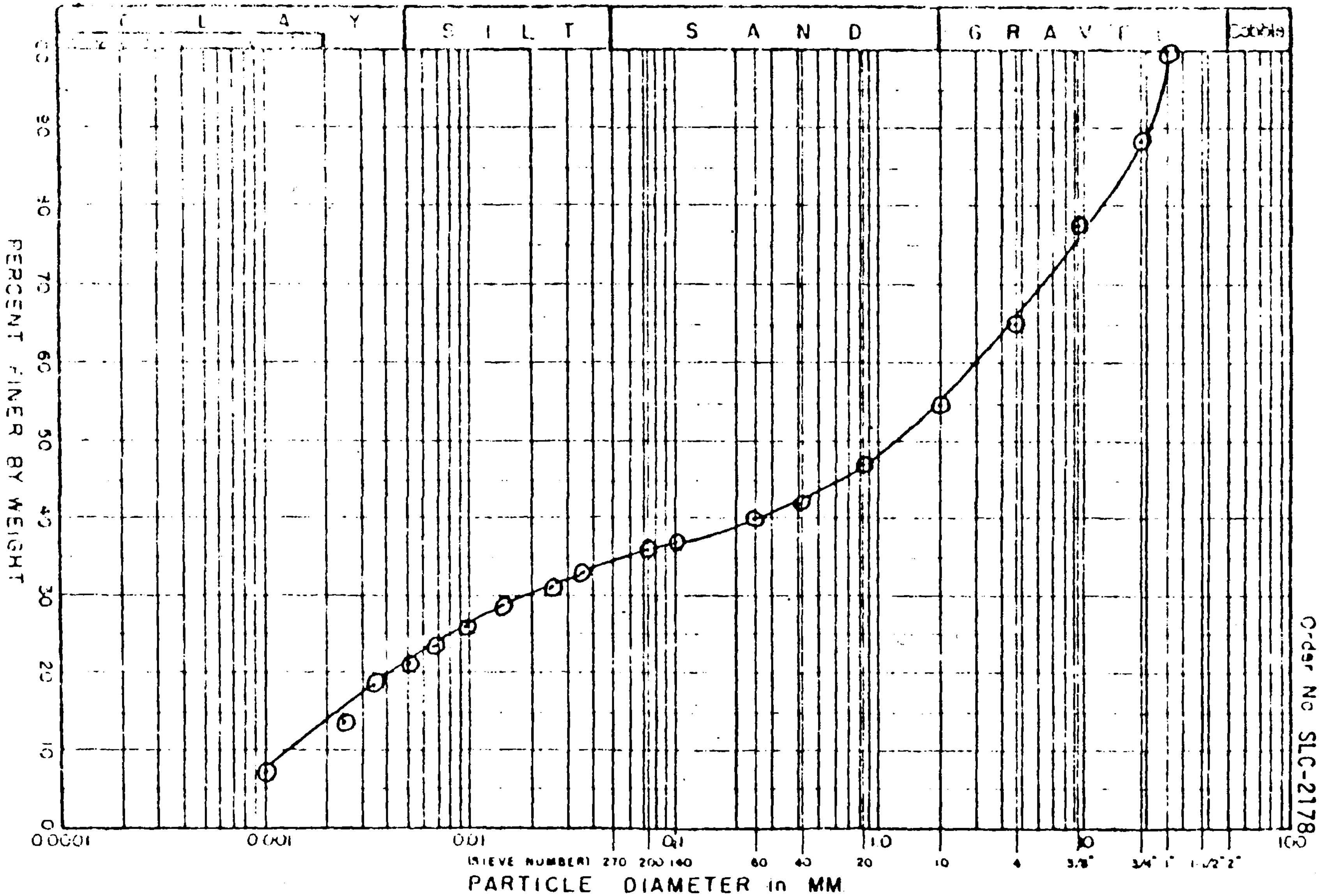
GRAIN SIZE DISTRIBUTION CURVES

Sample No.	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
#3 DH-2 at 37 ft. Manti Slide		specific gravity (-#10)	DK 2.74	6-2-76	DK	6-2-76



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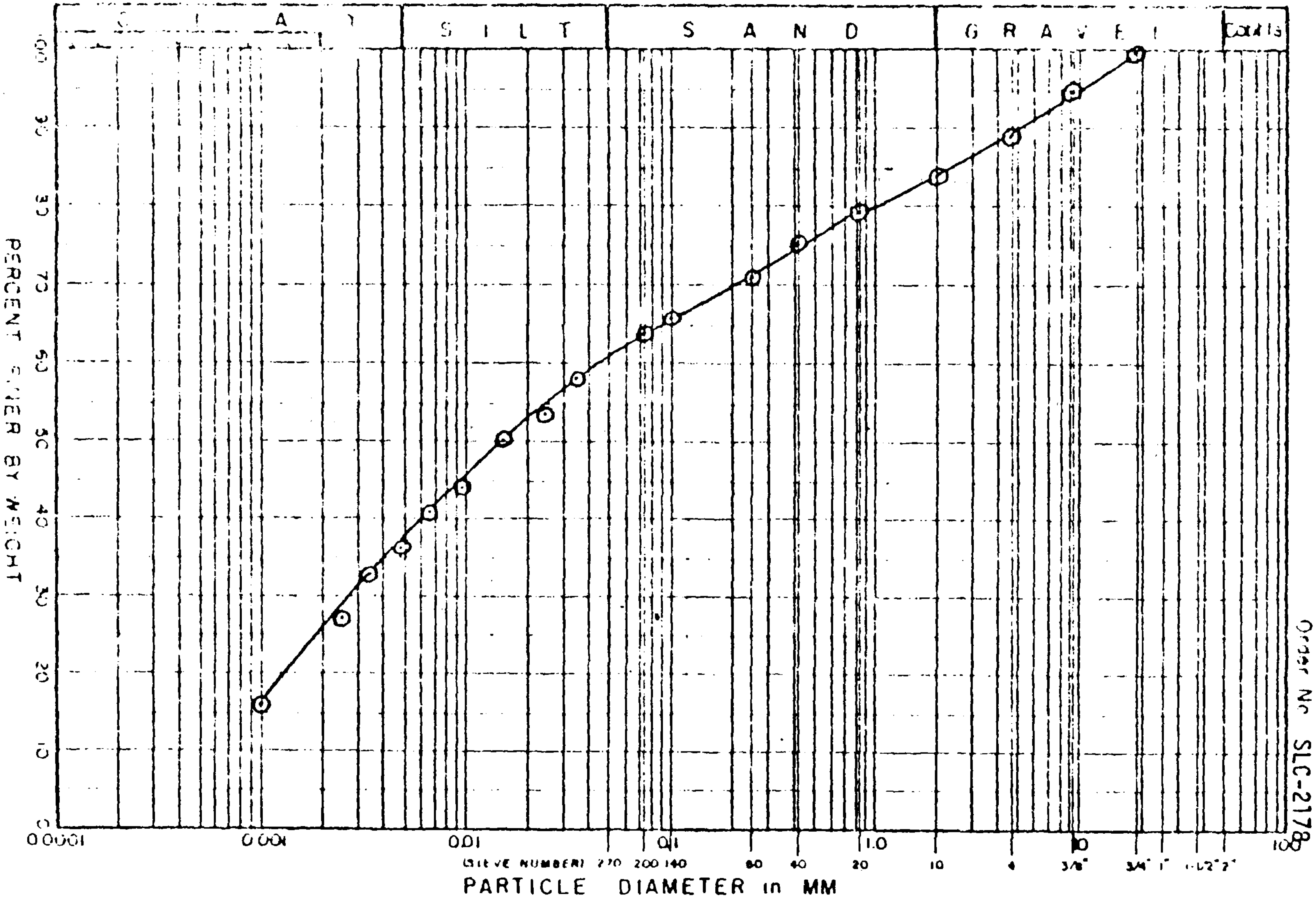
P.O. 1854

GRAIN SIZE DISTRIBUTION CURVES

Sample No.	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
#7 DH-2 at 58 ft. Mantl Slide		specific gravity (-#10)	DK 2.72	6-2-76	DK	6-2-76



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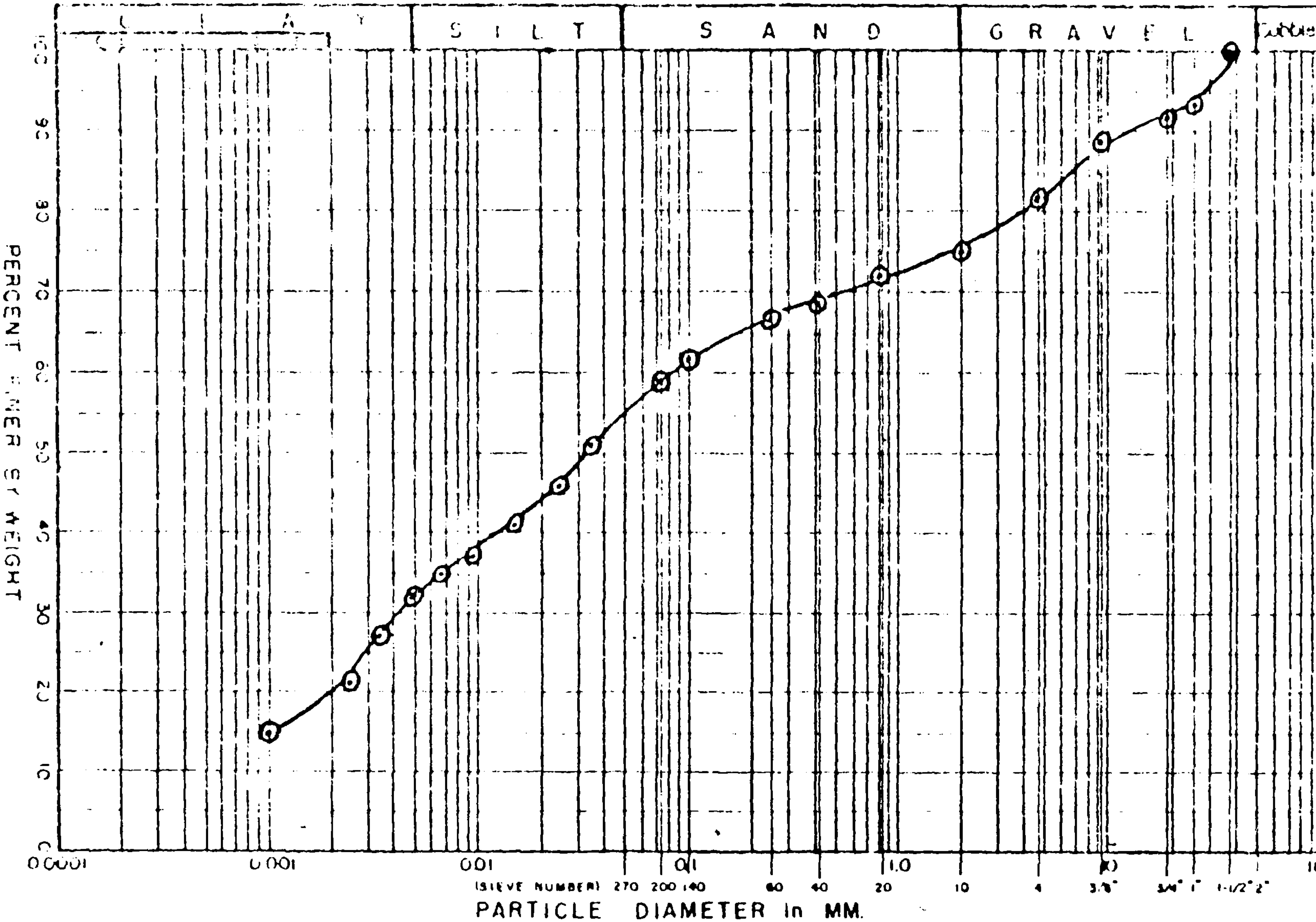
Order No. SLC-2178

GRAIN SIZE DISTRIBUTION CURVES

Sample No	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
DH-2 11 at 77 ft. Mantl Slide		apparent specific gravity (-#10) 2.67 moisture content 6.1%	DK	6-18-76	DK	6-21-76



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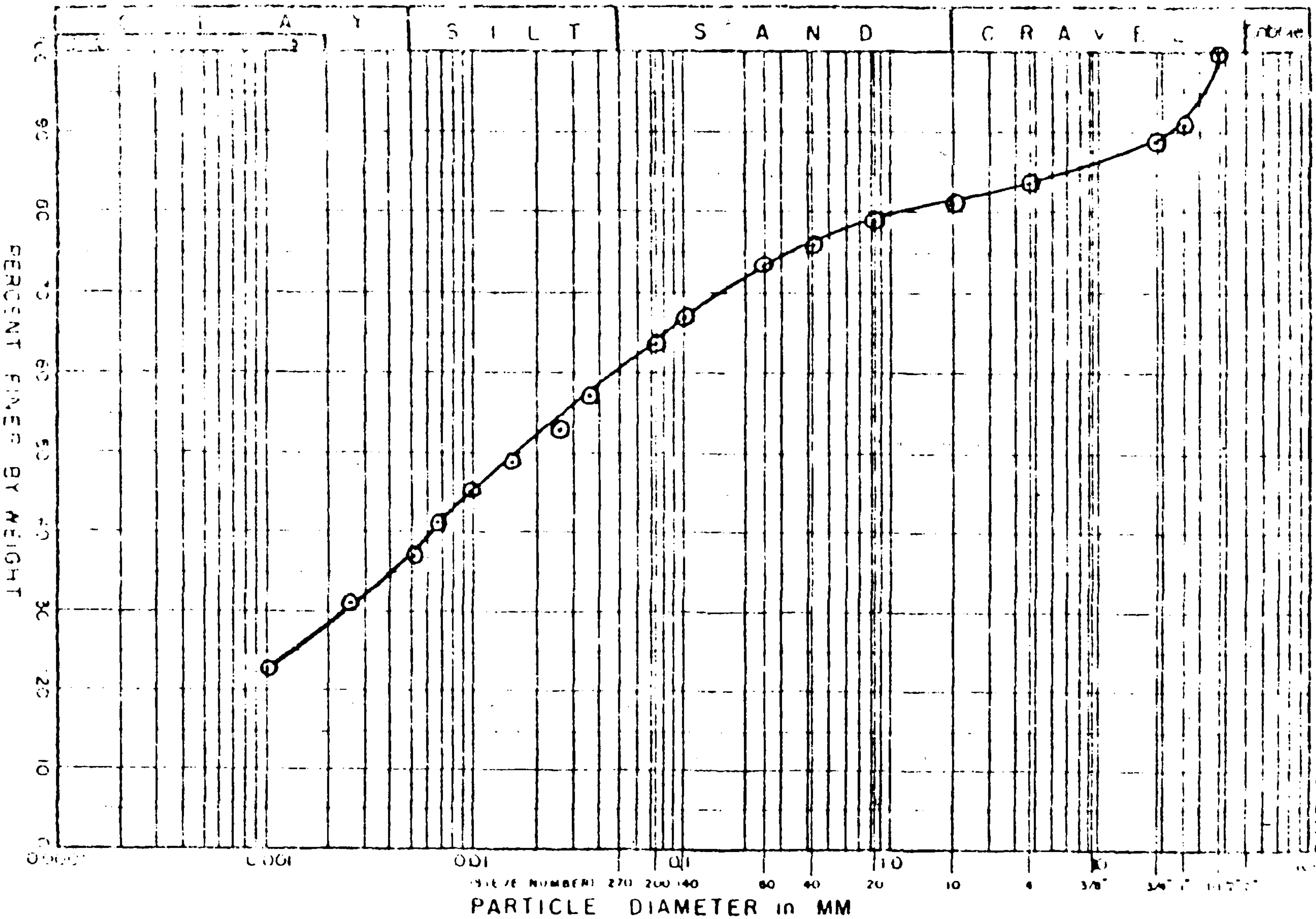
Order No SLC-2178

P.O. 1855

GRAIN SIZE DISTRIBUTION CURVES

Sample No.	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
29 DH-2 at 154 ft. Mantl Slide		apparent specific gravity (-#10) 2.57 moisture content 10.6%	DK	6-21-76	DK	6-21-76



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SLC-2178

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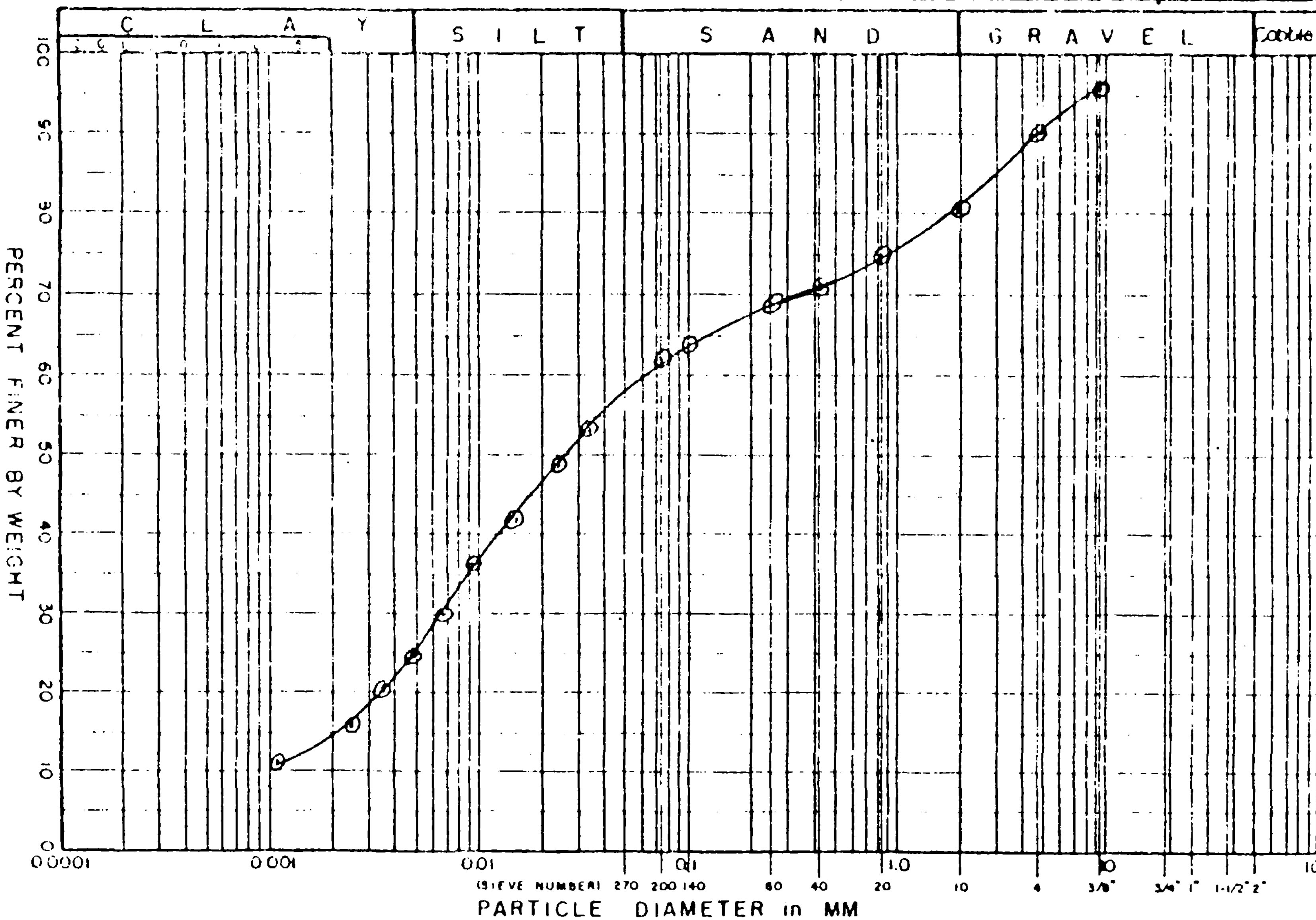
GRAIN SIZE DISTRIBUTION CURVES

Sample No	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
DH3-5	———	Specific Gravity (-#10) 2.669	DP	7-21-76	DP	7-22-76

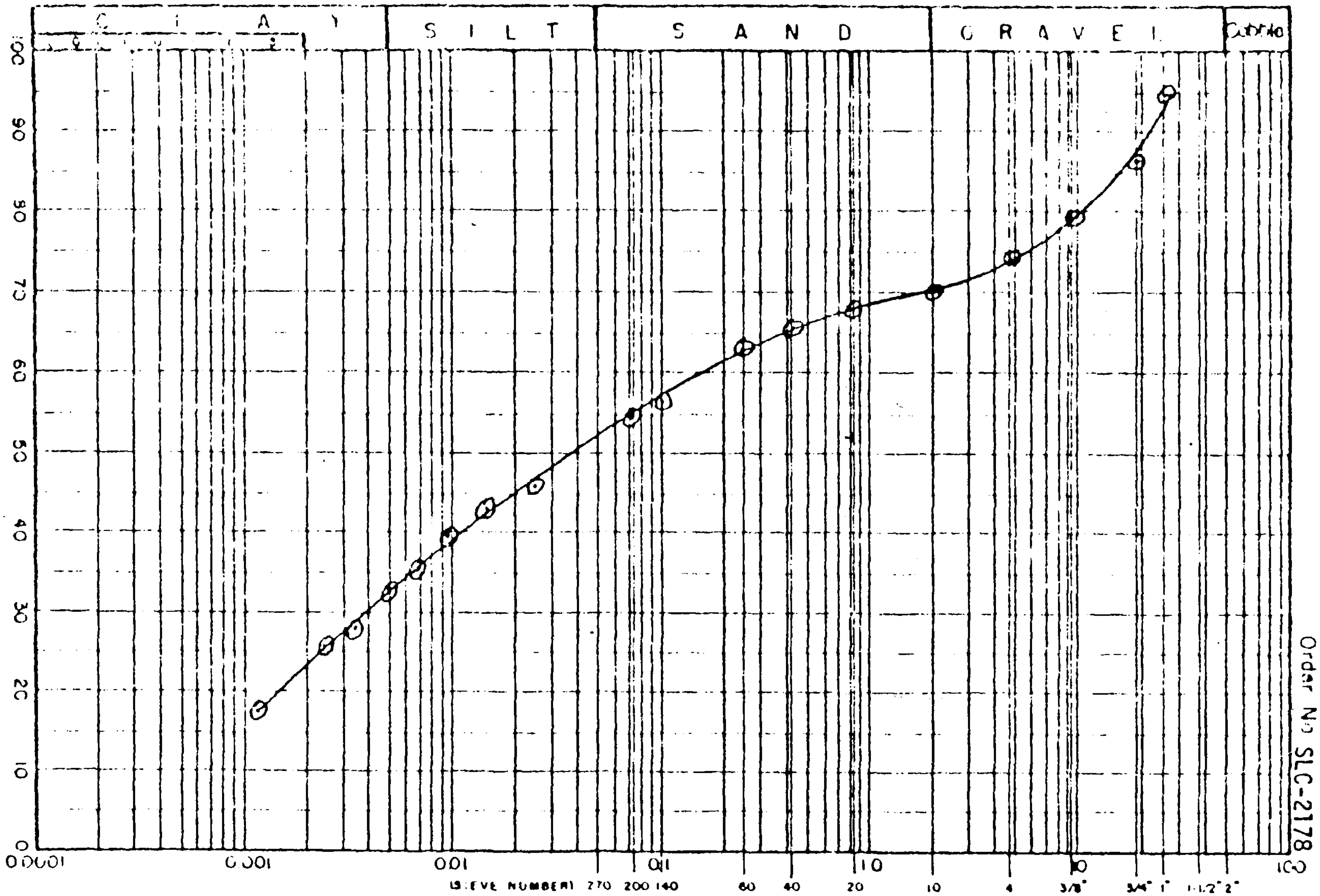


PITTSBURGH TESTING LABORATORY

Order No SLC-2178

GRAIN SIZE DISTRIBUTION CURVES

Sample No	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
DH3-11		Specific Gravity (-#10) 2.626	DP	7-21-76	DP	7-22-76



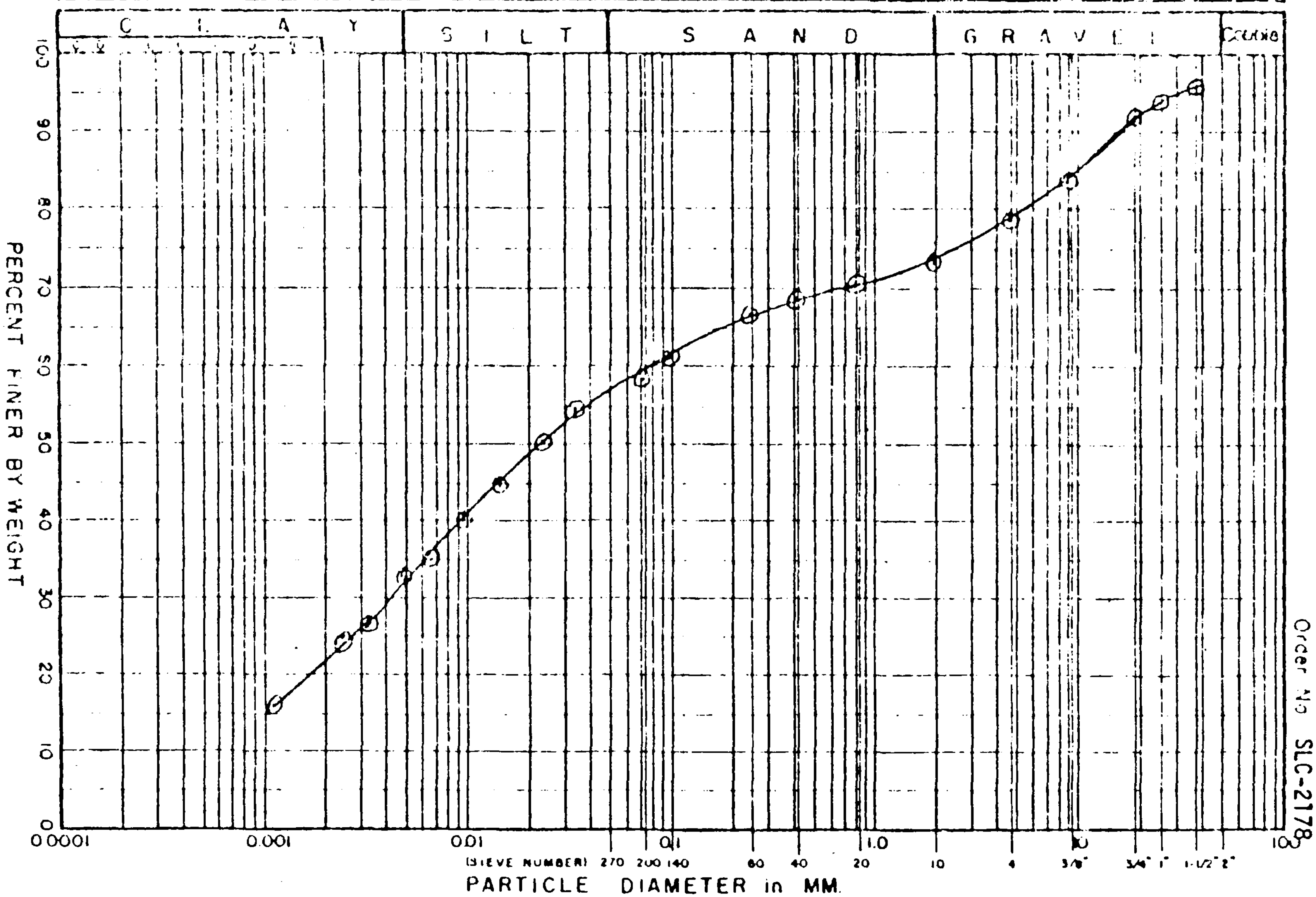
PITTSBURGH TESTING LABORATORY

Order No SLC-2178

Caldwell, Richards & Sorenson, Inc.

GRAIN SIZE DISTRIBUTION CURVES

Sample No	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
DH3-19	———	Sp. Gravity (-#10) 2.549	DP	7-21-76	DP	7-21-76

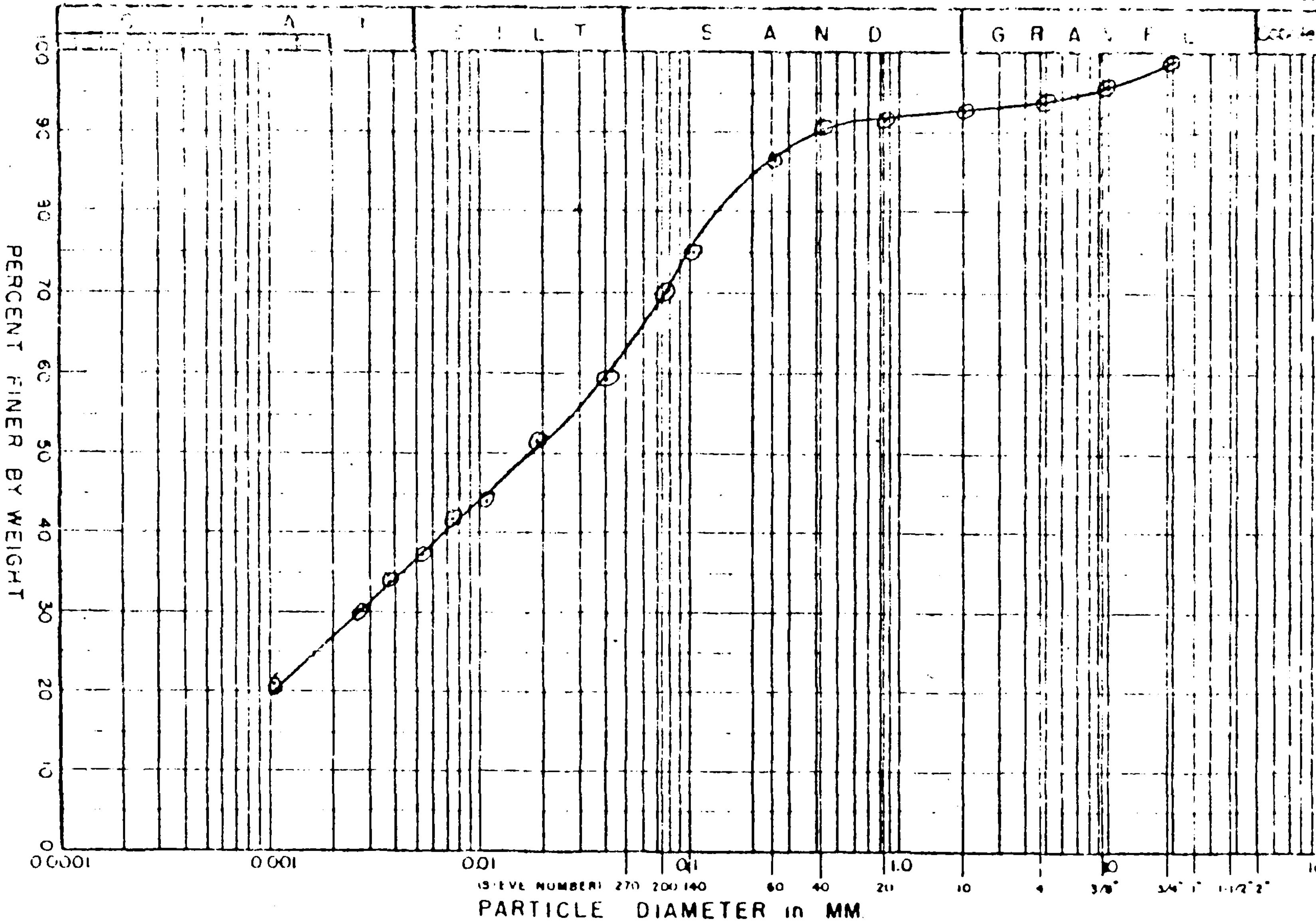


PITTSBURGH TESTING LABORATORY

Order No SLC-2178

GRAIN SIZE DISTRIBUTION CURVES

Sample No	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
DH3-23		Specific Gravity (-#10) 2.51	DP	7-21-76	DP	7-22-76



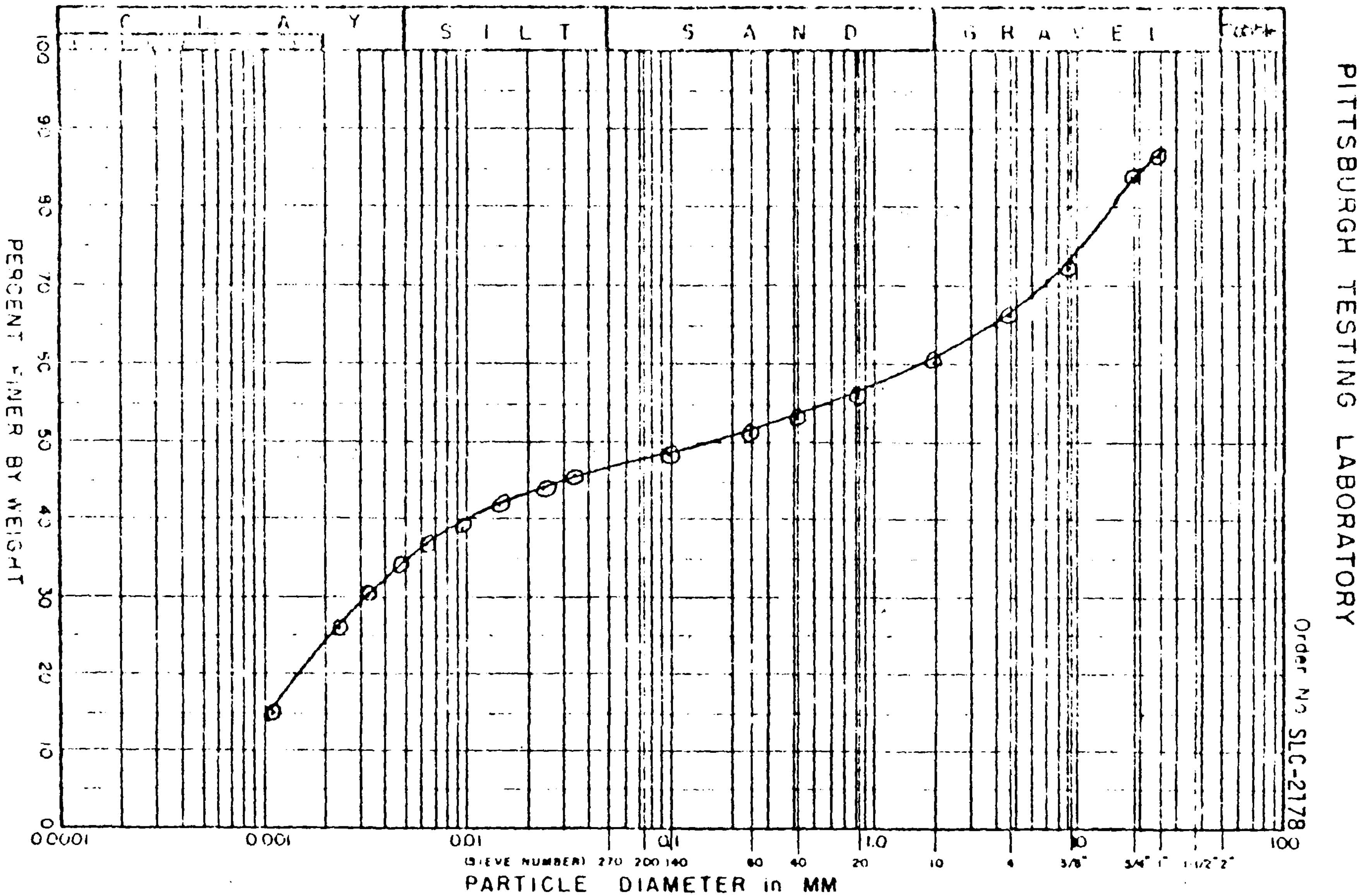
Order No SLC-2178

PITTSBURGH TESTING LABORATORY

Caldwell, Richards & Sorenson, Inc.

GRAIN SIZE DISTRIBUTION CURVES

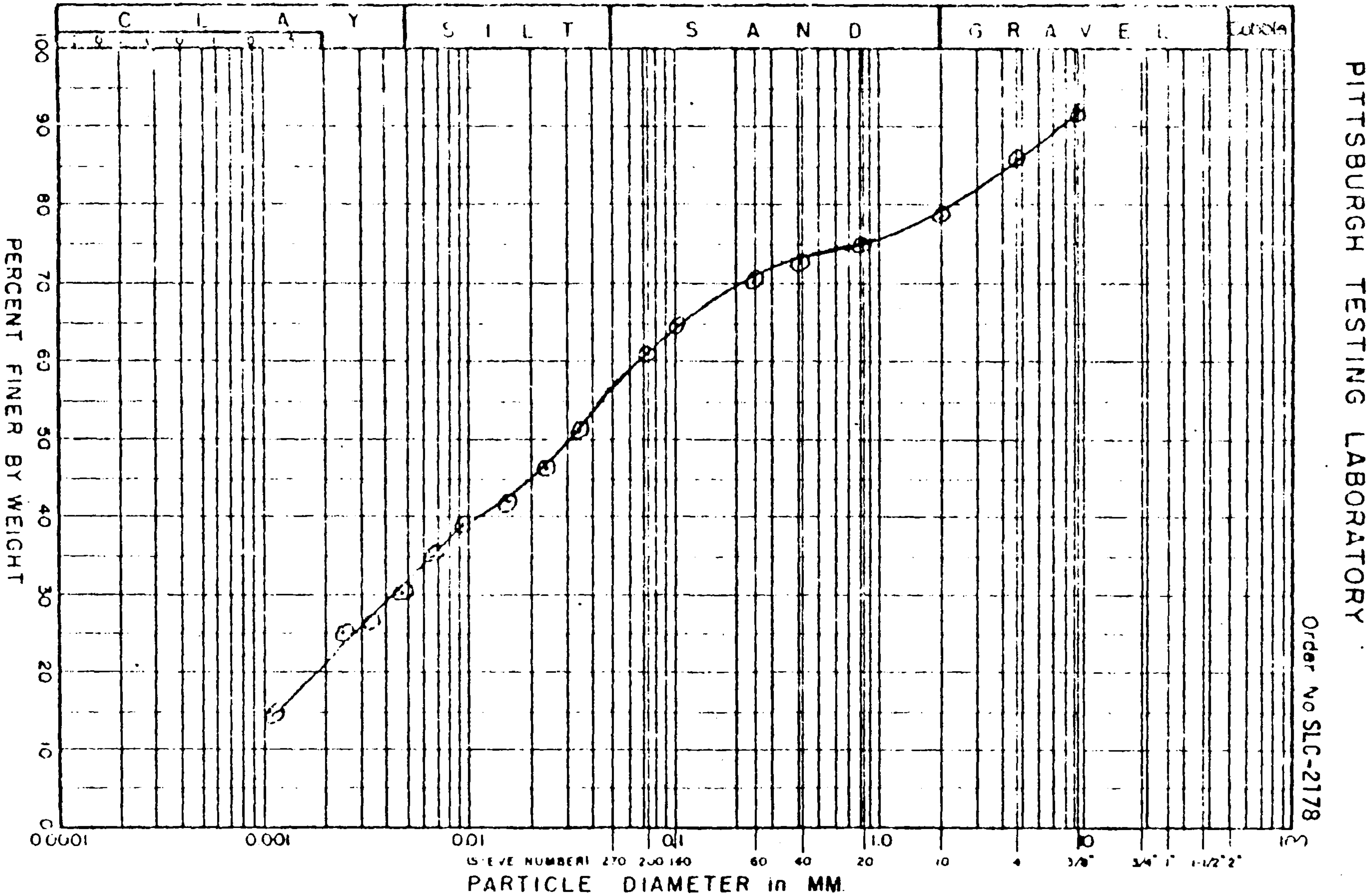
Sample No	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
DH4-3	———	SP Gr. (-#10) 2.622	DP	7-21-76	DP	7-22-76



Caldwell, Richards & Sorenson, Inc.

GRAIN SIZE DISTRIBUTION CURVES

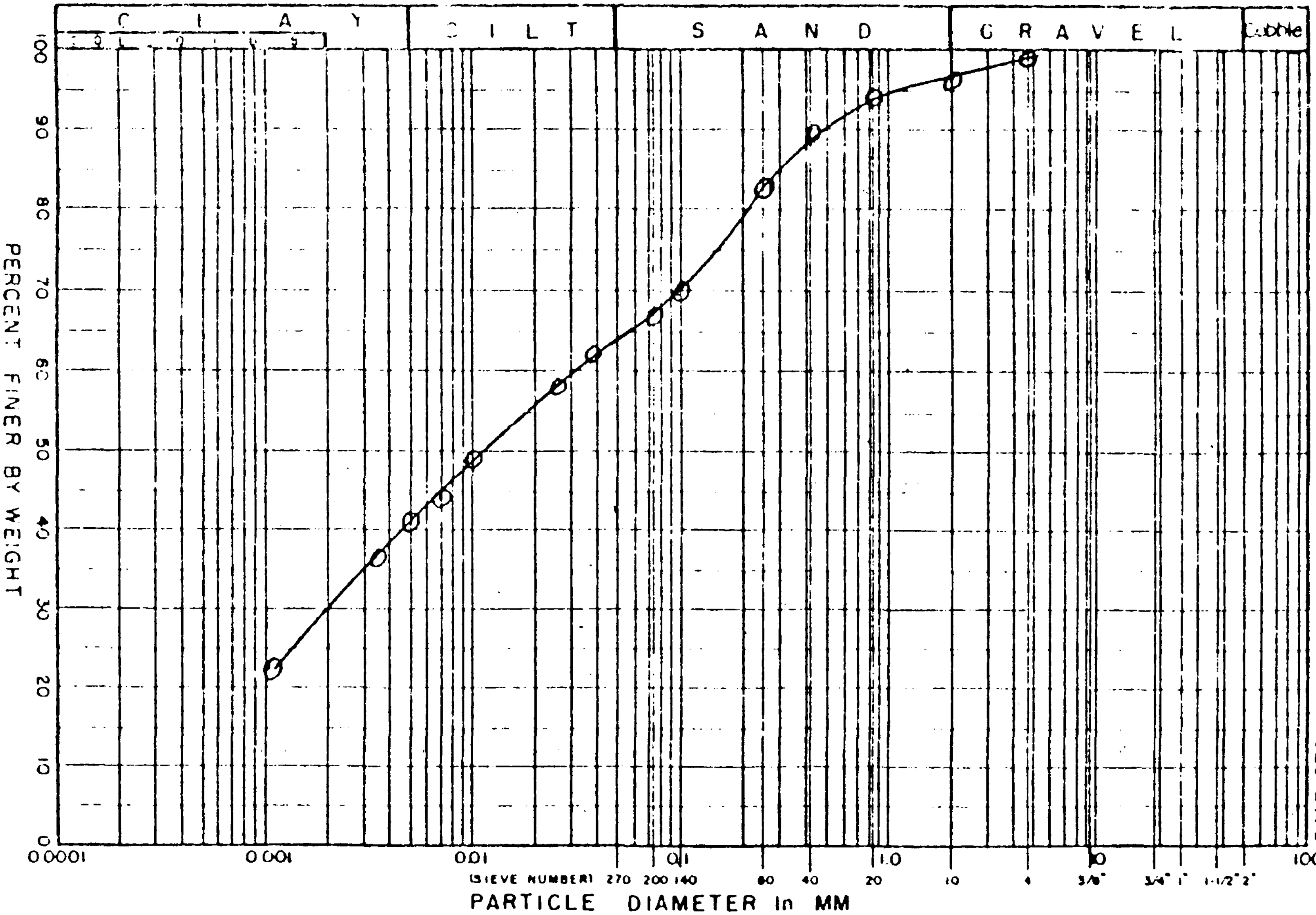
Sample No	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
DH4-7		Specific Gravity (-#10) 2.629	DP	7-21-76	DP	7-22-76



Caldwell, Richards & Sorenson, Inc.

GRAIN SIZE DISTRIBUTION CURVES

Sample No	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
DH4-11		Specific Gravity (-#10) 2.375	DP	7-21-76	DP	7-22-76



PITTSBURGH TESTING LABORATORY

Order No SLC-2178

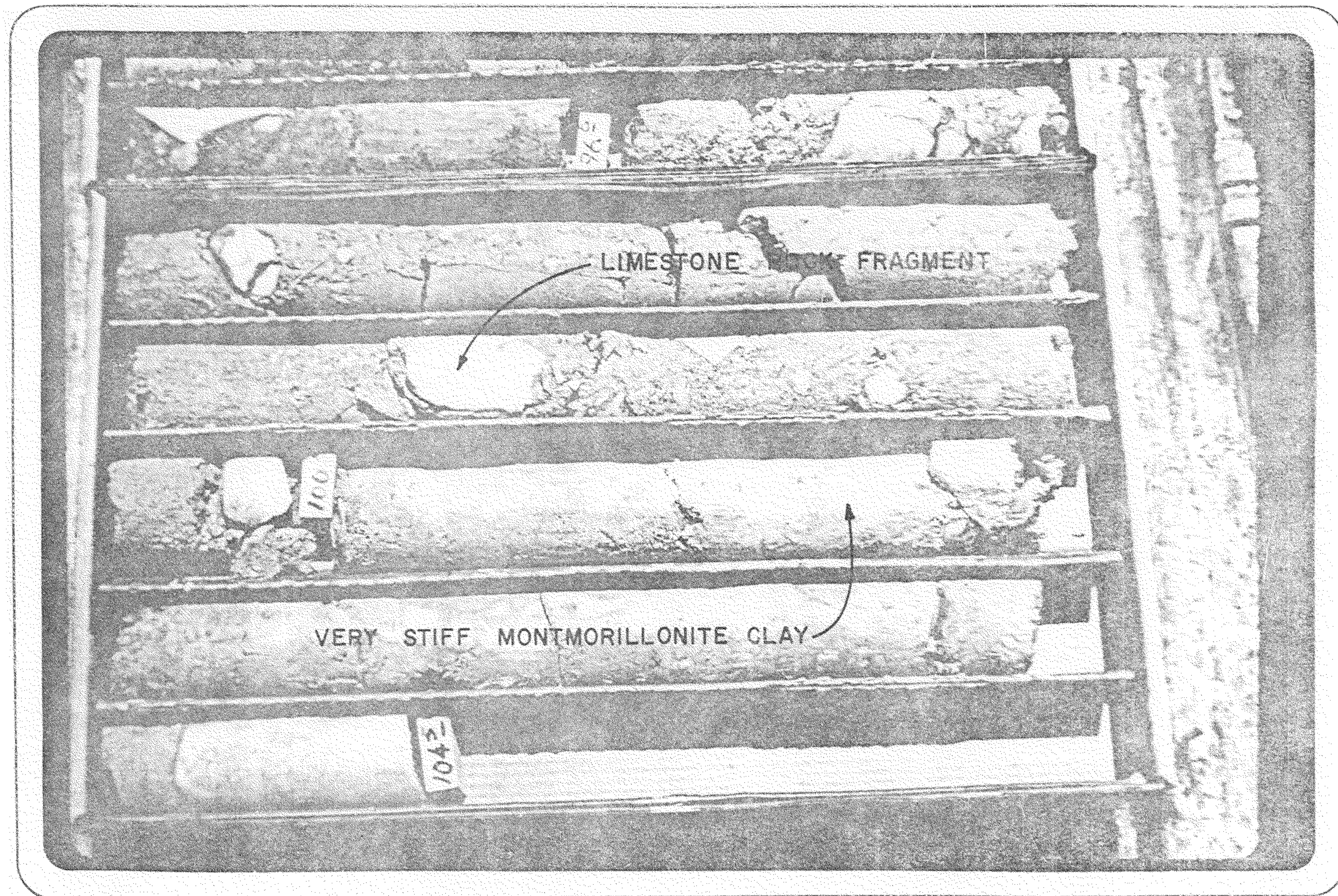


PHOTO 2 — TYPICAL DENSE GLACIAL TILL DH-1 95' TO 104'

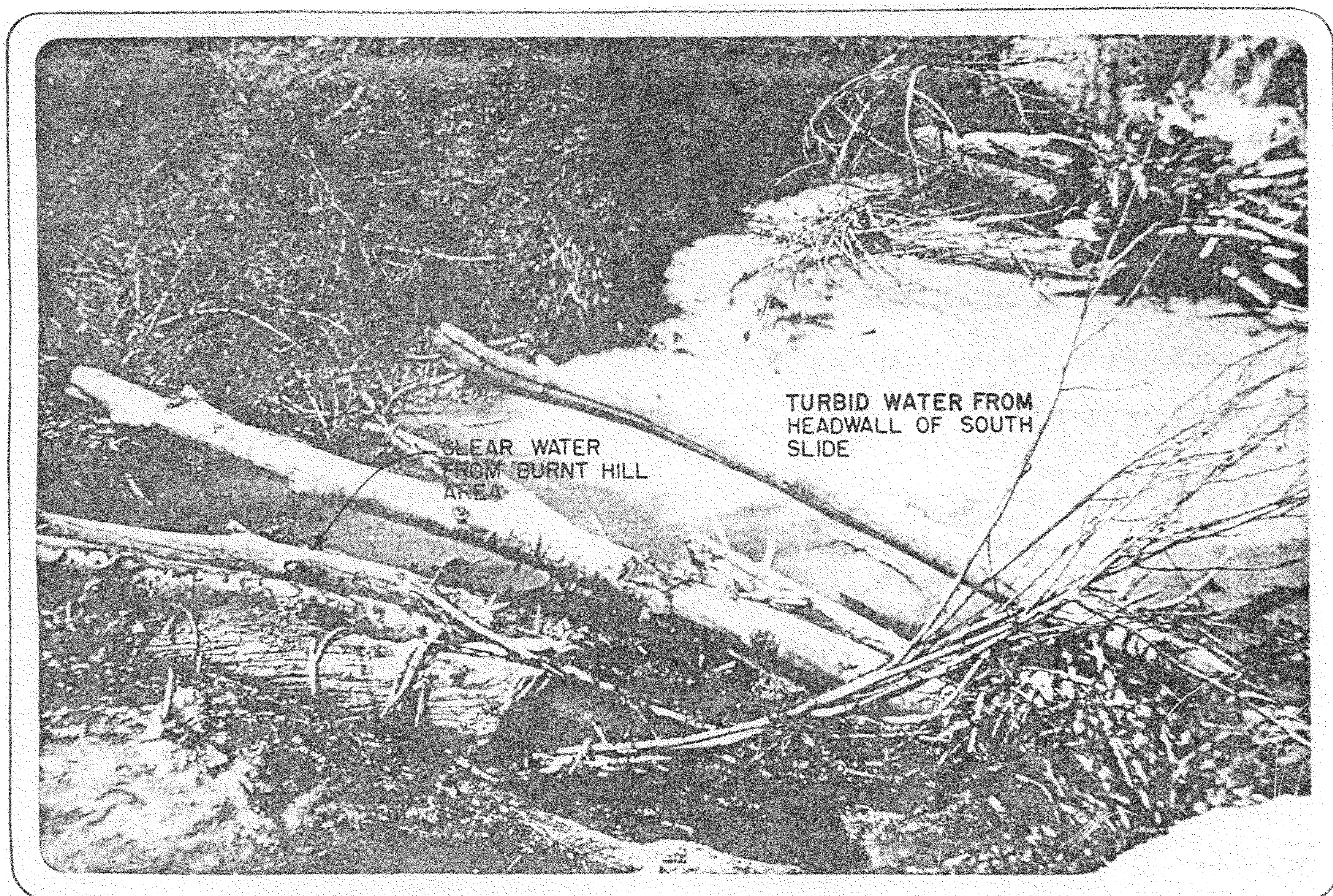


PHOTO 3 — MIXING OF CLEAR WATER FROM BURNT HILL FORK AND TURBID WATER FROM THE SOUTH FORK OF COTTONWOOD CREEK

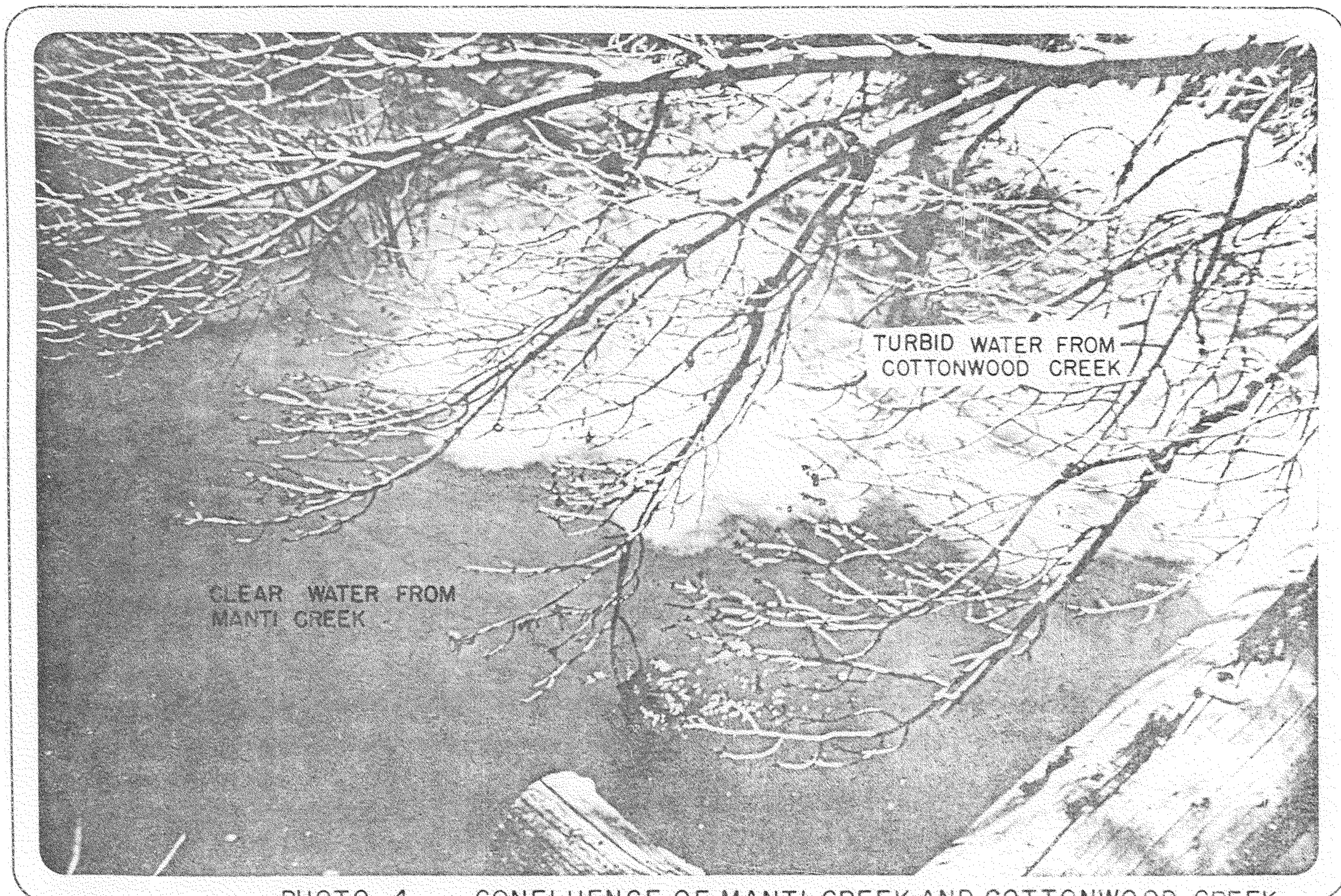


PHOTO 4 — CONFLUENCE OF MANTI CREEK AND COTTONWOOD CREEK
SHOWING MIXING OF CLEAR AND TURBID WATERS

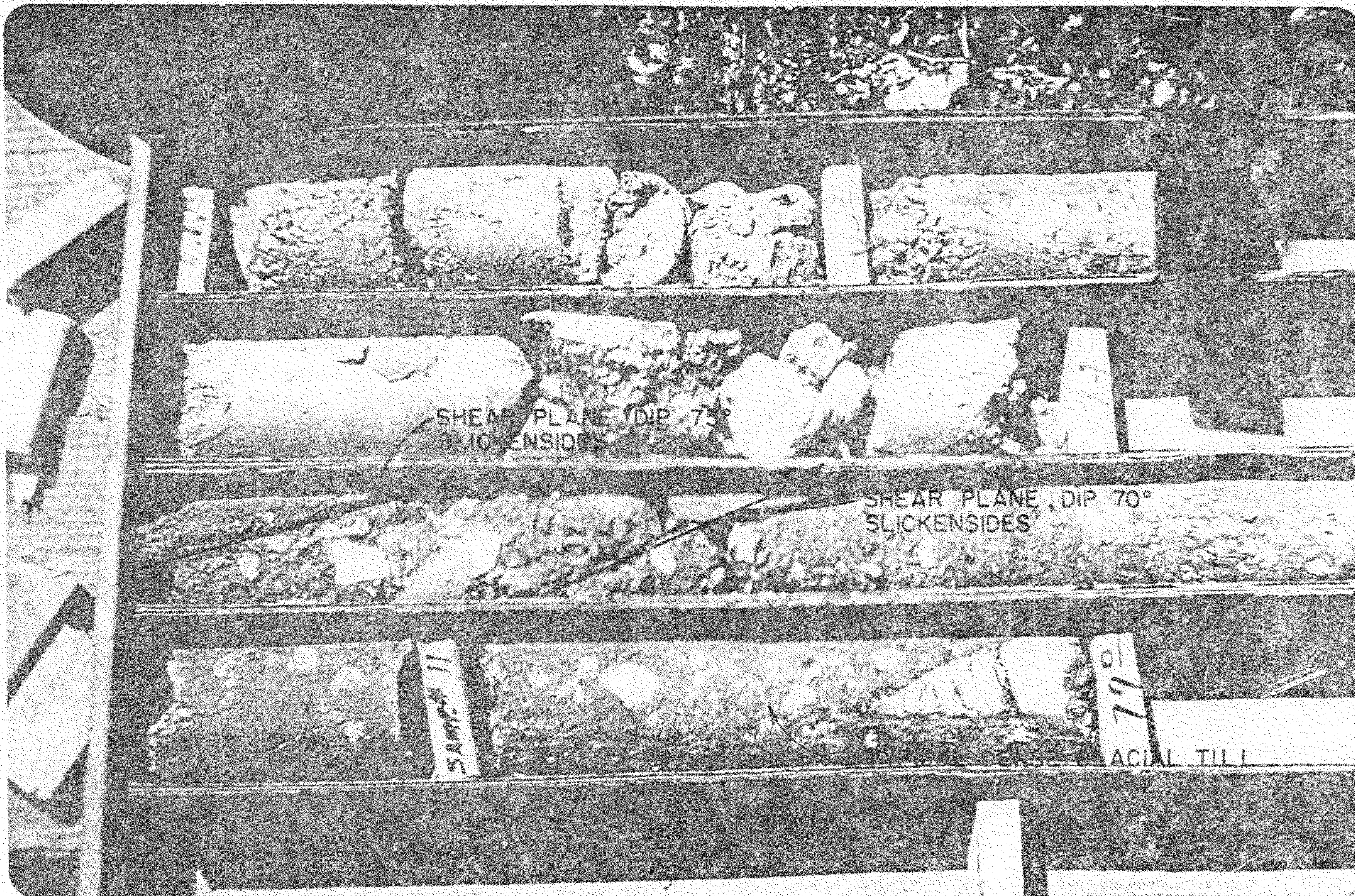


PHOTO 5 — GLACIAL TILL, NC CORE FROM DH-2
SHOWING SHEAR PLANES

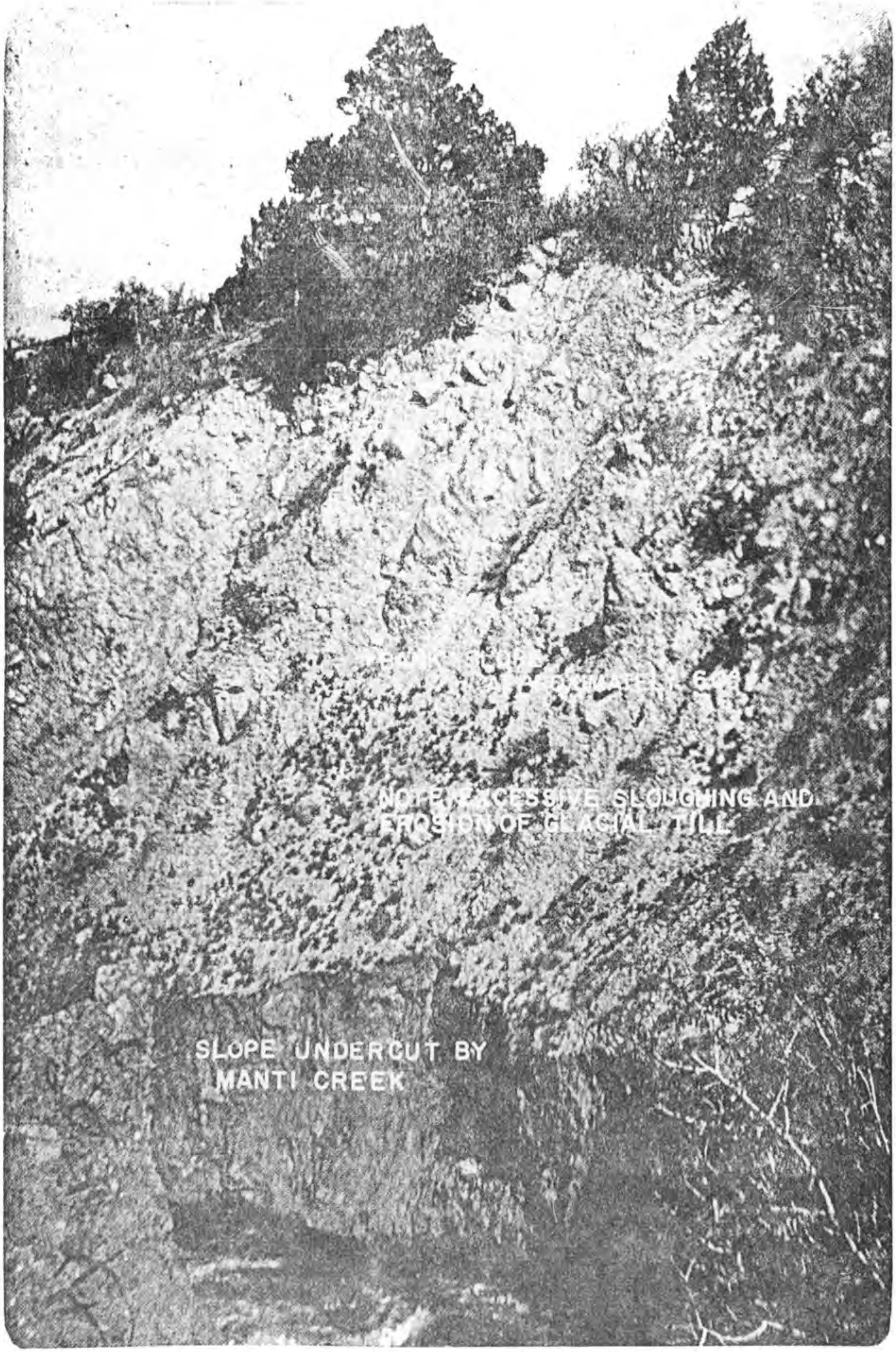


PHOTO 6 – TAKEN AT BASE OF STABILITY
SECTION I

PHOTO 1 TAKEN AT BASE OF STABILITY
SECTION 2

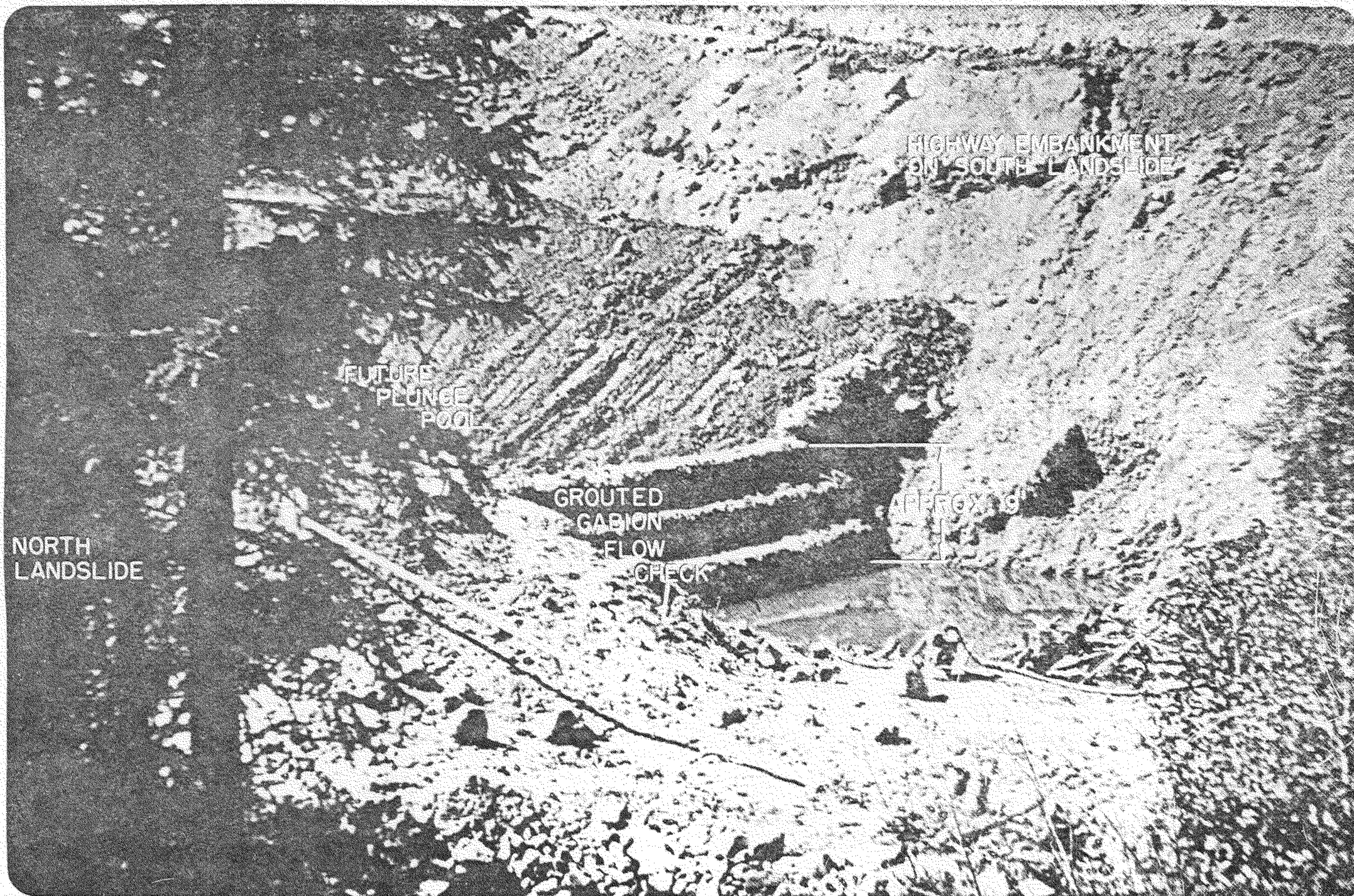


PHOTO 8 - CONSTRUCTION OF STABILIZED CHANNEL
VAIL PASS, COLORADO

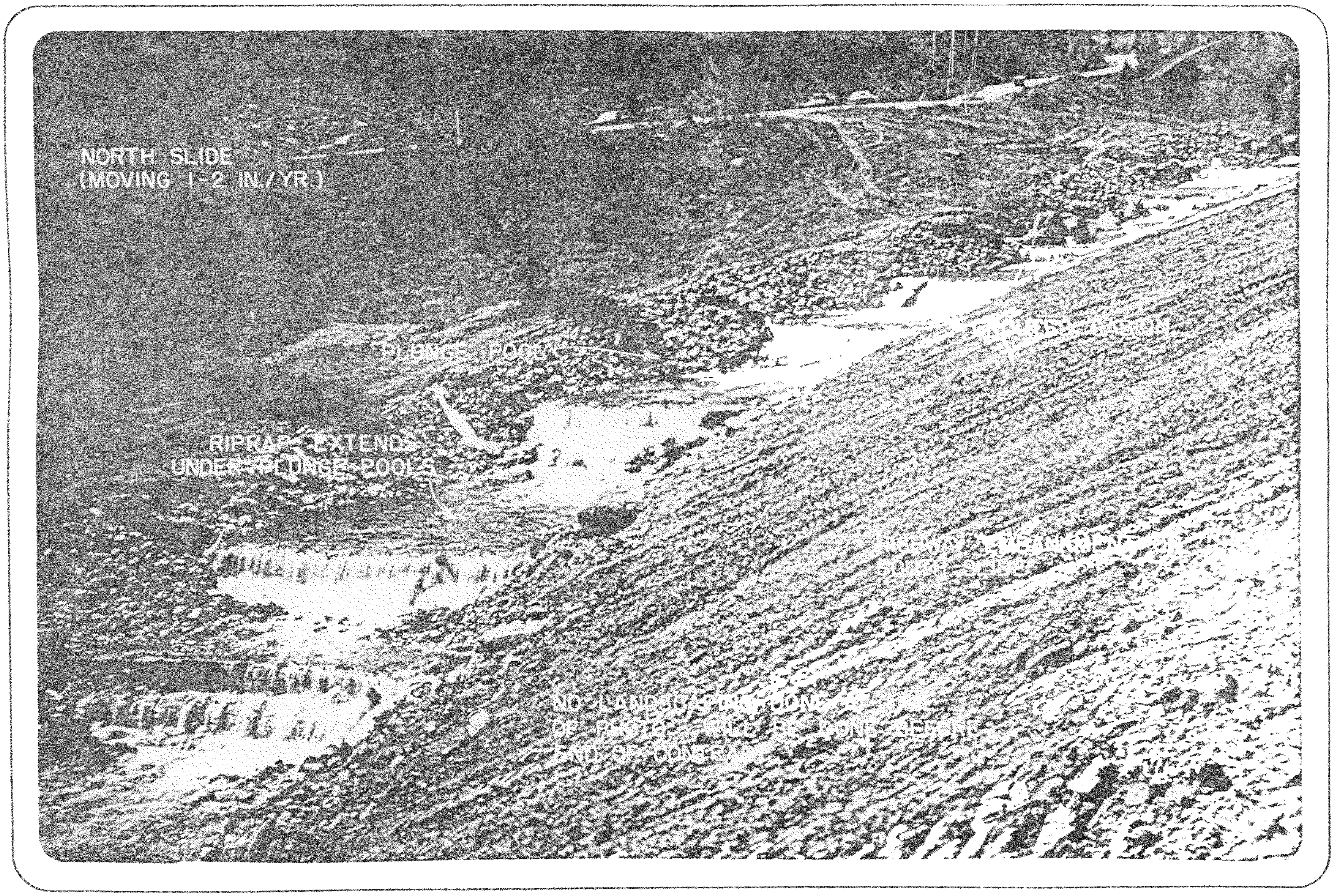


PHOTO 9 — COMPLETED STABILIZED CHANNEL ACROSS TWO LANDSLIDES
VAIL PASS, COLORADO

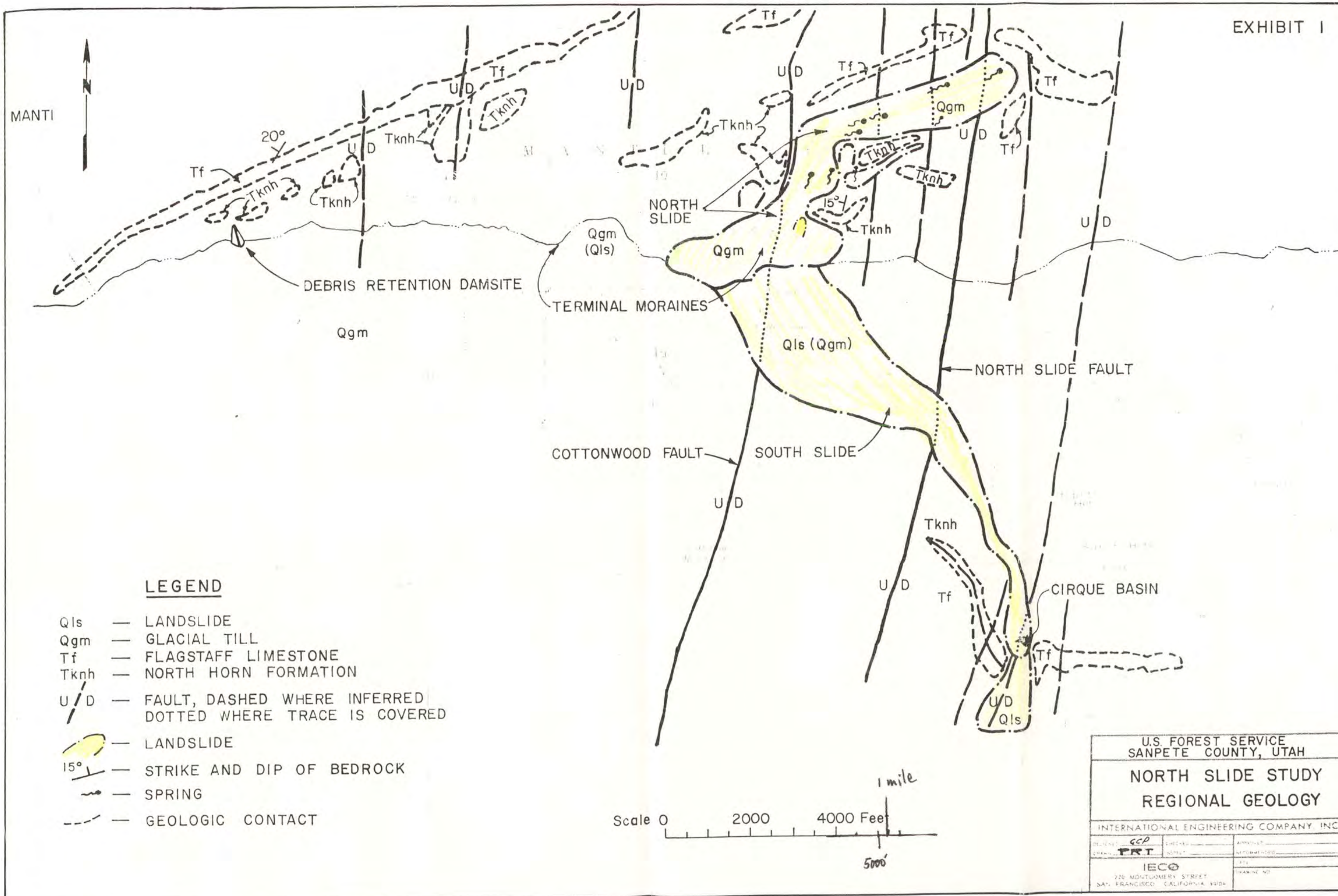
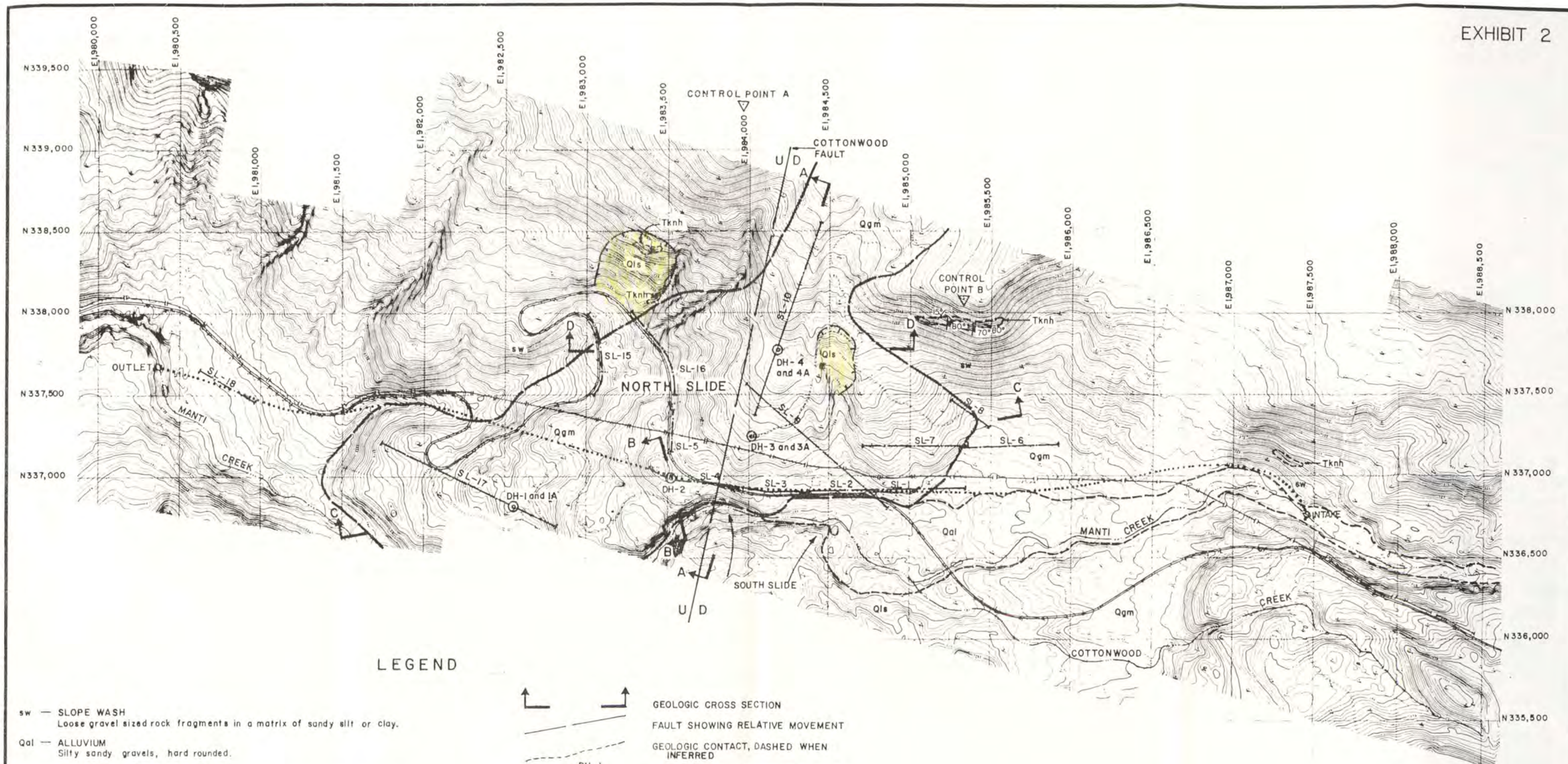


EXHIBIT I
MANTI
N
20°
Tf
Tknh
U D
Qgm
(Qls)
NORTH SLIDE
15°
DEBRIS RETENTION DAMSITE
TERMINAL MORAINES
Qls (Qgm)
NORTH SLIDE FAULT
COTTONWOOD FAULT
SOUTH SLIDE
CIRQUE BASIN
Qls
LEGEND
Qls — LANDSLIDE
Qgm — GLACIAL TILL
Tf — FLAGSTAFF LIMESTONE
Tknh — NORTH HORN FORMATION
U / D — FAULT, DASHED WHERE INFERRED DOTTED WHERE TRACE IS COVERED
— LANDSLIDE
15° — STRIKE AND DIP OF BEDROCK
— SPRING
— GEOLOGIC CONTACT
Scale 0 2000 4000 Feet
1 mile
5000'
U.S. FOREST SERVICE
SANPETE COUNTY, UTAH
NORTH SLIDE STUDY
REGIONAL GEOLOGY
INTERNATIONAL ENGINEERING COMPANY, INC.
IECO
220 MONTGOMERY STREET
SAN FRANCISCO CALIFORNIA

EXHIBIT 2



LEGEND

sw — SLOPE WASH
Loose gravel sized rock fragments in a matrix of sandy silt or clay.

Qal — ALLUVIUM
Silty sandy gravels, hard rounded.

Qls — LANDSLIDE
Active slides in glacial till and bedrock with broken disturbed surfaces.

Qgm — GLACIAL TILL
Dense gravel in a matrix of brown and gray montmorillonite clay or silt.

Tknh — NORTH HORN FORMATION
Interbedded brown and gray hard sandstone and gray and buff soft siltstone and shale.

GEOLOGIC CROSS SECTION
FAULT SHOWING RELATIVE MOVEMENT
GEOLOGIC CONTACT, DASHED WHEN INFERRED
DH-1 and IA — EXPLORATORY AND INCLINOMETER HOLE
15 — STRIKE AND DIP
70 — STRIKE AND DIP OF MAJOR JOINT SETS
SL-3 — SEISMIC LINE
Qls — LANDSLIDE
SURFACE SURVEY CONTROL POINT
MANTI WATER PIPELINE
ACCESS ROAD
JEEP ROAD
PROPOSED BY-PASS PIPELINE

SCALE 0 500 1000 FEET

U.S. FOREST SERVICE
SANPETE COUNTY, UTAH

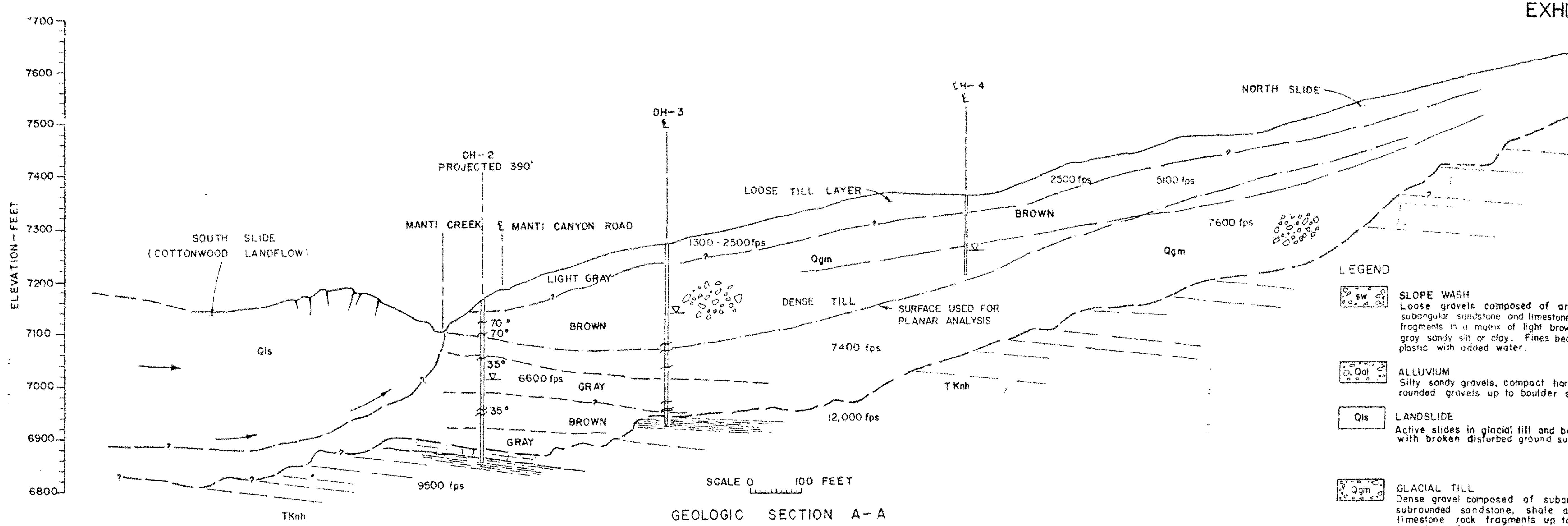
NORTH SLIDE STUDY

NORTH SLIDE GEOLOGY AND DRILL HOLE LOCATIONS

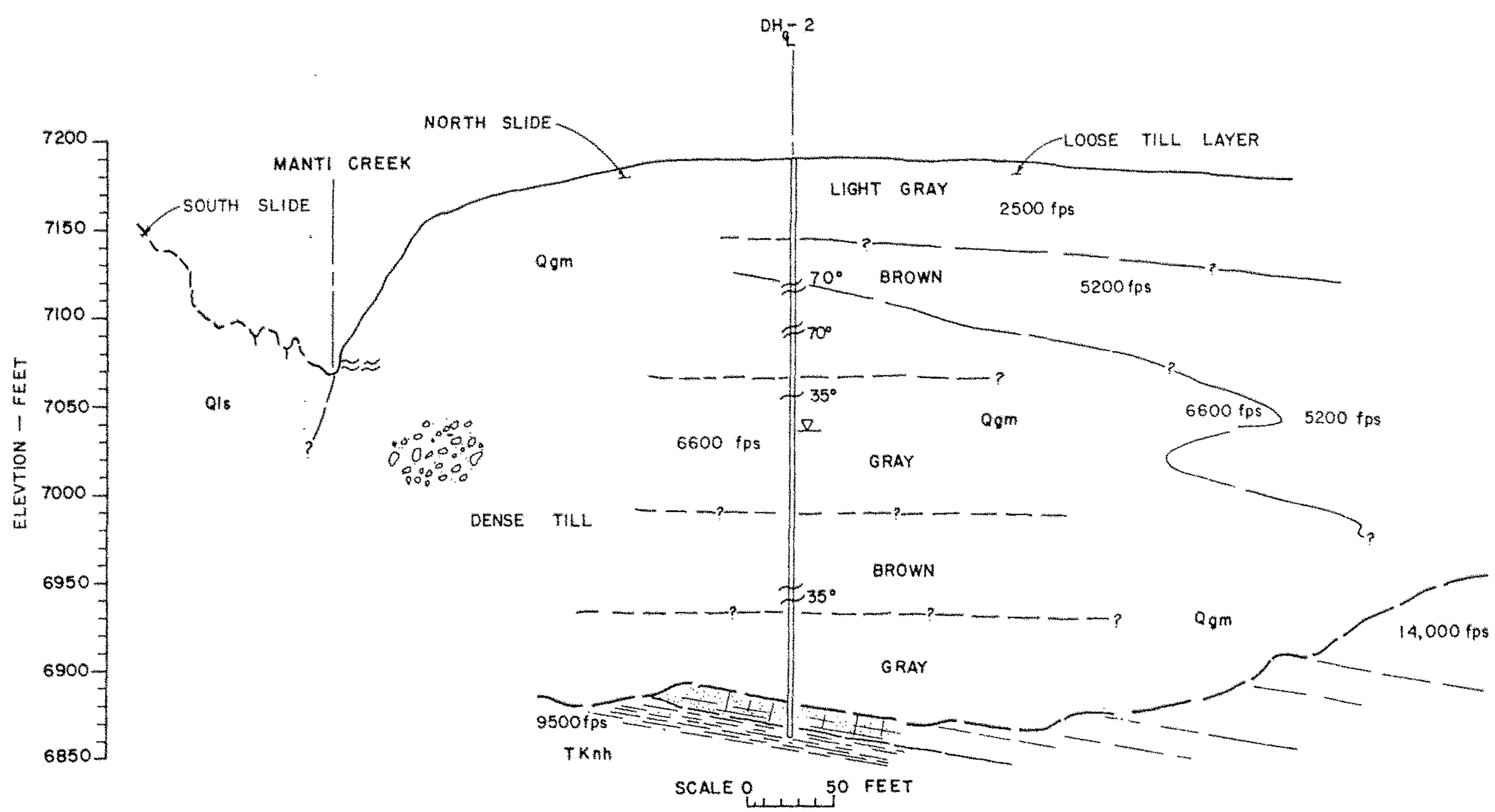
INTERNATIONAL ENGINEERING COMPANY, INC.

DESIGNED CCP	CHECKED [signature]	APPROVED
DRAWN ASC.	INSPECT	RECOMMENDED
IECO 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		DATE 9-1-76
		DRAWING NO.

EXHIBIT 3



GEOLOGIC SECTION A-A



GEOLOGIC SECTION B-B

LEGEND

SW — SLOPE WASH
Loose gravels composed of angular to subangular sandstone and limestone rock fragments in a matrix of light brown and gray sandy silt or clay. Fines become slightly plastic with added water.

Qal — ALLUVIUM
Silty sandy gravels, compact hard fresh rounded gravels up to boulder size.

Qls — LANDSLIDE
Active slides in glacial till and bedrock with broken disturbed ground surfaces.

Qgm — GLACIAL TILL
Dense gravel composed of subangular to subrounded sandstone, shale and limestone rock fragments up to boulder size in a fine grained matrix of brown and gray montmorillonite clay or silt, well consolidated. Fines are very stiff, nonplastic at natural moisture, become plastic with medium dry strength upon addition of water.

TKnh — NORTH HORN FORMATION
Early Tertiary – Late Cretaceous interbedded sandstone siltstone and montmorillonitic shale. Sandstone is light reddish brown to gray, cross-bedded medium to coarse grained, hard. Siltstone is gray to dark gray, soft, massive. Shale is light brown to buff, soft. Average strike N 45° E dip 15 – 20° NW.

~35° Shear plane or shear zone. Slickensides in dark gray clay. Dip of shear planes given.

Contact between geologic zones as differentiated by drill hole and seismic data, queried where approximate.

▽ Groundwater level and profile.

U D Fault, dashed where uncertain.

SCALE AS NOTED

U.S. FOREST SERVICE
SANPETE COUNTY, UTAH

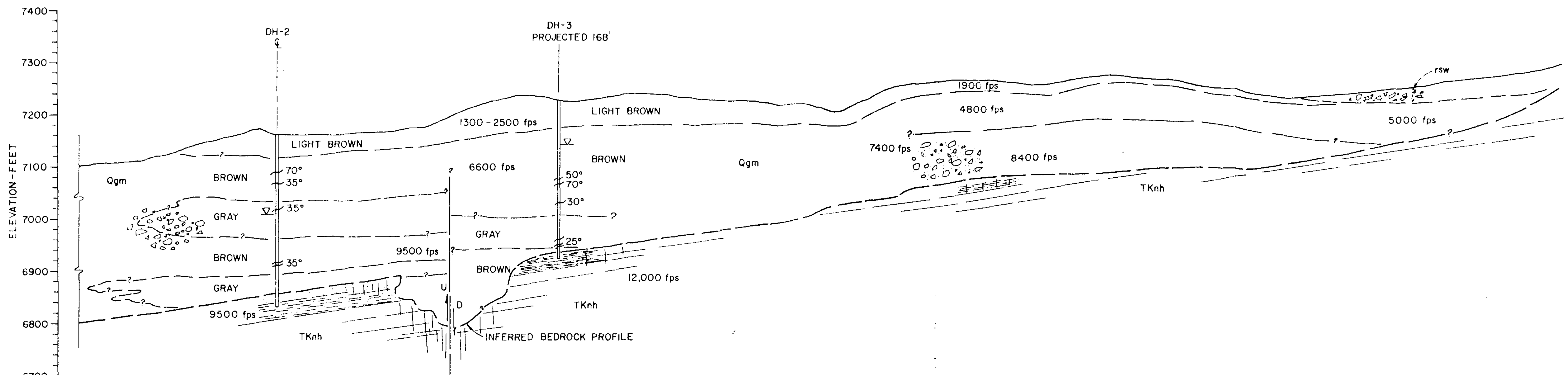
NORTH SLIDE STUDY

GEOLOGIC CROSS SECTIONS
A-A & B-B

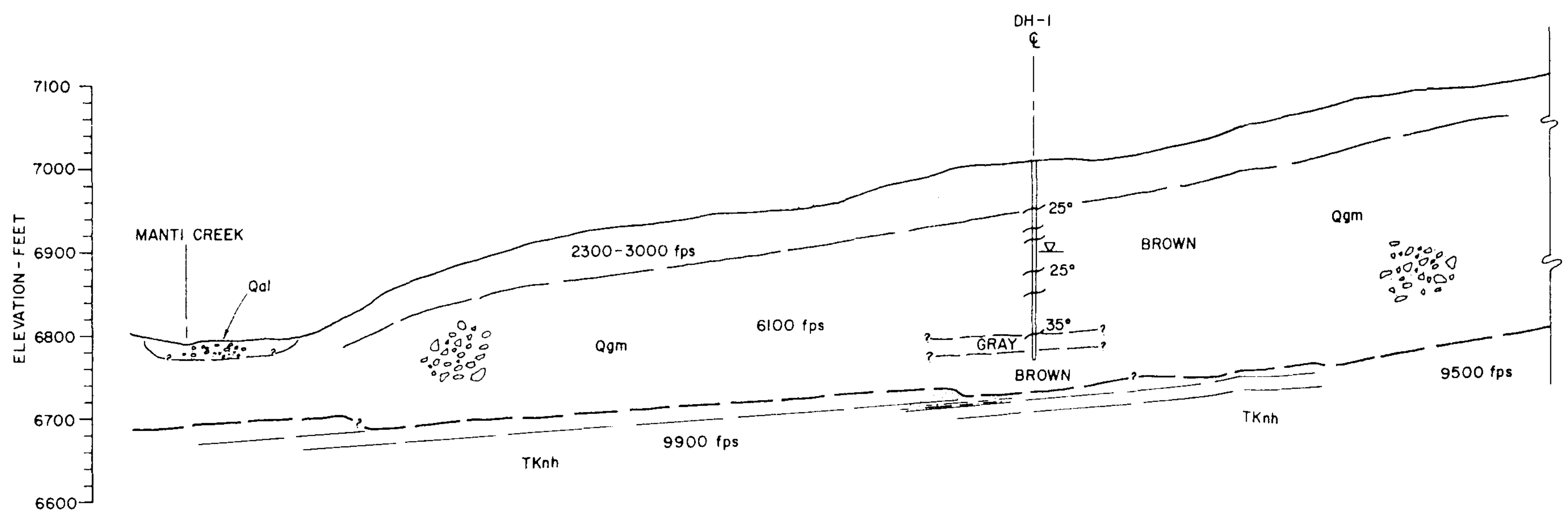
INTERNATIONAL ENGINEERING COMPANY, INC.

DESIGNED ccp	CHECKED	APPROVED
DRAWN BSO	INSPECT.	RECOMMENDED
IECO 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		DATE 9-1-76 Rev 1-24-77
		DRAWING NO

EXHIBIT 4



GEOLOGIC SECTION C-C



GEOLOGIC SECTION C-C
CONTINED

NOTE: FOR LEGEND SEE EXHIBIT 3

SCALE 0 100 200 FEET

U.S. FOREST SERVICE
SANPETE COUNTY, UTAH

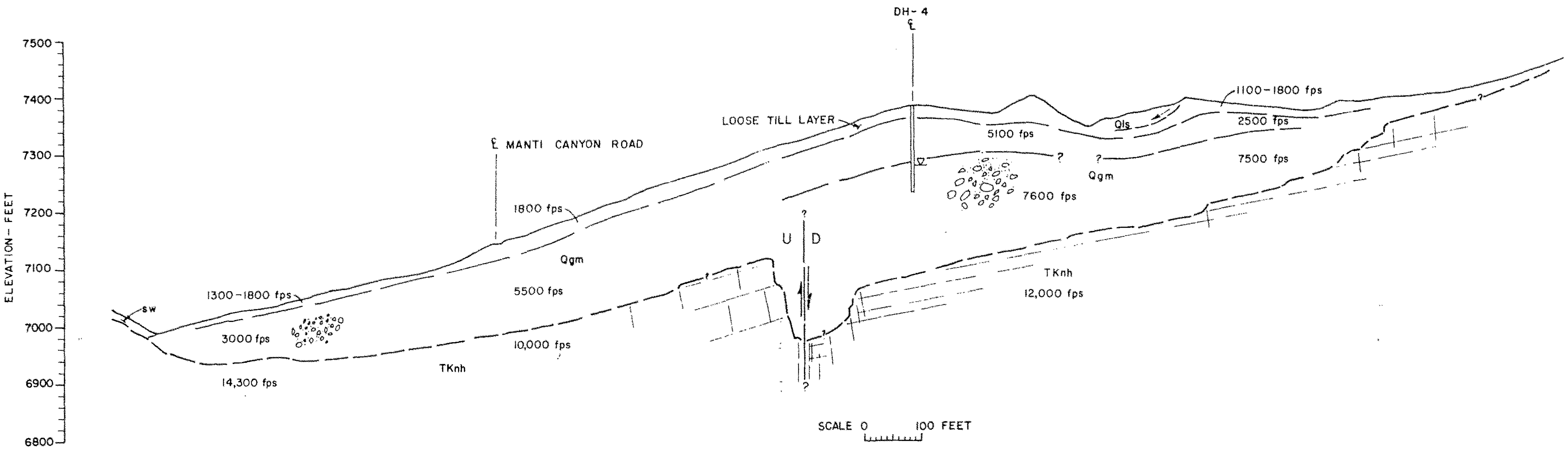
NORTH SLIDE STUDY

GEOLOGIC CROSS SECTION
C-C

INTERNATIONAL ENGINEERING COMPANY, INC.

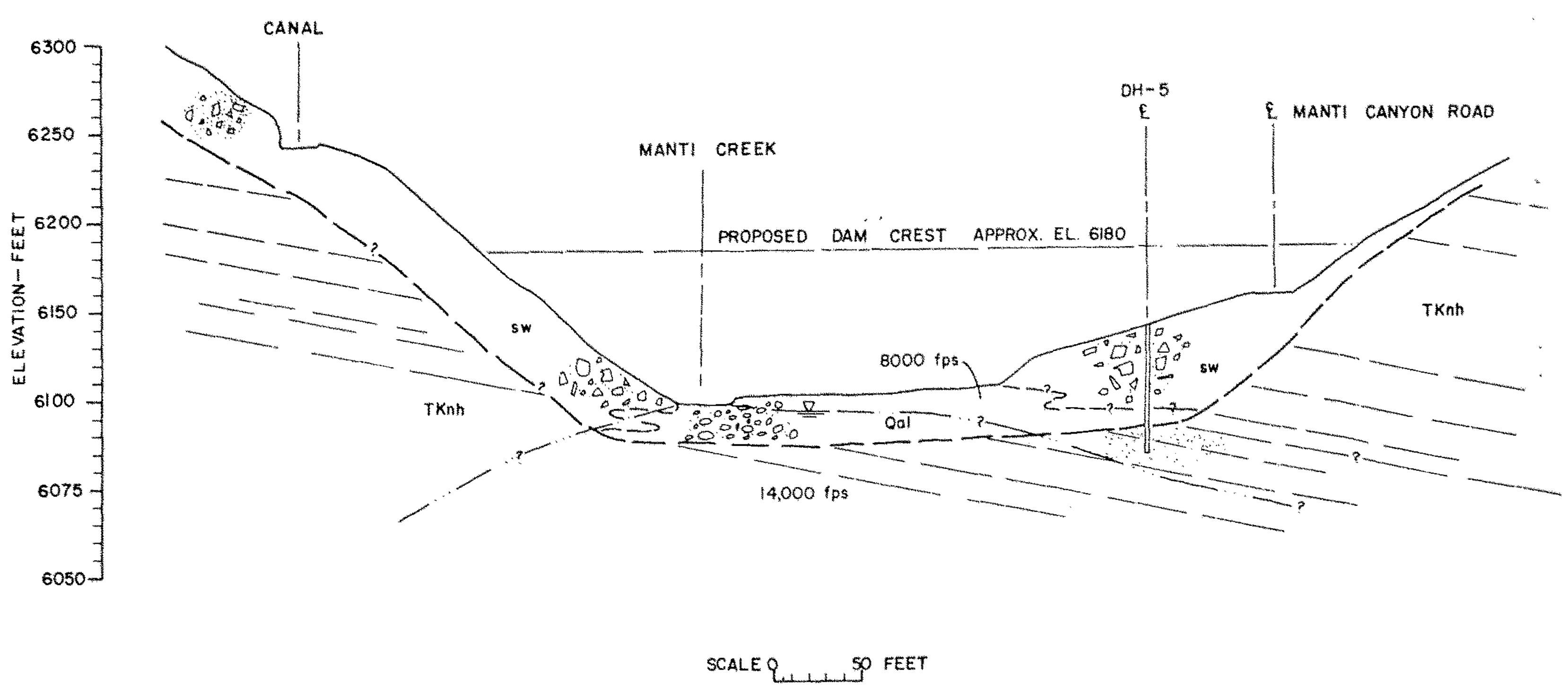
DESIGNED CCP	CHECKED [signature]	APPROVED
DRAWN ET	INSPECT	RECOMMENDED
IECO 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		DATE 9-1-76 Rev 1-24-77 DRAWING NO

EXHIBIT 5



GEOLOGIC SECTION D-D

NOTE: FOR LEGEND SEE EXHIBIT 3



GEOLOGIC SECTION E-E

SCALE AS NOTED

U.S. FOREST SERVICE
SANPETE COUNTY, UTAH

NORTH SLIDE STUDY

GEOLOGIC CROSS SECTIONS

D-D & E-E

INTERNATIONAL ENGINEERING COMPANY, INC.

DESIGNED CCP	CHECKED	APPROVED
DRAWN	INSPECT	RECOMMENDED
IECO 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		DATE 9-1-76 Rev. 1-24-77
		DRAWING NO

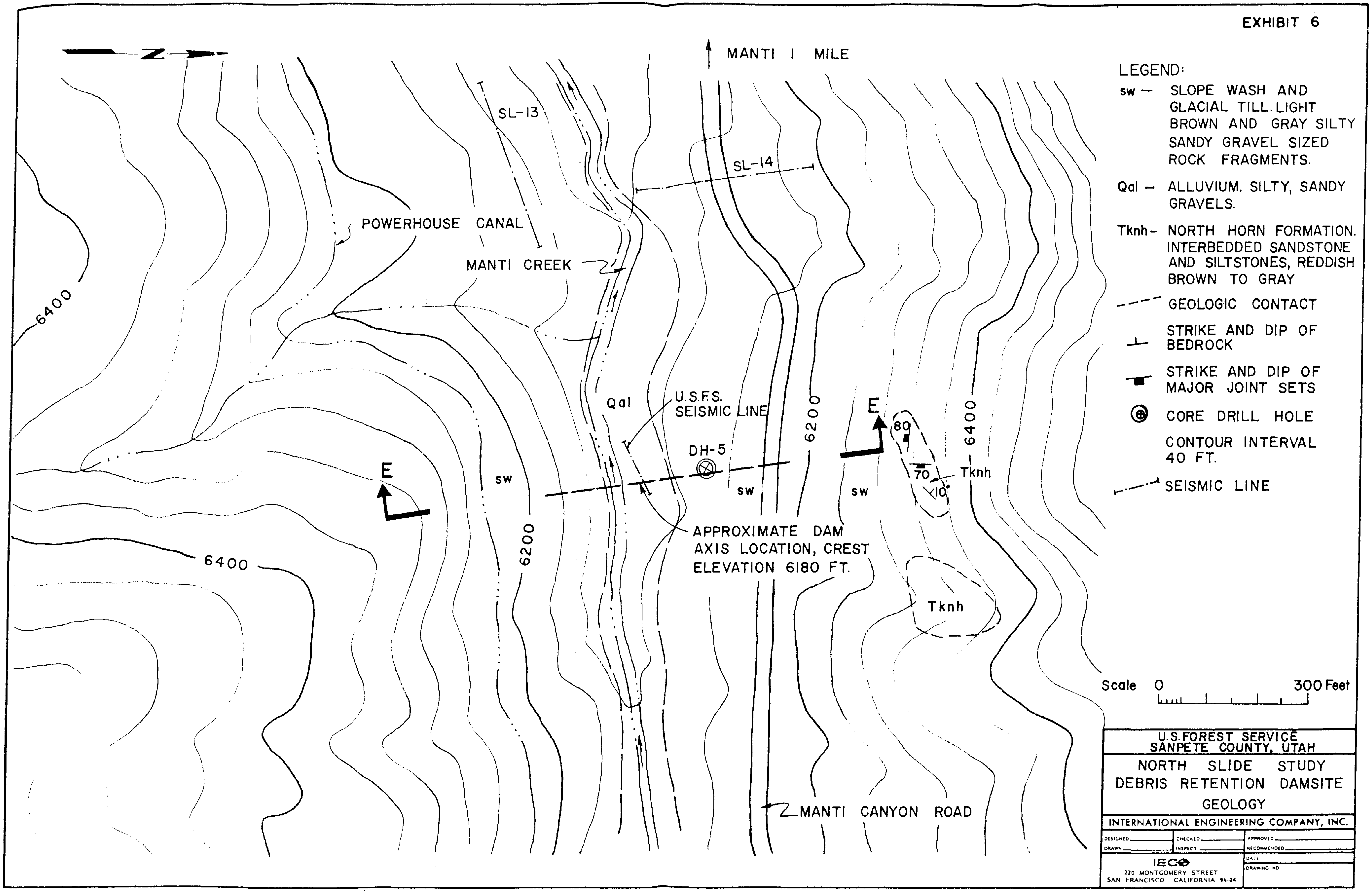
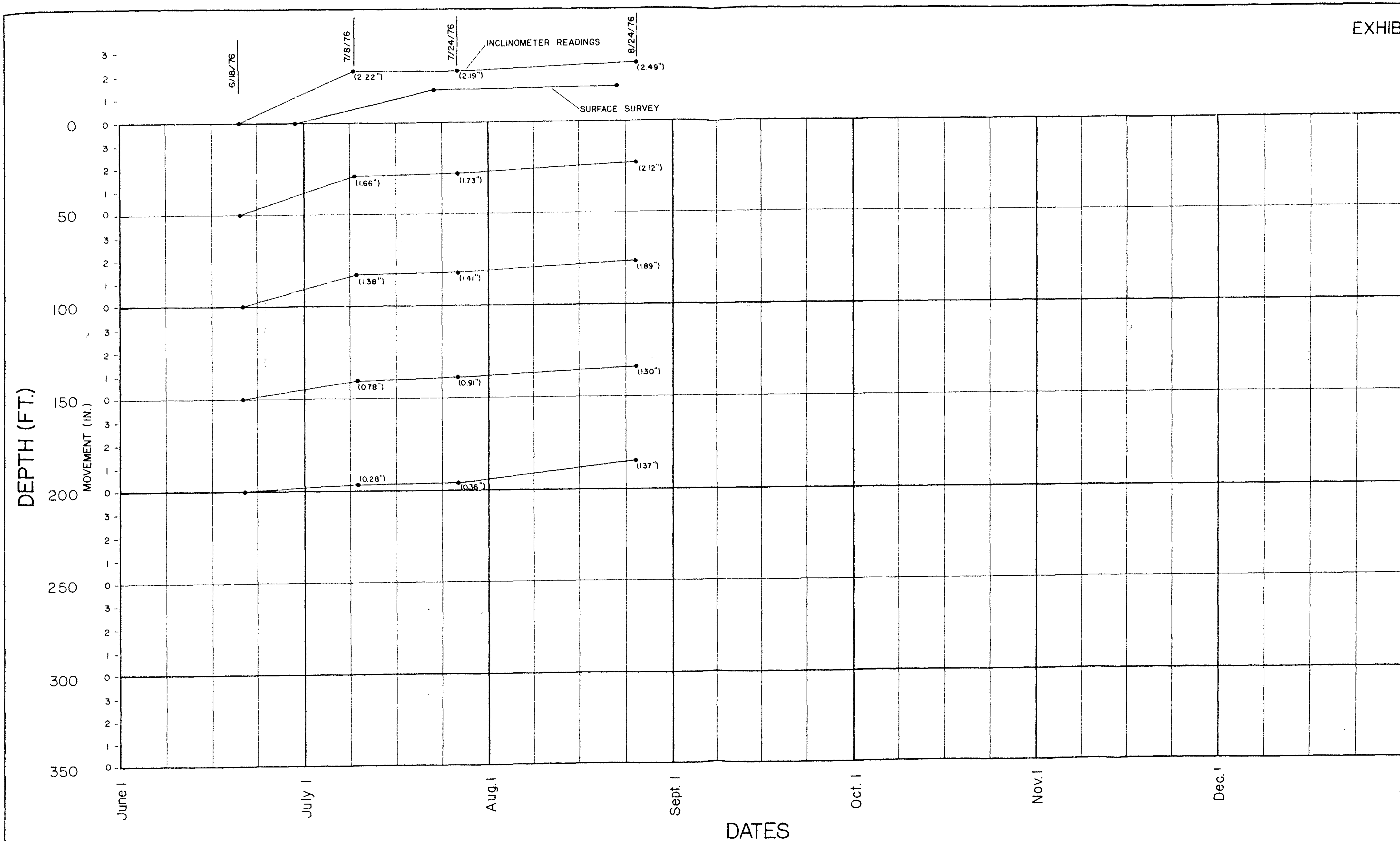


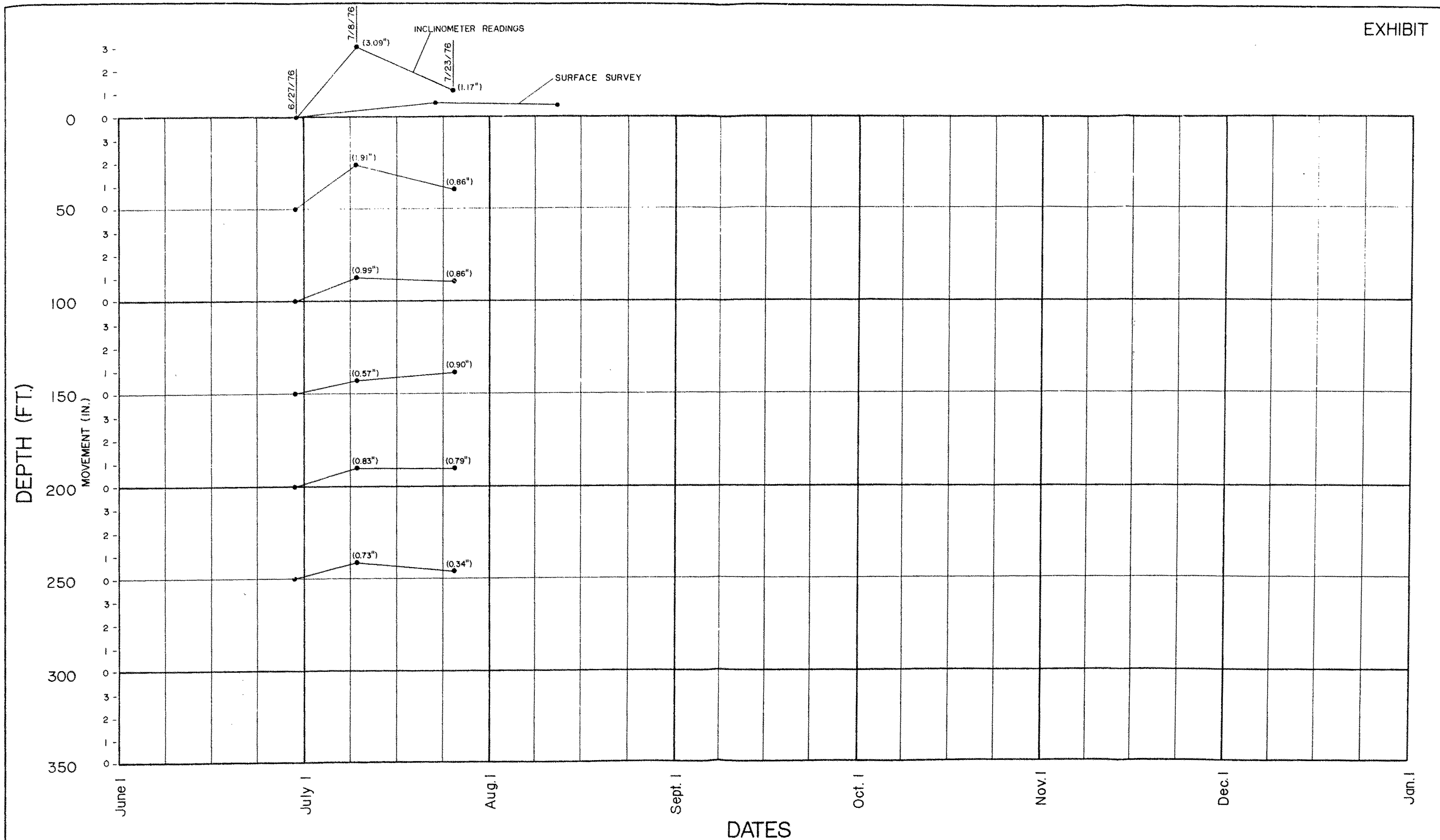
EXHIBIT 6
N
MANTI 1 MILE
LEGEND:
sw — SLOPE WASH AND GLACIAL TILL. LIGHT BROWN AND GRAY SILTY SANDY GRAVEL SIZED ROCK FRAGMENTS.
Qal — ALLUVIUM. SILTY, SANDY GRAVELS.
Tknh - NORTH HORN FORMATION. INTERBEDDED SANDSTONE AND SILTSTONES, REDDISH BROWN TO GRAY
GEOLOGIC CONTACT
STRIKE AND DIP OF BEDROCK
STRIKE AND DIP OF MAJOR JOINT SETS
CORE DRILL HOLE
CONTOUR INTERVAL 40 FT.
SEISMIC LINE
SL-13
SL-14
POWERHOUSE CANAL
MANTI CREEK
6400
6200
Qal
U.S.F.S. SEISMIC LINE
DH-5
E
sw
80
70
10
Tknh
APPROXIMATE DAM AXIS LOCATION, CREST ELEVATION 6180 FT.
MANTI CANYON ROAD
Scale 0 300 Feet
U.S. FOREST SERVICE
SANPETE COUNTY, UTAH
NORTH SLIDE STUDY
DEBRIS RETENTION DAMSITE
GEOLOGY
INTERNATIONAL ENGINEERING COMPANY, INC.
DESIGNED
CHECKED
APPROVED
DRAWN
INSPECT
RECOMMENDED
DATE
DRAWING NO
IECO
220 MONTGOMERY STREET
SAN FRANCISCO CALIFORNIA 94104

EXHIBIT 7



NORTH SLIDE MOVEMENT
FROM INCLINOMETER READINGS AND SURFACE SURVEYS
HOLE NO. 1A

SLIDE MOVEMENT
DH-1A



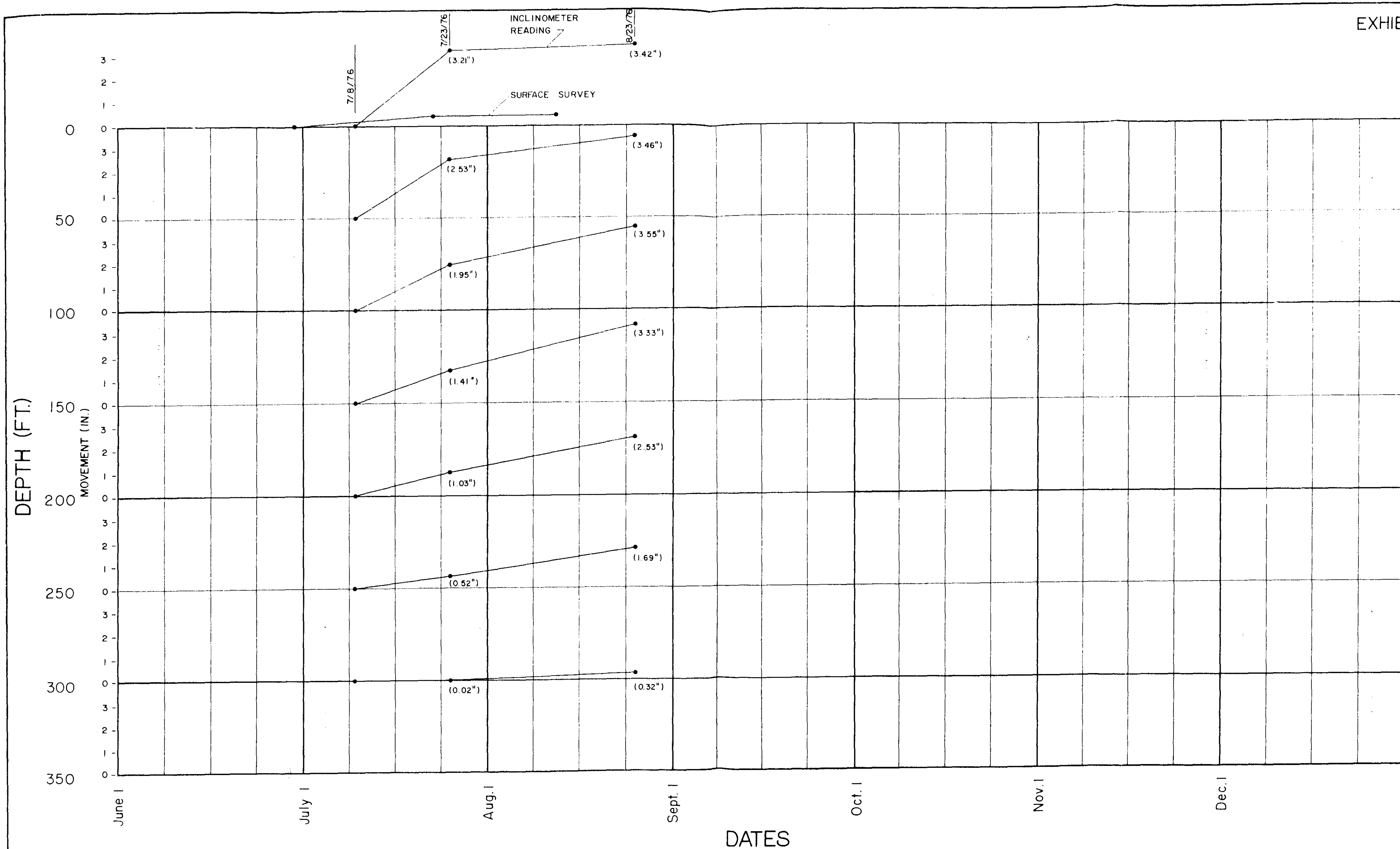
NORTH SLIDE MOVEMENT

FROM INCLINOMETER READINGS AND SURFACE SURVEYS

HOLE NO. 2

SLIDE MOVEMENT
DH-2

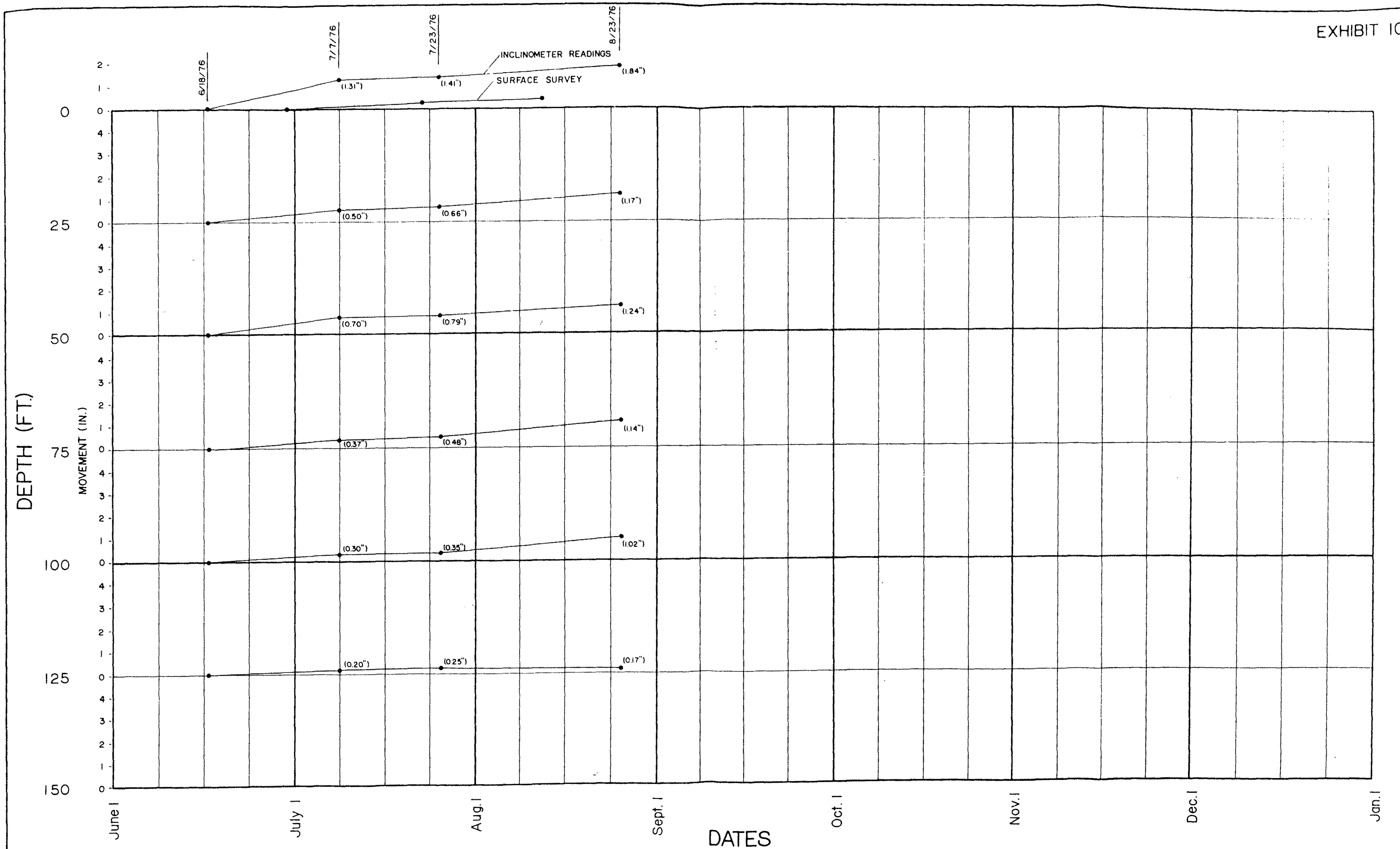
EXHIBIT 9



NORTH SLIDE MOVEMENT
FROM INCLINOMETER READINGS AND SURFACE SURVEYS
HOLE NO. 3A

SLIDE MOVEMENT
DH-3A

EXHIBIT 10

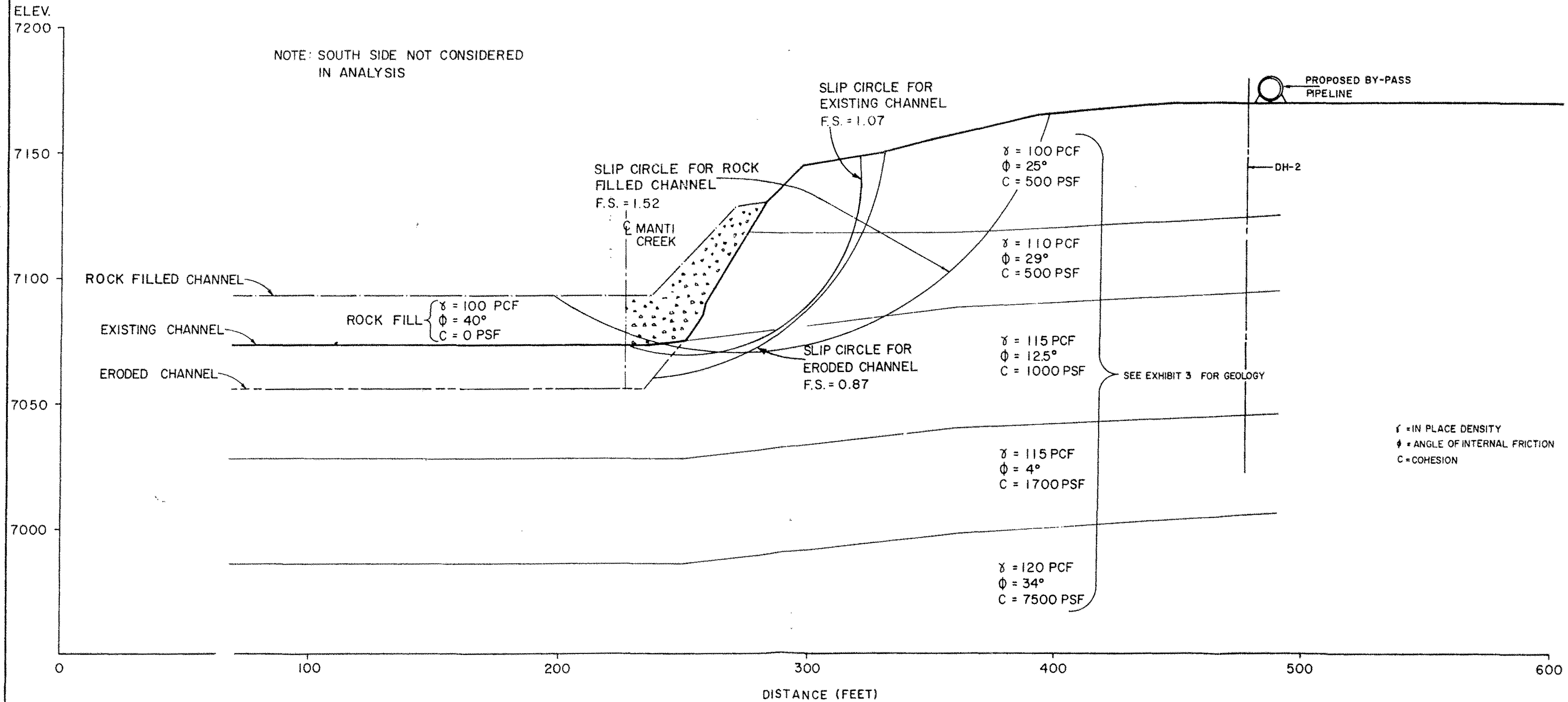


NORTH SLIDE MOVEMENT

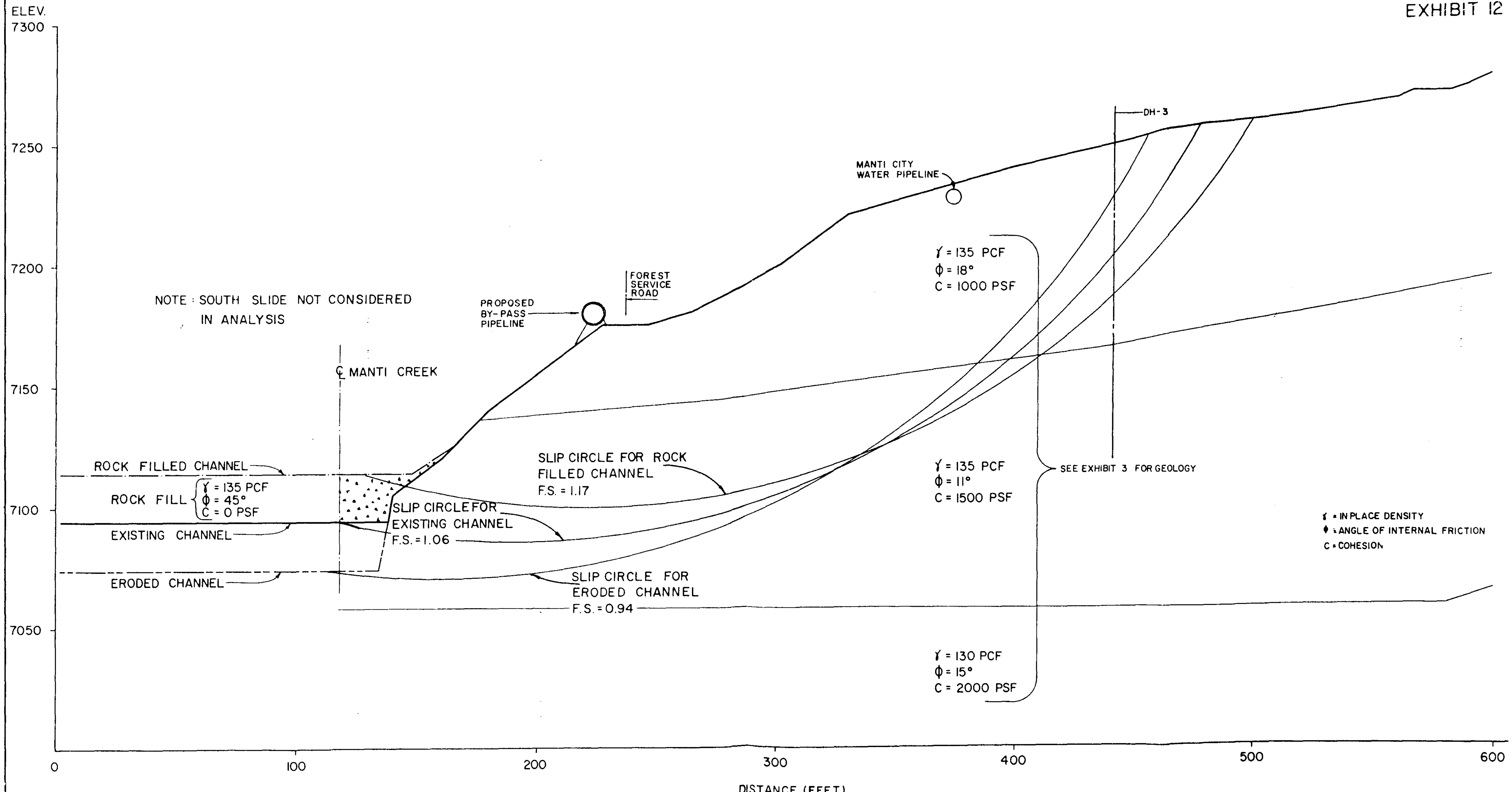
FROM INCLINOMETER READINGS AND SURFACE SURVEYS

HOLE NO. 4A

SLIDE MOVEMENT
DH-4A



NORTH SLIDE
STABILITY ANALYSIS SECTION I

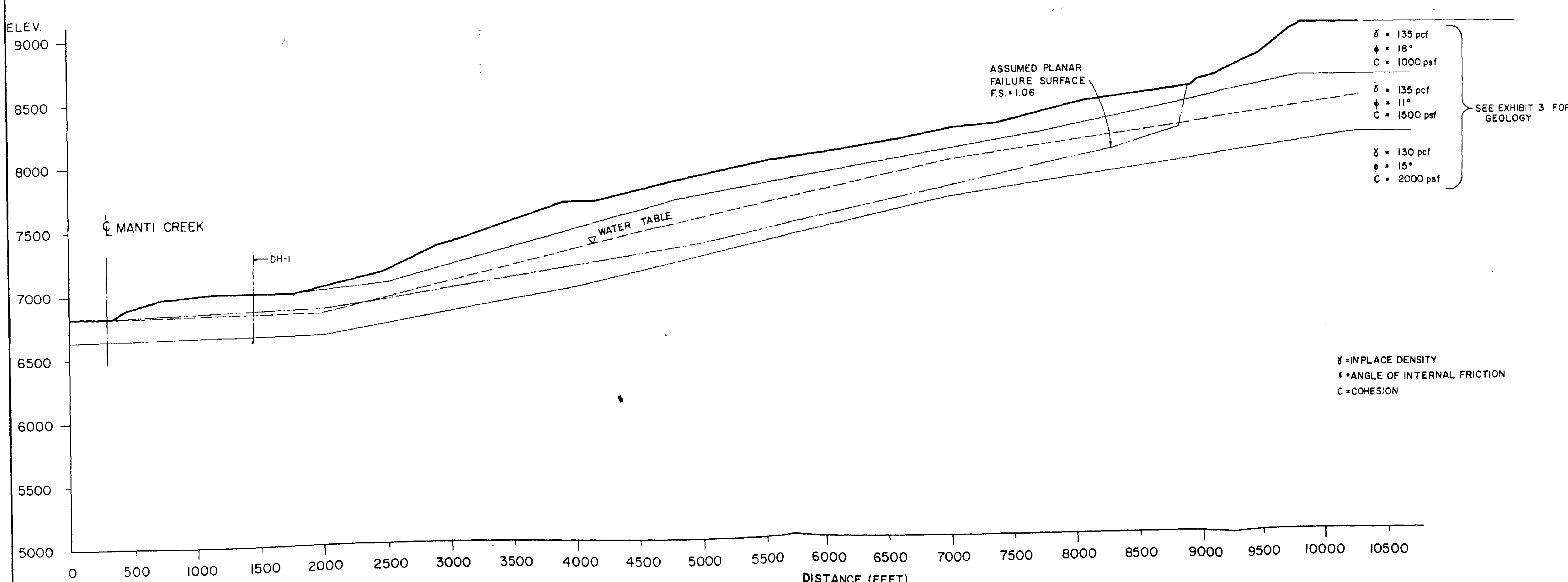


NORTH SLIDE

STABILITY ANALYSIS SECTION 2

SECTION 2

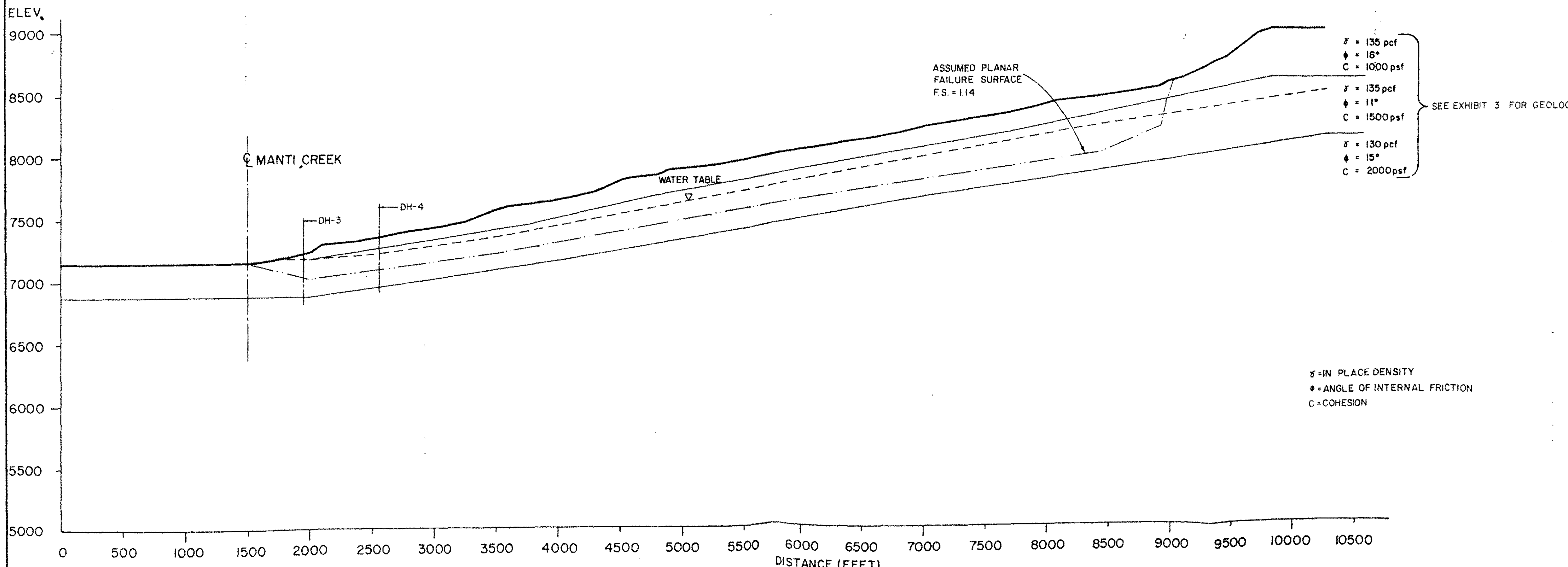
EXHIBIT 13



NORTH SLIDE
STABILITY ANALYSIS SECTION 3

SECTION 3

EXHIBIT 14



NORTH SLIDE

STABLITY ANALYSIS SECTION 4

SECTION 4