

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



CALDWELL, RICHARDS & SORENSEN, INC.



INTERNATIONAL ENGINEERING COMPANY, INC.

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CONSULTING
ENGINEERS



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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.

A
MORRISON
KNUDSEN
COMPANY

U. S. Department of Agriculture

-2-

September 2, 1976

Subject: Interim Geotechnical Report
Manti Canyon North Slide Stability Studies

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

Very truly yours,



G. Bryce Bennett
Executive Vice President

E R R A T A

INTERIM REPORT

- o Page 2-5, first line.

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

- o Page 2-17, third from last line.

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

- o Page 2-29, second from last line.

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

* * *

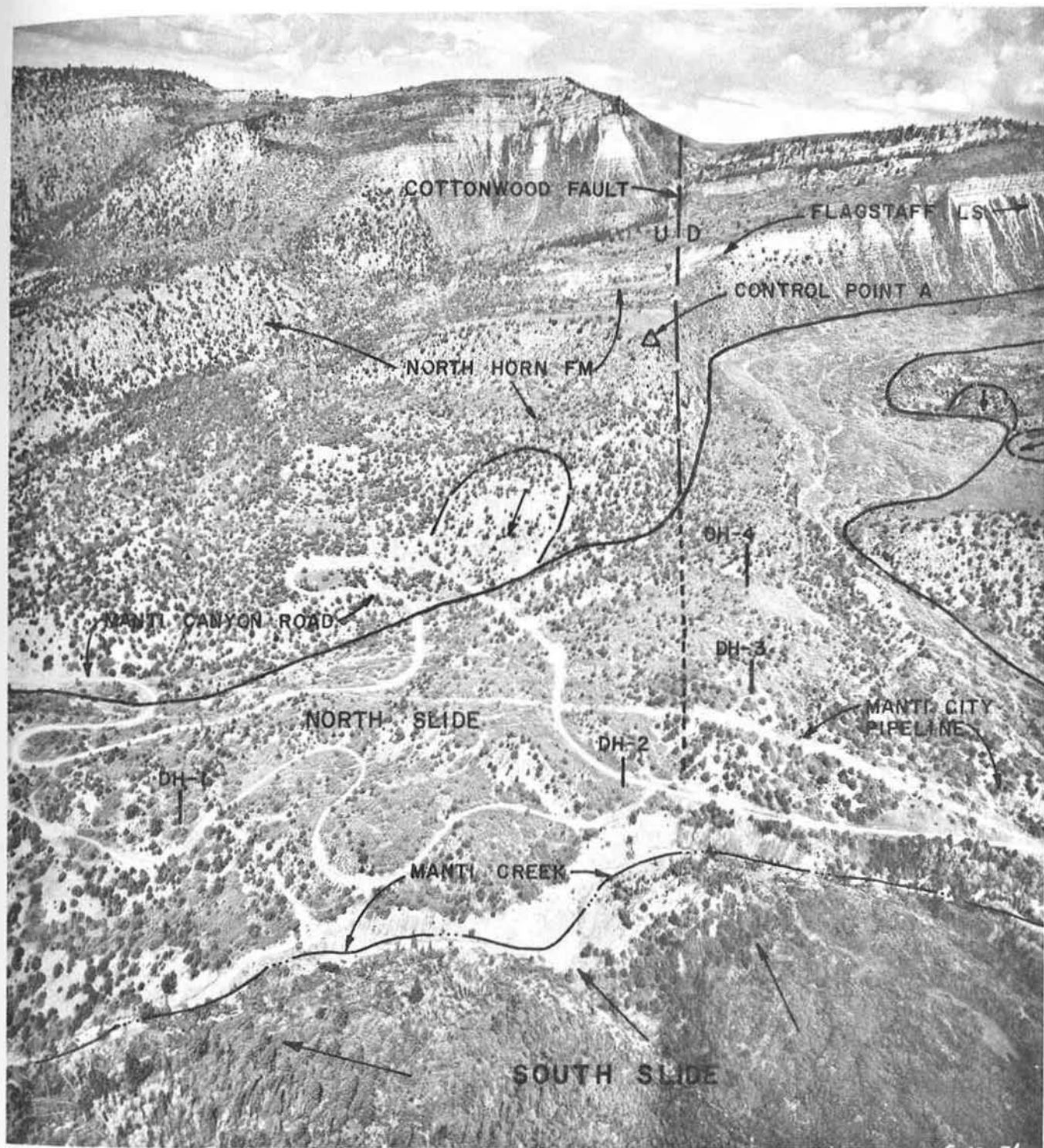


PHOTO 1 - PORTION OF NORTH SLIDE

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SUMMARY

CONCLUSIONS AND RECOMMENDATIONS

SUMMARY,
CONCLUSIONS AND RECOMMENDATIONS

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.
- Inclinator 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

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.

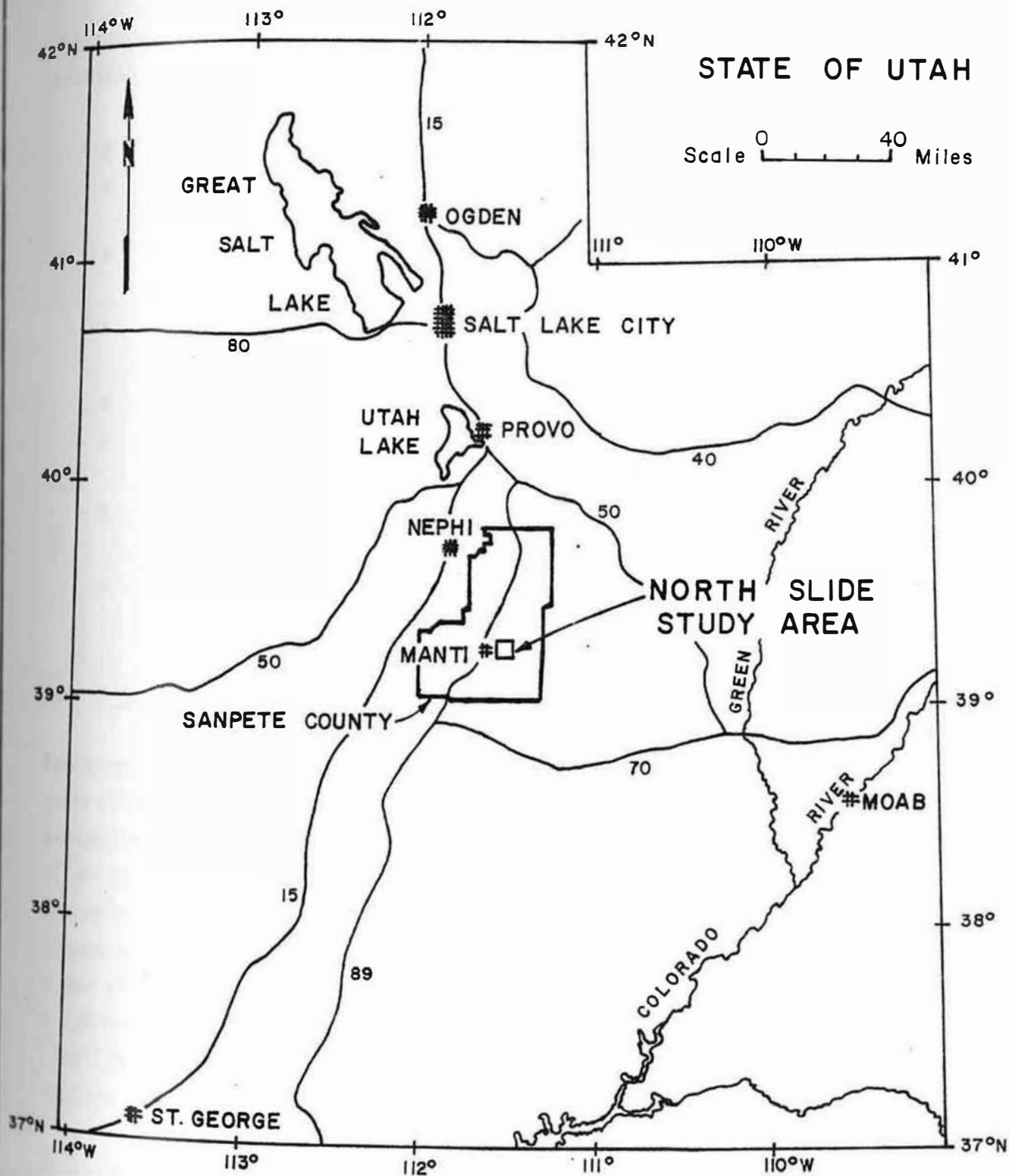


FIGURE 1-1—LOCATION OF THE NORTH SLIDE STUDY AREA

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

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

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	Specific Gravity
Hydrometer	Clay Mineralogy
Liquid Limit	Triaxial Compression
Plastic Limit	Direct Shear
Plastic Index	Unit Weight
Moisture Content	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 323.5	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)

<u>Site</u>	<u>Coordinates</u>		<u>Elevation (feet)</u>
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 read-out 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° . 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° to 20° and crops out on the canyon walls.

Reference:
Bull. 85, Utah Geological and
Mineralogical Survey, Aug.
1970, p.18, fig.6 and plate I.

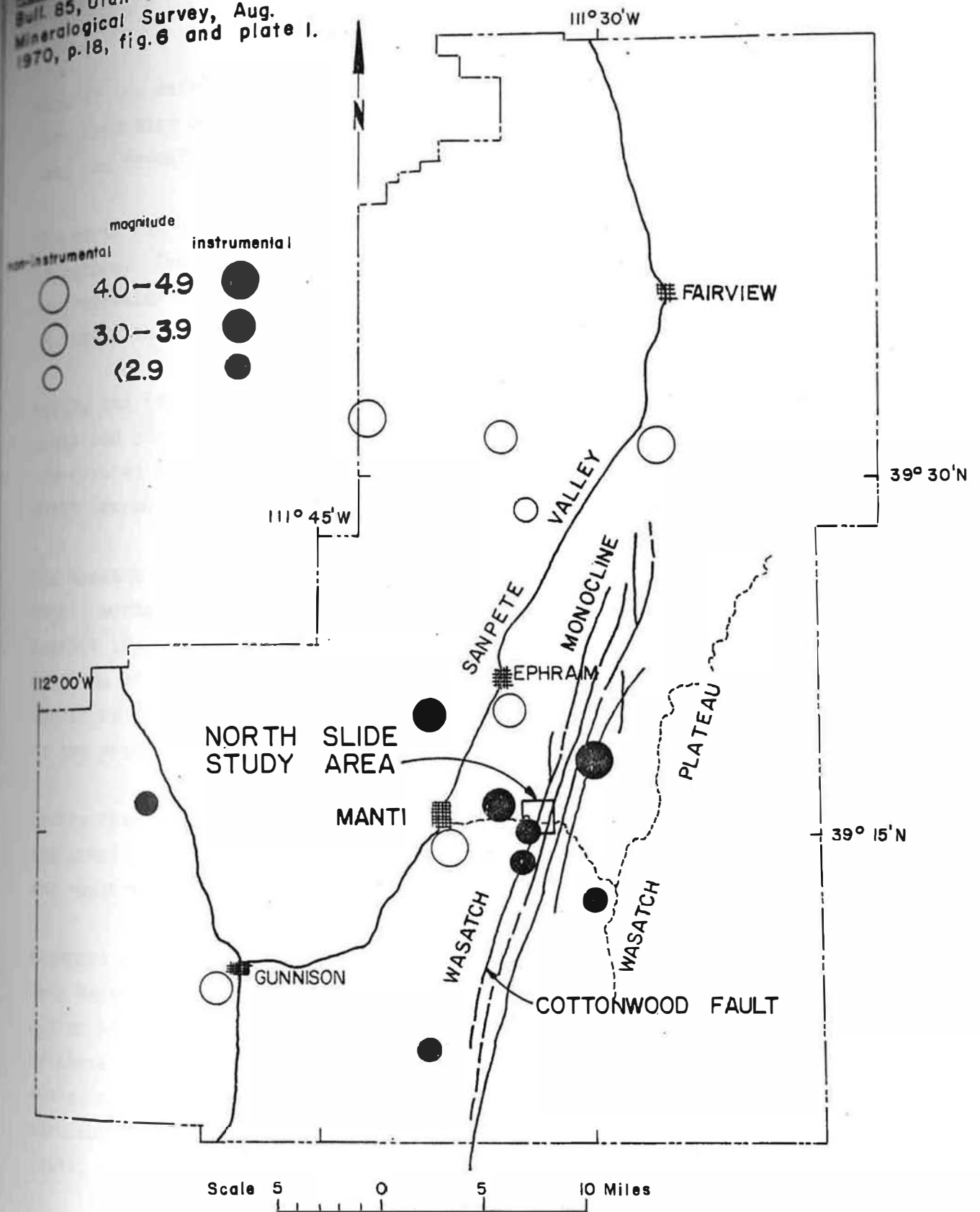


FIGURE 2-1 — EARTHQUAKE EPICENTERS IN SANPETE COUNTY, 1850-1964 AND MAJOR FAULTS ON AND ADJACENT TO STUDY AREA

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 $N20^{\circ}E$ 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.

8. 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°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	2nd Layer		3rd Layer		Bedrock (North Horn Formation)	
		Velocity	Depth	Velocity	Depth	Velocity	Depth	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.

- * 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)

<u>Sample</u>		<u>Major Minerals</u>	<u>Minor Minerals</u>
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)

<u>Sample</u>		<u>Silicate Clay Minerals</u>			<u>Others Minerals</u>
		<u>Montmorillonite</u>	<u>Mica</u>	<u>Kaolinite</u>	
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)

<u>Sample</u>		<u>Sodium</u>	<u>Potassium</u>	<u>Calcium</u>	<u>Magnesium</u>
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

<u>Drill Hole</u>	<u>Depth - Feet</u>	
	<u>June 25, 1976</u>	<u>August 23, 1976</u>
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° to 80° . 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 movement 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.
- Inclinator 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

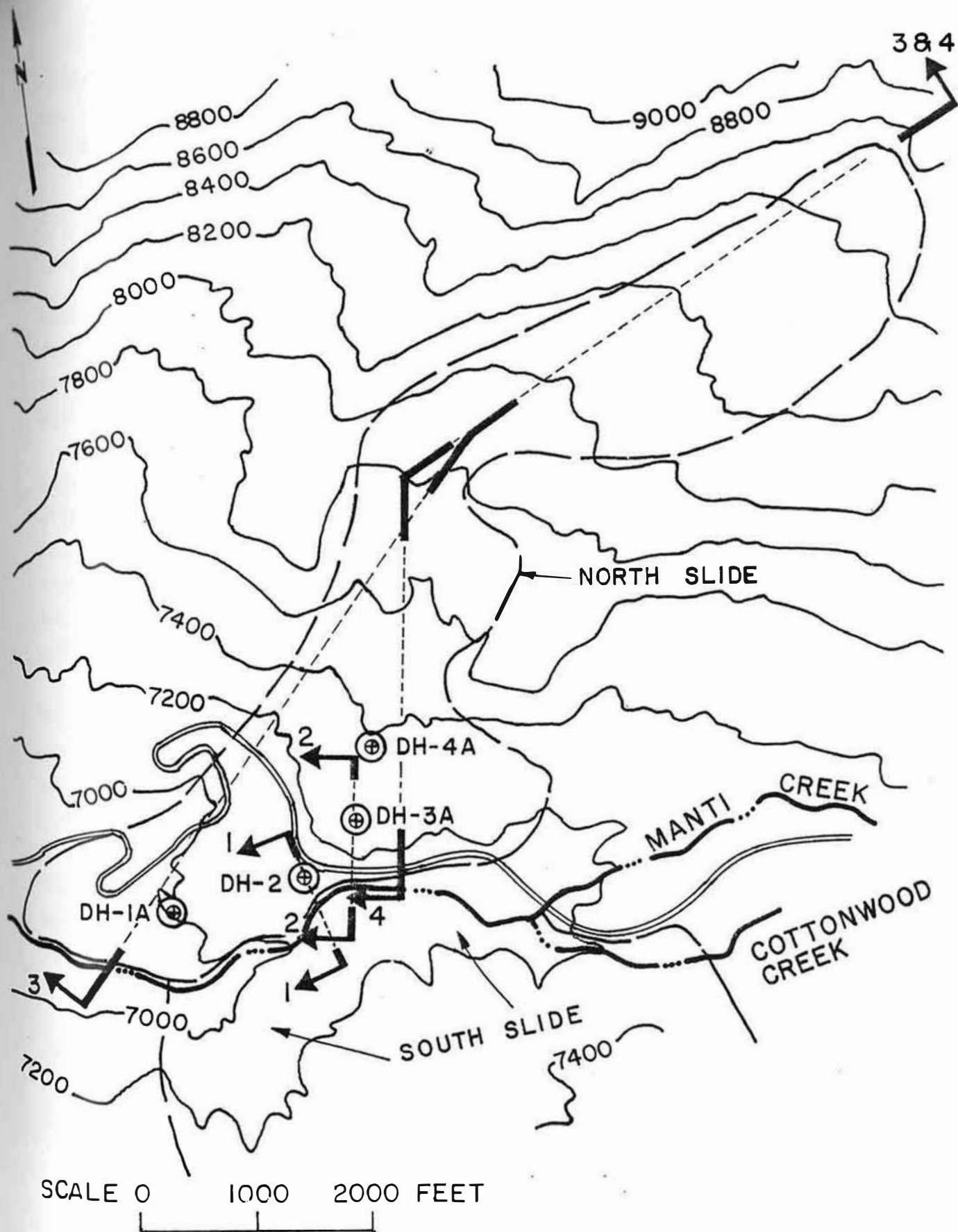


FIGURE 2-2 — LOCATION OF STABILITY ANALYSIS SECTIONS

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. Strength Parameters - 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	ϕ^0	c-ksf	σ_n -ksf	τ -ksf	ϕ^0	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	20.2	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	3.6						
4	8	122.5	142.2	7.8	54.4	13.0						
4	9	136.2	138.8	7.9	36.6	3.6	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. Stability of Section 1 - 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. Stability of Section 2 - 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.

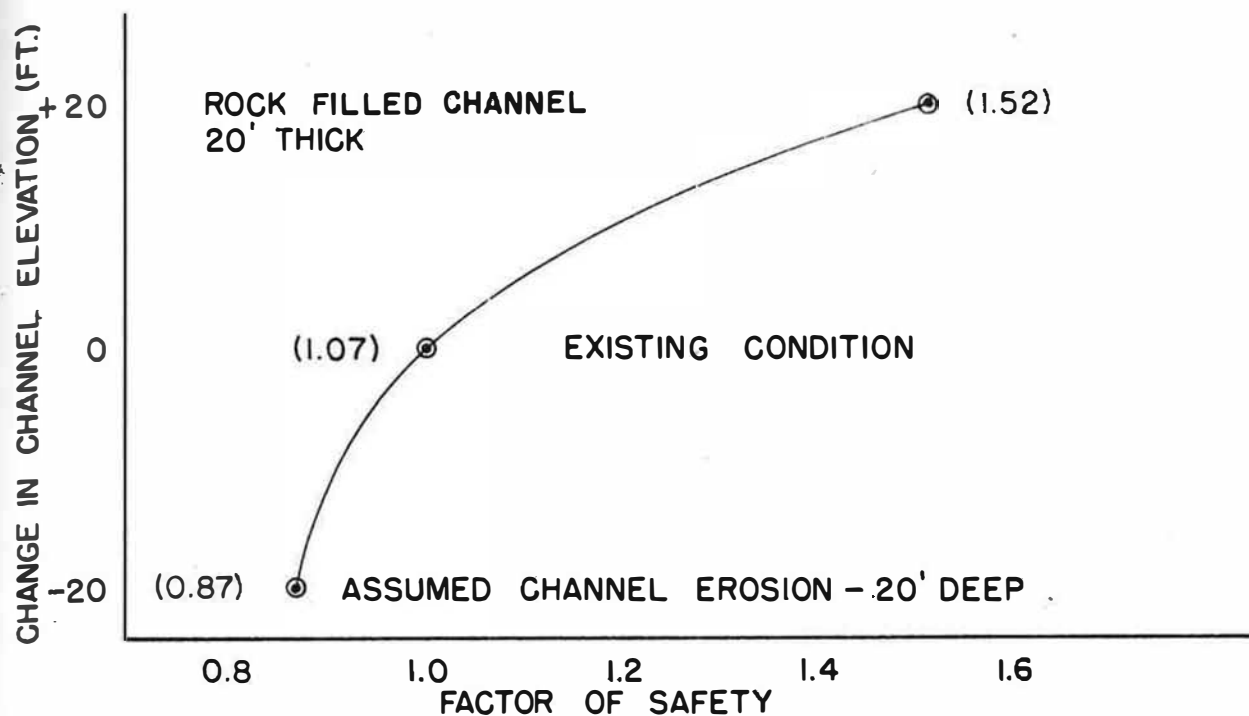


FIGURE 2-3 — FACTOR OF SAFETY OF NORTH SLIDE
BISHOP STABILITY ANALYSIS — SEC. 1

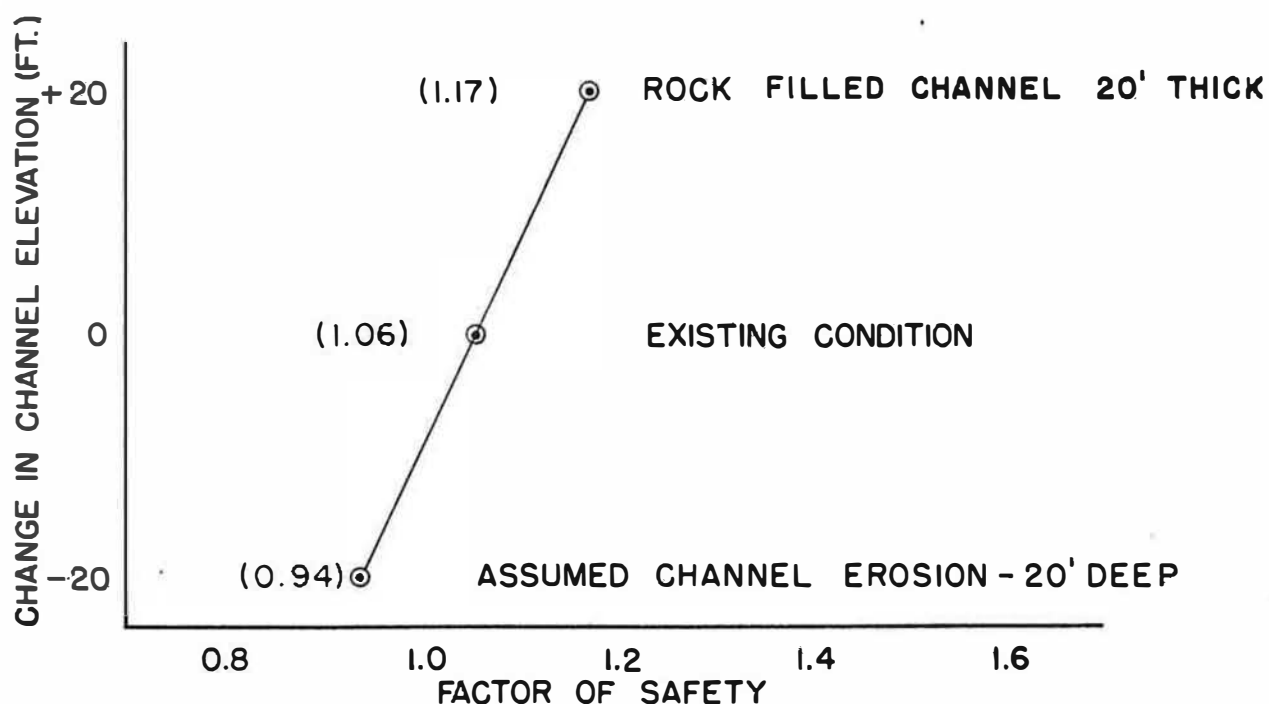


FIGURE 2-4 — FACTOR OF SAFETY OF NORTH SLIDE
BISHOP STABILITY ANALYSIS — SEC. 2

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. Stability of Section 4 - 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

<u>Inclinometer Hole</u>	<u>Vertical Movement (inches)</u>	<u>Vertical Rate (in/yr.)</u>	<u>Horizontal Movement (inches)</u>	<u>Horizontal Rate (in/yr.)</u>	<u>Horizontal Direction (degrees)</u>
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

<u>Depth (ft)</u>	<u>Material Type</u>	<u>Permeability (cm/sec)</u>
34	Sandy gravel slope wash	3.48×10^{-2}
57	Sandy gravel slope wash	1.46×10^{-4}
57-70	Fractured sand- stone 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 dam-site 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° E and dip 15° NW or into the abutment.

Two major joint sets were observed on outcrops. One set strikes N 50° E and dips 70° southeast. The other strikes N 80° W and dips 80° 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.

APPENDIX A
DRILL LOGS AND SOIL GRADATION CURVES

DRILL LOG		PROJECT		Manti Slide Study		JOB NO.		614-02		HOLE NO.		DH-1			
SITE				BEGUN		COMPLETED		HOLE SIZE		ANGLE FROM HORIZ. & BEARING					
near toe north Manti Slide				6/15/76		6/19/76		NC		Vertical					
COORDINATES				DEPTH/EL. GROUND WATER		GROUND EL.		DEPTH/EL. TOP OF ROCK							
N. 336,817 E. 1.982,553				none		7005.0		None							
DRILLING CONTRACTOR				CORE RECOV. LENGTH/%		SAMPLES		CORE BOXES		DEPTH/EL. BOTTOM OF HOLE					
Boyles Bros. Drilling Co.				207.0 ft./99%		18		20		232.9/6772.1					
DRILL MAKE AND MODEL				LOGGED BY:											
Longyear 44				C.C. Payton & J. A. Cercone											
SAMPLE DATA		% RECOVERY		REMARKS		ELEVATION		DEPTH		GRAPHIC LOG		BOX/SAMPLE NO.		MATERIAL CLASSIFICATION	
TYPE TOOL AND DIA.		METHOD N-BLOW COUNT ADVANCE		WATER LEVELS WATER RETURN DRILLING FLUID CASING DEPTH										PHYSICAL DESCRIPTION	
tricone 5 5/8"				first 20ft. drilled with rock-bit-100% water return.		7005.0		0						GLACIAL DEBRIS, consolidated, primarily made up of subrounded to sub-angular 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.	
NC		50		4" casing set at 20 ⁰ ft.				10							
		82		SPT-0.6ft. penetration No recovery. Began drilling with NC-wire line, regular core barrel. SPT-(Standard Penetration Test) 2"dia. split spoon sampler driven with 140 lb. hammer.				20		#1					
		50		SPT- 0.3ft. penetration 0.1ft. recovery				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.	
		100						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)	
		50		SPT-almost no penetration				50		#3				57.6to 58.2ft. shear zone with slickensides a gray clay dipping approximately 25 ⁰ moisture content 130	
		13/44/50		SPT- 1.4ft. penetration 1.2ft. recovered				60		#4				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				70		#5					
		92													

HOLE NO.
DH-1

DRILL LOG				PROJECT Manti Slide Study		JOB NO. 614-02		HOLE NO. DH-1	
SAMPLE DATA				REMARKS WATER LEVELS WATER RETURN DRILLING FLUID CASING DEPTH	ELEVATION	DEPTH	GRAPHIC LOG BOX/SAMPLE NO	MATERIAL CLASSIFICATION PHYSICAL DESCRIPTION	
TYPE TOOL AND DIA.	METHOD N- BLOW COUNT	ADVANCE	RECOVERY%						
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.		90	#9	83.0 to 84.0 shear zone with slickensides. $\phi = 13^\circ$ cohesion 1.5 ksf Dry density 126.0 lb./ft. ³	
	24/40/50			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.	
			100			100		Increase in moisture at 92 ft. to 20% matrix is sandy clay, gray, with liquid limit of 43% - PI = 19%	
	28/50			SPT- 1.0ft. penetration 0.9ft. recovered		110	#11		
			99	80% drill fluid return		120			
	19/50			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.	
			100			140			
	50			SPT-0.4ft. penetration 0.4ft. recovered		150	#13	shear plane at 148.0 dips 25° $\phi = 5^\circ$ cohesion = 32 ksf	
			100					HOLE NO. DH-1	

DRILL LOG

PROJECT Manti Slide Study

JOB NO.
614-02HOLE NO.
DH-1

SAMPLE DATA				REMARKS WATER LEVELS WATER RETURN DRILLING FLUID CASING DEPTH	ELEVATION	DEPTH	GRAPHIC LOG BOX/SAMPLE NO.	MATERIAL CLASSIFICATION	
TYPE TOOL AND DIA.	METHOD N- BLOW COUNT	ADVANCE	RECOVERY %					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.		160			
				75% drilling fluid return:				Sandstone boulder	
	50			SPT-0.1ft.penetration		170	#15		
				0.1ft. recovered					
			100	Lost drilling fluid at 180.0 ft.		180			
	30	50		SPT-0.8ft.penetration		190	#16	Consolidated glacial debris primarily sandstone and limestone boulders in a sandy clay	
			93	0.8ft. recovered					
				No drilling fluid return		200		Shear zone between 203-208.5ft, dark gray clay, shear planes, slickensides, dip 35 degrees. $\phi = 22^\circ$ cohesion 1.2 ksf.	
	50			SPT -0.4ft.penetration		210	#17		
			100	no sample recovered				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		220	#18		
			96	0.3ft.recovered				Brown weathered sandstone boulder in matrix of brown soft clayey sand.	
				Inclinometer casing installed in drill hole		230			
				to a depth of 231.7 ft.		232		Bottom of Hole 232.9ft. Elevation 6772.1 f	

HOLE NO.
DH-1

DRILL LOG		PROJECT		JOB NO.		HOLE NO.	
		Manti Slide Study		614-02		DH-2	
SITE		Bottom of canyon near Manti Creek		BEGUN	COMPLETED	HOLE SIZE	ANGLE FROM HORIZ. & BEARING
				5/19/76	6/1/76	4"	Vertical
COORDINATES		N.336,986 E.1.983,522		DEPTH/EL. GROUND WATER		GROUND EL.	DEPTH/EL. TOP OF ROCK
						7166.0	306.0/6860.0
DRILLING CONTRACTOR		Boyles Bros. Drilling Co.		CORE RECOV. LENGTH/%	SAMPLES	CORE BOXES	DEPTH/EL. BOTTOM OF HOLE
				176 ft/67%	39	22	328.0ft/6838.0
DRILL MAKE AND MODEL		Longyear 44		LOGGED BY:			
				C.C. Payton & J.A. Cercone			
SAMPLE DATA				REMARKS			
TYPE TOOL AND DIA.	METHOD N-BLOW COUNT	ADVANCE	RECOVERY	ELEVATION	DEPTH	GRAPHIC LOG	BOX/SAMPLE NO.
				MATERIAL CLASSIFICATION			
				PHYSICAL DESCRIPTION			
Tricone and 4" casing				3 7/8" tricone bit inside 4" casing.	7166.0		
				17.5 lost water return.			
				SPT(Standard Penetration Test)			
				2" dia. split spoon sampler driven with 140 lb. hammer.			
	8/14/14			SPT 1.5ft. penetration	20		#1
	Sh			2.5" Shelby tube	30		#2
	11/24/14			SPT-1.5ft. penetration	40		#3
	Sh			0.2ft. penetration	50		#4
	50			SPT-0.2ft. penetration	60		#5
	Sh			No recovery	70		#6
				4" casing set at 59.0ft,			
	60			SPT-0.5ft. penetration			
	Sh			Started drilling w/NC-wire line, reg. core barrel			
NC	41/50			SPT-1ft penetration			#9

HOLE NO.
DH-2

DRILL LOG

PROJECT Manti Slide Study

JOB NO.
614-02HOLE NO.
DH-2

SAMPLE DATA				REMARKS WATER LEVELS WATER RETURN DRILLING FLUID CASING DEPTH	ELEVATION	DEPTH	GRAPHIC LOG BOX/SAMPLE NO.	MATERIAL CLASSIFICATION	
TYPE TOOL AND DIA.	METHOD N- BLOW COUNT	ADVANCE	RECOVERY					PHYSICAL DESCRIPTION	
NC			50	Drilling with NC-wire line reg. core barrel SPT - 0.7ft. penetration		70		GLACIAL DEBRIS, Consolidated, abundant boulders in a matrix of fine sandy clays. Shear planes with slickensides dip 70°-75°, $\phi = 34^\circ$, cohesion = 7.5ksf Natural moisture 6.1% Gravels are subangular to subrounded fine gravel to boulder sizes, hard.	
	50/		100	0.7ft recovered					
	50			SPT-1.0ft. penetration		80			
			100						
	45/50			SPT-1.0ft. penetration				Shear zone indicated by a dark gray clay with abundant slickensides damp, very stiff, plastic, dips 70°-75°	
			100	0.3ft. recovered					
	50			SPT-0.2ft. penetration		90			
				No recovery					
	32/50			SPT-0.8ft. penetration				clayey sandy gravels, very stiff, slightly moist, medium dry strength, medium toughness, plastic	
	50			SPT-0.1ft. penetration		100			
			90	No recovery					
	31/50			SPT-0.7ft. penetration				<u>Change in Color</u> GLACIAL DEBRIS 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.	
			85	0.7ft. recovered					
	34/50			SPT-0.7ft. penetration		110			
			100	0.4ft. recovered					
	45/50			SPT-0.9ft. penetration					
			100						
			17			120			
	29/30/50			SPT-1.4ft. penetration					
			80	0.5ft. recovered					
	20/50			SPT-0.7ft. penetration		130			
			80	No recovery					
	50			SPT-0.1ft. penetration					
			45	No recovery.					
	20/50			SPT-0.8ft. penetration		140			
			28	0.5ft. recovered					
	33/50			SPT-0.9ft. penetration					
			36	0.5ft. recovered		150			

HOLE NO.
DH-2

DRILL LOG

PROJECT

Manti Slide Study

JOB NO.

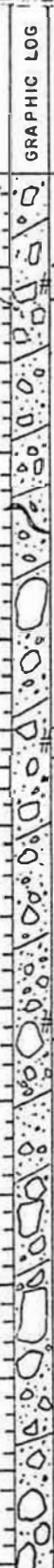
614-02

HOLE NO.

DH-2

TYPE TOOL AND DIA.	SAMPLE DATA		REMARKS WATER LEVELS WATER RETURN DRILLING FLUID CASING DEPTH	ELEVATION	DEPTH	GRAPHIC LOG BOX/SAMPLE NO	MATERIAL CLASSIFICATION PHYSICAL DESCRIPTION
	METHOD N. BLOW COUNT	ADVANCE RECOVERY					
NC	28/50	50	SPT-1.0ft.penetration No recovery		150	#24	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.
	60	80	SPT-0.4ft.penetration 0.2ft.recovered			#25	
		88					
	17/50	50	SPT-1.0ft.penetration No recovery		160	#26	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
		94					
	19/41/50	50	SPT-1.4ft.penetration 1.3ft.recovered			#27	
	13/28/50	50	SPT-1.0ft.penetration No recovery		170	#28	
		100					
	20/50	50	SPT-0.8ft.penetration No recovery			#29	
		43					
	50	60	SPT-0.3ft.penetration 0.3ft.recovered		180	#30	
	50	90	SPT-0.1ft.penetraiton No recovery.			#31	
		50			190		
	26 40/50	50	SPT-1.1ft.penetration 0.4ft.recovered			#32	
		66			200		
		50					<u>Change in Color</u> 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.
		100					
		100					
	50	80	SPT-0.5ft.penetration 0.2ft.recovered		210	#33	
		100					
	50	100	SPT-0.3ft.penetration 0.1ft.recovered		220	#34	
	50	100	SPT-0.1ft.penetration No recovery.			#35	
		100			230		

HOLE NO.
DH-2

DRILL LOG			PROJECT		Manti Slide Study		JOB NO 614-02		HOLE NO. DH-2	
TYPE TOOL AND DIA.	SAMPLE DATA		% RECOVERY	REMARKS WATER LEVELS WATER RETURN DRILLING FLUID CASING DEPTH	ELEVATION	DEPTH	GRAPHIC LOG BOX/SAMPLE NO	MATERIAL CLASSIFICATION		
	METHOD N- BLOW COUNT	ADVANCE						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		100	SPT-0.3ft. penetration 0.1ft. recovered		240		— 243.5- dark gray clay, moist, plastic stiff.		
			100	No drilling fluid return				— 248.2- shear plane, dip 35° slicken sides in dark gray clay, stiff plastic, $\phi=12^\circ$ C= 0.8 ksf		
			89			-250		<u>Change in Color</u>		
			66					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		100	SPT-0.5ft. penetration 0.2ft. recovered		260	37	scattered dark gray clay irregular thin layers mixed with gray clay.		
			80					core can be broken with hand pressure but it is difficult.		
			20			-270		Gradual increase in large gravel and cobbled sized rock fragments. Hard, gray and light gray, fresh, sandstones, limestones and occasional quartzite rock fragments.		
			100					TOP OF BEDROCK		
	50			SPT-0.1ft. recovered			38	SANDSTONE, light reddish brown, fine to medium grained		
			82			280		HOLE NO. DH-2		
			100							
			100	Drilling rate average 8 ft/hr with NC wire line diamond core barrel		-290				
			74			300				
			74							
		66	4" casing reamed to 305° ft.	6860.0	306					
		78	Drilling fluid return		310					

DRILL LOG				PROJECT		JOB NO.		HOLE NO.	
				Manti Slide Study		614-02		DH-2	
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			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						
			100					SILTSTONE, dark gray, soft, bedded, bedding plane dip 15 - 20 degrees.	
50		9	SPT-0.3ft. penetration 0.3ft. recovered		39				
				Inclinometer casing installed to a depth of 325 ft.				BOTTOM OF HOLE Depth 328.0 Elevation 6838.0	

HOLE NO.
DH-2

DRILL LOG		PROJECT		Manti Slide Study		JOB NO.		614-02		HOLE NO.		DH-3	
SITE				center of study area		BEGUN		6/7/76		COMPLETED		6/26/76	
COORDINATES				N. 337,242 E. 1,984,015		HOLE SIZE		NC		ANGLE FROM HORIZ. BEARING		vertical	
DRILLING CONTRACTOR				Boyles Bros. Drilling Co.		DEPTH/EL. GROUND WATER		none		GROUND EL.		7272.0	
DRILL MAKE AND MODEL				Mobil Drill B-56 and Longyear 44		CORE RECOV. LENGTH/%		248.5ft./75%		SAMPLES		30	
						CORE BOXES		23		DEPTH/EL. TOP OF ROCK		334.0/6938.0	
						DEPTH/EL. BOTTOM OF HOLE		350.0/6922.0		LOGGED BY:		C.C. Payton & J.A. Cercone	
SAMPLE DATA		REMARKS		ELEVATION		DEPTH		GRAPHIC LOG		BOX/SAMPLE NO.		MATERIAL CLASSIFICATION	
TYPE TOOL AND DIA.		METHOD N-BLOW COUNT ADVANCE		WATER LEVELS WATER RETURN DRILLING FLUID CASING DEPTH								PHYSICAL DESCRIPTION	
4" casing bit				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'.		30				#2			
4/3/4				SPT-0.8ft. recovered 1.5ft. penetration						#3			
sh				4" casing placed in hole to 40 ft.		40				#4			
NC wire-line diamond core bit and 5 ft. regular core bit				Started drilling w/NC-wire line regular core barrel 5 ft. long.		50						Gradational change in mtl and color	
43/19/36				SPT-1.0ft. recovered 1.5ft. penetration		60				#5		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	
				No drilling fluid return		70						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	

DRILL LOG				PROJECT		JOB NO.		HOLE NO.	
				Manti Slide Study		614-02		DH-3	
SAMPLE DATA				REMARKS	ELEVATION	DEPTH	GRAPHIC LOG	BOX/SAMPLE NO.	MATERIAL CLASSIFICATION
TYPE TOOL AND DIA.	METHOD N-BLOW COUNT	ADVANCE	RECOVERY						
NC			80	No drilling fluid return		70			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. Sample No. 6 - Direct Shear Test Ø = 15º cohesion 1.7 ksf Dry density 126.0 lb/ft³ 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. natural moisture 12.6% specific gravity 2.63 30% gravel sized rock fragments 16% sand 54% plastic fines (CL) liquid limit 23.8% PI = 10.4%
			100			80			
	15/41	50		SPT-1.2ft.penetration 0.7ft.recovered				#6	
			100						
	46	50		SPT-0.7ft.penetration		90		#7	
			60						
			60						
	50			SPT-0.2ft.penetration No recovery		100		#8	
			65						
			57	Average drilling rate w/NC diamond bit - 10 ft/hr		110			
			56						
			60						
			54			120			
	50			SPT- 0.2ft.penetration				#9	
			64	0.2ft. recovered		130			
		96							
		52			140				
		96							
17	50		SPT - ft. of penetration			#10			
		79	ft. recovered		150				

HOLE NO.
DH-3

HOLE NO.
DH-3

DRILL LOG

PROJECT

Manti Slide Study

JOB NO

614-02

HOLE NO

DH-3

SAMPLE DATA				REMARKS	ELEVATION	DEPTH	GRAPHIC LOG	BOX/SAMPLE NO	MATERIAL CLASSIFICATION	
TYPE TOOL AND DIA	METHOD N-BLOW COUNT	ADVANCE	% RECOVERY						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	SPT- 0.9ft. penetration 0.9ft. recovered						
			76			180				
			62							
	25	50				190		#11		
			33							
			78							
	28	50		SPT-0.7ft. penetration		200		#12	Dark gray clay, shear plane dip 50 degrees	
			38							
	20	48	50	SPT- 1.2ft. penetration 1.2ft. recovered.				#13	Dark blue-gray sandy clay-very stiff, shear plane at 206.0 dip 70 degrees.	
			68							
	21	50		SPT-0.6ft. penetration 0.2ft. recovered		210		#14	Brown clayey sandy gravels, dense, slightly moist, as above. 27% gravel sized rock fragments 16.0% sand 57.0% plastic fines (CL) liquid limit 22.0% PI = 8.7% natural moisture 7.1%	
			40							
			15			220				
			40							
			64							
			100			230				

HOLE NO.
DH-3

DRILL LOG

PROJECT Manti Slide Study

JOB NO.
614-02HOLE NO.
DH-3

TYPE TOOL AND DIA.	SAMPLE DATA		REMARKS WATER LEVELS WATER RETURN DRILLING FLUID CASING DEPTH	ELEVATION	DEPTH	GRAPHIC LOG BOX/SAMPLE NO.	MATERIAL CLASSIFICATION PHYSICAL DESCRIPTION
	METHOD N- BLOW COUNT	ADVANCE RECOVERY %					
NC		72			230		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.
		62			240		
	50	88	SPT- 0.4ft. penetration 0.4ft. recovered				
		100					
		96			250		
		48					
		48			260		
		74					
	24 50	25	SPT-0.9 ft. penetration 0.9 ft. recovered		270		
		100			280		
	60	84	SPT- 0.5ft. penetration 0.4ft. recovered				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
		100			290		
	50		SPT- 0.4ft. penetration 0.4ft. recovered				
		100			300		
	25 50	94	SPT-0.9 ft. penetration 0.9ft. recovered		310		

HOLE NO.
DH-3

DRILL LOG

PROJECT

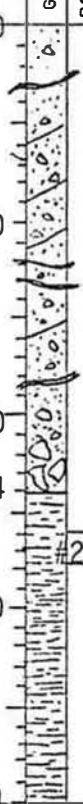
Manti Slide Study

JOB NO.

614-02

HOLE NO.

DH-3

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

HOLE NO.
DH-3

HOLE NO.
DH-3

DRILL LOG

PROJECT Manti Slide Study

JOB NO.
614-02HOLE NO.
DH-4

SITE upper most site in study area

BEGUN
6/20/76COMPLETED
6/23/76HOLE SIZE
NCANGLE FROM HORIZ. BEARING
VerticalCOORDINATES
N. 337.794 N. 1.984.184DEPTH/EL. GROUND WATER
noneGROUND EL.
7361.0DEPTH/EL. TOP OF ROCK
NoneDRILLING CONTRACTOR
Boyles Bros. Drilling Co.CORE RECOV. LENGTH/%
1158 / 89SAMPLES
5CORE BOXES
13DEPTH/EL. BOTTOM OF HOLE
150.5/7210.5DRILL MAKE AND MODEL
Longyear 44

LOGGED BY:

C.C. Payton & J.A. Cercone

SAMPLE DATA				REMARKS	ELEVATION	DEPTH	GRAPHIC LOG	BOX/SAMPLE NO.	MATERIAL CLASSIFICATION PHYSICAL DESCRIPTION
TYPE TOOL AND DIA.	METHOD N-BLOW COUNT	ADVANCE	RECOVERY %						
5 5/8" Tricone				Started hole with a 5 5/8" tricone bit	7361.0				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			
NC	11	50		0 ⁹ ft. penetration 4" dia. casing placed to a depth of 20 ⁰ ft.		20		#1	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% slight color change, mixed brown and light gray, very stiff clayey sand matrix around fresh, hard light gray rock fragments.
			79						
	50			SPT- 0.3ft. penetration 0.3 ft. recovered		30		#2	
			67						
			95	Started drilling at 20.0 ft. with NC-wire line core bbl and diamond bit.		40			
			66						
	50			Average drilling rate with NC-wire line regular core barrel is 10 ft/hr		50			
			73						
			95						
			96						
			80						
			100	100% return of drilling fluid light brown		60			
			40						
			100			70			

HOLE NO.
DH-4

DRILL LOG				PROJECT Manti Slide Study		JOB NO. 614-02	HOLE NO. DH-4	
SAMPLE DATA			REMARKS WATER LEVELS WATER RETURN DRILLING FLUID CASING DEPTH	ELEVATION	DEPTH	GRAPHIC LOG	BOX/SAMPLE NO.	MATERIAL CLASSIFICATION PHYSICAL DESCRIPTION
TYPE TOOL AND DIA.	METHOD N- BLOW COUNT	ADVANCE RECOVERY						
		100						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.
		45						
		53						
		83						
		100						
		60						
		100						
		50	SPT-0.4 ft. penetration 0.4 ft. recovered				#3	
		78						
		100						
		100						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
		85						
		100						
		100						
		85						
		100						
		98						
		50	SPT-0.3 ft. penetration 0.3 ft. recovered				#4	
		100						
		96						
		55						Increase in subangular gravels clayey sandy gravels, glacial debris, mottled yellowish brown, brown and gray fines. Dry density = 140 lb/ft. ³ Ø = 32° cohesion = 2.2 ksf
		60						
		100						
		55	Hole bottomed at 150.0ft. as designated by the U.S. Forest Service					
		32	SPT-0.9ft. penetration				#5	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.

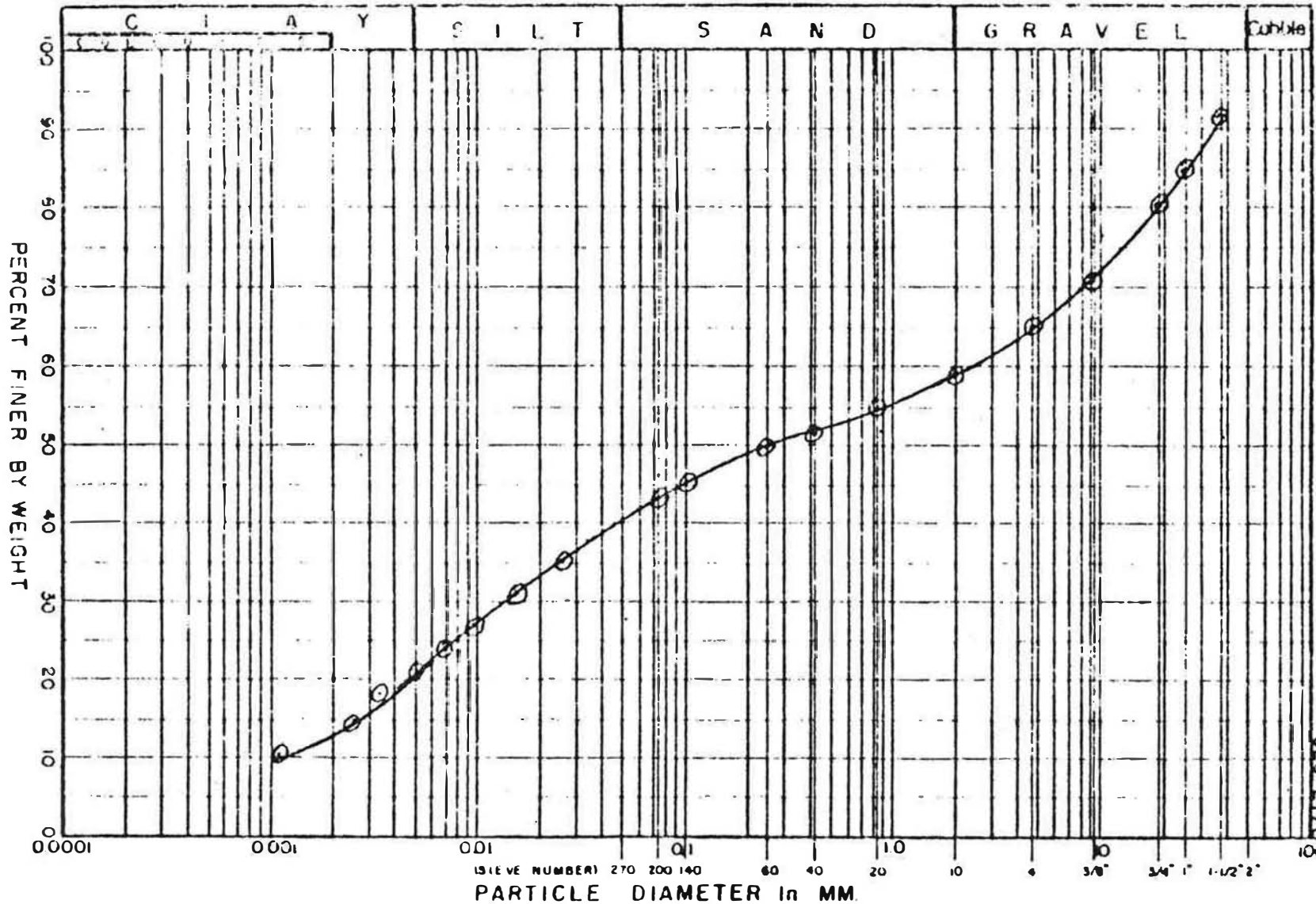
DRILL LOG		PROJECT		JOB NO.		HOLE NO.																									
		Manti Slide Study		614-02		DH-5																									
SITE		Dam Site Right Abutment		BEGUN	COMPLETED	HOLE SIZE	ANGLE FROM HORIZ. BEARING																								
				6/15/76	6/16/76	NC	Vertical																								
COORDINATES		None determined		DEPTH/EL. GROUND WATER		GROUND EL.	DEPTH/EL. TOP OF ROCK																								
				none		6140.0	57.5 ft./6082.5																								
DRILLING CONTRACTOR		Boyles Bros. Drilling Company		CORE RECOV. LENGTH/%	SAMPLES	CORE BOXES	DEPTH/EL. BOTTOM OF HOLE																								
				13.6ft. 59%	6	2	70 ft./6070																								
DRILL MAKE AND MODEL		Mobil Drill B-56		LOGGED BY:																											
				J. Cercone and F.D. Nielson																											
SAMPLE DATA				REMARKS				ELEVATION				DEPTH				GRAPHIC LOG				BOX/SAMPLE NO.				MATERIAL CLASSIFICATION				PHYSICAL DESCRIPTION			
TYPE TOOL AND DIA.	METHOD N-BLOW COUNT	ADVANCE	RECOVERY																												
Tricone				Drilled with tricone rock bit				6140.0																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.								20				#2															
		11/9/9		SPT-1.5ft. penetration 0.9 ft. recovered								30				#3															
	Sh			0.5 ft. recovered								40				#4															
				Lost water circulation at 30.0																											
				At 37ft. open end permeability test.																											
				$k = 3.48 \times 10^{-2}$ cm/sec																											
		11/12/32		SPT - 1.5ft. penetration								50				#5															
				Started drilling with NC-wire line regular core barrel.																											
NC				At 57ft. open end permeability test.																											
				$k = 1.46 \times 10^{-4}$ cm/sec																											
NC-CS	50			SPT - 0.1 ft. penetration no recovery								60				#6								Alluvium - some rounded rock fragments gravel to cobble sized, a few larger boulders in a matrix of sandy silt.							
				Permeability test between 57-70 ft																											
				$k = 5.16 \times 10^{-5}$ cm/sec								70												TOP OF BEDROCK							
																								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.							

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

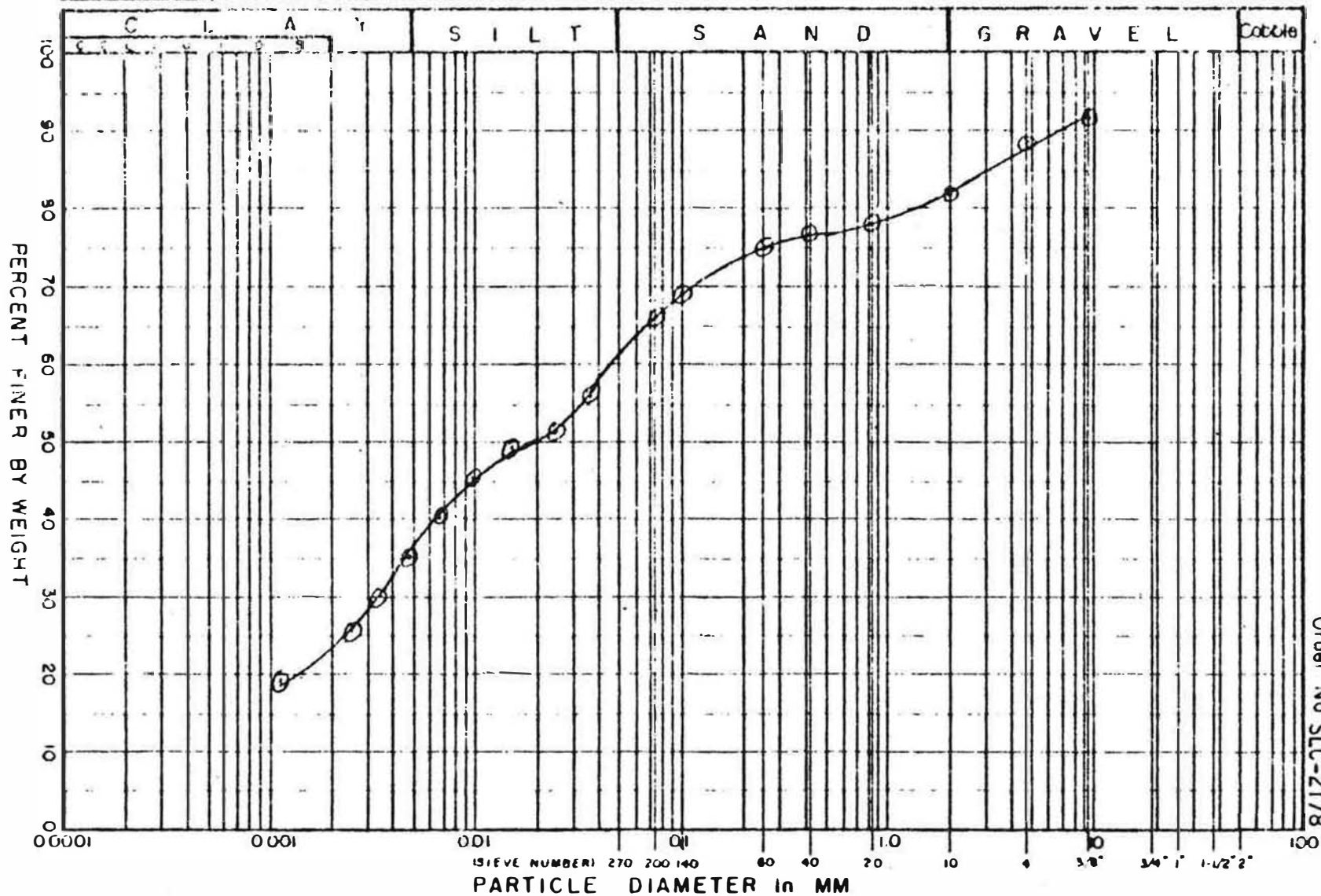


PITTSBURGH TESTING LABORATORY

Order No. SLC-21783

GRAIN SIZE DISTRIBUTION CURVES

Sample No	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
DH1-4		specific gravity (-#10) 2.64	DP	7-21-76	DP	7-22-76

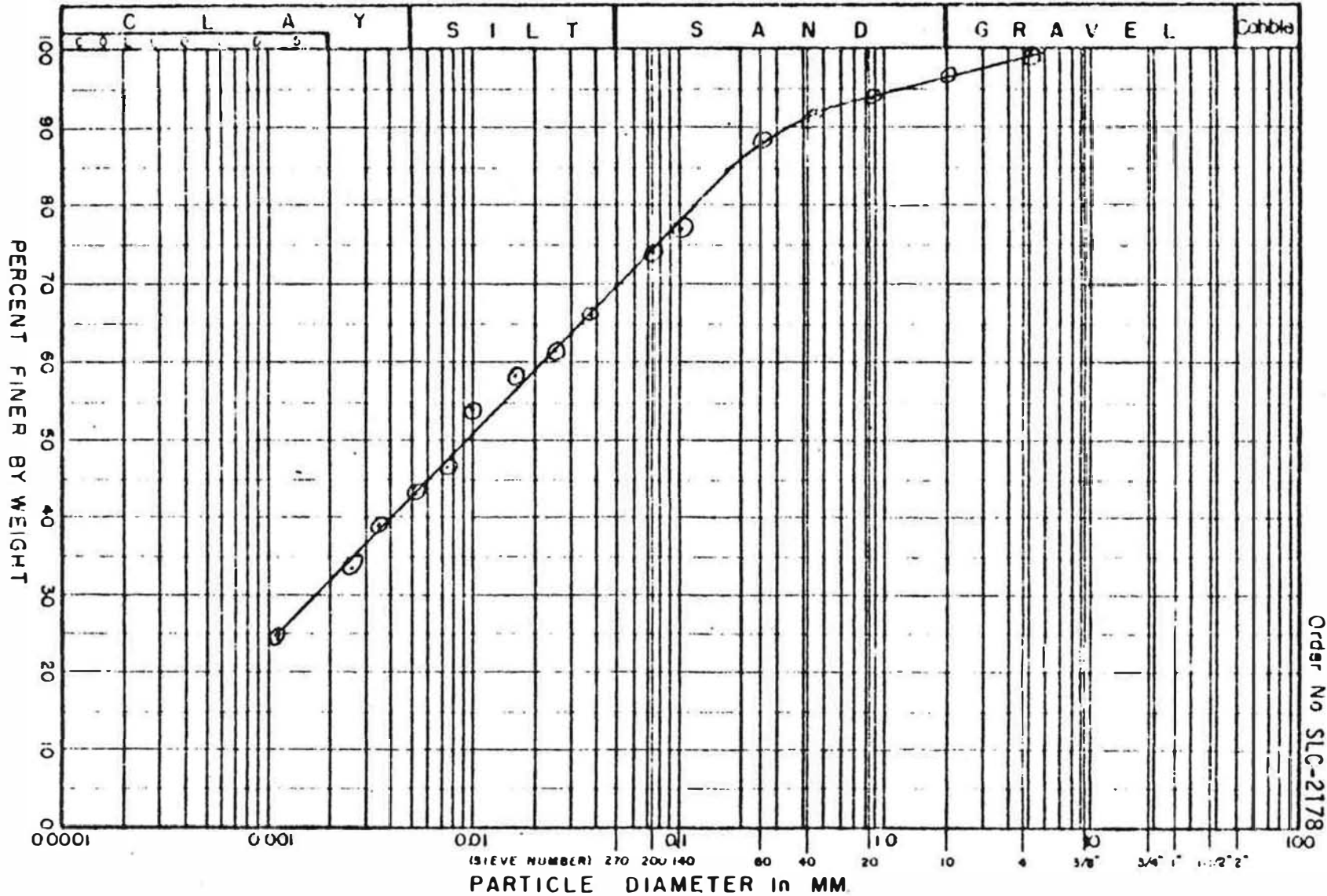


PITTSBURGH TESTING LABORATORY

Order No SLC-2178

GRAIN SIZE DISTRIBUTION CURVES

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

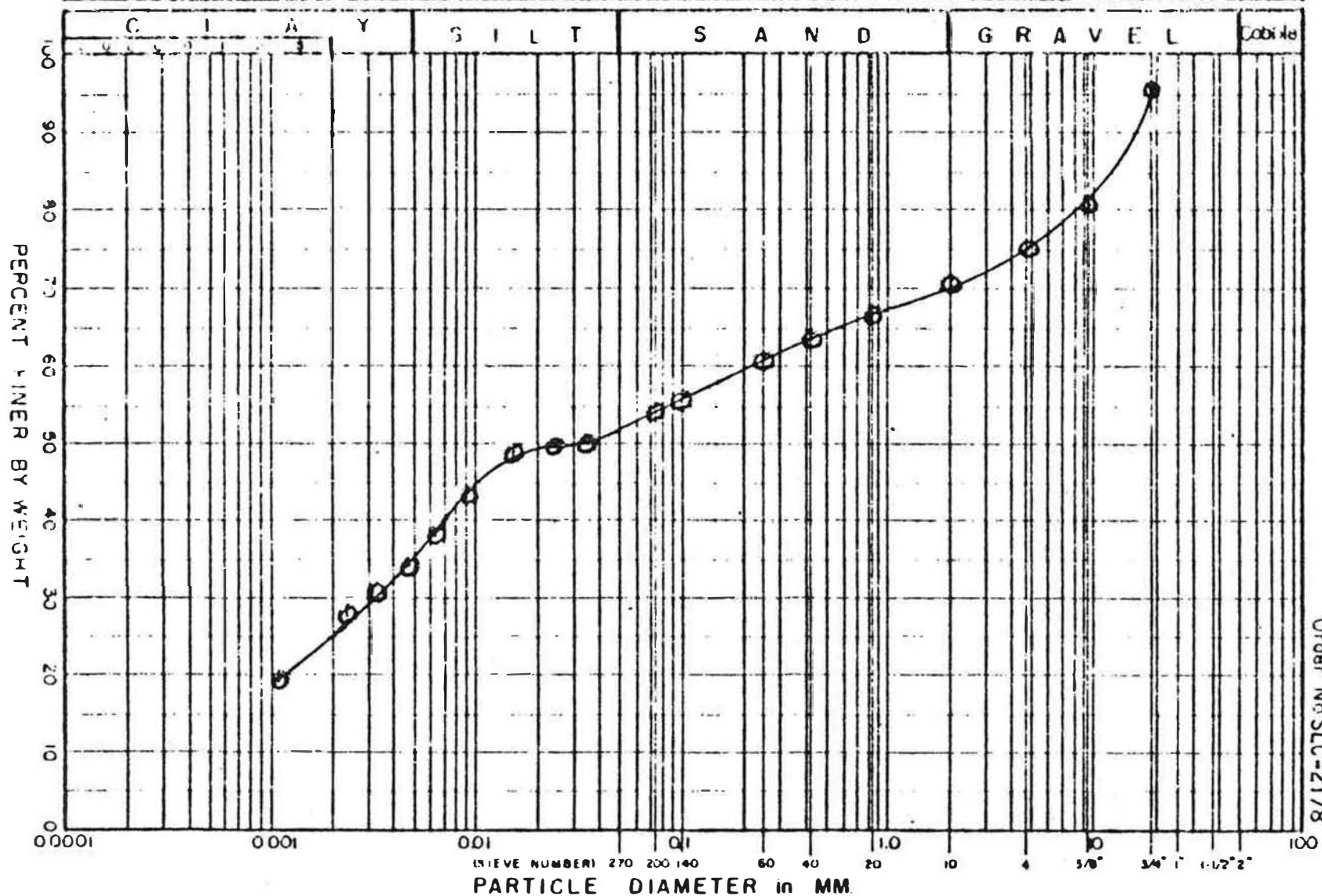


PITTSBURGH TESTING LABORATORY

Order No SLC-2178

GRAIN SIZE DISTRIBUTION CURVES

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

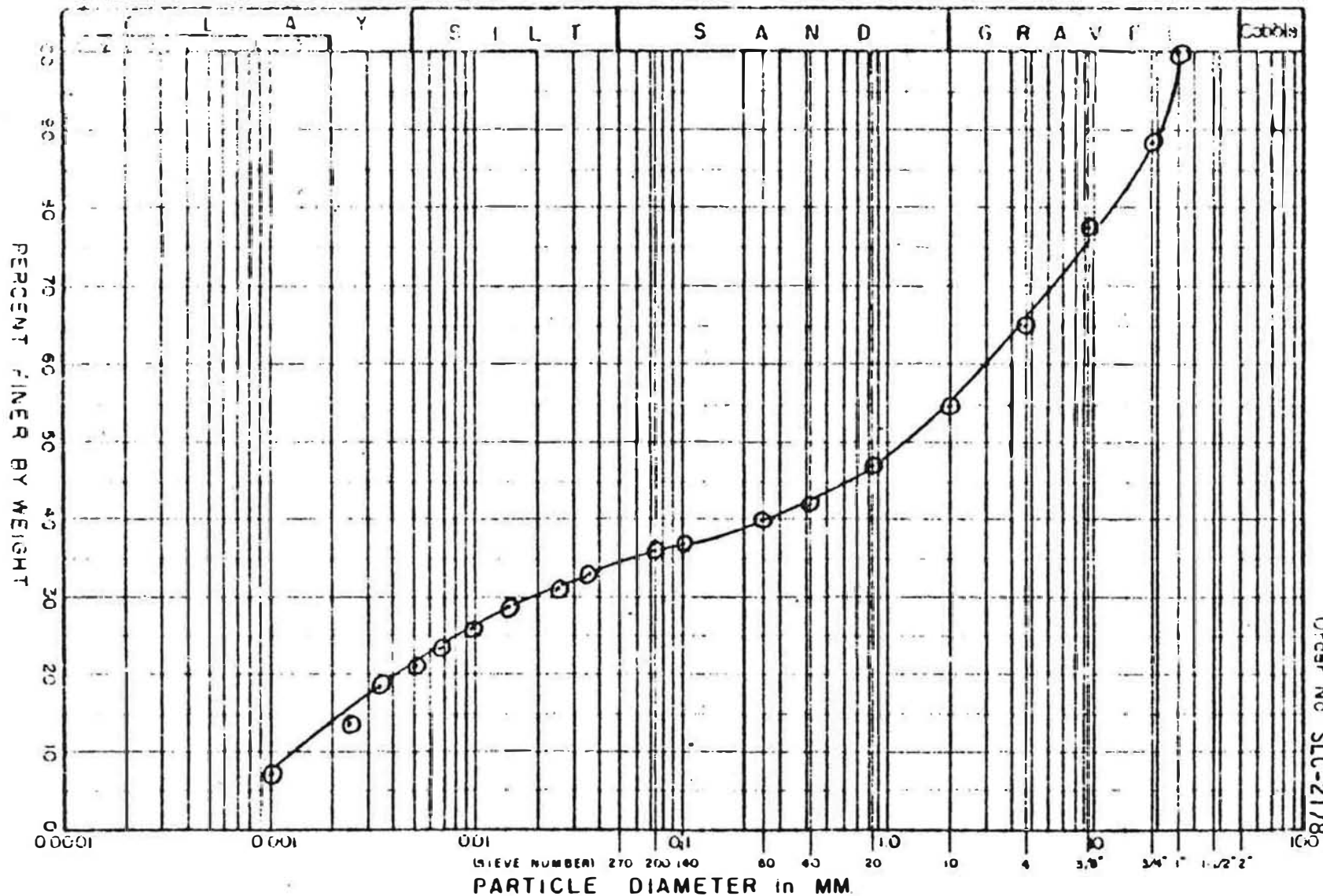


PITTSBURGH TESTING LABORATORY

Order No SLC-2178

GRAIN SIZE DISTRIBUTION CURVES

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

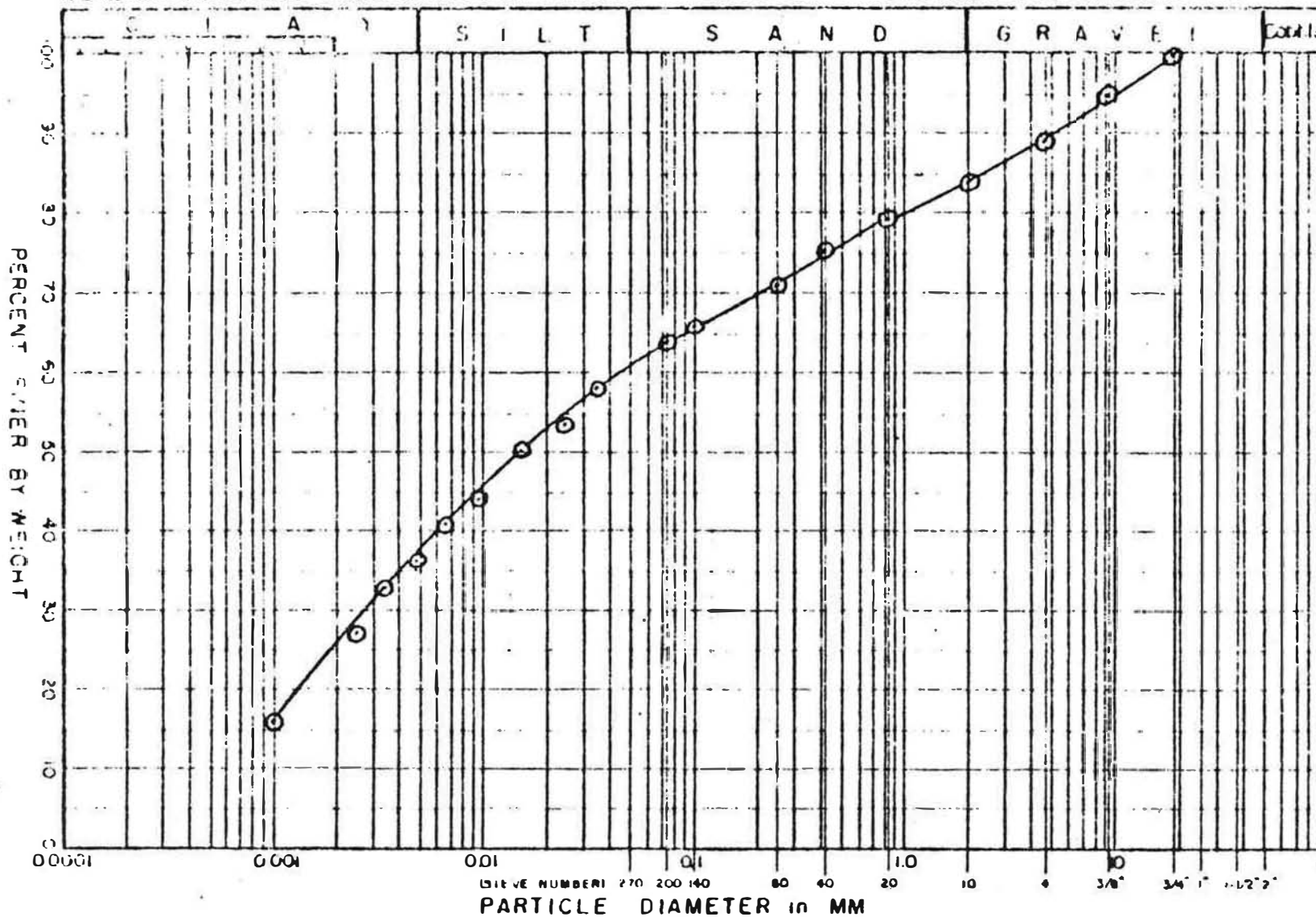


PITTSBURGH TESTING LABORATORY

Order No SLC-21780

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	6-2-76	DK	6-2-76
			2.72			



PITTSBURGH TESTING LABORATORY

Order No. SLC-2178

GRAIN SIZE DISTRIBUTION CURVES

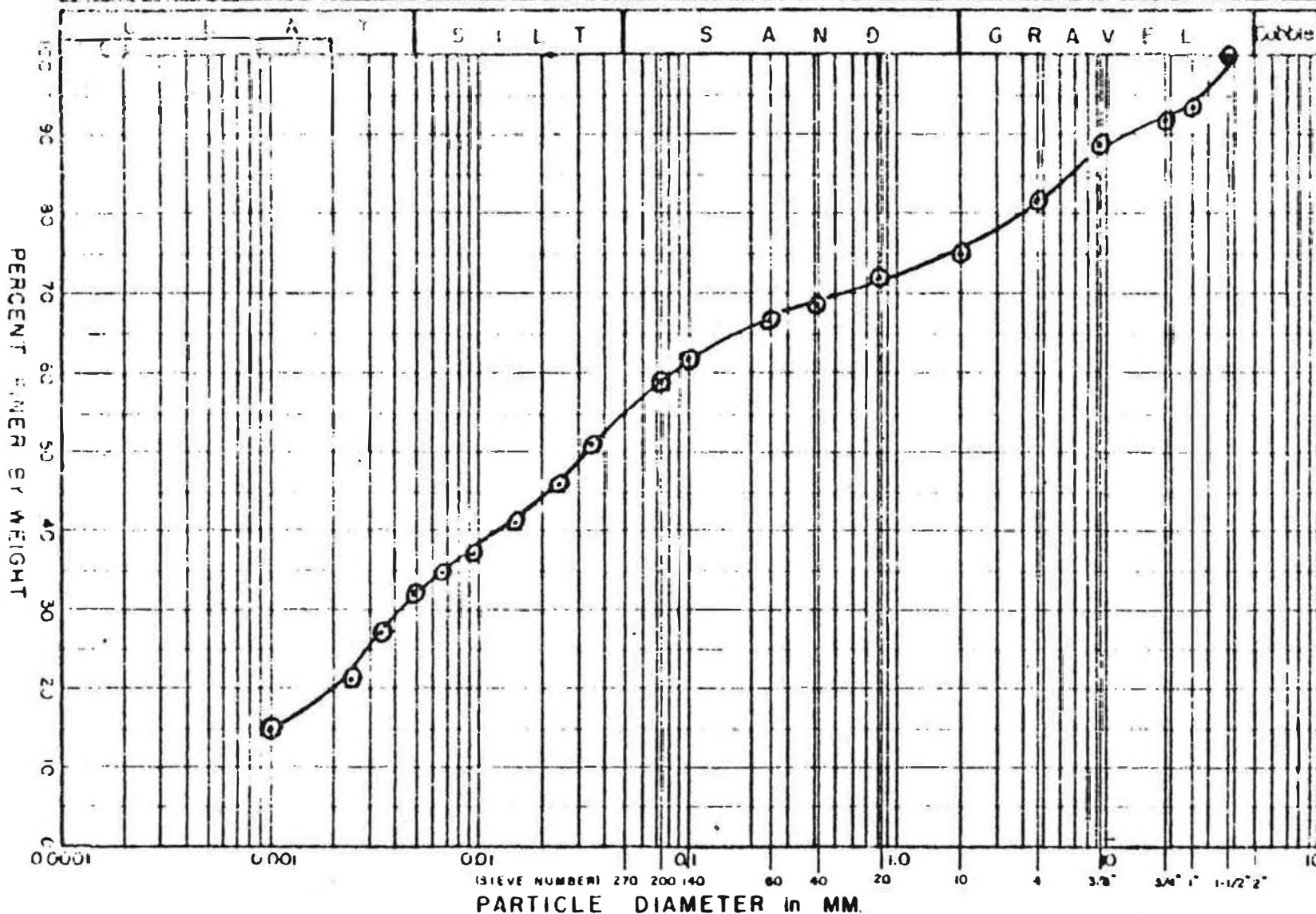
Sample No	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
DH-21 at 77 ft. Mantl Slide	— — — — —	apparent specific gravity (-710) 2.67 moisture content 6.1%	DK	6-18-76	DK	6-21-76

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PITTSBURGH TESTING LABORATORY

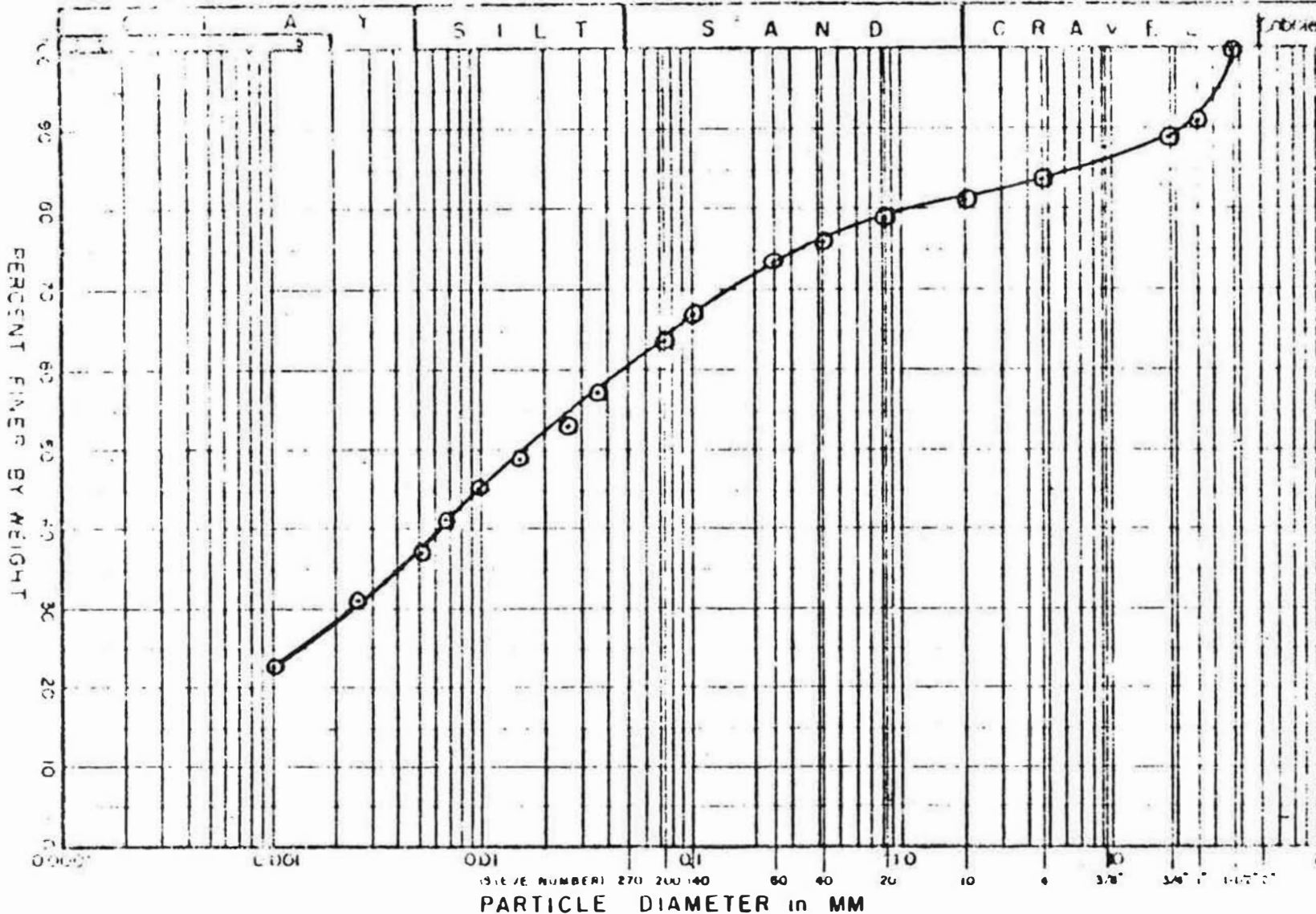
Order No SLC-2178

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



Caldwell, Richards & Sorensen, Inc.

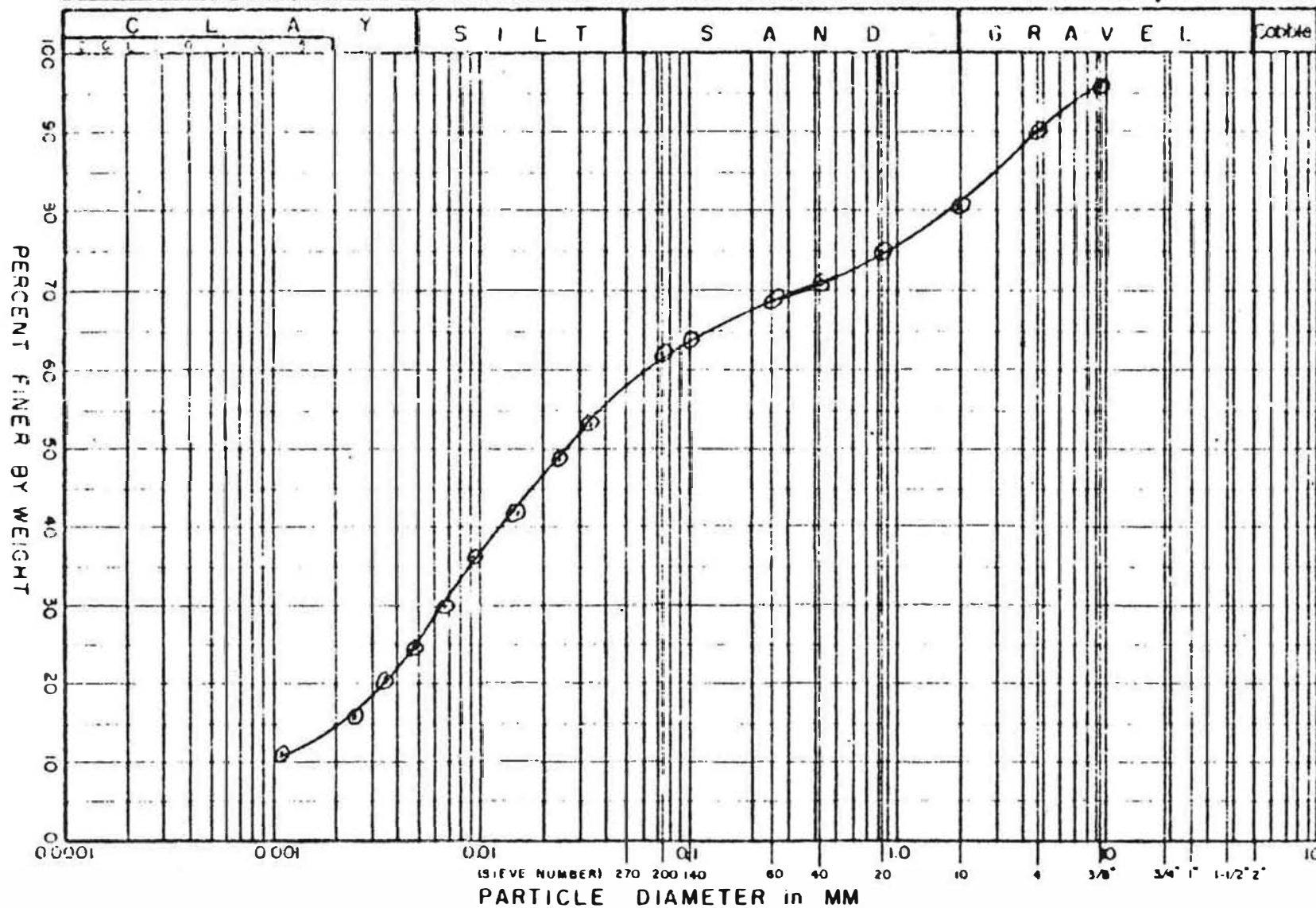
PITTSBURGH TESTING LABORATORY

Order No. SLC-2178

P.O. 1855

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

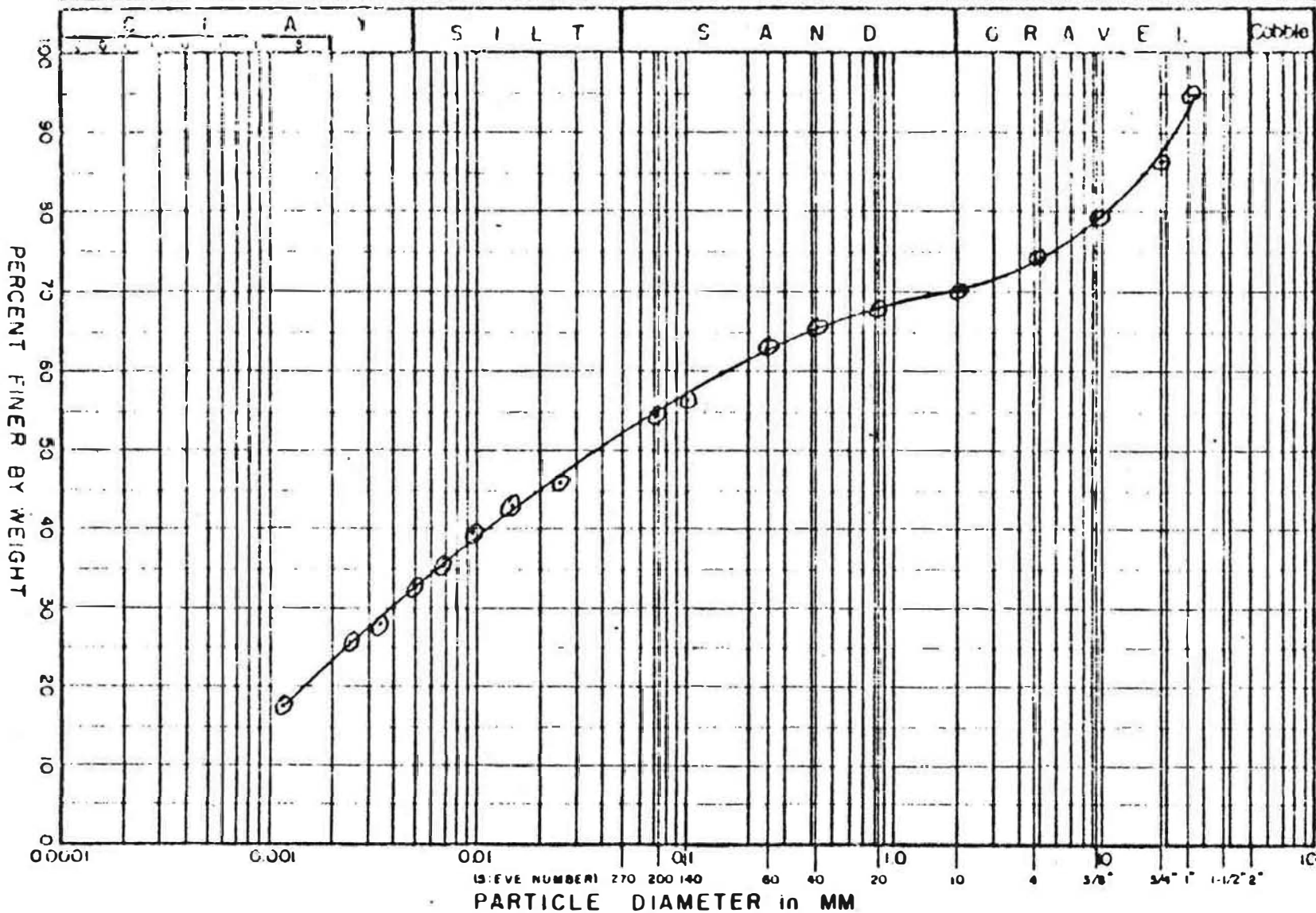


PITTSBURGH TESTING LABORATORY

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

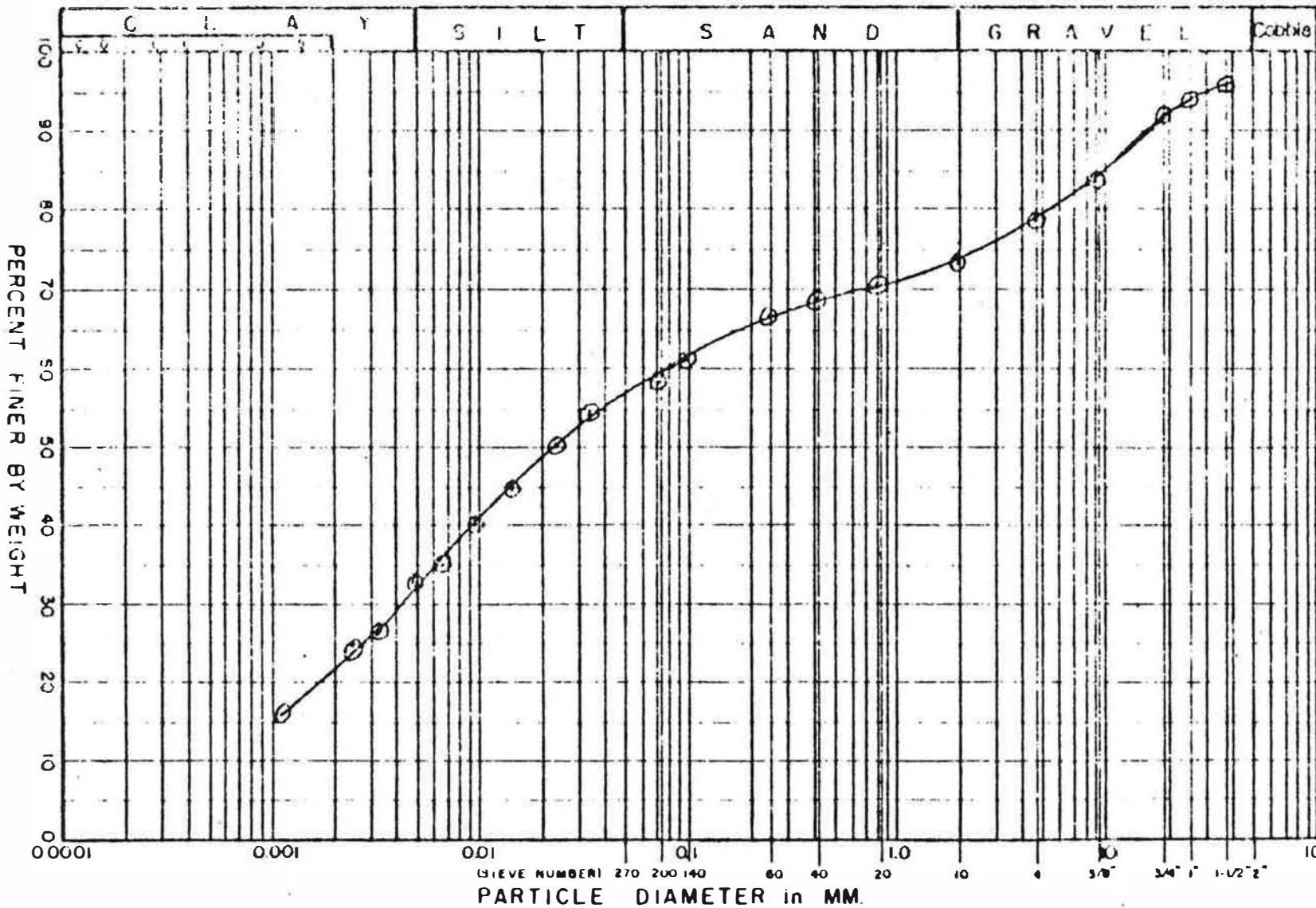


PITTSBURGH TESTING LABORATORY

Order No SLC-2178

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

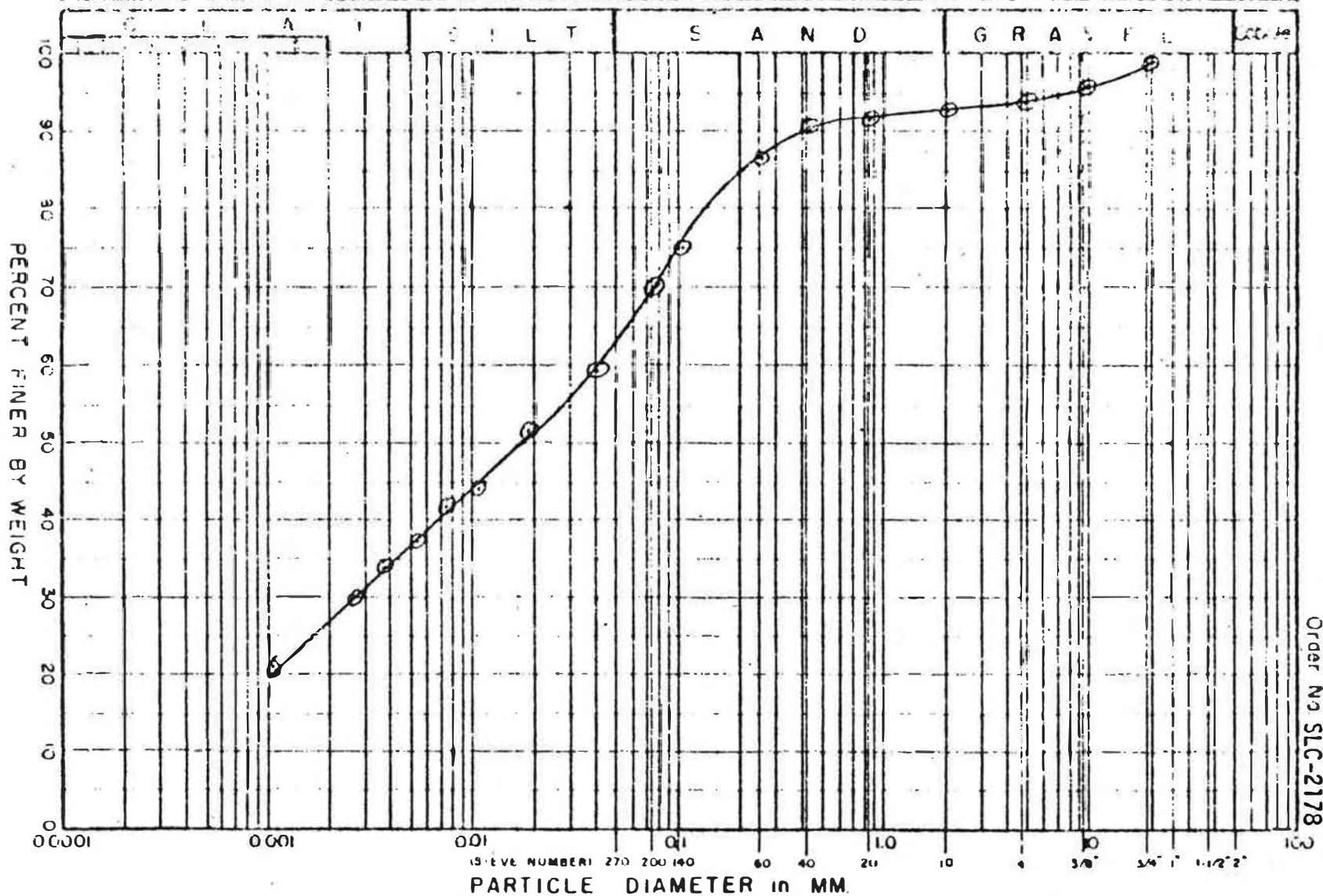


PITTSBURGH TESTING LABORATORY

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

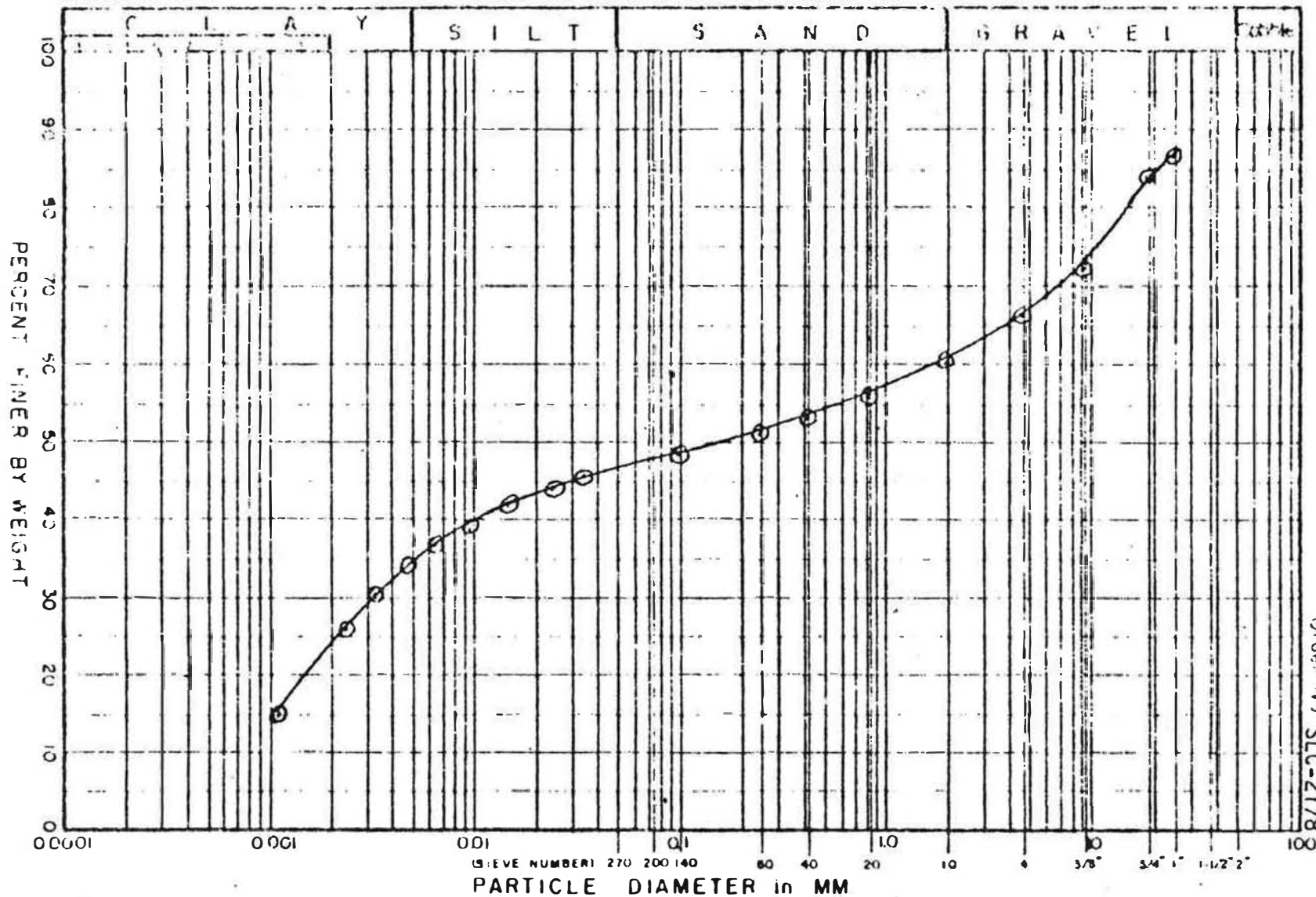


PITTSBURGH TESTING LABORATORY

Order No SLC-2178

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

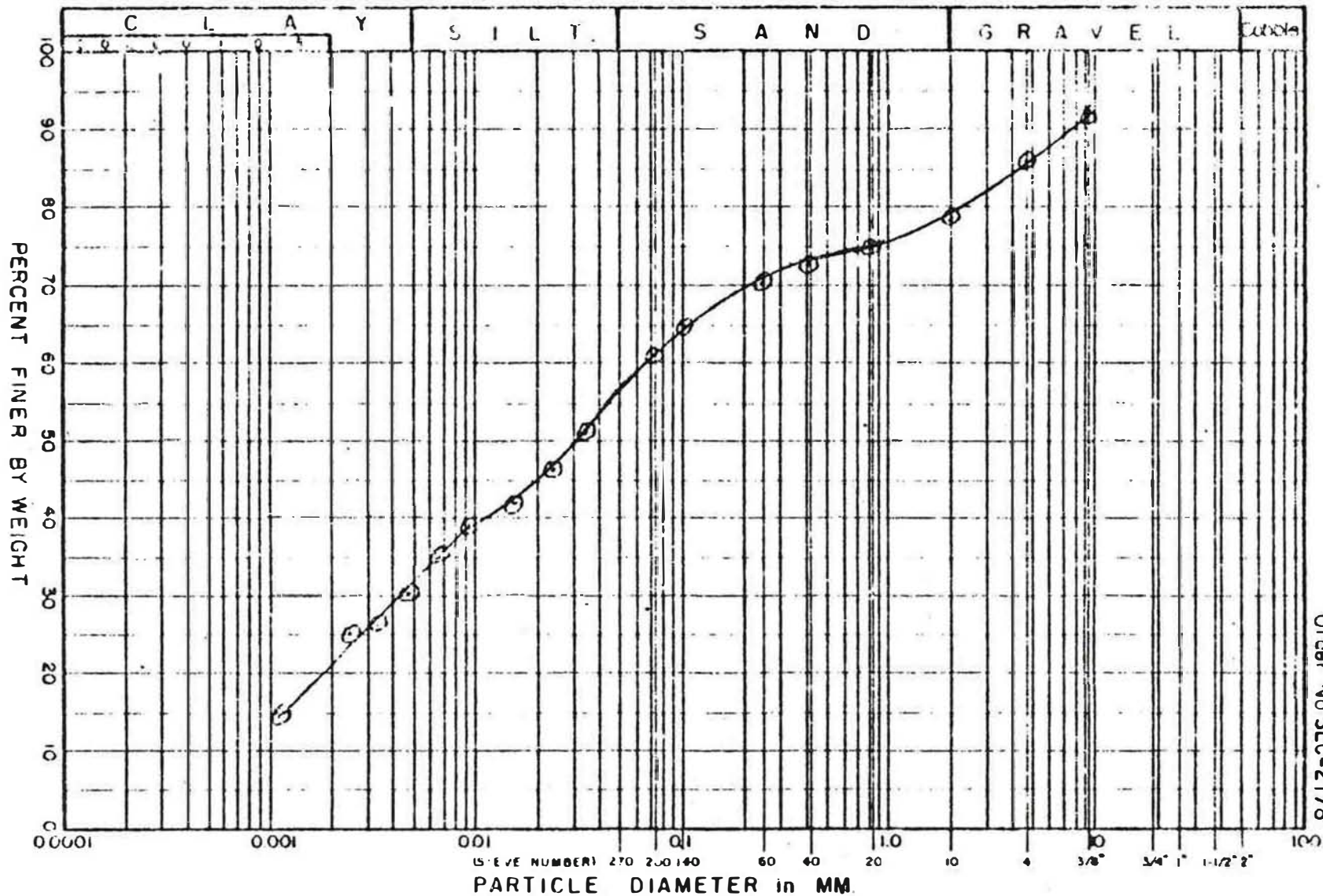


Order No SLC-2178

PITTSBURGH TESTING LABORATORY

GRAIN SIZE DISTRIBUTION CURVES

Sample No	Line Symbol	Textural Classification	Tested By	Date	Plotted By	Date
PH4-7		Specific Gravity (-#10) 2.629	DP	7-21-76	DP	7-22-76

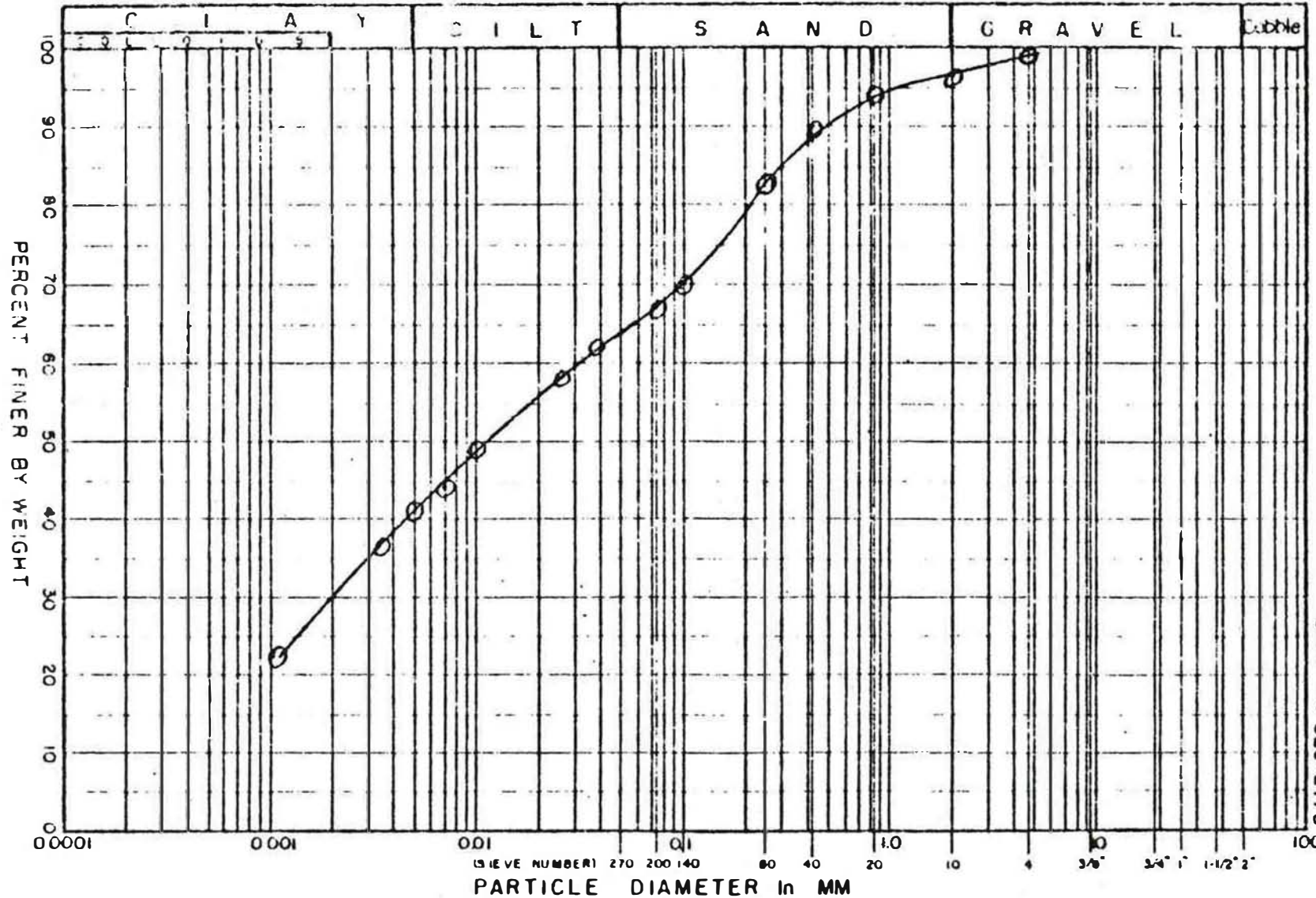


PITTSBURGH TESTING LABORATORY

Order No SLC-2178

GRAIN SIZE DISTRIBUTION CURVES

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



PITTSBURGH TESTING LABORATORY

Order No SLC-2178

APPENDIX B
PHOTOGRAPHS

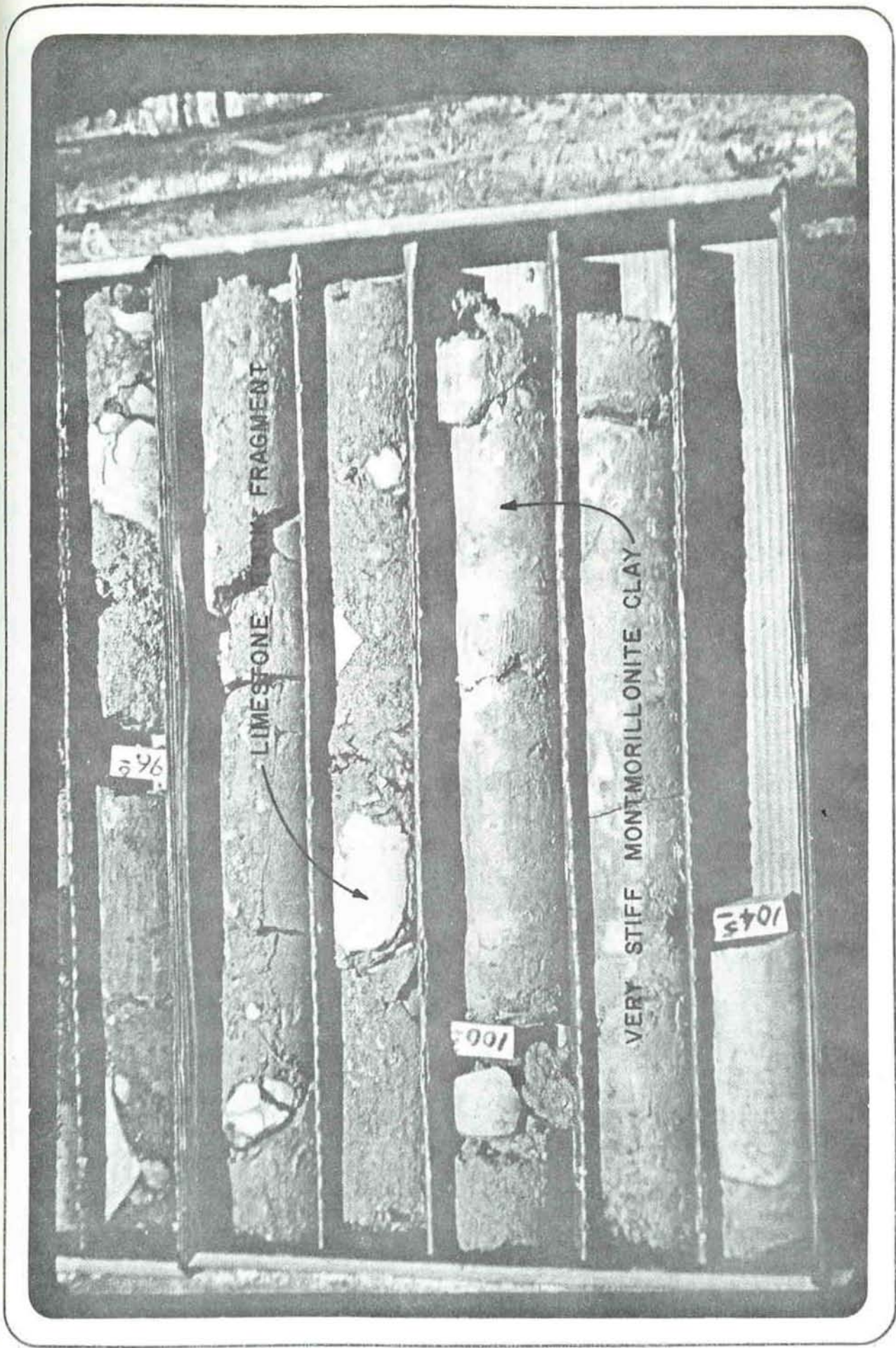
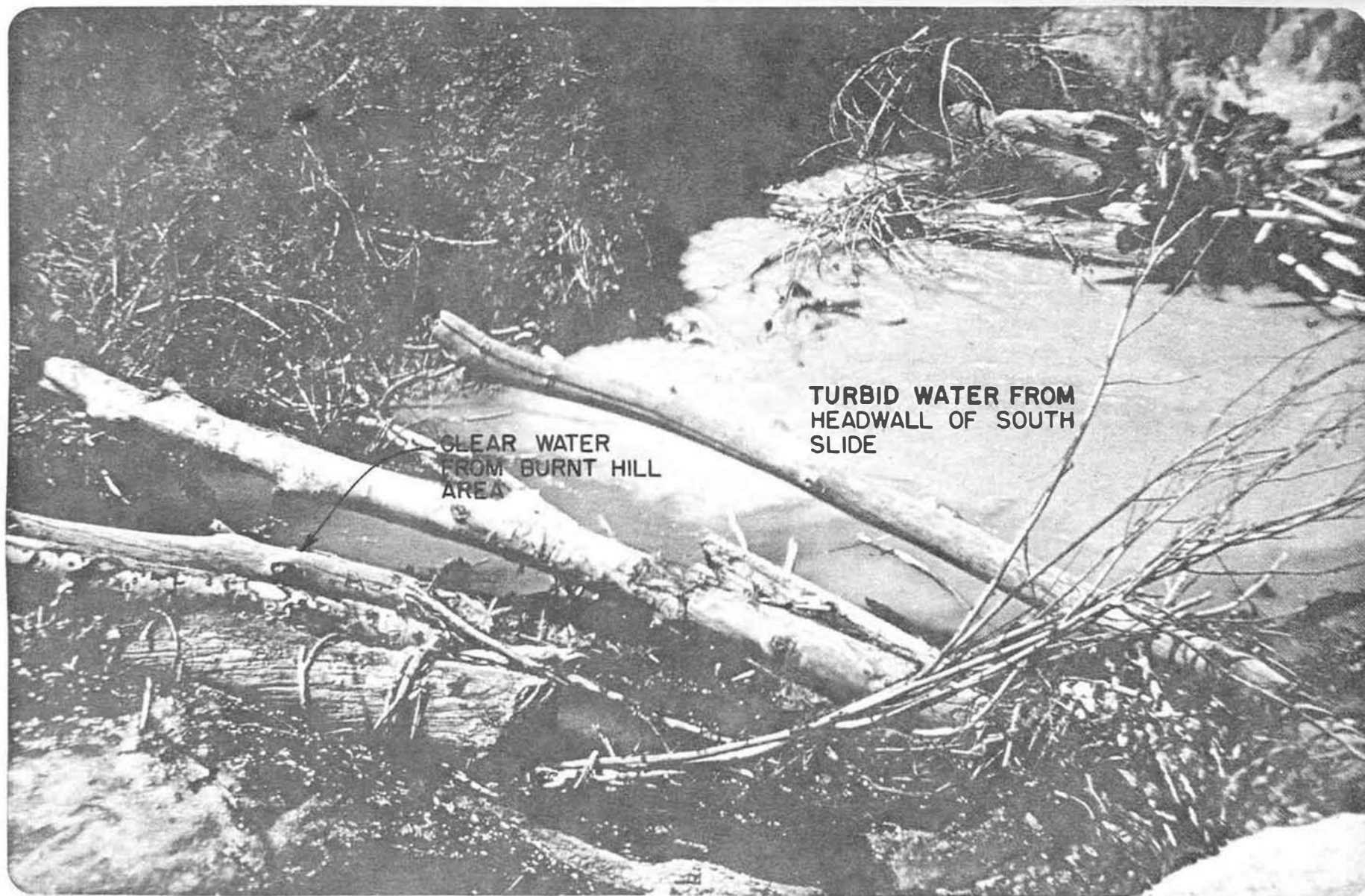


PHOTO 2 — TYPICAL DENSE GLACIAL TILL DH-1 95' TO 104'



CLEAR WATER
FROM BURNT HILL
AREA

TURBID WATER FROM
HEADWALL OF SOUTH
SLIDE

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

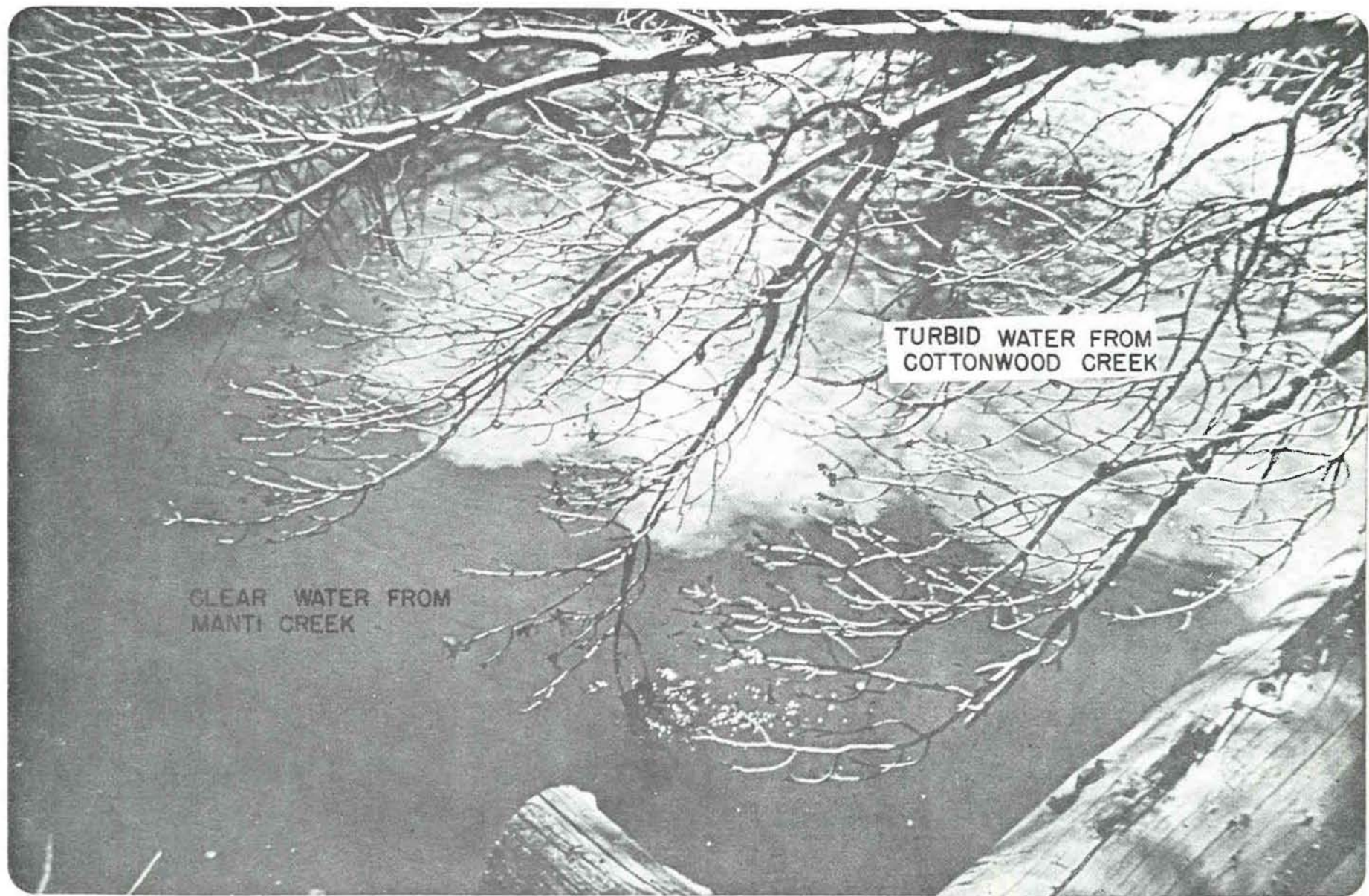


PHOTO 4 - CONFLUENCE OF MANTI CREEK AND COTTONWOOD CREEK
SHOWING MIXING OF CLEAR AND TURBID WATERS

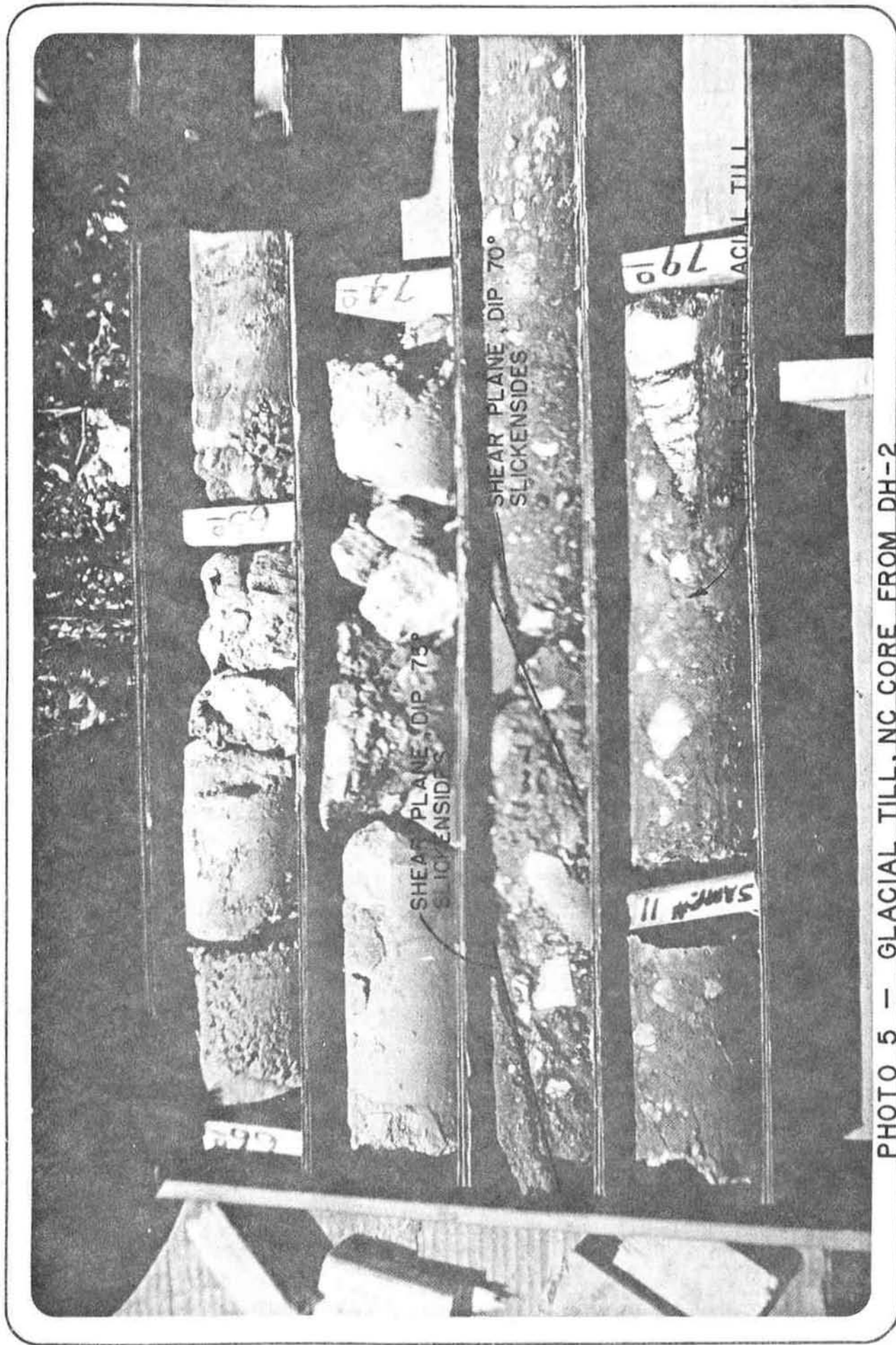


PHOTO 5 - GLACIAL TILL, NC CORE FROM DH-2

SHOWING SHEAR PLANES



BANK SLOPE
APPROXIMATELY 60°

NOTE EXCESSIVE SLOUGHING AND
EROSION OF GLACIAL TILL

SLOPE UNDERCUT BY
MANTI CREEK

PHOTO 6 - TAKEN AT BASE OF STABILITY
SECTION I

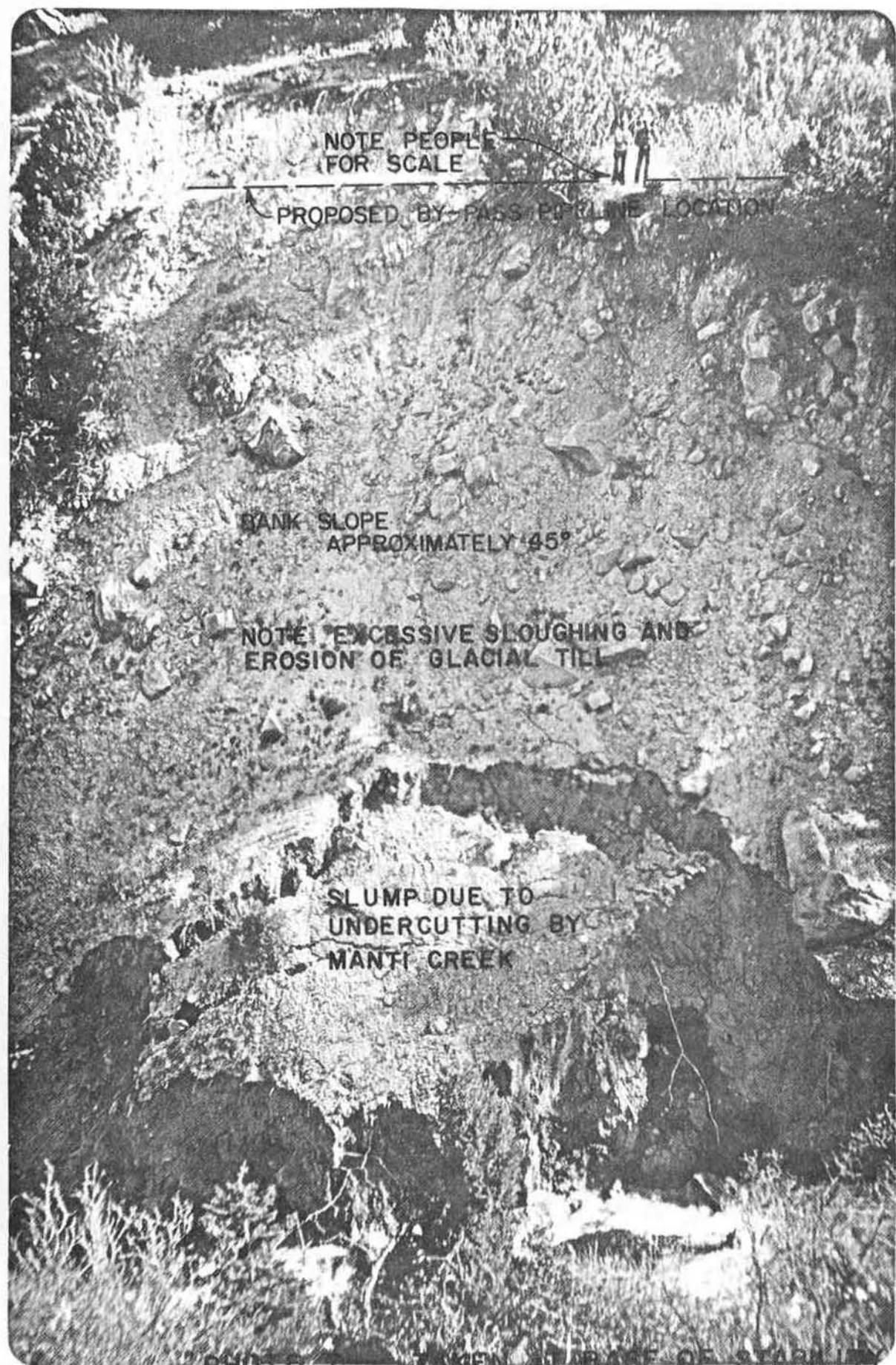


PHOTO 1 TAKEN AT BASE OF STABILITY
SECTION 2

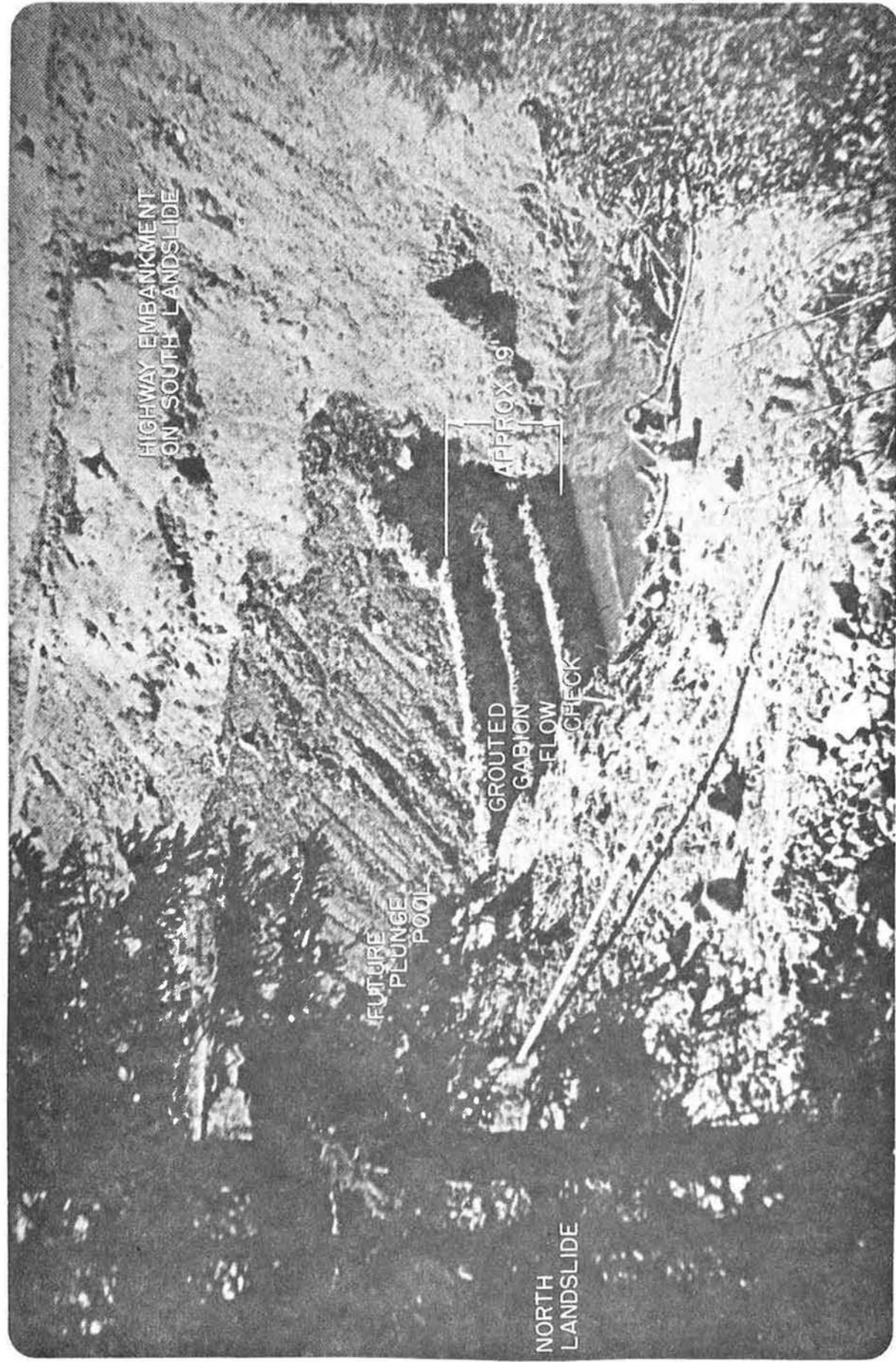


PHOTO 8 - CONSTRUCTION OF STABILIZED CHANNEL
VAIL PASS, COLORADO

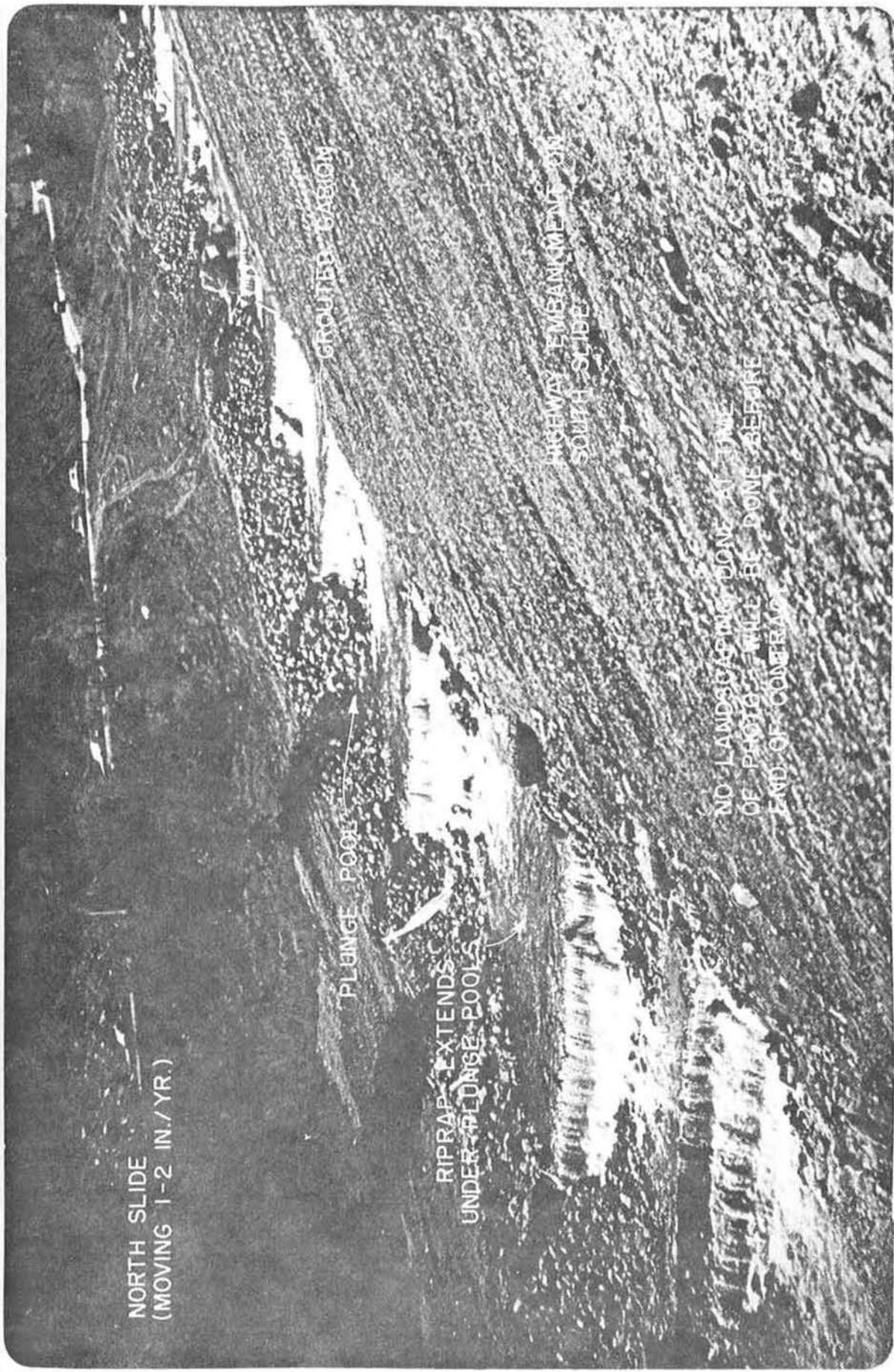
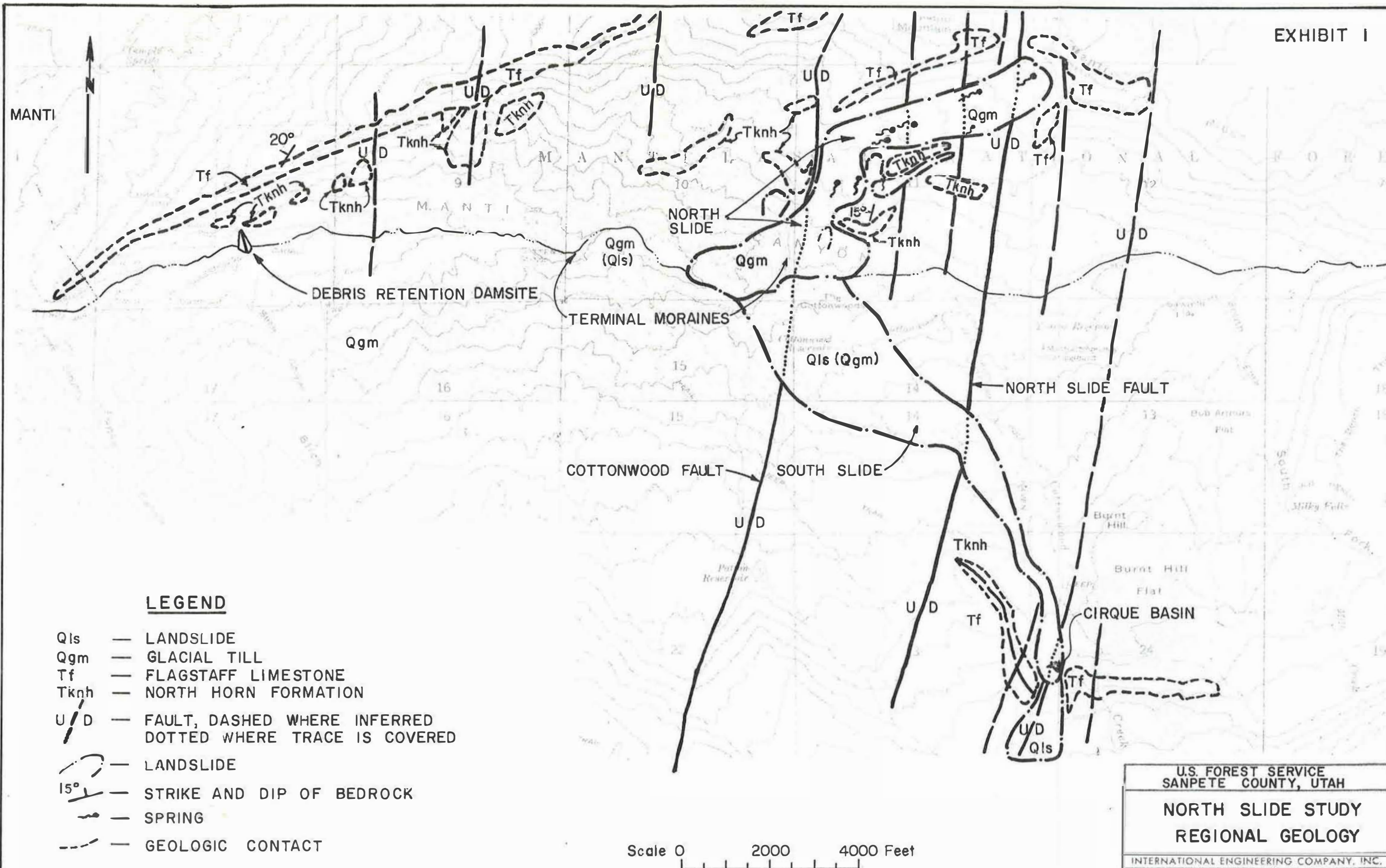


PHOTO 9 — COMPLETED STABILIZED CHANNEL ACROSS TWO LANDSLIDES
VAIL PASS, COLORADO

APPENDIX C
EXHIBITS

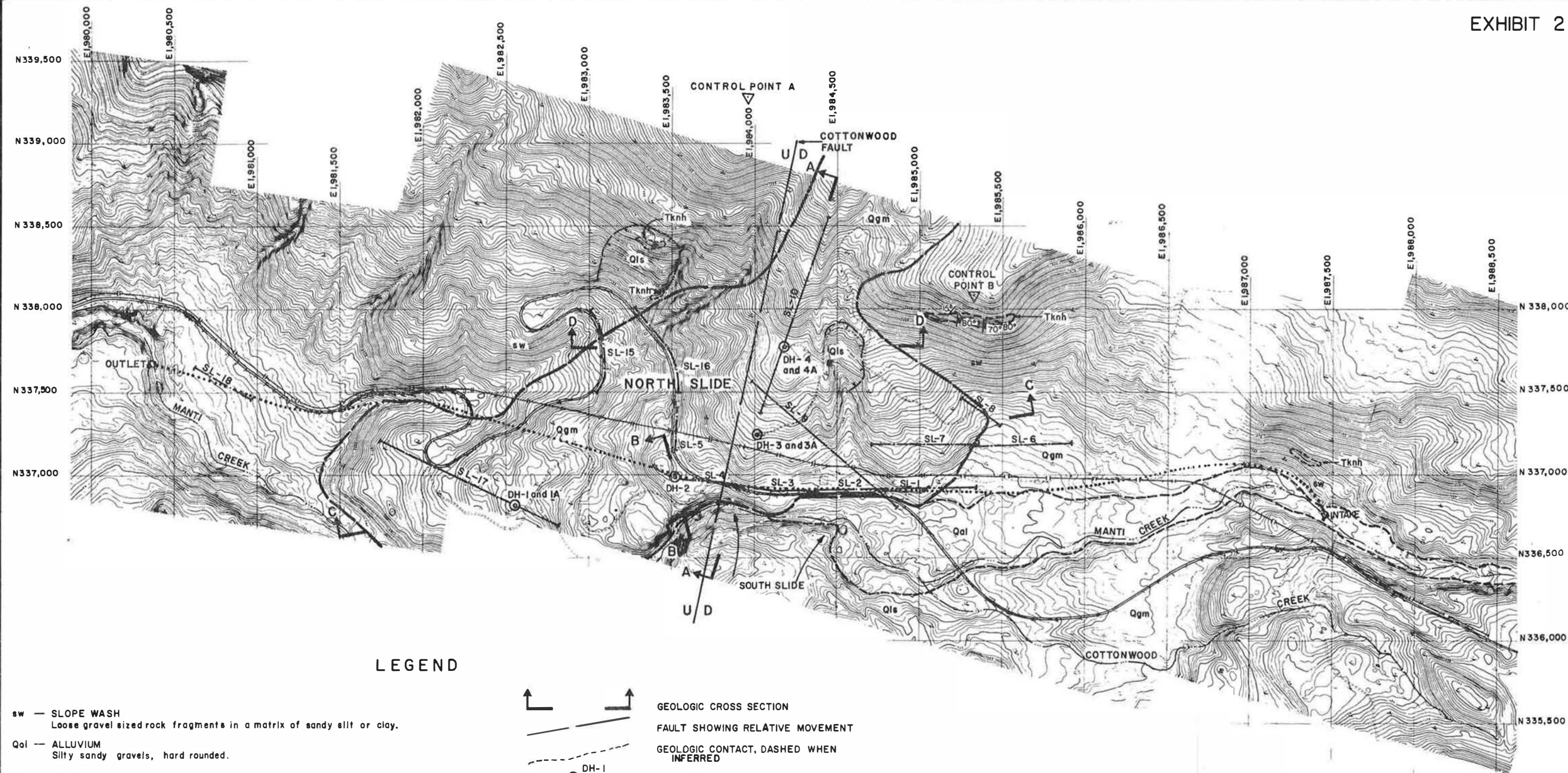


U.S. FOREST SERVICE
SANPETE COUNTY, UTAH

**NORTH SLIDE STUDY
REGIONAL GEOLOGY**

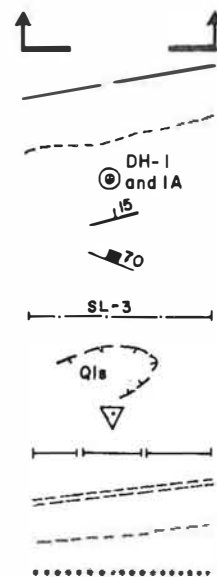
INTERNATIONAL ENGINEERING COMPANY, INC.

DESIGNED GCP	CHECKED	APPROVED
DRAWN PRI	NOTED	RECOMMENDED
IECO 270 MONTGOMERY STREET SAN FRANCISCO, CALIFORNIA 94104		DATE DRAWING NO.



LEGEND

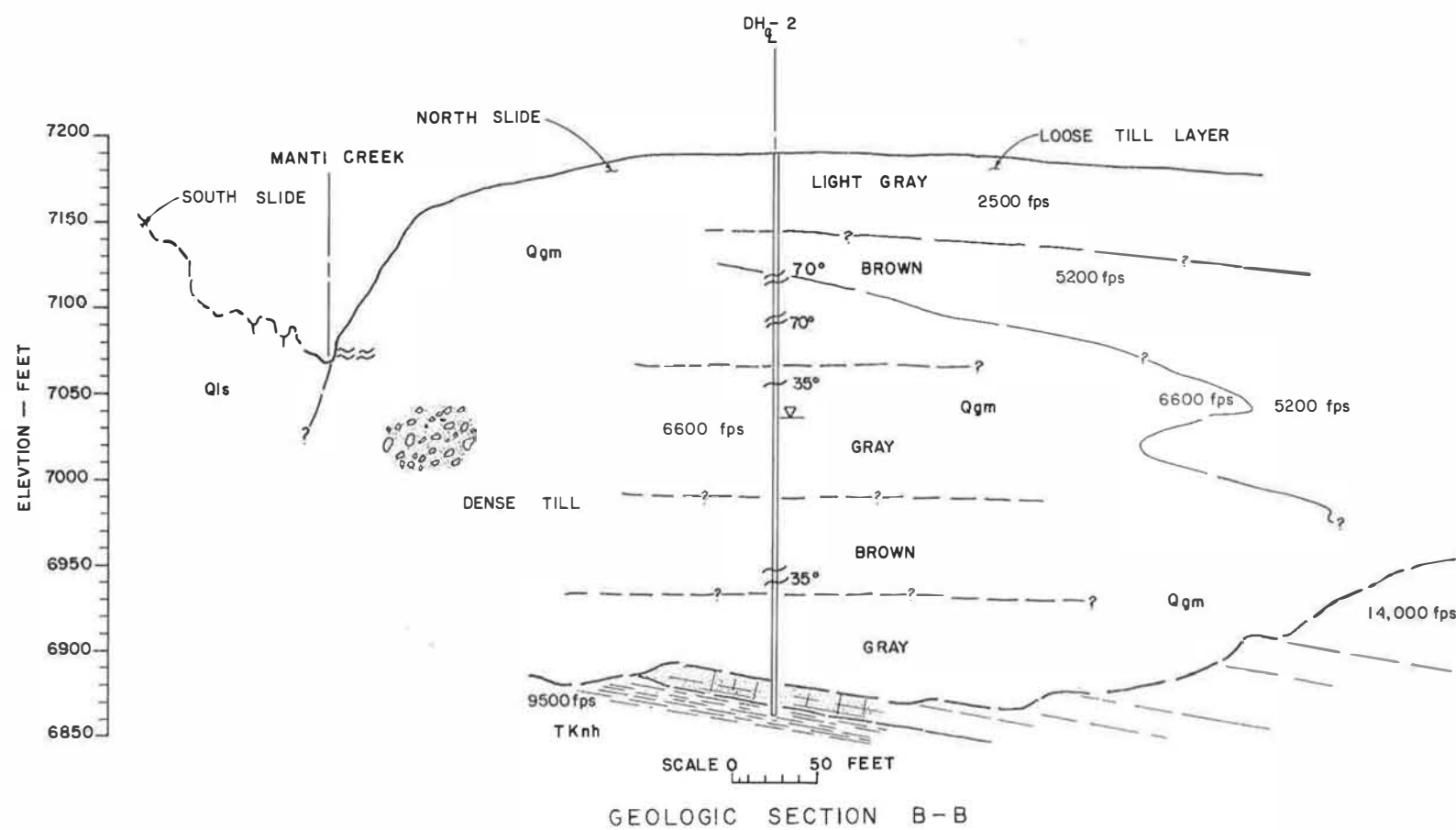
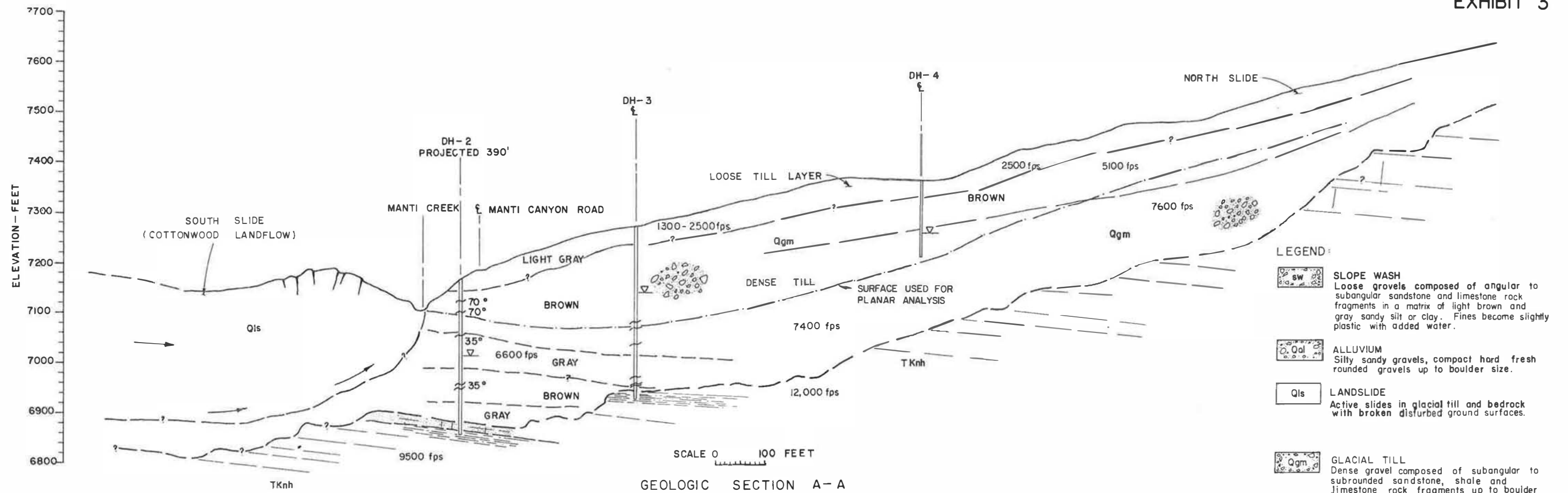
- sw — SLOPE WASH
Loose gravel sized rock fragments in a matrix of sandy silt or clay.
- Qal — ALLUVIUM
Silty sandy gravels, hard rounded.
- Qls — LANDSLIDE
Active slides in glacial till and bedrock with broken disturbed surfaces.
- Qgm — GLACIAL TILL
Dense gravel in a matrix of brown and gray montmorillonite 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
- EXPLORATORY AND INCLINOMETER HOLE
- STRIKE AND DIP
- STRIKE AND DIP OF MAJOR JOINT SETS
- SEISMIC LINE
- LANDSLIDE
- SURFACE SURVEY CONTROL POINT
- MANTI WATER PIPELINE
- ACCESS ROAD
- JEEP ROAD
- PROPOSED BY-PASS PIPELINE

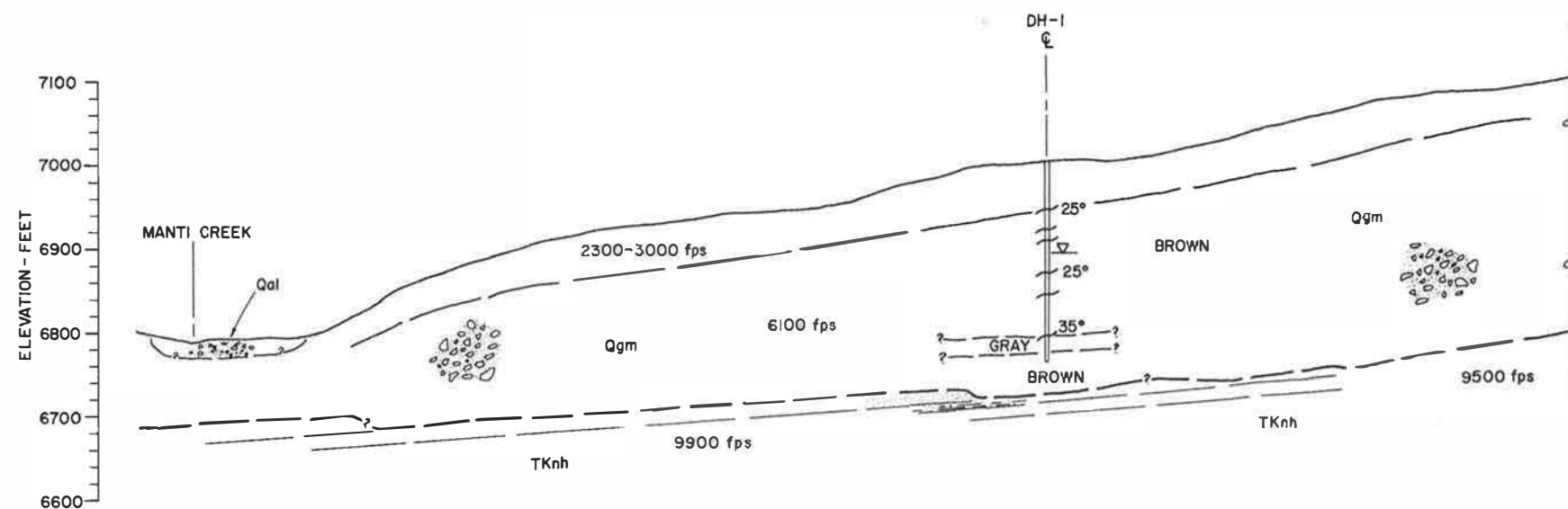
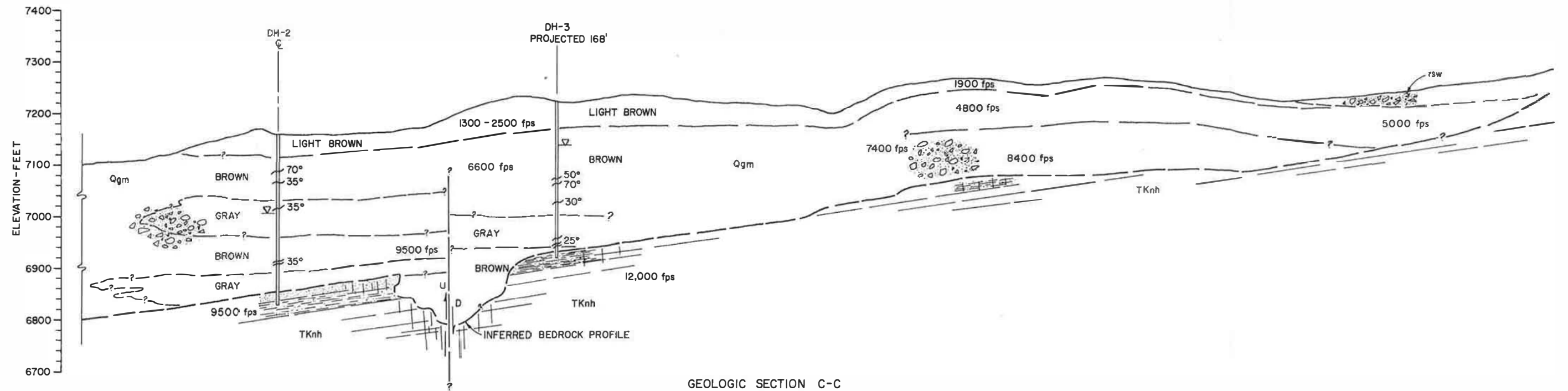
SCALE 0 500 1000 FEET

U.S. FOREST SERVICE SANPETE COUNTY, UTAH		
NORTH SLIDE STUDY		
NORTH SLIDE GEOLOGY AND DRILL HOLE LOCATIONS		
INTERNATIONAL ENGINEERING COMPANY, INC.		
DESIGNED <i>CCP</i>	CHECKED <i>ASC</i>	APPROVED
DRAWN <i>ASC</i>	INSPECT	RECOMMENDED
IECO 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		DATE 9-1-76 DRAWING NO



SCALE AS NOTED

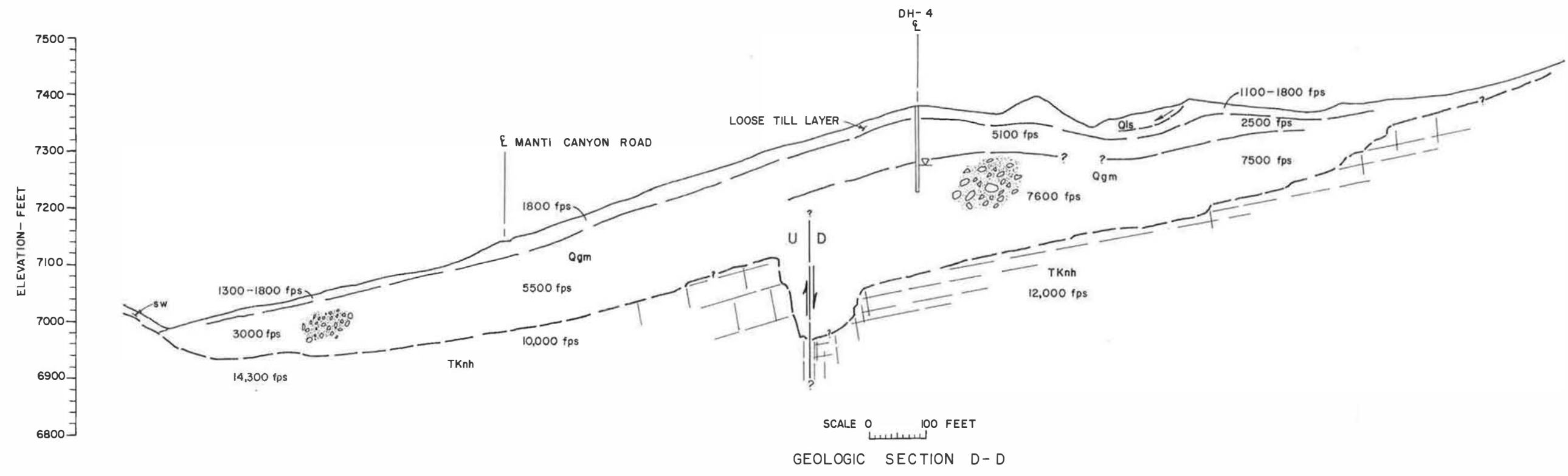
U.S. FOREST SERVICE SANPETE COUNTY, UTAH NORTH SLIDE STUDY GEOLGIC CROSS SECTIONS A-A & B-B		
INTERNATIONAL ENGINEERING COMPANY, INC.		
DESIGNED <u>CEP</u>	CHECKED _____	APPROVED _____
DRAWN <u>ASB</u>	INSPECT _____	RECOMMENDED _____
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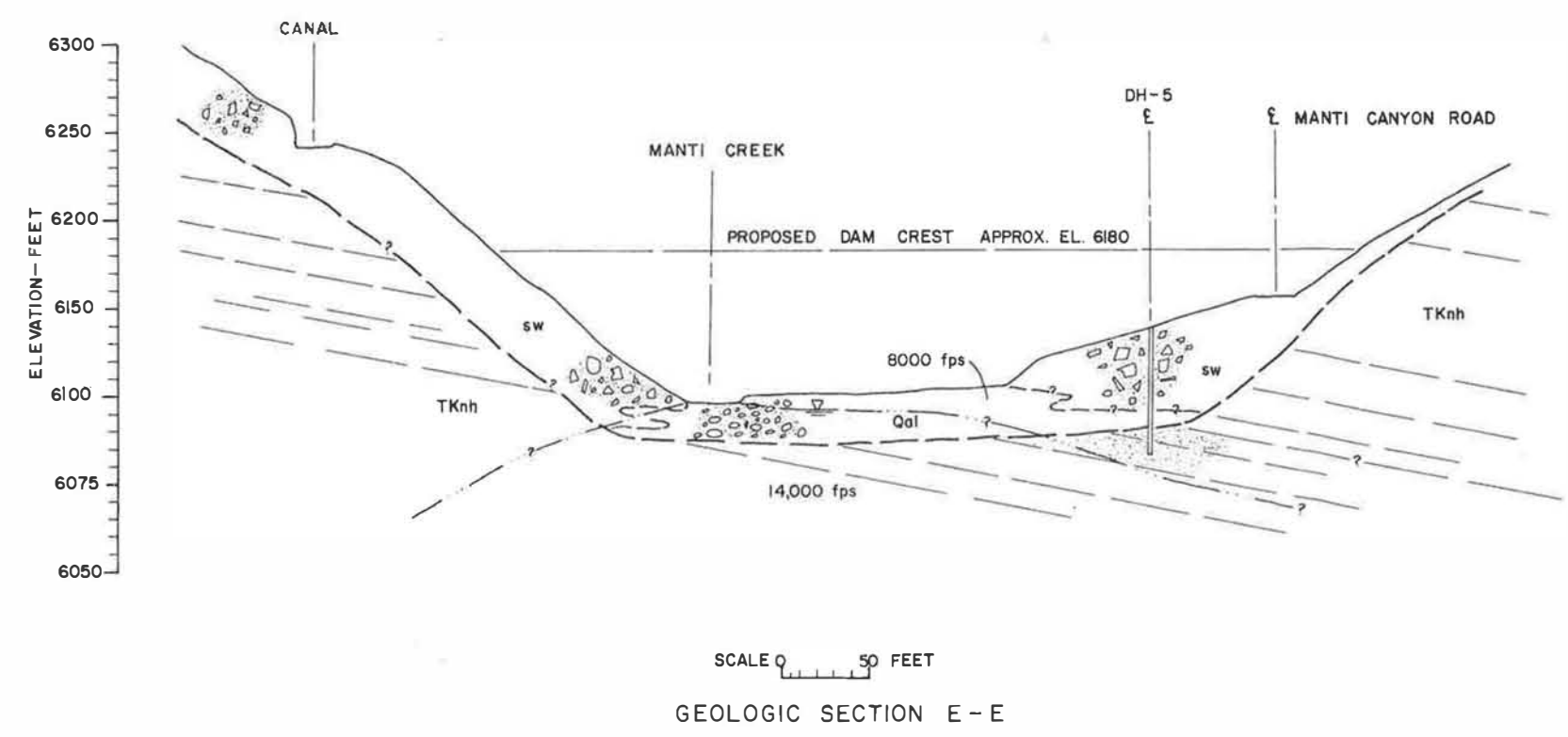
NOTE: FOR LEGEND SEE EXHIBIT 3

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 <u>CCP</u>	CHECKED <u>gk</u>	APPROVED _____
DRAWN <u>ET</u>	INSPECT _____	RECOMMENDED _____
IECO 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		DATE <u>9-1-76</u> REV. <u>1-24-77</u> DRAWING NO. _____

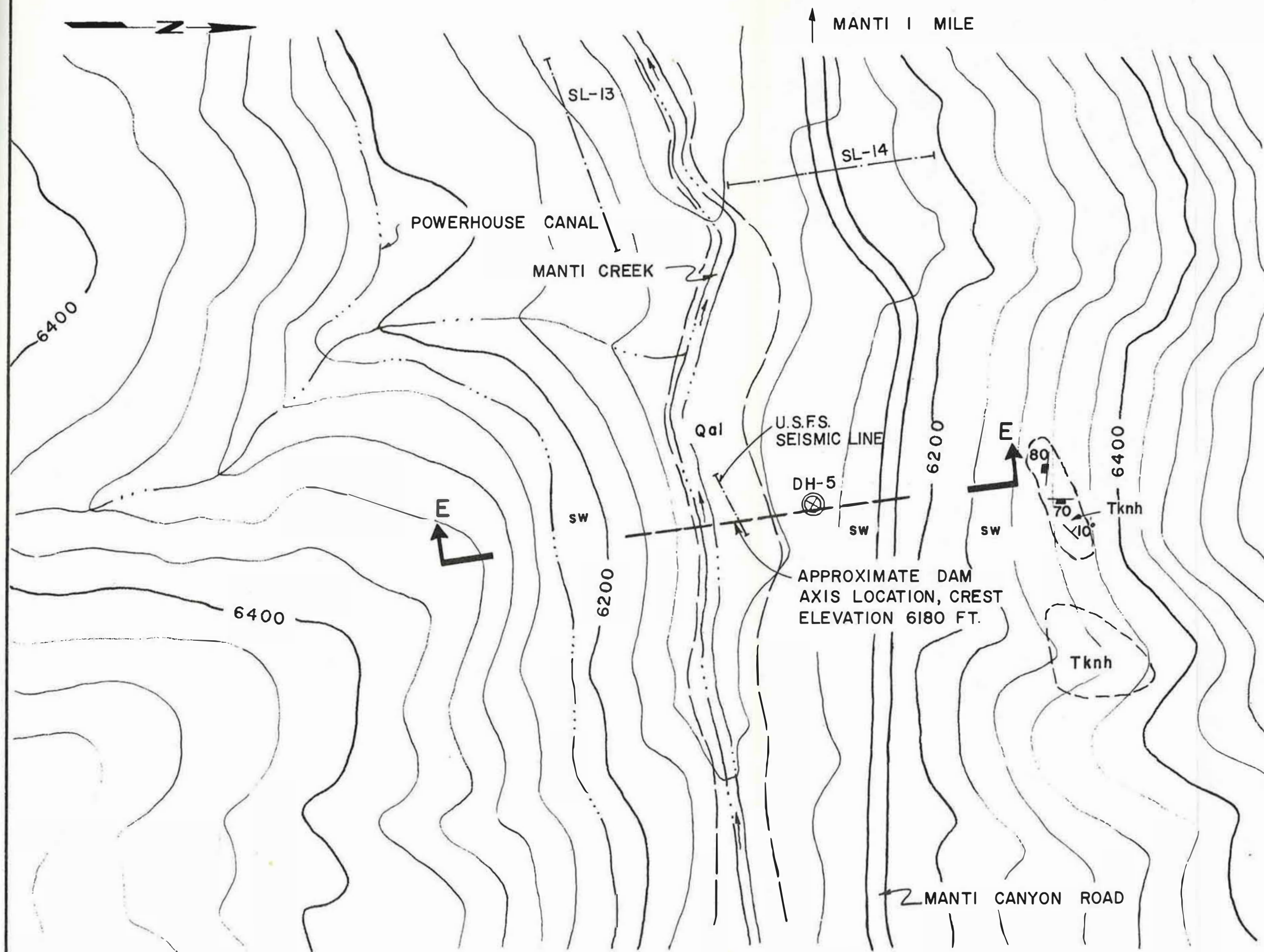


NOTE: FOR LEGEND SEE EXHIBIT 3



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 <i>C.P.</i>	CHECKED <i>[Signature]</i>	APPROVED _____
DRAWN <i>[Signature]</i>	INSPECT _____	RECOMMENDED _____
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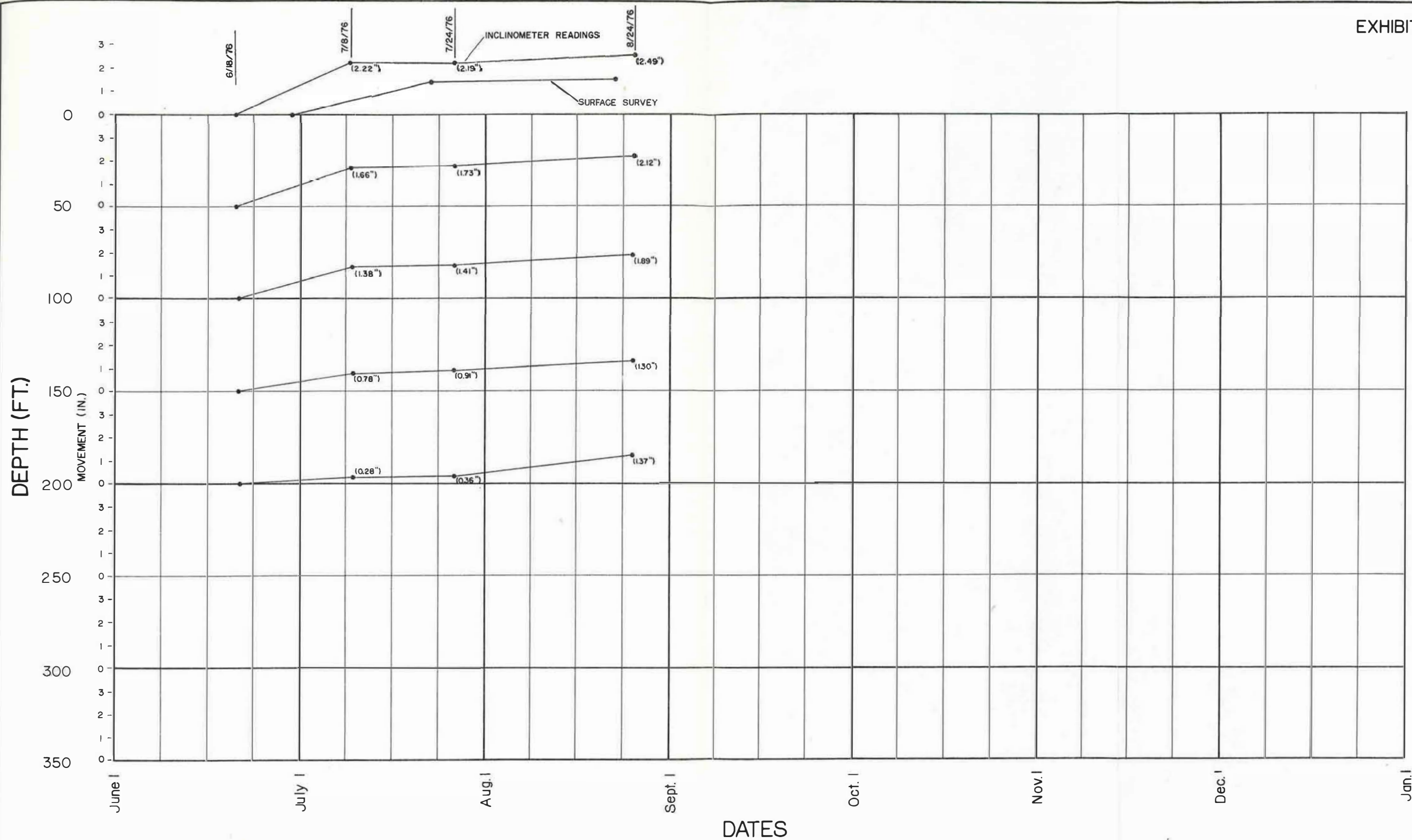


LEGEND:

- 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

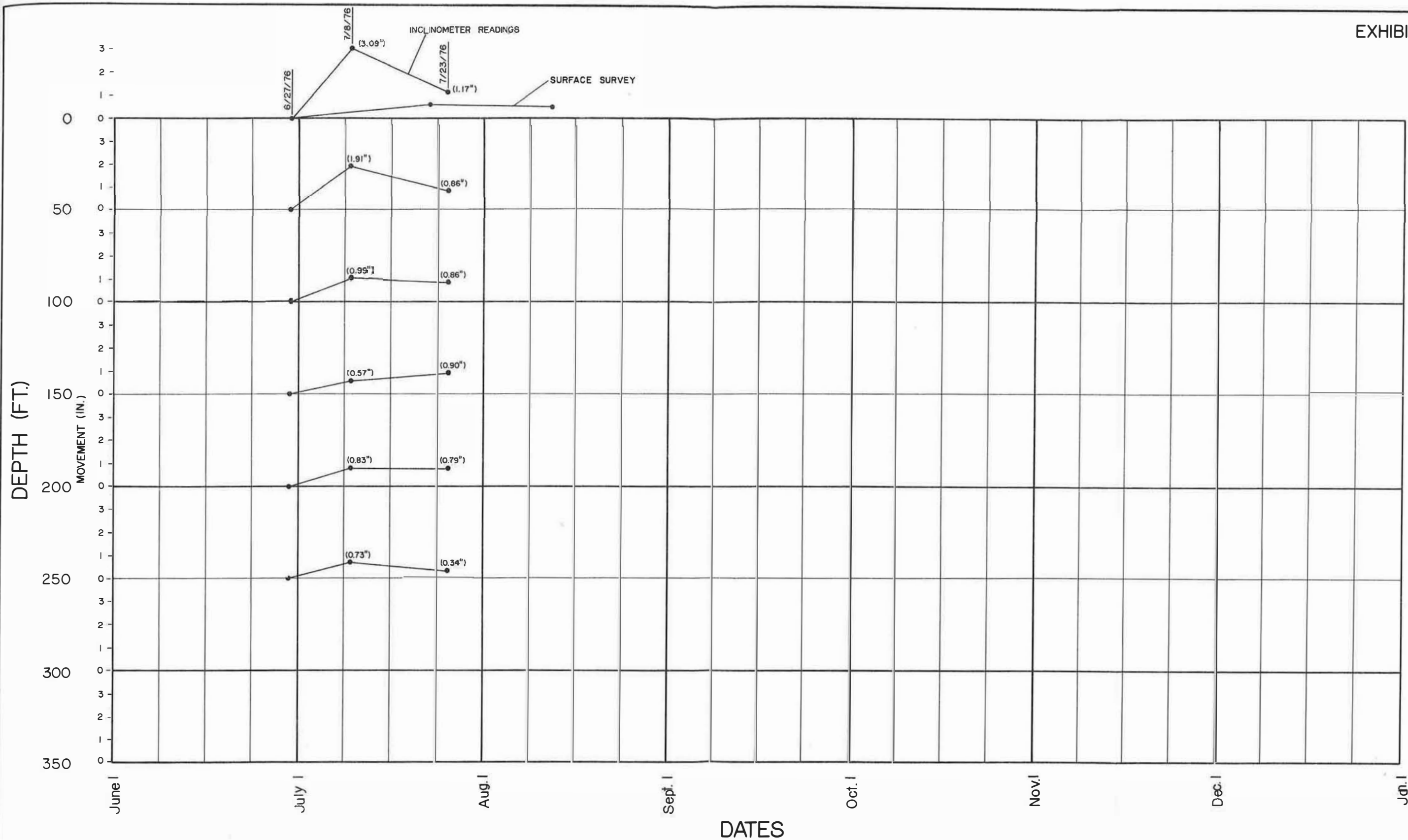
Scale 0 300 Feet

U.S. FOREST SERVICE SANPETE COUNTY, UTAH		
NORTH SLIDE STUDY DEBRIS RETENTION DAMSITE GEOLOGY		
INTERNATIONAL ENGINEERING COMPANY, INC.		
DESIGNED _____	CHECKED _____	APPROVED _____
DRAWN _____	INSPECT _____	RECOMMENDED _____
IECO 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		DATE _____ DRAWING NO. _____



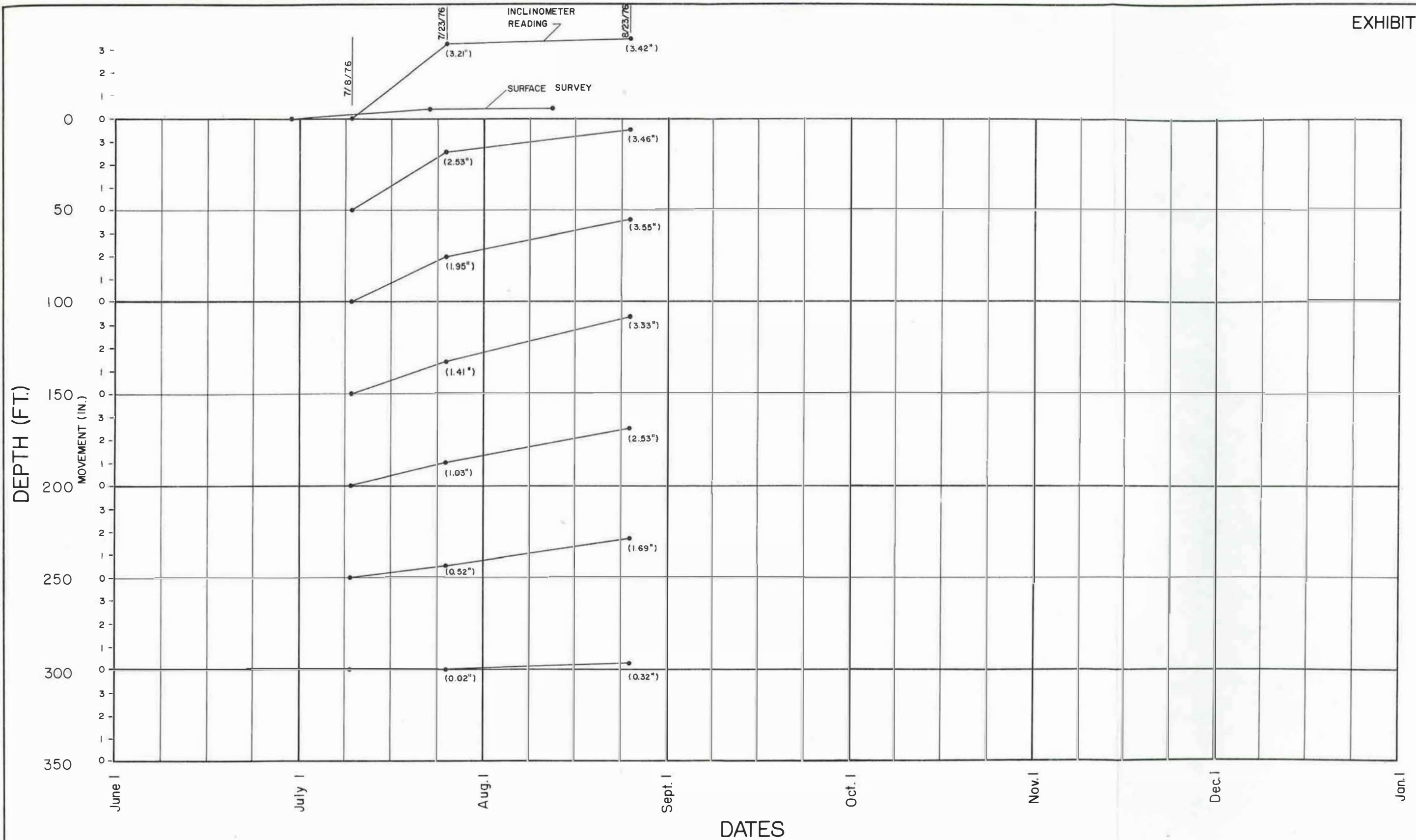
NORTH SLIDE MOVEMENT
FROM INCLINOMETER READINGS AND SURFACE SURVEYS
HOLE NO. 1A

SLIDE MOVEMENT
DH-1A



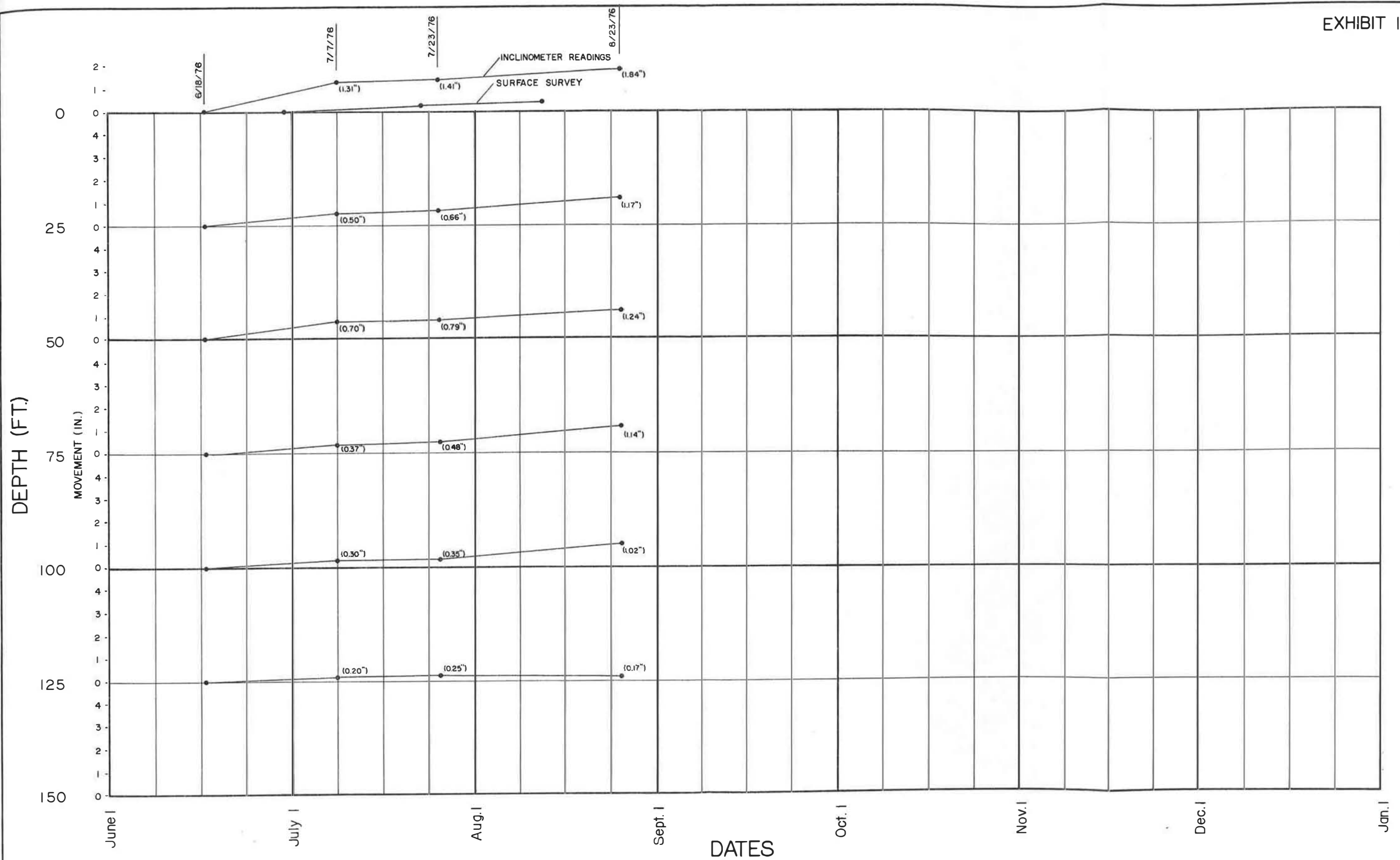
NORTH SLIDE MOVEMENT
FROM INCLINOMETER READINGS AND SURFACE SURVEYS
HOLE NO. 2

SLIDE MOVEMENT
DH-2



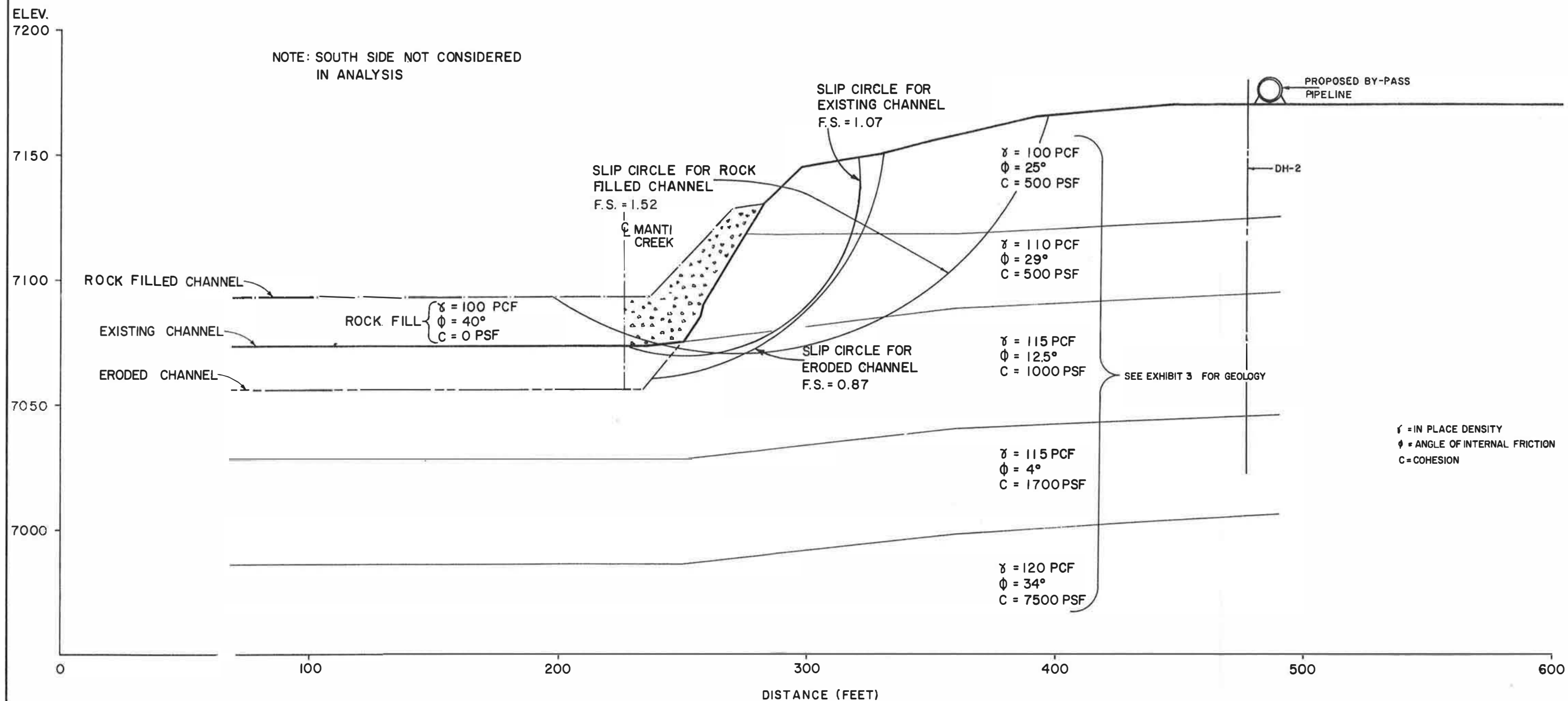
NORTH SLIDE MOVEMENT
FROM INCLINOMETER READINGS AND SURFACE SURVEYS
HOLE NO. 3A

SLIDE MOVEMENT
DH-3A

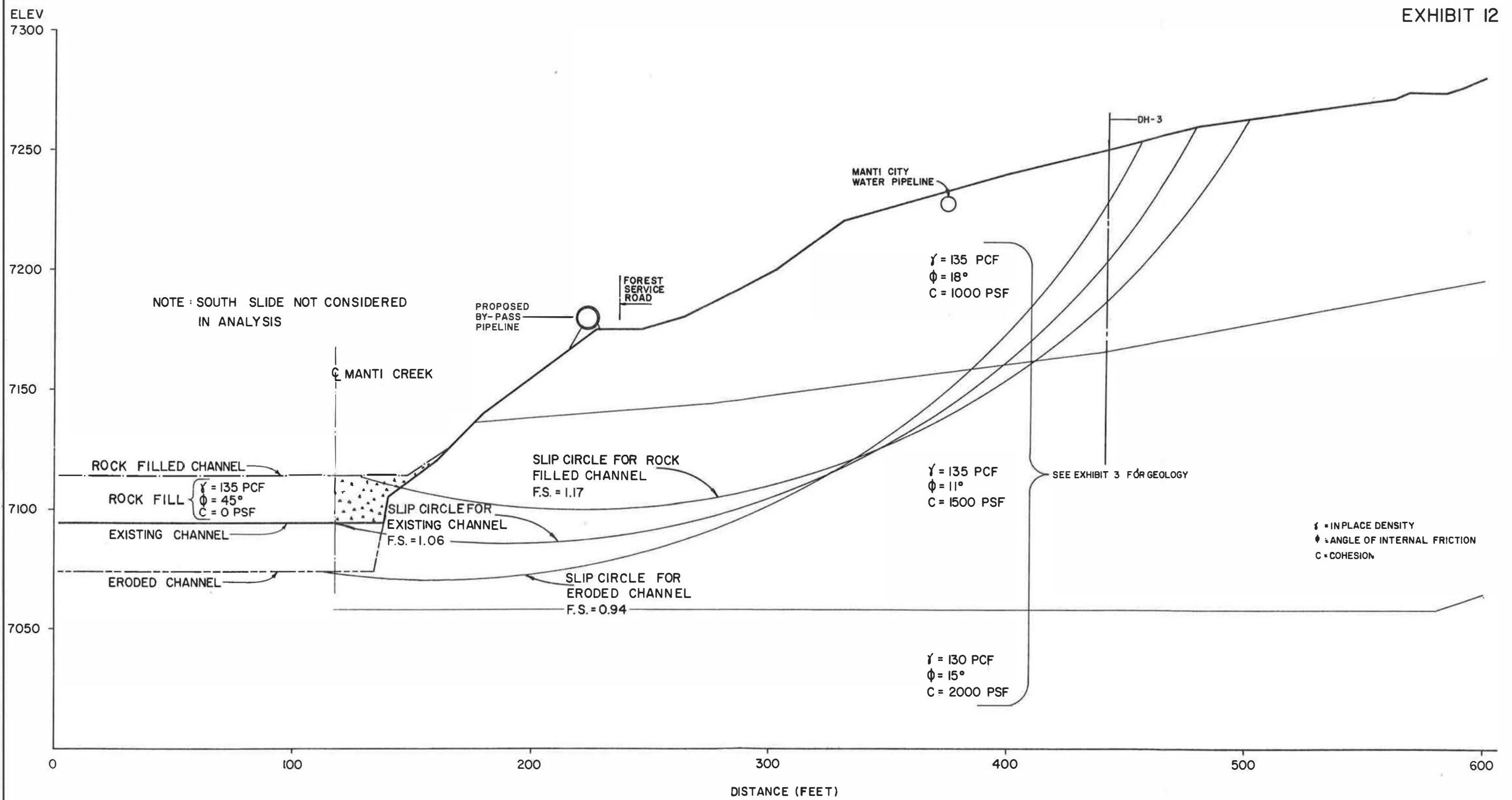


NORTH SLIDE MOVEMENT
FROM INCLINOMETER READINGS AND SURFACE SURVEYS
HOLE NO. 4A

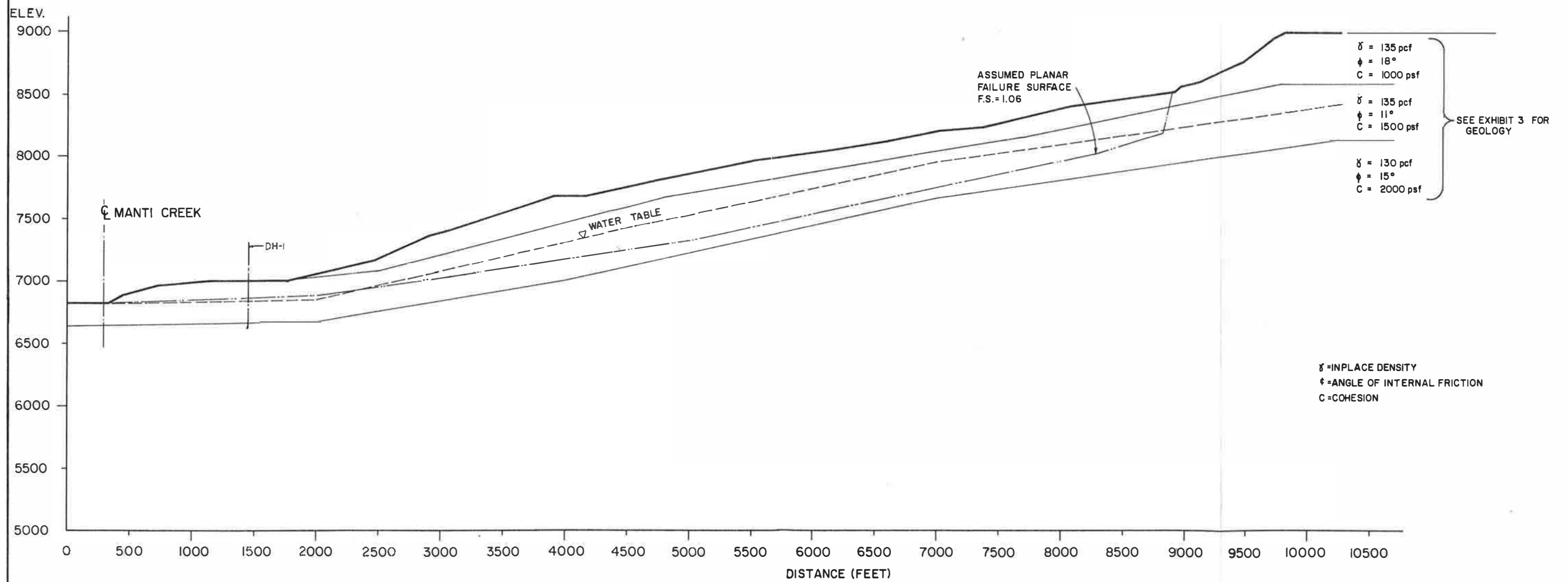
SLIDE MOVEMENT
DH-4A



NORTH SLIDE STABILITY ANALYSIS SECTION I

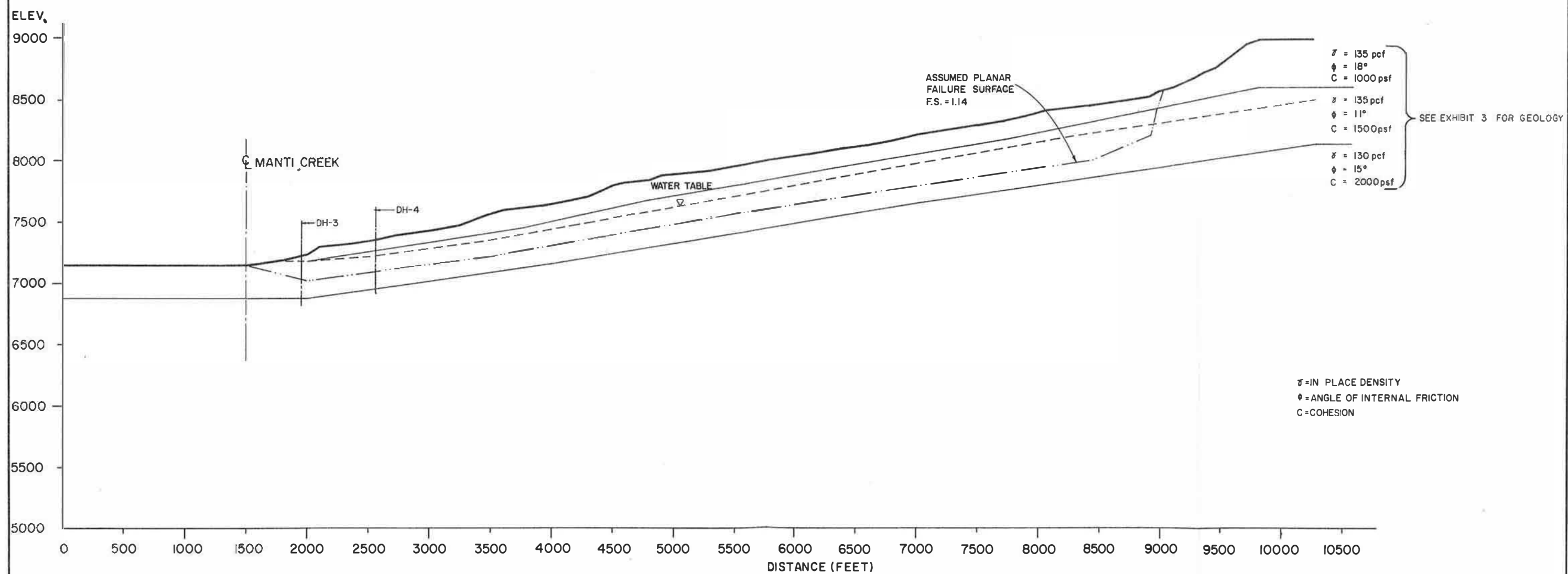


NORTH SLIDE
STABILITY ANALYSIS SECTION 2



NORTH SLIDE
STABILITY ANALYSIS SECTION 3

SECTION 3



NORTH SLIDE STABILITY ANALYSIS SECTION 4

SECTION 4