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SUSITNA HYDROELECTRIC PROJECT

1982 SUPPLEMENT
TO
THE 1980-81 GEOTECHNICAL REPORT

VOLUME 1

TEXT

DECEMBER 1982

Prepared by:

ACRES

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

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1 - INTRODUCTION

1.1 - General

The Susitna Hydroelectric Project is located within the upper reaches of the Susitna River basin in south-central Alaska (Figure 1.1). The 1980-82 hydroelectric development feasibility studies were performed by Acres American Incorporated (Acres) under contract to the Alaska Power Authority (The Power Authority).

The overall objectives of the study were:

- To determine technical, economic and financial feasibility of the Susitna Hydroelectric Project to meet the future power needs of the Railbelt Region of the State of Alaska;

- To examine the environmental consequences of constructing the Susitna Hydroelectric Project; and

- To file a license application with the Federal Energy Regulatory Commission (FERC) should the project be deemed feasible.

As part of the Plan of Study (POS), a geotechnical exploration program (Task 5) was undertaken at the proposed damsite locations of Watana and Devil Canyon, and along the access and transmission corridors. Results of the 1980-81 exploration program were presented in the 1980-81 Geotechnical Report submitted to The Power Authority in March 1982(1). Since the submittal of that report, additional geotechnical work was performed during the summer/fall of 1982. The purpose of this report is to provide a supplement to the 1980-81 Geotechnical Report. The work performed in 1982 was directed at augmenting and further defining specific site geologic and geotechnical conditions at the Watana and Devil Canyon sites. Therefore, some of the information and data presented in the previous report has been superseded by this supplemental report. Specific sections, figures, and tables that have been superceded have been so denoted in Table 1.1.

This report has been written with the intent of providing a fully comprehensive understanding of the major subjects addressed in the 1982 work without continued reference to the 1980-81 report. However, to get a full understanding of the site geotechnical conditions at Watana and Devil Canyon, both documents will be required.

1.2 - Project Description and Location

The Watana and Devil Canyon sites had been previously studied by the U.S. Bureau of Reclamation (USBR) and the U.S. Army Corps of Engineers (COE) over a period of years from 1952 to 1979.

The current feasibility scheme calls for a large embankment dam with an underground powerhouse at Watana, and a high concrete arch dam with underground powerhouse at the Devil Canyon site. General site arrangements for Watana are shown in Figures 1.2 and 1.3. The general arrangement drawing for Devil Canyon is included as part of Figure 9.2, and is presented in more comprehensive detail in the 1980-81 Geotechnical Report.

The area of study is located within the Coastal Trough Province of south-central Alaska, with a drainage of approximately 6,000 square miles. The Susitna River is glacier-fed, with headwaters on the southern slope of the Alaska Range. From its proglacial channel in the Alaska Range, the Susitna River passes first through a broad, glaciated, intermontane valley of knob and kettle, and braided channel topography. Swinging westward along the edge of the Copper River lowlands, it enters the deep valleys which include the proposed damsites, winding through the Talkeetna Mountains until it emerges into a broad glacial outwash valley leading to Cook Inlet near Anchorage.

The Watana site is located at approximately river mile 184 between Tsusena and Deadman Creeks. The Watana damsite is located in a relatively broad U-shaped valley rising in steps, with steep lower portion breaking into somewhat flatter slopes and becoming much gentler near the top. Access to the lower sections is limited by vertical rock outcrops. Gravel bars, some of which are quite wide, are exposed in the river bed during low water flows. The river at this site is approximately 500 feet wide and is relatively turbulent and swift flowing.

The Devil Canyon site occupies a very narrow bedrock gorge at approximately river mile 152.

1.3 - Plan of Study

(a) Objectives

As detailed in the 1980-81 Geotechnical Report, the objectives of the geotechnical program were to determine the surface and subsurface geology and geotechnical conditions for the feasibility of:

- A large rockfill dam, underground powerhouse, and associated structures at Watana site;

- A concrete dam with underground powerhouse and associated structures at Devil Canyon site;

- Transmission line to connect the proposed development with the existing power grid system; and

- Access roads to the proposed development.

(b) Scope

To accomplish these objectives, Acres undertook eight subtasks ranging from Data Collection and Review through the exploration programs to data compilation and report preparation.

As a result of that work, additional areas at the Watana site were considered to warrant the further studies which were undertaken during the summer of 1982. Those areas were the:

- Watana Relict Channel;
- Fog Lakes Relict Channel;
- Borrow Site D;
- Damsite Geology, with specific attention to the upstream diversion portal and downstream portal areas.

This work was undertaken in a multi-disciplinary approach using personnel experienced in geology, rock mechanics, and geotechnical engineering.

Due to cost, scheduling, and logistical constraints, the scope of the 1982 program was designed to provide additional information in these particular areas, which would be used for developing a more comprehensive geotechnical program (1983-1985). Therefore, this report serves as an interim progress report to be updated as ongoing work proceeds.

1.4 - Report Content

This supplemental report is presented in nine sections: summary and the conclusions of the study in Section 2; detailed scope of geotechnical investigations in Section 3; geology of the Watana area in Section 4; results of the geotechnical investigations at the Watana damsite in Section 5; Watana Relict Channel in Section 6; Fog Lakes Relict Channel in Section 7; Watana Quarry and Borrow Sites in Section 8; and Devil Canyon damsite in Section 9.

An index map showing the locations of maps used in this report is shown on Figure 1.4.

Appended to the report are the 1982 drilling logs, laboratory test data, and seismic refraction surveys report.

Engineering significance and applications of the data developed from the geotechnical program are presented in the Susitna Feasibility Report[2] and the Supplement to the Susitna Feasibility Report[3]. This document, therefore, stands as a referenced document in those reports.

1.5 - Acknowledgements

Drilling at the site was performed by Denali Drilling, Incorporated, Anchorage, under the direct supervision and direction of Acres American personnel. Seismic refraction surveys for 1982 were performed by Woodward-Clyde Consultants. Survey control and brushing, instrumentation reading, and assistance in the onsite laboratory was provided by R&M Consultants.

Logistical support was provided by Air Logistics, Inc., under subcontract to Acres.

The results of the 1982 activities were presented to Dr. Peck of the Acres External Panel and Dr. H. Seed and Dr. A. Merritt of The Power Authority's Panel in November, 1982. Acres is grateful for their comments and critical review of the information.

TABLE 1.1: CHANGES AND MODIFICATIONS TO THE 1980-81 GEOTECHNICAL REPORT TABLES AND FIGURES

1980-81 Table No.	1982 Table No.	Subject (1980-81 Report)
3.1	(3)	*Summary of Previous Investigations - Watana Damsite
3.2	(3)	*Summary of Previous Investigations - Borrow Site D - Watana
3.3	(3)	*Summary of Previous Investigations - Borrow Sites E, F, and C - Watana
3.4	(3)	*Summary of Previous Investigations - Devil Canyon Damsite
3.5	(3)	*Summary of Previous Investigations - Borrow Site G - Devil Canyon
4.1	4.1	Geologic Time Scale
5.1	(3)	*Summary of the 1980-81 Investigation - Watana Damsite
5.2	(3)	*Summary of the 1980-81 Investigation - Devil Canyon Damsite
5.3	(3)	*Summary of the 1980-81 Seismic Refraction Line Data
5.4	(3)	*Summary of 1980-81 Investigation - Borrow Site D - Watana
5.5	(3)	*Summary of 1980-81 Investigation - Borrow Site E - Watana
5.6	(3)	*Summary of 1980-81 Investigation - Borrow Site G - Devil Canyon
5.7	(3)	*Summary of 1980-81 Investigation - Borrow Site H - Watana
5.8	(3)	*Summary of 1980-81 Investigation - Borrow Sites I and J - Watana
5.9		Summary of Rock Tests - Watana
5.10		Summary of Rock Tests - Devil Canyon
6.1	5.1	*Watana Seismic Velocity Correlations
6.2	5.2, 5.3, 5.4	*Watana Joint Characteristics
6.3		Watana RQD Summary
6.4		Watana Borehole Rock Quality Distribution
6.5		Watana Rock Test Summary - Diorite, Quartz-Diorite, Granodiorite
6.6		Watana Rock Test Summary - Andesite Porphyry
6.7	Figure 6.2	*Quaternary Stratigraphy of Buried Channel Area
6.8	Figures 8.4-8.17, Appendix B	Material Properties - Borrow Site D
6.9	Figs., 8.3, 8.7	*Gradation Results - Borrow Site D
6.10	8.1, 8.3	Material Properties - Borrow Site E
6.11		Material Properties - Borrow Site H

(1) *1980-81 Table/Figure is either superceded in entirety by Supplemental Report Table/Figure; or 1982 Table/Figure is supplementary to 1980-81 Table/Figure.
(2) No 1982 listing means 1980-81 Table/Figure remains unchanged.
(3) Summarized in project survey and instrumentation data files.

TABLE 1.1 (Cont'd)

1980-81 Table No.	1982 Table No	Subject (1980-81 Report)
6.12		Material Properties - Borrow Sites I and J
7.1		Devil Canyon Seismic Velocity Correlations
7.2		Devil Canyon Joint Characteristics
7.3		Devil Canyon Tailrace Tunnel - Joint Characteristics
7.4		Devil Canyon RQD Summary
7.5		Devil Canyon - Borehole Rock Quality Distribution
7.6		Devil Canyon Rock Test Summary - Mafic Dikes and Argillite
7.7		Devil Canyon Rock Test Summary - Graywacke
7.8	Figure 9.1, Tables 9.1-9.3	Material Properties - Borrow Site G

(1) *1980-81 Table/Figure is either superceded in entirety by Supplemental Report Table/Figure, or 1982 Table/Figure is supplementary to 1980-81 Table/Figure.

(2) No 1982 listing means 1980-81 Table/Figure remains unchanged.

(3) Summarized in project survey and instrumentation data files.

TABLE 1.1 (Cont'd)

1980-81 Figure No.	1982 Figure No	Subject (1980-81 Report)
1.1	1.1	General Location Map
1.2	1.2, 1.3	*Watana General Arrangement
1.3	9.2	*Devil Canyon General Arrangement
4.1	4.1	*Regional Geology Map
5.1a	3.2	*Watana: Damsite Vicinity Exploration Map
5.1b	3.1	*Watana: Exploration Map
5.2		Devil Canyon Exploration Map
5.3	3.4	Borehole Typical Instrumentation
5.4		Borehole Typical Instrumentation
6.1	1.4	Watana Index Map
6.2	5.1	*Watana Top of Bedrock and Surficial Geologic Map
6.3	5.1, 5.12, 5.16	*Watana Geologic Map
6.4	5.3, 5.13	*Watana Geologic Section W-1
6.5	5.4	*Watana Geologic Section W-2
6.6	5.5, 5.17	*Watana Geologic Section W-3
6.7	5.6	*Watana Geologic Section W-4
6.8	5.7	*Watana Geologic Section W-5
6.9		Watana Andesite Porphyry Flow Structure and Inclusions
6.10		Watana Fracture Zone in Andesite Porphyry
6.11		Watana Felsic Dike in Diorite
6.12		Watana Joint Station Plots
6.13	5.8	*Watana Composite Joint Plots
6.14	5.9	*Watana Typical Shear
6.15	5.10	*Watana Shear/Alteration Zone
6.16	5.14, 5.15	Watana "The Fins"
6.17		Watana Geologic Features GF4A, GF4B, and GF5
6.18	5.11	*Watana Geologic Features Downstream of Centerline
6.19	5.18, 5.19	*Watana "Fingerbuster" Area North Bank
6.20	5.20	*Watana Geologic Feature GF7B
6.21		Watana Rock Tests
6.22		Watana Static Elastic Properties for Andesite and Diorite
6.23		Watana Direct Shear Tests
6.24		Watana Unconfined Compressive Strength Test Results
6.25		Watana Point Load Test Data
6.26		Watana Rock Permeability
6.27	5.21	*Watana Thermistor Data
6.28	6.11	*Watana Thermistor Data - Relict Channel
6.29	6.11, 8.21	*Watana Thermistor Data - Borrow Site D and Borrow Site H
6.30	6.5	Watana Relict Channel Photos

(1) * 1980-81 Table/Figure is either superceded in entirety by Supplemental Report Table/Figure, or 1982 Table/Figure is supplementary to 1980-81 Table/Figure.
(2) No 1982 listing means 1980-81 Table/Figure remains unchanged.

Table 1.1 (Cont'd)

1980-81 Figure No.	1982 Figure No.	Subject (1980-81 Report)
6.31	6.4, 6.6	*Watana Relict Channel Section
6.32	6.1, 6.2, 6.3	*Watana Relict Channel and Borrow Site D/ Stratigraphic Fence Diagram
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6.34		Watana Relict Channel Profiles
6.35	6.7	*Relict Channel - Top of Bedrock
6.36	8.1	*Watana Borrow Sites Index Map
6.37		Watana Quarry Site A - Plan and Sections
6.38		Quarry Site B - Plan and Sections
6.39		Borrow Sites C and F
6.40	8.2	Borrow Site D - Plan
6.41	8.3	*Watana Borrow Site D - Range of Gradations
6.42	6.8	Watana Borrow Site D - Material Gradation Types
6.43	8.18	Borrow Site E - Plan
6.44		Borrow Site E - Sections
6.45		Watana Borrow Site E - Range of Gradations
6.46		Watana Borrow Site E - Stratigraphic Unit Gradations
6.47		Borrow Site C and F - Range of Gradations
6.48		Borrow Site H - Plan
6.49		Watana Borrow Site H - Range of Gradations
6.50		Watana Borrow Site H - Stratigraphic Unit Gradations
6.51	8.19	Borrow Site I - Plan
6.52		Borrow Site J - Plan
6.53		Borrow Sites E, I, and J - Photos and Typical Sections
6.54		Quarry Site L - Plan and Sections
7.1		Devil Canyon Index Map
7.2		Devil Canyon Top of Bedrock and Surficial Geologic Map
7.3		Devil Canyon Geologic Map
7.4		Geologic Sections DC-1
7.5		Geologic Sections DC-2
7.6		Geologic Sections DC-3
7.7		Geologic Sections DC-4
7.8		Geologic Sections DC-5
7.9		Geologic Sections DC-6
7.10		Geologic Sections DC-7

(1) * 1980-81 Table/Figure is either superceded in entirety by Supplemental Report Table/Figure, or 1982 Table/Figure is supplementary to 1980-81 Table/Figure.
(2) No 1982 listing means 1980-81 Table/Figure remains unchanged.

Table 1.1 (Cont'd)

1980-81 Figure No.	1982 Figure No.	Subject (1980-81 Report)
7.11		Devil Canyon Typical Argillite/Graywacke
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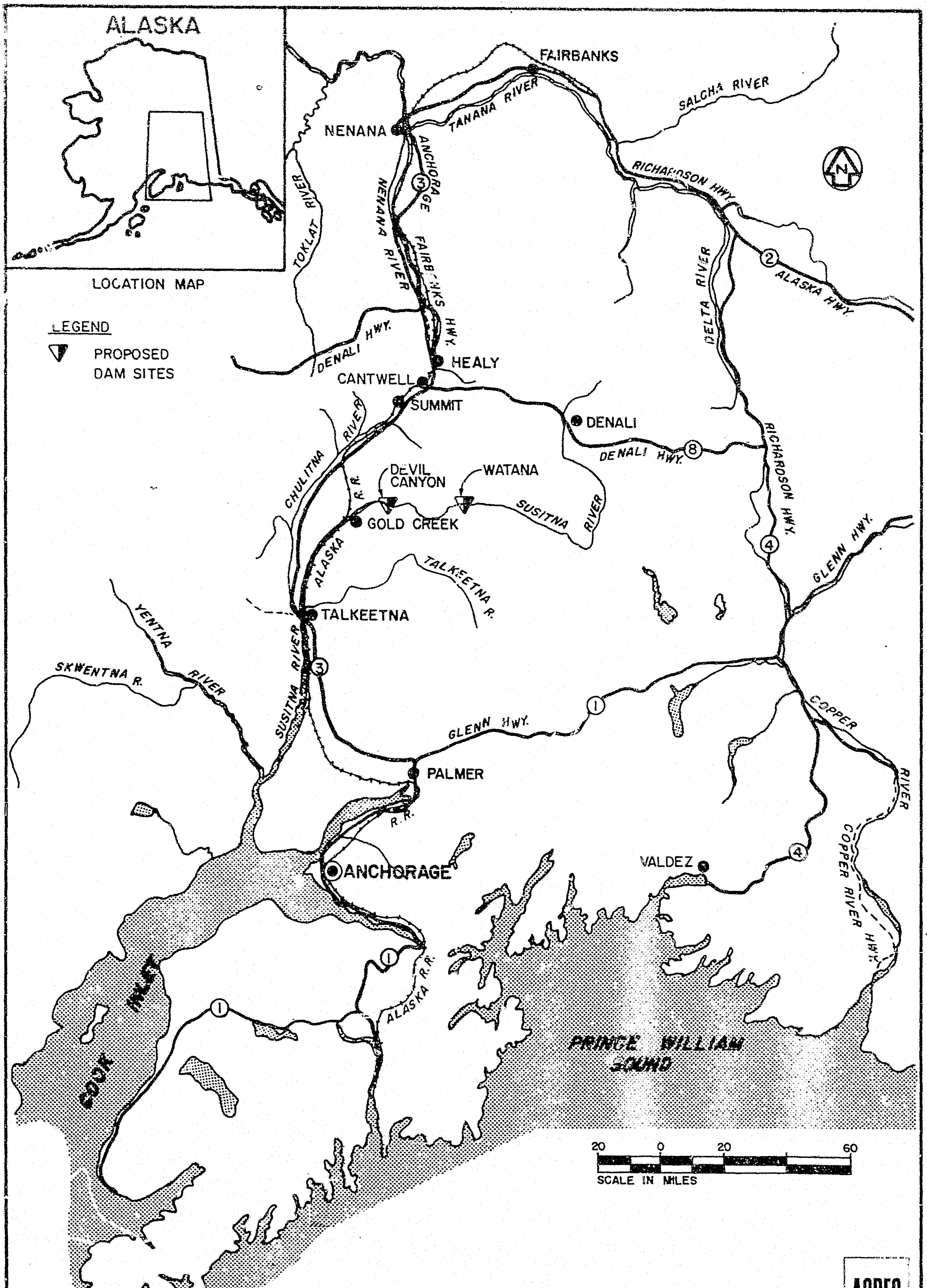
7.13		Devil Canyon Joint Plots
7.14		Devil Canyon Tailrace Geology
7.15		Devil Canyon Rock Tests
7.16		Devil Canyon Static Elastic Properties for Argillite and Graywacke
7.17		Devil Canyon Direct Shear Tests
7.18		Devil Canyon Unconfined Compressive Strength Test Results
7.19		Devil Canyon Point Load Test Data
7.20		Rock Permeability
7.21	9.3	*Thermistor Plots - Damsite
7.22		Borrow Site G - Plan
7.23		Borrow Site G - Sections
7.24		Devil Canyon Borrow Site G - Range of Gradations
7.25		Devil Canyon Borrow Site G - Stratigraphic Unit Gradations
7.26		Devil Canyon - Quarry Site K

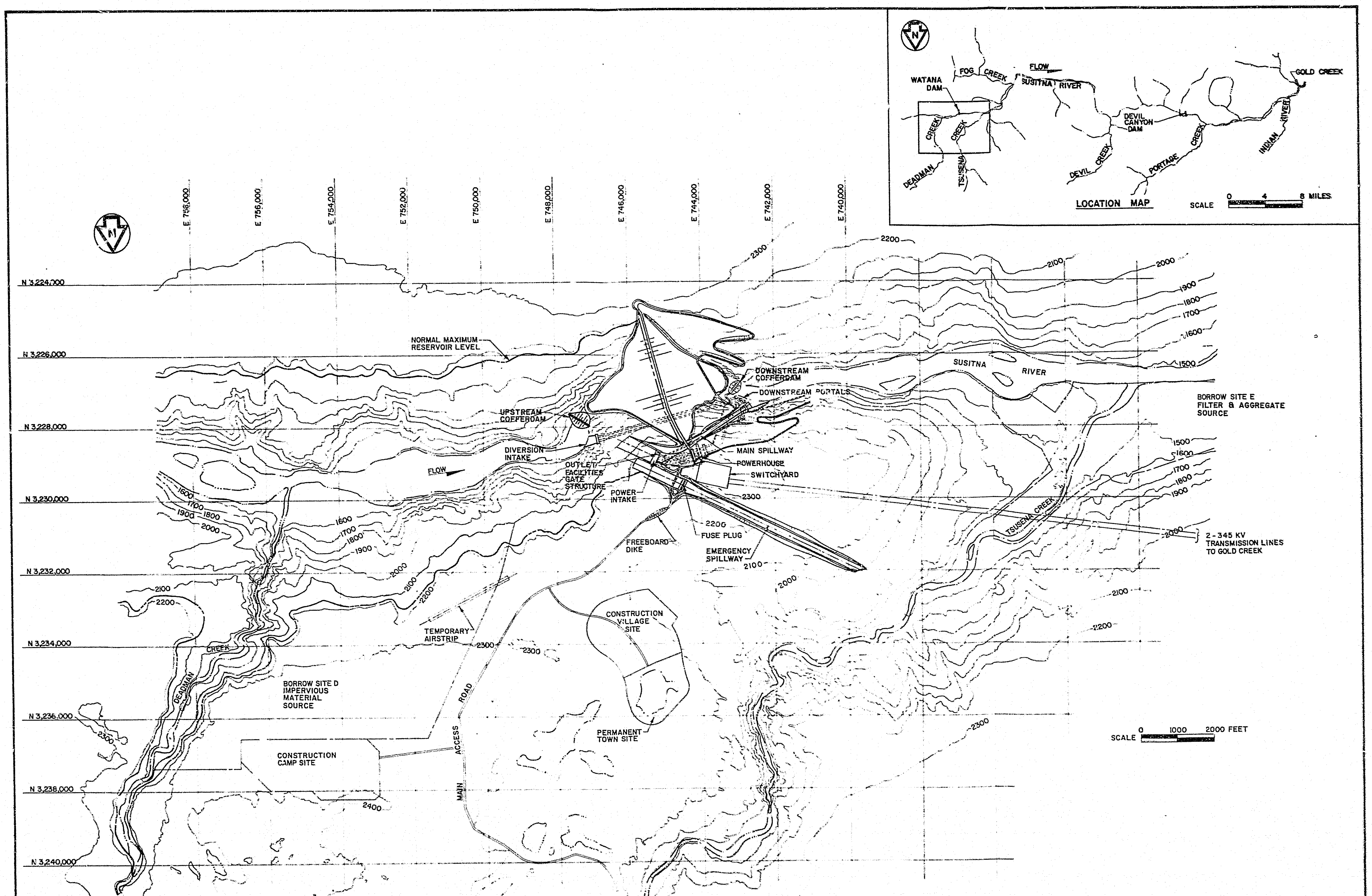
(1) * 1980-81 Table/Figure is either superceded in entirety by Supplemental Report Table/Figure, or 1982 Table/Figure is supplementary to 1980-81 Table/Figure.

(2) No 1982 listing means 1980-81 Table/Figure remains unchanged.



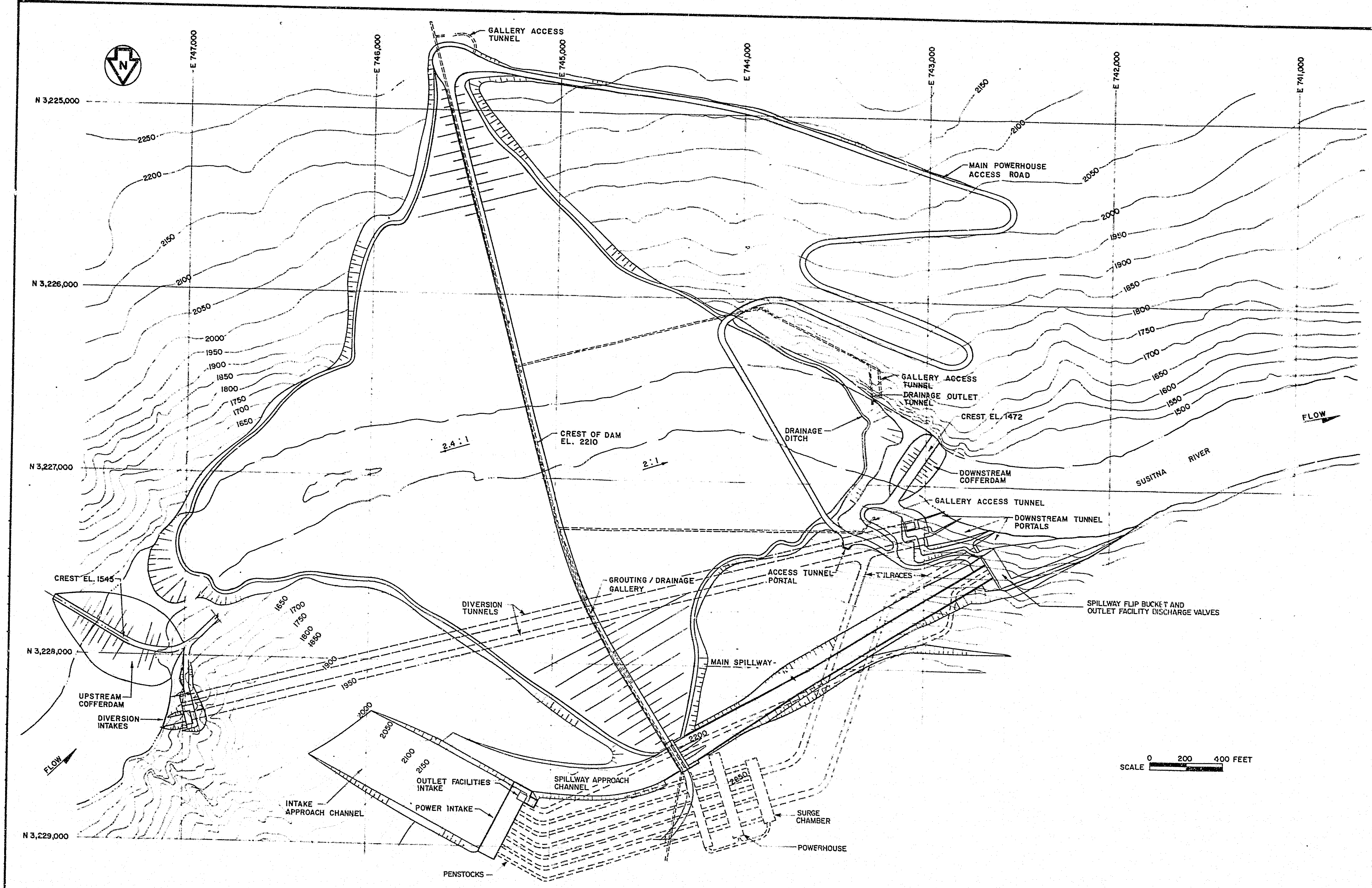
LOCATION MAP

FIGURE 1.1



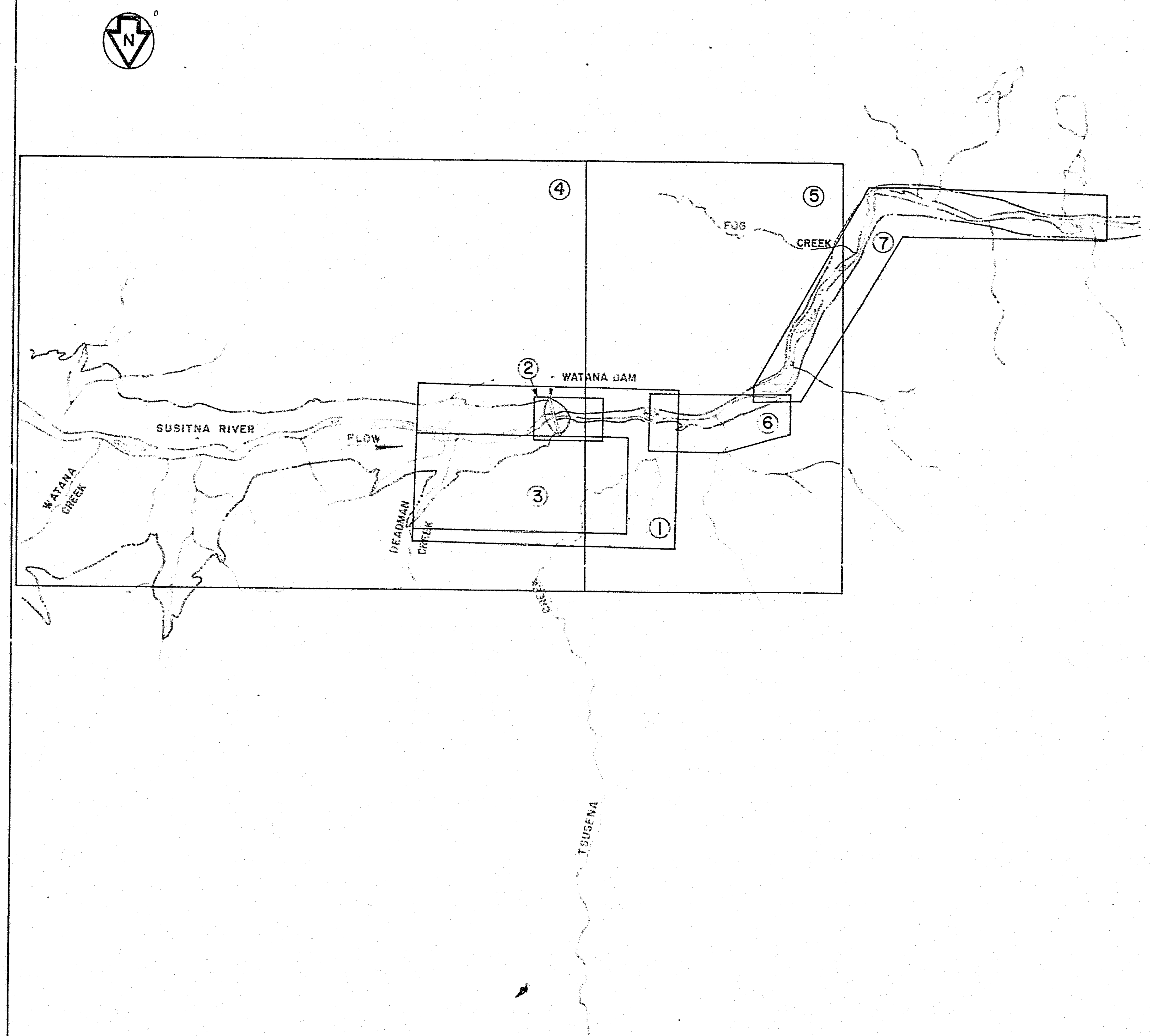
WATANA
GENERAL ARRANGEMENT

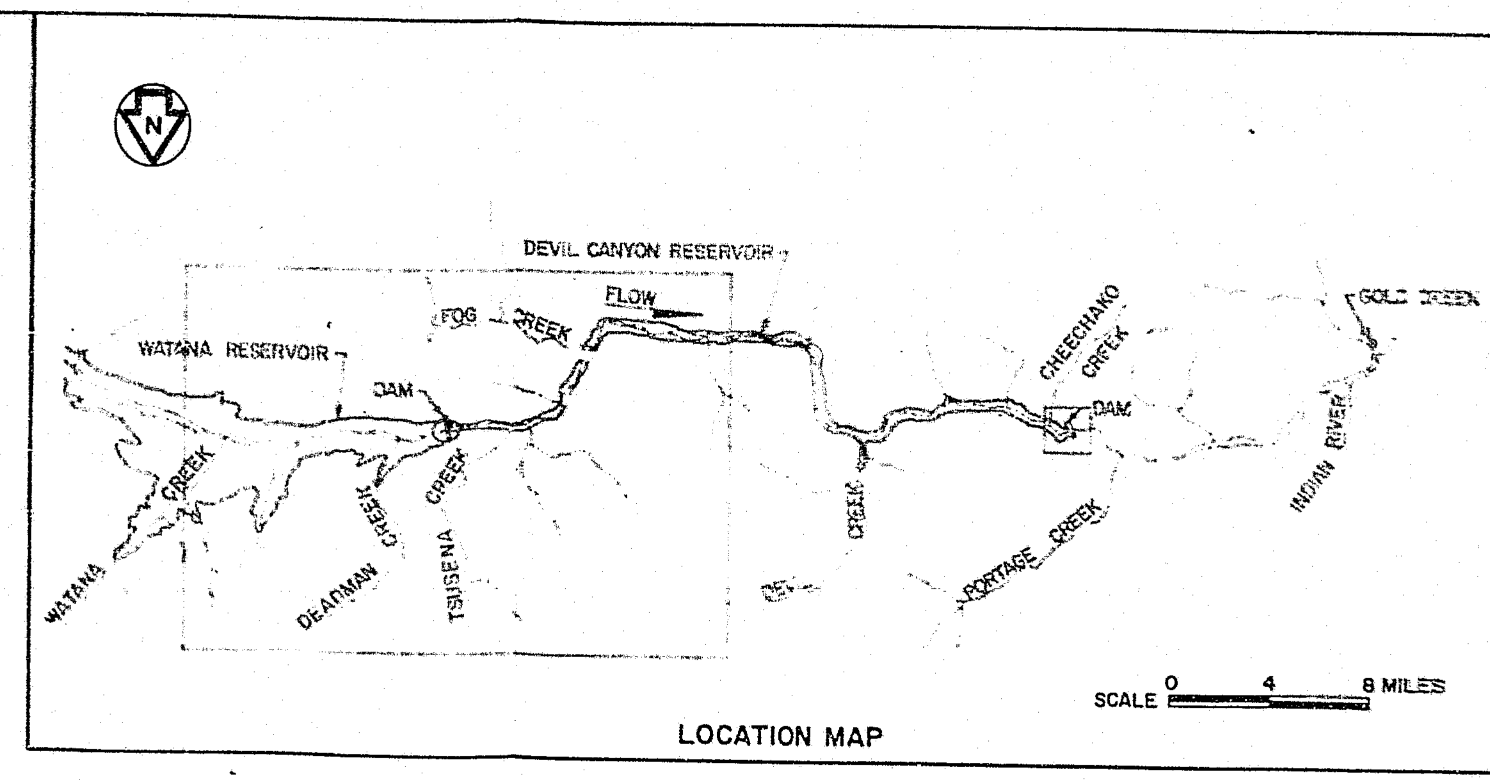
FIGURE 1.2



WATANA DAM
GENERAL ARRANGEMENT

FIGURE 1.3





LOCATION MAP

BLOCK NO.	AREA COVERED		SCALE*	FIGURE REFERENCE
1	DAMSITE VICINITY:	GENERAL ARRANGEMENT	1" = 2500'	FIGURE 1.2
		STRATIGRAPHIC UNIT MAPS	1" = 2500'	FIGURE 6.6
		TOP OF BEDROCK	1" = 2500'	FIGURE 6.7
		BORROW MATERIAL ISOPACHS	1" = 2500'	FIGURE 8.2
2	DAMSITE:	GENERAL ARRANGEMENT	1" = 500'	FIGURE 1.3
		EXPLORATIONS	1" = 500'	FIGURE 3.1
		SURFICIAL GEOLOGY AND TOP OF BEDROCK	1" = 500'	FIGURE 5.1
		GEOLOGIC MAP	1" = 500'	FIGURE 5.2
2	PORTAL AREAS:	GEOLOGIC MAPS	1" = 100'	FIGURE 5.12, 5.16
3	RELICT CHANNEL/BORROW SITE D:	EXPLORATIONS	1" = 1000'	FIGURE 3.2
		GEOLOGIC MAP	1" = 1000'	FIGURE 6.1
4	FOG LAKES RELICT CHANNEL:	EXPLORATIONS	1" = 5000'	FIGURE 3.3
		TOP OF BEDROCK	1" = 5000'	FIGURE 7.1
4 & 5	WATANA AREA:	GEOLOGIC MAP	1" = 5000'	FIGURE 4.1
6	BORROW SITE E:	GEOLOGY AND EXPLORATIONS	1" = 1000'	FIGURE 8.18
7	BORROW SITE I	GEOLOGY AND EXPLORATIONS	1" = 2500'	FIGURE 8.19

* REDUCED 11" x 17" REPORT FORMAT

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FIGURE 1.4

2 - SUMMARY AND CONCLUSION

The following subsection presents the findings and conclusions of the 1982 geotechnical work. These conclusions supplement and/or supersede those conclusions set forth in the 1980-81 Geotechnical Report (1). Unless specifically addressed below, the study results and conclusions presented on Reference 1 remain unchanged.

2.1 - Watana Site

(a) Results of Study

- Work performed in 1982 showed that overburden on the dam abutments is generally shallow, seldom exceeding 30 feet, with talus slopes and alluvium-filled gullies locally having 50 to possibly as much as 100 feet of overburden.

- Two types of alluvium have been identified in the damsite; Type 1, principally below water level, is sandy gravel, well graded with fine gravel to boulders; and Type 2, occurring principally on the south bank above river level, is a well graded sandy gravel with fragments ranging up to 2 feet but generally 4 to 6 inches.

- Two types of talus were identified in the damsite, Type 1 is primarily well exposed actively moving material, while Type 2 is generally heavily vegetated inactive material.

- A northwest trending hydrothermally altered zone up to 400 feet wide has been mapped on the south bank predominately downstream of the main dam centerline.

- Small shears, fracture zones and alteration zones were mapped in the damsite. These features generally parallel joint sets I, II and III.

- No evidence of recent faulting was found at the damsite.

- Drilling and seismic refraction surveys performed in the Watana Relict Channel confirmed that the exposed face at the entrance to the channel, along the north reservoir rim is on the order of 18,000 feet wide. The approximate channel width at the bedrock saddle dividing the Susitna River and Tsusena Creek (under maximum normal operating level of Elevation 2185) is about 15,000 feet with a maximum depth of 420 feet. Average hydraulic gradient from maximum pool level to Tsusena Creek is 9 percent.

- Overburden stratigraphy of the Watana Relict Channel/Borrow Site D has been modified and expanded from that determined during the 1981 investigations. Fourteen stratigraphic units have been classified in the area, based on mode of deposition. Modifications to the 1980-81 interpretation include the classification of Unit C as an ice disintegration deposit; breakdown of Unit G into waterlain and basal till facies (Units G and G'); reclassification of Unit I as an outwash; reinterpretation of Unit H as being discontinuous and of variable grain size; and identification of an additional basal till found in the southeastern portion of Borrow Site D, designated Unit M. Other findings of the 1982 drilling program confirmed previous interpretations of the stratigraphy, with local modifications.

- The ground water regime in the Watana Relict Channel/Borrow Site D is a combination of perched, artesian and possible confined conditions. Preliminary evaluation suggest that the more permeable stratigraphic units are discontinuous.

- Permafrost in the Watana Relict Channel/Borrow Site D is sporadic with no evidence of extensive ice lenses or ice crystals. Thermistor data show most temperatures to range between -0.5°C and +0.5°C.

- Material densities, as determined by Standard Penetration Tests (SPT), are high for the relict channel material.

- Bedrock surface drops below maximum pool elevation at the Fog Lakes Relict Channel for approximately 8000 feet from 0.5 to 10 miles upstream of the damsite. Maximum depth at the Fog Lakes Relict Channel is approximately 250 feet below pool elevation. Maximum hydraulic gradient for pool level to Fog Creek is approximately 0.3 percent over a distance of 4 to 5 miles.

- Although no borings were drilled in the Fog Lakes Relict Channel, the material, based on seismic velocities, are assumed to be dense tills and glacio-fluvial deposits with significant areas of permafrost.

(b) Conclusions

Based on the work performed in 1982, the following conclusions regarding the Watana Site can be made:

- No geologic or geotechnical conditions were found to affect the feasibility of an embankment dam at the site.

- Rock conditions in the area of "The Fins" appear to be more severe than previously suspected in 1980-81. Conditions of joints and fractures in this area will have to be carefully evaluated in designing rock cuts and support for upstream diversion tunnel portals.

- No adverse geologic or geotechnical conditions were found that would impact on engineering design criteria set forth in the Susitna Feasibility Report (2).

- Although additional work remains to be done in the Watana Relict Channel to assess potential problems of piping and breaching of the reservoir by settlement or liquefaction, work performed during 1982 provided strong evidence that in the upper 200 to 250 feet of the channel, remedial work may not be required.

- At this time, no leakage or liquefaction risk is seen in the Fog Lakes Relict Channel.

- The sporadic permafrost found in Borrow Site D does not appear to cause problems in the development of the borrow site.

- Aggregate and freeze-thaw testing confirmed the suitability of quarry and borrow material for construction.

- While adequate borrow materials are readily available, the development of Borrow Site D will be controlled by the moisture criteria for core material.

2.2 - Devil Canyon

(a) Results of Study

- Groundwater and temperature data collected during 1982 confirm previous 1980-81 data.

- Concrete aggregate tests performed on Borrow Site G material confirmed suitability of material for construction.

- Freeze-thaw testing of Quarry Site K showed questionable durability results.

(b) Conclusions

- No geologic or geotechnical conditions were found during 1982 to adversely affect the Devil Canyon development as presented in the Susitna Feasibility Report (2).

- Although Borrow Site G material was found suitable for construction, test results were variable based on location of samples. Further detailed testing in this area will be required.

- Freeze-thaw tests on Quarry Site K material are questionable, suggesting that the samples from K may have been disturbed prior to testing. Additional testing will be required.

3 - SCOPE OF GEOTECHNICAL INVESTIGATIONS

3.1 - Introduction

Studies performed during the 1980-81 program raised a number of questions regarding the Watana Damsite area, the Watana Relict Channel, Borrow Site D, and the Fog Lakes Relict Channel.

During the summer of 1982, Acres initiated additional geotechnical investigations to supplement those carried out during the 1980-81 investigations. These investigations were undertaken at the Watana site from July through September, 1982.

Specific areas requiring additional studies were:

- Watana Damsite
  - extent of mapped geologic features to include shears, alteration and fracture zones;
  - bedrock conditions in the upstream and downstream portal areas;
  - geology of "The Fins" and "Fingerbuster" shear zones;
- Watana Relict Channel
  - channel geometry;
  - stratigraphy;
  - continuity of stratigraphic sequence;
  - material properties;
  - ground water;
  - permafrost;
- Borrow Site D
  - material properties;
  - stratigraphy;
  - material quantities;
  - ground water;
  - permafrost;
- Fog Lakes Relict Channel
  - channel geometry;
  - stratigraphy;
  - ground water
  - permafrost;

To answer these areas of concern, Acres undertook a limited geotechnical program that involved exploratory drilling, field mapping, seismic refraction surveys, laboratory testing and installation instrumentation. This section discusses the scope of these investigations.

3.2 - Geologic Mapping

(a) Introduction

The Acres geologic mapping program for the Susitna Hydroelectric Project was undertaken to define the lithology and structure of the area for the proposed damsites. The mapping program has been performed in four phases: Summer 1980, Winter 1980-81, Summer 1981, and Summer 1982. Results of the Summer 1982 mapping program are presented in this report. Previous mapping is discussed in the 1980-81 Geotechnical Report (1). The principal objectives of the 1982 program were to perform detailed and general mapping to:

- Refine existing geologic interpretations of the Watana damsite particularly with respect to civil structure arrangements.
- Define the surficial sediments in the Watana Relict Channel/ Borrow Site D area.
- Determine the extent of the Fog Lakes Relict Channel.
- Define the surficial geology of Borrow Sites E and I.
- Establish a geologic model for the damsite area.

Mapping during the 1982 Summer program was done during July, August and September by a team of two geologists. The geologic data collected consisted of identifying outcrops and noting size, orientation, lithology, weathering characteristics, jointing and other structures in the rock. All significant features were photographed. Details of the results are presented in Sections 4, 5, and 7.

(b) Watana Area

Regional geologic mapping was performed in a broad area surrounding the Watana damsite to determine the extent of the diorite pluton underlying the site and its relation to the surrounding geologic units. Mapping was done by airphoto interpretation, aerial reconnaissance and ground checking. Data was plotted on aerial photographs and later transferred to a topographic map. Both photograph and map scales were 1 inch equal to 2,000 feet.

The area covered during this program extended from approximately 11 miles east to 5.5 miles west of the Watana damsite, and from 4.5 miles south to 3.5 miles north of the site. Mapping was concentrated along the major drainages: Susitna River, Fog Creek, Deadman Creek, Tsusena Creek, and Bear Creek which flows through Borrow Site E. Results of the Watana area mapping are presented in Sections 4 and 7.

(c) Watana Damsite

Geologic mapping in the damsite was divided into the following areas: upstream cofferdam and diversion portal area, downstream cofferdam and portal area, and abutments. For precision mapping in the portal areas, a survey grid was established. Six survey control stations were established in the upstream portals area and eight in the downstream portals area. Additional stations were established on both north and south abutments throughout the damsite. Geologic mapping in the portal areas was done by the "Tape and Brunton" method at a scale of 1 inch equal to 100 feet. Survey control points were used at beginning and end points of traverses, and also for triangulation where necessary. Closure of the traverses was within 10 feet. Mapping in the upstream area was done on the north bank to Elevation 1,900 and on the south bank to about Elevation 1,600. Mapping of the downstream portal area was confined to the north bank up to Elevation 1,800, since the south bank was mapped in 1981. A seismic refraction survey was run in conjunction with the mapping program and is discussed in Section 3.4. These explorations are shown on Figure 3.1.

The full extent of shears, fracture zones and alteration zones were traversed where possible. Areas of loose and unstable rock were generally avoided for safety. Results of the damsite mapping are presented in Section 5.

Mapping of the abutments was done primarily on the north bank between the upstream portal area and approximately 300 feet downstream of the proposed centerline location. The "Tape and Brunton" method was used here, with a mapping scale of 1 inch equal to 200 feet. Several previously mapped outcrops downstream of the dam centerline on the south bank were revisited during 1982 to confirm previous geologic interpretation.

(d) Watana Relict Channel/Borrow Site D

Mapping in the Watana Relict Channel/Borrow Site D was done to define the stratigraphy of the sediments within the relict channel and to correlate units with those identified in the boreholes. Mapping was performed along both banks of Tsusena and Deadman Creeks. Tsusena Creek was mapped from about 1.6 to 2.6 miles upstream from its confluence with the Susitna River. Deadman Creek was mapped from the Susitna River to 1.6 miles upstream from the confluence. Mapping was done along the Susitna River from Deadman Creek downstream to the upstream portal area. The surficial deposits of the Watana Relict Channel area were also mapped from Deadman Creek to Tsusena Creek.

Geologic mapping was performed initially by aerial reconnaissance followed by ground traverses. Outcrops were marked on 1 inch equal to 400 feet aerial photographs. Elevations were taken using an altimeter. Data was subsequently transferred to a topographic map of the same scale. Results of the Watana Relict Channel/Borrow Site D mapping are presented in Section 6.

(e) Fog Lakes Relict Channel

Mapping of the Fog Lakes Relict Channel was performed to define the limits of the feature, and the stratigraphy of the infilling materials. Geologic mapping was done initially by aerial reconnaissance, followed by ground checking. Data, which included outcrop elevations, was plotted on aerial photographs at a scale of 1 inch equal to 2,000 feet and transferred to a topographic map at the same scale. Mapping was done along the north and south banks of the Susitna River upstream from the Watana damsite area to beyond Watana Creek, approximately 11 miles. This mapping was done in conjunction with the Watana Area mapping discussed in (b). Results of the Fog Lakes mapping are presented in Sections 4 and 7.

(f) Borrow Sites E and I

Mapping of the surficial geology in Borrow Sites E and I was performed primarily by airphoto interpretation, with limited ground checking and aerial reconnaissance. Geology was mapped on airphotos at a scale of 1 inch equal to 2,000, feet and subsequently transferred to a topographic map at a scale of 1 inch equal to 1,000 feet. Mapping extended from about 1 mile upstream of Borrow Site E to the previously defined downstream limit of Borrow Site I. Results of the Borrow Sites E and I mapping are presented in Section 8.

3.3 - Subsurface Investigations

A subsurface investigation program was undertaken during the summer of 1982 in the Watana Relict Channel and Borrow Site D. This program consisted of exploratory drilling, as well as field mapping and sampling of exposures in these areas.

Investigations in Borrow Site D centered on obtaining additional information on the stratigraphy of the area and on securing samples for laboratory characterization of borrow material properties. Watana Relict Channel investigations were aimed at refining the previously developed stratigraphy, determining leakage potential, and investigating the nature of the overburden materials with respect to hydrogeology, permafrost, and liquefaction potential.

A total of 16 rotary borings, numbered AH-D15 through AH-D30 were drilled in Borrow Site D and the Watana Relict Channel area using two Mobile B-61 drill rigs. In addition, 29 exposures were mapped and sampled. Drilling and sampling locations are shown on Figure 3.2, and are summarized on Table 3.1. Initially, holes were continuously drive sampled using a 3-inch-diameter, 2 foot lor split-spoon sampler driven with a 300 lb hammer. When sufficient stratigraphic data was developed, sampling was expanded to 5 foot intervals and at changes in strata or drilling conditions.

Drilling was initially planned to use hollow stem augers. Due to difficult drilling conditions encountered in the first hole (AH-D15), the method of drilling was changed to rotary drilling. Attempts were made to obtain undisturbed samples using 2 foot Shelby tubes as well as a 5 foot Dennison sampler. The extremely bouldery nature of several of the strata, however, prevented the successful recovery of undisturbed samples.

All drilling was supervised by Acres drilling inspectors, and all field logs were prepared at the drill site. Overburden exposures, investigated as part of the subsurface investigation, were logged in the field. Logs for drill holes are presented in the Appendix A.

A summary table of 1982 explorations, including borings and types of instrumentation installed is provided as Table 3.2. Test pit information has not needed corrections; however, survey data adjustments and borehole statistics additions and corrections have been made in numerous cases to the borehole data tables for previous explorations and are included in the project final survey data files.

3.4 - Seismic Refraction Surveys

A total of 92,439 linear feet of seismic refraction survey were run during September, 1982. Seismic lines were run at:

- Watana damsite Abutments: 21,373 linear feet;
- Watana Relict Channel/Borrow Site D: 26,018 linear feet;
- Fog Lakes Relict Channel: 45,048 linear feet;

Seismic refraction surveys were performed by Woodward-Clyde Consultants (WCC), and a summary of these investigations is indicated on Table 3.3. The details of the seismic refraction survey are provided in Appendix C.

Seismic refraction surveys in the Watana damsite area were undertaken to determine the amount of overburden present, characterize the bedrock surface, and to locate discontinuities and bedrock velocity variations. A total of fifteen lines were run, sequentially numbered SL82-1 through SL82-15. Locations of these lines were selected to supplement previous seismic work in the area, as well as to provide subsurface information in areas of the proposed civil structures. Locations of the damsite seismic lines are shown on Figure 3.1.

Watana Relict Channel/Borrow Site D seismic surveys were performed following those at the damsite. The purpose of these lines was primarily to provide supplemental information to further characterize the topography of the bedrock surface in the area, and to refine the interpretation of the Watana Relict Channel geometry. Seven lines were run in the area, numbered SL82-16 through SL82-22 and are shown on Figure 3.2.

Seismic work in the Fog Lakes area was carried out to verify the existence of a relict channel discovered during the 1980-81 investigations. Three long refraction lines were run in a direction anticipated to cross the thalweg of the relict channel. These lines are numbered SL82-FL1 through SL82-FL3 and are shown on Figure 3.3.

Results of the seismic refraction survey are discussed in Sections 5, 6, 7, and 8 and the survey report is attached as Appendix C.

3.5 - Laboratory Testing

(a) 1982 Field Testing

A soils laboratory was established on site to support the field program. Samples were shipped daily from the drill rigs to the laboratory for immediate testing. A total of more than 1000 samples were collected and tested. A summary of laboratory testing is shown on Table 3.4. Testing included determination of:

- grain size;
- moisture content;
- Atterberg limits; and
- Proctor densities.

Results of these tests are discussed in Sections 6 and 8.

(b) Continuing Tests

In addition to the field testing program, long-term freeze-thaw tests and concrete aggregate tests were completed for Quarry Sites A and K, and Borrow Sites E and G. The results of those tests are presented in Sections 8 and 9.

3.6 - Borehole Instrumentation

(a) Groundwater Levels

Throughout 1982, piezometric readings from all previously installed instruments were taken on a monthly schedule with the exception of several of the summer months for which additional data was not urgently needed.

In addition, attempts were made to return all unreadable piezometers to operating status by repairing damaged pneumatic tubing and emplacing protective covers over instrument heads.

All 1982 borings were instrumented with pneumatic and/or standpipe piezometers. The summary of new instrumentation installed in 1982 is presented in Table 3.2, while the primary characteristics of instrumentation installed in previous years has been summarized for reference information in the project survey and instrumentation files. Typical installation diagrams for the 1982 borings are provided on Figure 3.4.

The first readings of the new instruments after installation were made in October, 1982, with a second reading in mid-December, 1982. The data obtained in the October readings is included in Section 6; however, this data may not be representative since the piezometric levels may not have stabilized.

(b) Ground Temperatures

Thermistor readings were continued at monthly intervals. Several COE and 1980 borings were returned to service by repairing cables and placing protective casings over holes with permanent thermistor strings. In addition, antifreeze was added to several standpipe-type thermistor probe casings to avoid further difficulties with freezing of the water in the probe pipe. Several COE borings, which were filled with water or diesel fuel, remain nonfunctional during part or all of the year due to freezing and will require flushing and filling with antifreeze before they become fully operational.

During 1982, most of the 16 borings drilled in the Watana Relict Channel and Borrow Site D area had standpipe thermistor probe casing (PVC pipe) installed to the bottom of the hole. The closed-bottom pipe was filled with ethylene glycol antifreeze solution to be read with the portable thermistor cable. Casing was sized to allow downhole geophysical logging at a later date. One boring (AH-D20) was also instrumented with a multi-point thermistor string similar to those installed in diamond drilled borings at the Watana damsite. The results of the instrumentation program are presented in Sections 5, 6, 8, and 9.

TABLE 3.1: WATANA RELICT CHANNEL/BORROW SITE D
SUMMARY OF INVESTIGATIONS

INVESTIGATOR AND YEAR	TEST PITS		AUGER HOLES		ROTARY/CORE BORINGS	
	Number	Series	Number	Series	Number	Series
COE, 1978	14	TP-8 thru TP-21	24	AP-1 thru AP-24	11	DR-13 thru DR-20, DR-22, DR-26, DR-27
AAI, 1980-81	2	W-80	14	AH-D-1 thru AH-D-14	0	---
AAI, 1982	29	W-82	--	---	16	AH-D15 thru AH-D30

TABLE 3.2: WATANA RELICT CHANNEL/BORROW SITE D
SUMMARY OF 1982 DRILLING PROGRAM

HOLE NUMBER	LOCATION	SURFACE ELEVATION	DEPTH OF HOLE	INSTRUMENTATION
AH-D15	Borrow Site D	2313.9	84.0 ft	None
AH-D16	Borrow Site D	2271.3	193.0 ft	PN, T
AH-D17	Borrow Site D	2383.1	230.0 ft	SP, T
AH-D18	Borrow Site D	2341.4	189.3 ft	$PN_{(2)}$,T
AH-D19	Borrow Site D	2261.8	215.0 ft	$PN_{(2)}$,T
AH-D20	Watana Relict Channel	2162.1	151.5 ft	MPT
AH-D21	Borrow Site D	2272.7	188.7 ft	$PN_{(2)}$,T
AH-D22	Watana Relict Channel	2092.8	24.0 ft	PN, T
AH-D23	Watana Relict Channel	2163.0	160.0 ft	$PN_{(2)}$,T
AH-D24	Watana Relict Channel	2165.9	58.9 ft	PN, T
AH-D25	Watana Relict Channel	1986.7	90.0 ft	PN
AH-D26	Watana Relict Channel	2214.7	109.9 ft	PN
AH-D27	Borrow Site D	2148.8	195.0 ft	MPT
AH-D28	Borrow Site D	2226.3	234.0 ft	PN
AH-D29	Borrow Site D	2411.0	158.0 ft	PN
AH-D30	Watana Relict Channel	2221.4	100.0 ft	PN

PN = Pneumatic piezometer tip
SP = Standpipe piezometer, porous tip
MPT = Thermistor string
T = Polyvinylchloride (PVC) pipe filled with ethylene glycol for portable thermistor probe readings

TABLE 3.3: WATANA DAMSITE VICINITY
SUMMARY OF 1982 SEISMIC REFRACTION SURVEYS

LINE NUMBERS	LOCATION	LENGTH OF LINE (linear feet)	NUMBER OF SPREADS/SHOTS	PURPOSE - TO DETEMINE:*
SL82-1	Watana Damsite	1,300	3/8	Determine bedrock quality, detect shears in downstream portal area
SL82-2	Watana Damsite	550	1/3	Detect NW, N shears
SL82-3	Watana Damsite	550	1/3	Determine bedrock quality, detect shears in downstream portal area
SL82-4	Watana Damsite	1,950	4/11	Determine bedrock quality, detect shears in downstream portal area
SL82-5	Watana Damsite	3,375	7/20	General bedrock quality, NW and N trending shears in spillway area
SL82-6	Watana Damsite	1,650	3/9	Determine bedrock quality, detect shears in downstream portal area
SL82-7	Watana Damsite	350	1/3	Determine bedrock quality in portal and spillway area
SL82-8	Watana Damsite	1,100	2/6	Bedrock conditions in the "Fingerbuster", spillway flip-bucket area
SL82-9	Watana Damsite	1,100	2/6	General bedrock quality NW and N trending shears
SL82-10	Watana Damsite	1,100	2/6	Determine power intake area bedrock conditions, detect E-W shears
SL82-11	Watana Damsite	1,650	3/9	Determine limit of "The Fins", NW and N trending shears
SL82-12	Watana Damsite	2,200	4/12	Detect NW, N trending shears
SL82-13	Watana Damsite	1,550	3/9	Detect NW, N shears, western limit of "The Fins"
SL82-14	Watana Damsite	3,150	6/18	Detect "The Fins", NW and N trending shears
SL82-15	Watana Damsite	1,100	2/6	Determine if "The Fins" continue to the southeast
SL82-16	Watana Relict Channel	1,100	1/5	Provide fill-in data to produce consistent estimate of top of bedrock elevations
SL82-17	Watana Relict Channel	5,500	6/28	
SL82-18	Watana Relict Channel	6,600	6/29	
SL82-19	Watana Relict Channel	1,700	2/7	
SL82-20	Watana Relict Channel	6,400	6/27	
SL82-21	Borrow Site D	1,100	1/5	
SL82-22	Borrow Site D	3,200	3/14	
SL82-FL1	Fog Lakes Relict Channel	23,100	21/91	Determine width, location of relict channels determine approximate bedrock gradient of thalwegs
SL82-FL2	Fog Lakes Relict Channel	15,400	14/63	
SL82-FL3	Fog Lakes Relict Channel	6,600	6/28	

*NOTE:
All lines had a common purpose of detecting overburden thickness to provide data for preparation of top of bedrock maps; and to establish data continuity across gaps in previous data.

TABLE 3.4: WATANA RELICT CHANNEL/BORROW SITE D SUMMARY OF LABORATORY TESTING

INVESTIGATOR AND YEAR	SERIES	SAMPLES ATTEMPTED	SAMPLES RECOVERED	GRADATION ANALYSES	MOISTURE CONTENTS	ATTERBERG LIMITS
COE, 1978	TP	18	18	18	0	0
	AP	44	44	44	12	34
	DR	97	87	59	15	12
AAI, 1980-81	W80	2	2	2	2	2
	AH-D	146	111	37	39	21
AAI, 1982	W82	31	31	31	0	1
	AH-D	697	540	357	362	41
TOTAL, ALL INVESTIGATORS		1,035	833	548	430	111

TP = Test Pit
AP = Auger Probe
DR = Drill Hole, rotary
AH = Auger/Rotary overburden drill hole
W80 = Watana exposure sample (1980)
W82 = Watana exposure sample (1982)

TABLE 3.5: WATANA RELICT CHANNEL/BORROW SITE D SUMMARY OF LABORATORY TESTING

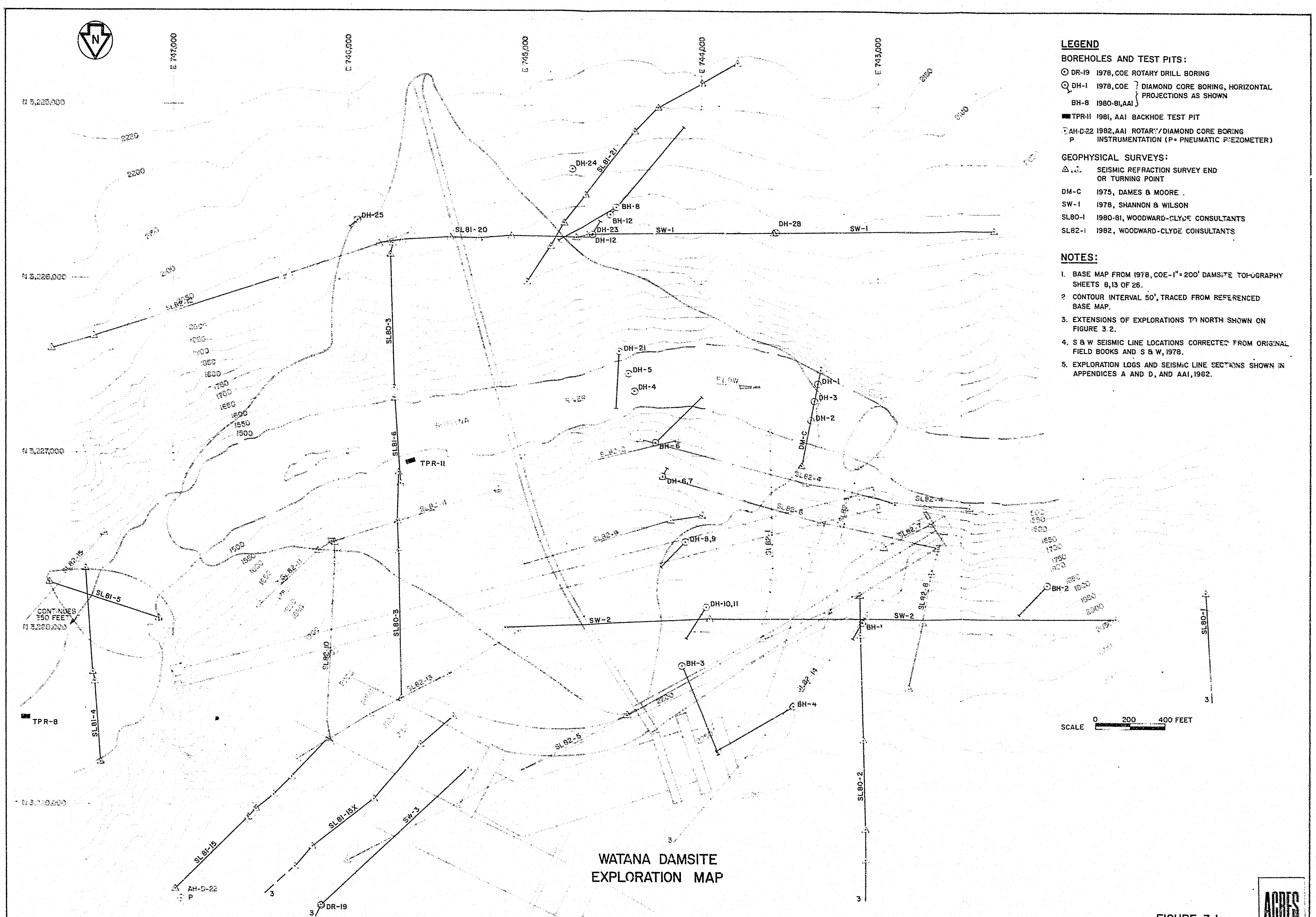
STRATIGRAPHIC UNIT	BLOW COUNTS	MOISTURE CONTENT	GRADATIONS	ATTERBERG LIMITS	PROCTOR STANDARD AND MODIFIED
C	91	64	78	4	1*
D	24	23	33	5	*
D'	14	11	12	2	*
M	48	38	32	5	0
E/F	199	112	137	16	8*
G	70	124	87	39	2
G'	40	19	31	1	0
H	9	6	7	0	0
I	52	24	32	1	0
J/J'	10	10	10	2	0
K	0	0	0	0	0
	557	431	459	75	11

*plus 1-1978 COE Composite Sample from units C through F

NOTE: This summary does not include testing from any AP Series (COE 1978) holes, DR Series (COE 1978), and AH-D Series (Acres 1980) because some borings could not be correlated by stratigraphic unit.

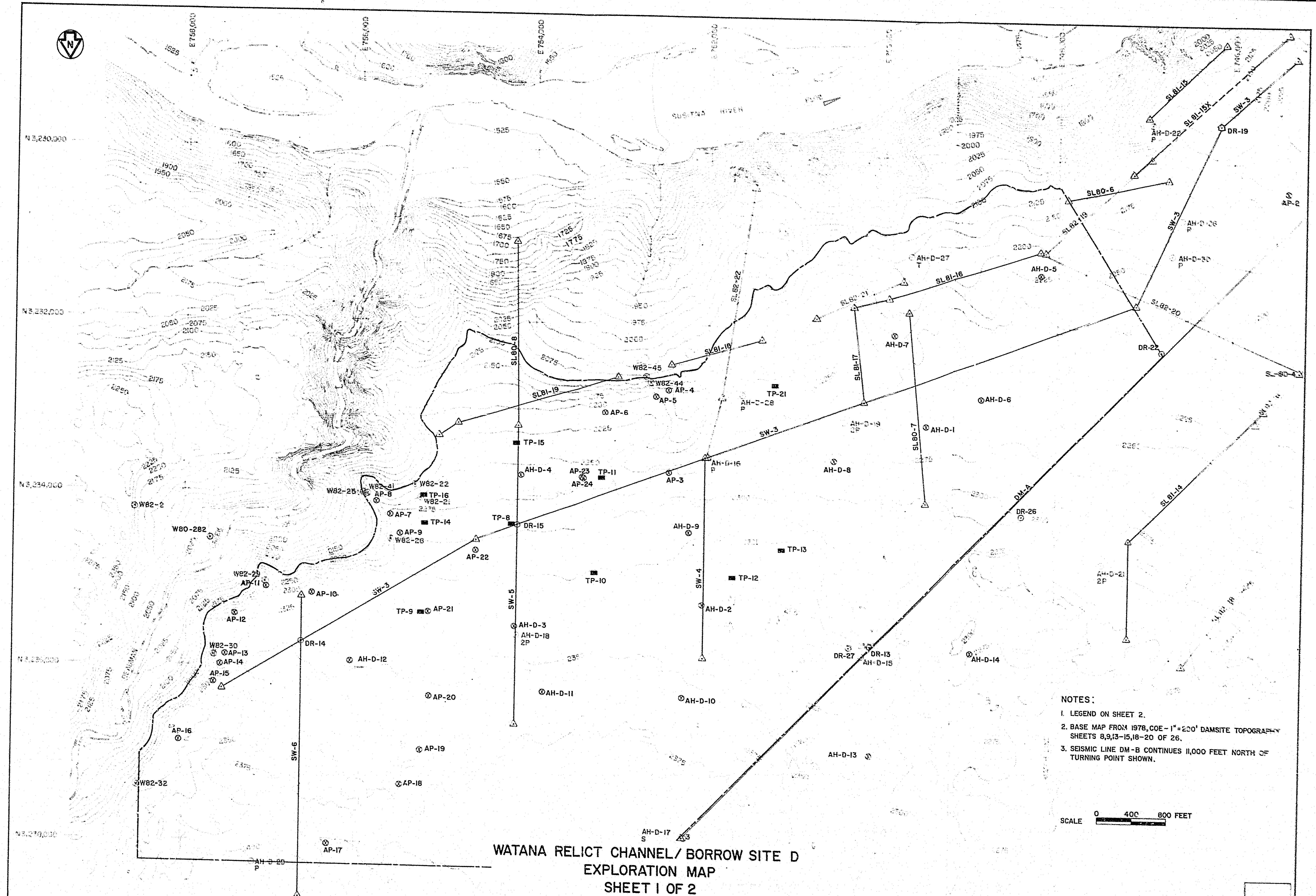
NOTE

All reference on the Figures to Appendix D should be changed to Appendix C.



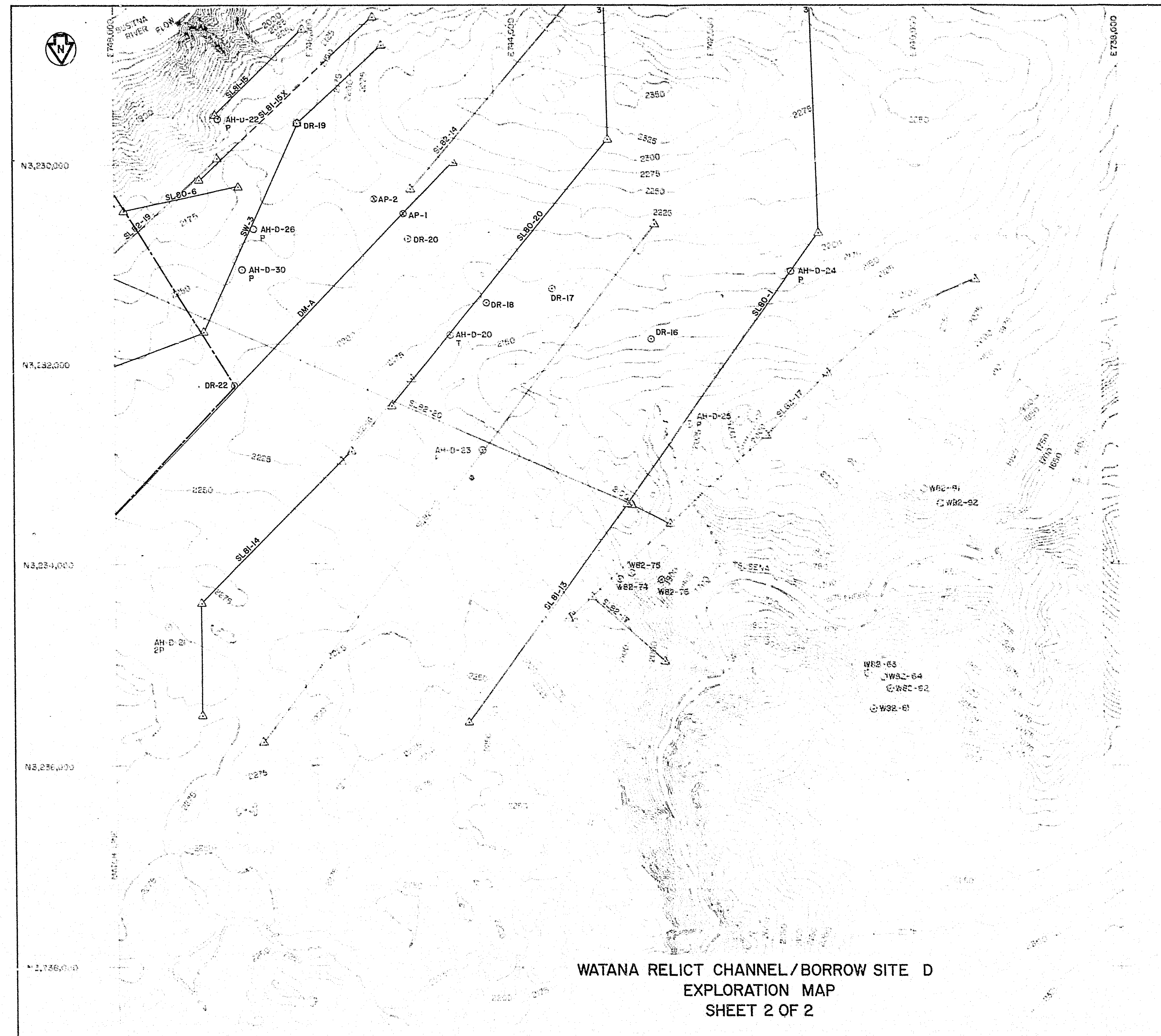
WATANA DAMSITE EXPLORATION MAP

FIGURE 3.1



WATANA RELICT CHANNEL/ BORROW SITE D
EXPLORATION MAP
SHEET 1 OF 2

FIGURE 3.2



WATANA RELICT CHANNEL / BORROW SITE D
EXPLORATION MAP
SHEET 2 OF 2

LEGEND

CONTACTS:

BORROW SITE LIMIT

GEOPHYSICAL SURVEYS:

SEISMIC REFRACTION SURVEY END OR TURNING POINT

DM-A 1975, DAMES & MOORE

SW-3 1978, SHANNON & WILSON

SL80-8 1980-81, WOODWARD-CLYDE CONSULTANTS

SL82-16 1982, WOODWARD-CLYDE CONSULTANTS

BOREHOLES AND TEST PITS:

DR-27 1978, COE ROTARY DRILL BORING

AP-21 1978, COE AUGER BORING

AH-D-12 1980, AAI AUGER BORING

AH-D-5 1982, AAI AUGER/ROTARY/DIAMOND CORE BORING

TP-11 1978, COE BACKHOE TEST PIT

W80-282 1980, AAI BULK SAMPLE LOCATION

W82-26 1982, AAI BULK SAMPLE LOCATION

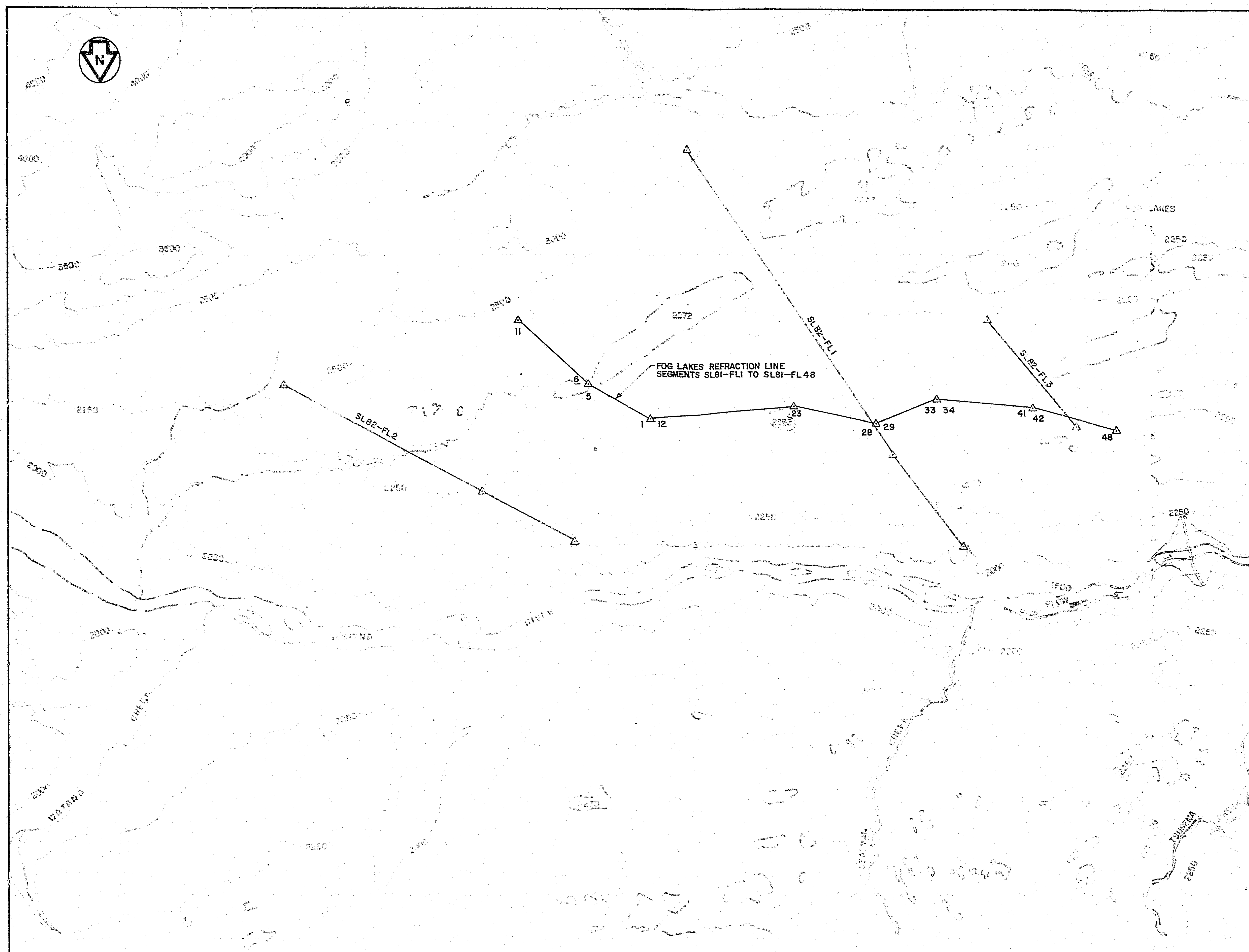
NOTES:

1. BASE MAP FROM 1978, COE-1"=200' DAMSITE TOPOGRAPHY SHEETS 7,8,12,13,17,18 OF 26.
2. CONTOUR INTERVAL 25 FEET, REDUCED AND TRACED FROM REFERENCED BASE MAPS.
3. EXTENSIONS OF EXPLORATIONS TO SOUTH AND DAMSITE EXPLORATION PLAN SHOWN ON FIGURE 3.1.
4. EXPLORATION LOGS AND SEISMIC LINE SECTIONS SHOWN IN APPENDICES A AND D, AND AAI, 1982.

SCALE 0 400 800 FEET

FIGURE 3.2

ACRES



LEGEND:

GEOPHYSICAL SURVEYS:

△,△ SEISMIC REFRACTION SURVEY END OR TURNING POINT.
SL81-FL1 1981, WOODWARD-CLYDE CONSULTANTS.
SL82-FL2 1982, WOODWARD-CLYDE CONSULTANTS.

NOTES:

1. BASE MAP MODIFIED FROM U.S.G.S. TALKEETNA MOUTAINS D-3 AND D-4 QUADRANGLE MAPS, SCALE 1 IN = 1 MI.
2. SEISMIC LINE SECTIONS SHOWN IN APPENDIX D AND AA1, 1982

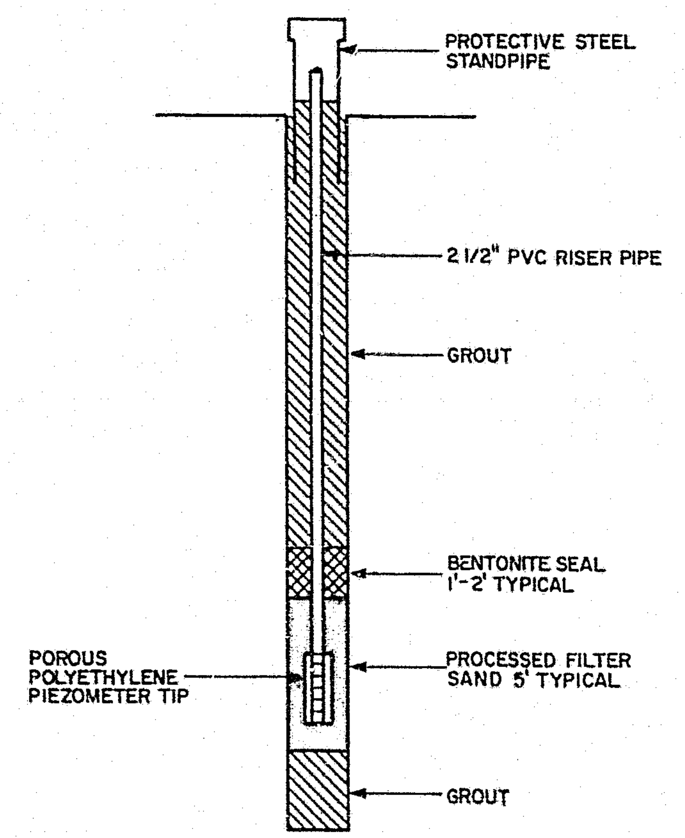
SCALE 0 2000 4000 FEET

WATANA
FOG LAKES RELICT CHANNEL
EXPLORATION MAP

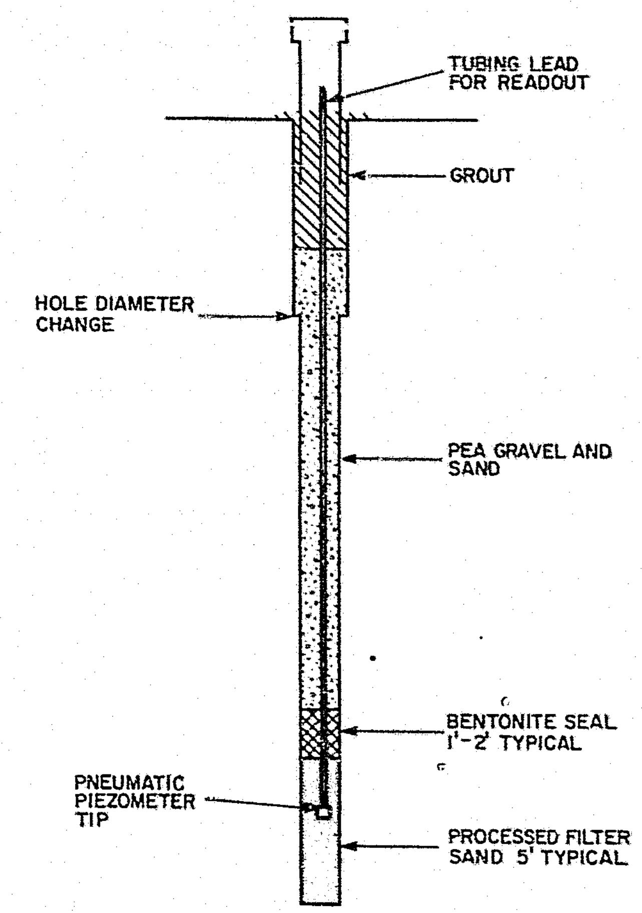
ACRES

FIGURE 3.3

TYPICAL STANDPIPE PIEZOMETER INSTALLATION



TYPICAL PNEUMATIC PIEZOMETER INSTALLATION (WITHOUT PVC PIPE)

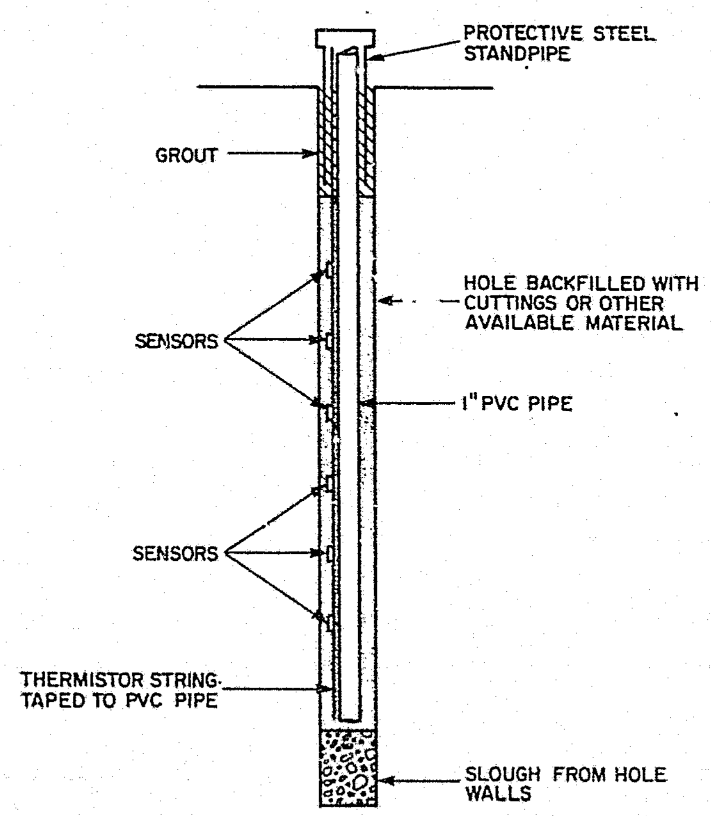


NOTES:

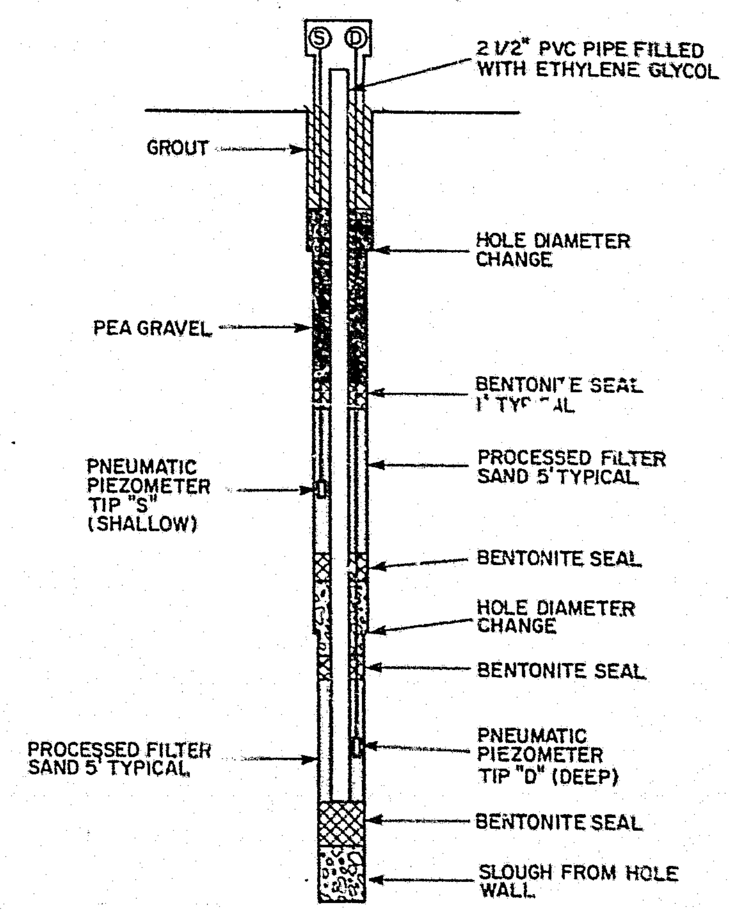
1) ALL DRAWINGS GRAPHICALLY REPRESENTED AND NOT TO SCALE.

2) HOLE DIAMETER CHANGES ARE DUE TO DRILLING TOOL SIZE CHANGE.

TYPICAL THERMISTOR STRING INSTALLATION



TYPICAL PNEUMATIC PIEZOMETER INSTALLATION (WITH PVC PIPE)



TYPICAL INSTRUMENTATION INSTALLATION DETAILS

FIGURE 3.4

ACRES

4 - WATANA AREA GEOLOGY

4.1 - Introduction

This section discusses the bedrock and surficial geology of the Watana area which includes the Watana damsite, Watana and Fog Lakes Relict Channels, and all the major quarry and borrow sites. A surficial geologic map of this area is presented in Figure 4.1. Detailed discussion of the regional geology is presented in the 1980-81 Geotechnical Report (1). The following discussions have been limited to the regional geology within the immediate Watana area.

4.2 - Overburden and Topography

The Watana area lies within the Upper Susitna River Basin in the Talkeetna Mountains of south-central Alaska. The river basin is a high, broad plain of low relief formed by repeated glaciations. The Susitna River has incised a deep (over 800 feet), east-west trending gorge into this plain. Numerous lakes and low rounded hillocks cover much of the area. Unconsolidated Quaternary sediments mantle the area (40) and are discussed in Section 4.5.

4.3 - Bedrock Stratigraphy

The oldest rocks which outcrop in the Watana area are a metamorphosed upper Paleozoic (Table 4.1) rock sequence which trends northeastward along the eastern portion of the Susitna River Basin in the Talkeetna Mountains (Figure 4.1). These rocks consist chiefly of coarse to fine grained clastic volcanic flows and tuffs of basaltic to andesitic composition, which locally contain marble interbeds. This sequence of rocks is unconformably overlain by Triassic and Jurassic metavolcanic and sedimentary rocks. These rocks, which consist of a shallow marine sequence of metamorphosed basalt flows interbedded chert, argillite, marble, and volcaniclastic rocks, are exposed in the eastern part of the Watana area along Watana Creek and in the Fog Lakes Relict Channel (see Section 7). Paleozoic and lower Mesozoic rocks are intruded by Jurassic plutonic rocks composed chiefly of granodiorite and quartz diorite. The Jurassic age intrusive rocks form the batholithic complex of the Talkeetna Mountains, both north and south of the Watana area (8).

The uplift of the Talkeetna Mountains and subsequent rapid erosion associated with this plutonic event resulted in the deposition of a thick turbidite sequence of argillite and graywacke during the Cretaceous. Following deposition, the region was uplifted, intruded and metamorphosed. These rocks underlie a large portion of the project area including the Devil Canyon damsite (10). In the Watana area, argillite and graywacke outcrop along the Susitna River primarily between Deadman Creek and the Talkeetna Thrust Fault, and also in the Fog Creek area.

ACRES

The Cretaceous rocks were intruded in the Watana area by a series of Tertiary age plutonic rocks ranging in composition from granodiorite to diorite.* The Watana damsite is underlain by one of these plutons. Diorite similar to that in the damsite is found in Deadman and Fog Creeks and north of Borrow Site D. Granodiorite is found near the site on Tsusena Creek (7). Whether these two rock types represent two plutons or differentiation within one pluton is not known.

Subsequent, but probably related to the emplacement of the plutons, was the extrusion of a sequence of volcanic rock and deposition of volcaniclastic rocks. These rocks consist primarily of andesitic to basaltic flows, but primarily andesite porphyry. The contact between the andesite porphyry and diorite pluton is exposed in the damsite area (Section 5.1).

Downstream of the damsite, a thick volcaniclastic sequence occurs in the andesite porphyry units. The volcaniclastic rock consists of several hundred feet of interbedded volcanic sandstone, siltstone and shale, and possible felsite, dipping gently to west. The upper andesite porphyry appears to unconformably overlie the tilted volcaniclastic rock, indicating two episodes of this volcanic activity.

The youngest Tertiary rocks in the damsite area are partially lithified sedimentary rocks consisting of conglomerate, sandstone, claystone and minor coal (11). These deposits are only exposed along Watana Creek north of the Fog Lakes Relict Channel.

4.4 - Tectonic History

At least three major episodes of deformation are recognized (10) for the Watana area:

- A period of intense metamorphism, plutonism, and uplift in the Jurassic;
- A similar orogeny during the middle to late Cretaceous; and
- A period of extensive uplift and denudation in the middle Tertiary to Quaternary.

The first period (early to middle Jurassic) was the first major orogenic event in the Susitna River Basin as it now exists. It was characterized by the intrusion of plutons and accompanied by crustal uplift and regional metamorphism.

Most of the structural features in the region are the result of the Cretaceous orogeny associated with the accretion of northwest drifting continental blocks into the North American plate. This plate convergence resulted in complex thrust faulting and folding which produced the pronounced northeast/southwest structural grain across the region. The argillite and graywacke beds were isoclinally folded along northwest trending folds during this orogeny. The majority of the structural features, of which the Talkeetna Thrust Fault is the most prominent in the Talkeetna Mountains, are a consequence of this orogeny. The Talkeetna Thrust is postulated as representing an old suture zone, involving the thrusting of Paleozoic, Triassic and Jurassic rocks over the Cretaceous sedimentary rocks (10, 11, 14, 15, 24). Other compressional structures related to this orogeny are evident in the intense shear zones roughly parallel to and southeast of the Talkeetna Thrust.

Tertiary deformations are evidenced by a complex system of normal, oblique slip, and high-angle reverse faults. Two prominent tectonic features of this period bracket the basin area. The Denali fault, a right-lateral, strike-slip fault 25 miles north of the Susitna River, exhibits evidence of fault displacement during Cenozoic time (9). The Castle Mountain-Caribou fault system, which borders the Talkeetna Mountains approximately 70 miles southeast of the sites, is a normal fault which has had displacement during the Holocene (13).

At the damsite, "The Fins" and "Fingerbuster" shear zone crosscuts Tertiary age volcanic rocks and may be related to this episode of deformation.

4.5 - Glacial History

A period of cyclic climatic cooling during the Quaternary resulted in repeated glaciation of southern Alaska. Little information is available regarding the glacial history in the upper Susitna River Basin. Unlike the north side of the Alaska Range, which is characterized by alpine type glaciation, the Susitna basin experienced coalescing piedmont glaciers from both the Alaska Range and the Talkeetna Mountains that merged and filled the upper basin area.

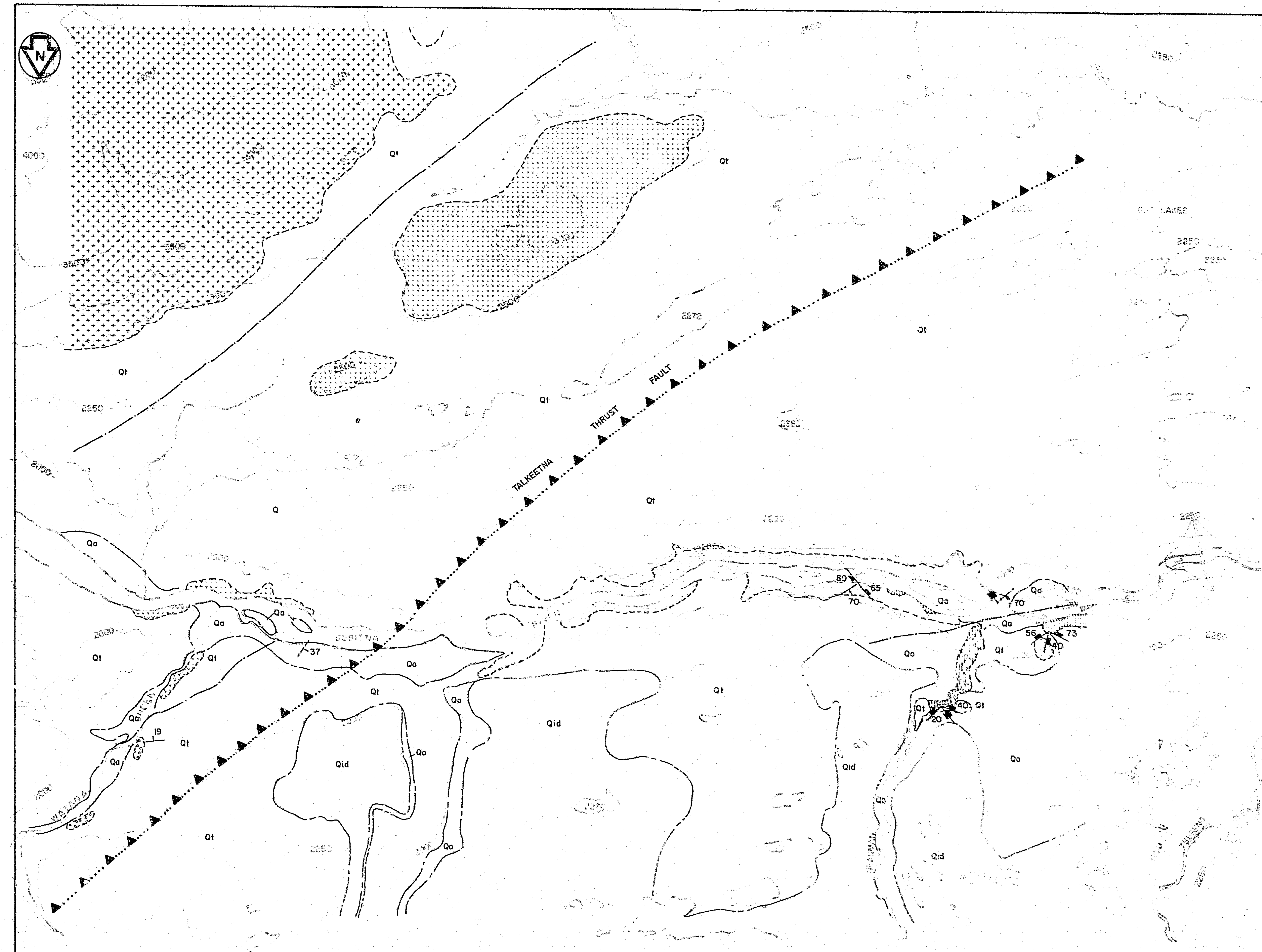
At least three periods of glaciation have been delineated for the area based on the glacial stratigraphy (18, 20). During the most recent period (late Wisconsinian), glaciers filled the adjoining lowland basins and spread onto the continental shelf (18). Waning of the ice masses from the Alaska Range and Talkeetna Mountains formed ice barriers which blocked the drainage of glacial meltwater and produced proglacial lakes.

As a consequence of repeated glaciations, the Susitna River basin is covered by varying thicknesses of till, outwash, lacustrine and ice disintegration deposits. The till is primarily a basal till which in the Fog Lakes area, is characterized by a fluted ground moraine surface. In the upper portion of Watana Creek, significant thicknesses of lacustrine deposits are exposed at the surface (not seen on this map) which resulted from proglacial lakes. On the north side of the Susitna River, from Tsusena Creek to just upstream of Deadman Creek, ice disintegration deposits are visible. These formed as a consequence of rapid deglaciation as the glaciers began thinning and were cut off from their source, leaving large debris covered glacier bodies which stagnated in place. This was the last glacial event in the Watana area as the glaciers which fed this area retreated to the north.

TABLE 4.1: GEOLOGIC TIME SCALE

ERA	PERIOD	EPOCH	GLACIATION	MILLION OF YEARS AGO
Cenozoic	Quaternary	Holocene Pleistocene	Wisconsinian Illinoian Kansan Nebraskan	1.8
	Tertiary	Pliocene Miocene Oligocene Eocene Paleocene		70
Mesozoic	Cretaceous Jurassic Triassic			230
Paleozoic	Permian Pennsylvanian Mississippian Devonian Silurian Ordovician Cambrian			600
Precambrian				

Reference (38)



LEGEND:

LITHOLOGY:

CENOZOIC

QUATERNARY

Qu	SURFICIAL DEPOSITS, UNDIFFERENTIATED, GENERALLY THIN
Qa	ALLUVIUM, ALLUVIAL TERRACES AND FANS.
Qid	ICE DISINTEGRATION DEPOSITS
Qo	OUTWASH.
Qt	TILL.

TERTIARY

- CONGLOMERATE, SANDSTONE AND CLAYSTONE.
- VOLCANICLASTIC SANDSTONE, SILTSTONE AND SHALE
- ANDESITE PORPHYRY, MINOR BASALT
- DIORITE TO QUARTZ DIORITE, MINOR GRANODIORITE
- BIOTITE GRANODIORITE

MESOZOIC

CRETACEOUS

- ARGILLITE AND GRAYWACKE.

TRIASSIC

- BASALTIC METAVOLCANIC ROCKS, METABASALT AND SLATE

PALEOZOIC

- BASALTIC TO ANDESITIC METAVOLCANIC ROCKS

CONTACTS:

- BEDROCK, DASHED WHERE INFERRED
- BEDROCK / SURFICIAL DEPOSITS, DASHED WHERE APPROXIMATE.
- SURFICIAL DEPOSITS, APPROXIMATE

STRUCTURE:

- THRUST FAULT, TEETH ON UPTHROWN SIDE
- SHEAR, NEAR VERTICAL TO VERTICAL UNLESS DIP SHOWN, EXTENT WHERE KNOWN AND / OR INFERRED.
- 55 JOINTS, INCLINED, VERTICAL
- 17 BEDDING, INCLINED, VERTICAL.
- SYNCLINAL AXIS.

NOTES:

1 GEOLOGY MODIFIED FROM CSEJTEY AND OTHERS, 1978

2 DETAIL MAPS OF THE WATANA DAMSITE ON FIGURES 52, 512 AND 516

3 BASE MAP MODIFIED FROM U.S.G.S. TALKEETNA MOUNTAINS D-3 AND D-4 QUADRANGLE MAPS, SCALE 1 INCH = 1 MILE

4 EXTENT OF LITHOLOGY AND STRUCTURE ARE BASED ON AIRPHOTO INTERPRETATION AND LIMITED FIELD INVESTIGATION AND ARE SUBJECT TO VERIFICATION THROUGH FUTURE DETAILED INVESTIGATIONS.

SCALE 0 2000 4000 FEET

WATANA DAMSITE AREA
GEOLOGIC MAP
SHEET 1 OF 2

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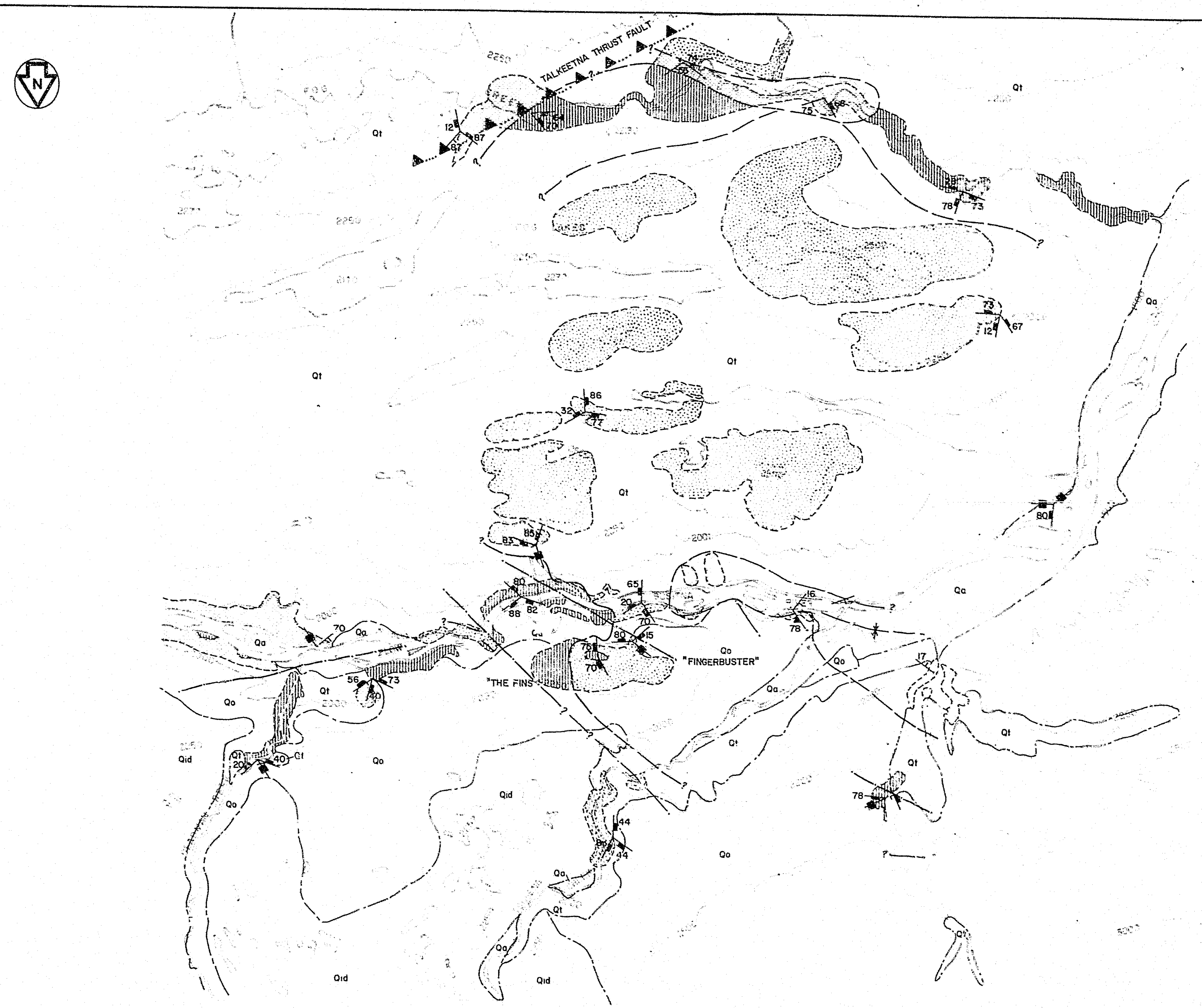
FIGURE 4.1

NOTE:
1. EXPLANATION FOR SYMBOLS ON SHEET 1



SCALE 0 2000 4000 FEET

WATANA DAMSITE AREA
GEOLOGIC MAP
SHEET 2 OF 2

FIGURE 4.1

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5 - RESULTS OF GEOTECHNICAL INVESTIGATIONS - WATANA DAMSITE

5.1 - Main Dam Foundation

(a) Overburden

(i) Introduction

A map showing the top of bedrock surface and the type and distribution of surficial sediments in the Watana damsite is presented on Figure 5.1. Geologic profiles depicting subsurface stratigraphy in the main damsite and borrow sites are presented in later sections. Determination of the overburden thickness and material types is based on geologic mapping, seismic refraction surveys, boreholes and test pits. Exploration locations are shown on Figure 3.1. Table 5.1 provides the correlation of seismic velocities with soil and rock types used for this study. Data used in developing these figures and tables is presented in Appendix C and the 1980-81 Geotechnical Report (1).

(ii) Damsite

Detailed geologic mapping and the additional 21,373 linear feet of seismic refraction survey performed during 1982 have resulted in a refinement of the top of bedrock and surficial geologic map presented previously (1). A detailed discussion of overburden conditions for the upstream cofferdam and portal area, downstream cofferdam and portal area, and intake and spillway areas is presented in Sections 5.2, 5.3 and 5.4 respectively. Refer to the 1980-81 Geotechnical Report for a discussion of overburden conditions in the main damsite area (1).

(b) Bedrock Lithology

(i) Introduction

The Watana site is located on the western side of a Tertiary age (Table 4.1) igneous plutonic body which consists primarily of diorite and quartz diorite (Section 4). This pluton is bounded in the west area by argillite, andesitic volcanic flows and volcaniclastic sedimentary rocks. These rocks have not been assigned formational names, but rather have been described by standard lithologic types (26) for mapping and correlation purposes.

The lithology and structure at the Watana damsite are shown on a geologic map, Figure 5.2, and five geologic sections, W-1 through W-5 (Figures 5.3 to 5.7). In addition, detailed geologic maps of the upstream and downstream

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cofferdam and portal areas are shown on Figures 5.12 and 5.16, as well as by geologic sections (Figures 5.13 and 5.17).

The geology shown in these figures is based on field mapping, boreholes, and seismic refraction data (Section 3). Where possible, mapped surface structure was correlated with subsurface drilling and seismic refraction data. However, the limited rock exposure and the widely spaced subsurface exploration data in the damsite frequently required extrapolation of geologic contacts and structural features over considerable distance. There are a number of uncertainties which exist in the interpretation of the nature of the materials in the 6,000 to 10,000 feet per second (fps) seismic velocity range. This material was interpreted to be bedrock, although velocities in this range are more typical of well consolidated soils. Bedrock outcrops, which occur in some of these lower velocity zones, consist of competent rock that would be expected to have higher seismic velocities. Therefore, future investigations will be necessary to confirm the location and continuity of the features shown in the figures, and of the top of rock mapping.

For simplicity, borehole information shown on Figures 5.3 through 5.7 is limited to features five feet or greater in thickness. More detailed information is contained in Appendix C, and Appendices B, D, H, and I of the 1980-81 Geotechnical Report (1).

The following subsections address the site lithology.

(ii) Plutonic Rocks

At the Watana site, the pluton is nearly continuously exposed in large outcrops along the south bank between Elevations 1650 and 1900. On the north bank, outcrops are generally smaller and less frequent (Figure 5.1). The rocks of the pluton are primarily diorite and quartz diorite, with lesser amounts of granodiorite. These varied lithologies are probably the result of chemical variations within the parent magma, primarily increasing in silica content from diorite to granodiorite. The rock types are observed in both outcrop and boreholes to grade smoothly from one to the other. A 20-foot-wide gradational contact between the diorite and quartz diorite is exposed at river level on the south bank approximately 1,000 feet upstream from the dam centerline. Similar contacts are found in boreholes BH-6 and BH-8 (Appendix B, Reference 1) over 0.3 feet at Elevation 1[illegible]94 and 3.8 feet at Elevation 1708, respectively. Since no mappable pattern was found to differentiate these three rock types, they have been combined on the geologic map and sections under the general name of diorite.

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The diorite is described as a crystalline igneous rock which is predominantly medium greenish gray, but varies to light gray and light to medium greenish gray in the granodiorite and quartz diorite phases, respectively. The texture is massive with no foliation. Grain size varies from fine (less than 1mm) to medium (1-5mm) but is usually medium. The diorite is generally composed of 60 to 80 percent feldspar, 0 to 10 percent quartz, and 20 to 30 percent mafics.

Quartz content of the quartz diorite ranges up to 20 percent but is usually 10 to 15 percent. The feldspar consists primarily of medium grained, euhedral plagioclase with minor amounts of fine grained anhedral orthoclase. In the granodiorite, orthoclase content is about 10 percent. Quartz, when present, is fine grained and intergrown between the feldspar crystals. Mafic minerals, consisting of biotite and hornblende, are generally fine grained. The hornblende is often partially chloritized. Trace amounts of sulphides and carbonate also occur within the diorite. Inclusions of argillite have been observed in the diorite in "The Fins" and the "Fingerbuster" areas (Figure 5.2).

The diorite is generally fresh and hard to very hard. The rock is slightly weathered along the joint surfaces to depths of about 50 to 80 feet. There is generally a very thin (less than 2 inches) weathering rind on most outcrops.

The pluton has been intruded by both mafic and felsic dikes which are discussed below.

Zones of hydrothermal alteration occur within the diorite. The alteration has caused the chemical breakdown of the feldspars and mafic minerals. The feldspars have altered to kaolinite clay and the mafics have altered to chlorite. Hydrothermal alteration is discussed in detail in Section 5.1(c).

(iii) Andesite Porphyry

The name andesite porphyry is used for a varied group of apparently related extrusive rock types (28). The andesite porphyry occurs along the western side of the dior ,e pluton and is exposed in outcrops on both sides of the Susitna River (Figure 5.2). On the south bank, outcrops occur across from the "Fingerbuster" and at approximate Elevation 1750 immediately downstream from the dam centerline. Andesite porphyry was drilled in boreholes BH-4 (Figure 5.3), BH-8 (Figure 5.4), and BH-2 (Figure 5.6) to depths of 96.0, 43.0 and 103.0 feet, respectively. Borehole DH-28 bottomed at 125 feet in the porphyry (Figure 5.7). Andesite porphyry dikes are also found interspersed in the diorite. On

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the north bank, the andesite is exposed at river level in the "Fingerbuster" area and in scattered outcrops to about Elevation 2350.

The andesite porphyry is a light to medium dark greenish gray volcanic rock similar in composition to the diorite pluton. The color becomes lighter with increasing amounts of lithic inclusions. The groundmass is aphanitic (grains visible only with the aid of a microscope) with generally 10 to 30 percent of fine to medium grained plagioclase feldspar phenocrysts. Lithic inclusions are found throughout the andesite porphyry but are most concentrated near the contact with the diorite. Concentrations of subrounded to subangular fragments, up to 6 inches in diameter, of quartz diorite, argillite and volcanic rocks were found above the diorite contact in BH-8 (Appendix B, Reference 1). The andesite porphyry is fresh to slightly weathered and hard. Hydrothermal alteration is not common in the andesite porphyry.

The andesite porphyry also contains layers or zones of dacite and latite. The latite occurs in the "Fingerbuster" area and the dacite in Quarry Site A (28).

These varied rock types appear to be irregular and discontinuous in the site area and could not be mapped over large areas. Therefore, the term andesite porphyry has been used as a general term for all of these volcanic units.

Outcrops on the south bank near the diorite contact contain from 30 to 50 percent lithic fragments in an andesite matrix. Flow structures are visible in outcrops and boreholes in the areas of abundant lithic fragments. On the south bank, about 350 feet northeast of DH-28, the flow structure strikes east-west and dips 20° to the south. In the "Fingerbuster" area, flow structures strike northwest-southeast and dip 15° to the west. A photograph of the andesite porphyry with numerous lithic inclusions, as well as, flow structure lineation, is shown in the 1980-81 Geotechnical Report[1].

(iv) Contact Between Andesite Porphyry and Diorite

The contact between the andesite porphyry and the underlying diorite has been mapped immediately downstream from the proposed dam centerline, extending in a general northwesterly direction across the south abutment and northerly across the north abutment (Figure 5.2). On the south bank it is intersected in BH-8 and BH-12, and is exposed in one outcrop west of the dam centerline at about Elevation 1750. At this point, between 400 to 800 feet northeast of DH-28, the diorite is generally fresh to slightly weathered and unfractured. The andesite porphyry is slightly to moderately weathered and fractured up to 10 to 15 feet above the contact. A photograph of the closely to very closely spaced joints in the andesite porphyry immediately above the diorite contact is shown in the 1980-81 Geotechnical Report(1).

Where the contact is exposed on the south bank, minor shearing, less than 1 inch wide, occurs between the andesite porphyry and the diorite. The contact in this area strikes nearly east-west with a dip of 45° to the south. In BH-8, the andesite porphyry/diorite contact is found at a depth of 43.0 feet. From 38.4 to 43.0 feet, thin layers of andesite porphyry are moderately to severely weathered with layers of silty sand. Core loss in this zone was 1.1 feet with only 50 percent drill water return. The contact in BH-12 was intersected at a depth of 63.7 feet. Unlike BH-8, the andesite above the contact (from 54.8 to 63.7 feet) is fresh to moderately weathered with generally closely to moderately closely spaced joints. The contact occurs over a 3-inch-wide zone where the andesite porphyry interfingers with the diorite. The diorite is fresh below the contact. Core recovery was generally 100 percent through the contact zone with variable RQDs. Permeabilities were on the order of 10^{-5} cm/sec.

On the north bank, the contact is not exposed but was intersected in BH-2 and BH-4. In BH-4, very closely spaced joints with silt and clay coating occur in the andesite porphyry from 94.1 feet to the contact at 96.0 feet. As in BH-12, very thin fingers of andesite porphyry penetrate the diorite at the contact. The diorite below the contact is slightly weathered with iron oxide staining in the upper 0.5 foot. RQDs are quite low, ranging from 0 to 51 percent in the upper 15 feet of the diorite. Permeabilities, however, are low at about 10^{-6} cm/sec. The contact from river level (Elevation 1450) to about Elevation 2000 in this area is coincident with a major north-south trending shear zone (Section 5.1[c]). This zone, which was drilled in BH-2, showed low RQDs and core loss. This poor quality rock is the result of post-intrusion shearing and not necessarily representative of the contact. Above Elevation 2000, where the contact is not coincident with the major shear zone, the contact is assumed to dip gently to moderately northwest.

(v) Dikes

The diorite pluton has been intruded by both mafic and felsic dikes. No dikes were found in the andesite porphyry. Because of their small size, the dikes could not be delineated as mappable units.

Felsic dikes are found in outcrops and in all boreholes. Felsic dikes are light gray and aphanitic to medium grained, but generally fine grained. The felsic dikes are composed primarily of feldspar (plagioclase and orthoclase) with up to 30 percent quartz and less than 10 percent mafics. Contacts with the diorite are tight and "welded". The felsic dikes are hard, fresh, and unfractured. Dike widths are up to 6 feet but generally less than 0.5 feet. Felsic dikes have been found offset up to 16 inches by shears and healed shears in outcrop (Section 5.2 [c] and in boreholes (BH-3 at 702.7 and 801.3 feet). A photograph of a typical felsic dike which was offset along a shear is shown in the 1980-81 Geotechnical Report(1).

Mafic dikes are less common at the site than the felsic dikes. They are rarely seen in outcrop but were found locally in boreholes BH-1, BH-2, BH-8, and BH-12. The mafic dikes, consisting of andesite or diorite, are dark green to dark green gray. Grain size is aphanitic to very fine, with fine to medium grained plagioclase phenocrysts. The mafic dikes are hard and fresh with tight contacts. Dike widths are generally less than 1 foot, although in BH-2, an andesite dike was drilled from 245.8 to 277.8 feet. Diorite inclusions were also found in this dike. A possible mafic dike was mapped on the south bank at river level upstream from the centerline. This dike is approximately 5 feet wide and consists of fine grained diorite. The dike is very closely to closely jointed and occurs in a talus-filled gully. The trend of the dike is northwest-southeast parallel to a major joint set. As with the felsic dikes, the mafic dikes could not be mapped over an extensive area.

A large mafic dike, 350 to 400 feet wide, has intruded into the diorite upstream from the proposed diversion tunnel intake portal. Outcrops occur in "The Fins" on the north bank and in Quarry Site L on the south bank (Figure 5.2). The dike is porphyritic with an aphanitic to fine grained groundmass. Medium grained phenocrysts, consisting primarily of plagioclase feldspar and lesser amounts of hornblende, comprise up to 10 percent of the rock in "The Fins" and 20 to 30 percent on the south bank. The bedrock in this area has been termed a diorite porphyry. The rock is fresh, hard, and generally massive with rare occurrences of compositional layering or possible flow structure. Inclusions in this unit consist of rounded diorite and tabular argillite fragments from 1 to 6 inches long. Contacts with the inclusions are sharp and tight.

The diorite porphyry becomes less porphyritic and more aphanitic near the contacts with the diorite pluton. The western contact in "The Fins" is coincident with a 10-foot-wide shear/alteration zone (see Section 5.2 [c]). The eastern contact is not exposed.

(c) Bedrock Structure

(i) Introduction

This section discusses the structural geology at the Watana damsite and its relation to proposed site facilities. This section is presented in three subsections: joints; shears, fracture zones, and alteration zones; and significant geologic features.

(ii) Joints

Joint data were recorded at all outcrops, as well as at nine joint stations (WJ-1 through WJ-9) which were selected for detailed joint measurements(1). Joint stations were chosen at representative areas having good three-dimensional exposure of major structures and in the major rock types: diorite, andesite porphyry, and diorite porphyry. At outcrop and joint stations, the orientations of major and minor joint sets were recorded, as well as the condition of the joint surfaces, spacing, and any mineralization or coating.

Joint measurements were plotted on the lower hemisphere of a Schmidt equal-area stereonet and contoured at 1, 3, 5, 7, 10, and 15 percent. An example illustrating the plotting method (6) is presented on Figure 5.8. Joint station plots are shown in the 1980-81 Geotechnical Report(1).

Composite joint plots were constructed from both joint station and outcrop data. The site was divided into four quadrants (northeast, southeast, southwest, and northwest). A composite plot for each quadrant is shown on Figure 5.8.

Two major and two minor joint sets were mapped at the Watana site and are identified on the composite and joint station plots. Sets I and II are major sets which occur throughout the site area. Sets III and IV are minor sets which are generally less prominent but may be locally strong. Each joint set is discussed below. Table 5.2 is a summary of joint set orientations, dips, spacings, surface conditions, and structural relations. The joint sets are common to all rock types at the damsite.

This discussion is based on mapped surface jointing. Because the orientations of joints and fractures in the boreholes were not determined, it is not possible to correlate between joints in outcrop and those encountered at depth. Joints in boreholes are discussed in Reference 1.

Joint Set I is the most prominent set at Watana. The average orientation of the four quadrants is 300° (Table 5.2). Set I consists of two subsets, Ia and Ib, which vary in strike by 20° to 30°, but with similar dips. Subset Ia generally trends from 320° to 330° with most dips between

85°SW and 80°NE. This subset is most strongly developed in the southeast quadrant. Subset Ib is usually the more strongly developed of the two subsets, particularly in the northwest and southwest quadrants. Subset Ib generally strikes from 295° to 310° with an average dip of 75° northeast.

Set I joint surfaces are primarily planar and smooth to locally rough and have an average spacing of 2 feet. Joint surfaces in the diorite porphyry in "The Fins" are pitted and rough where feldspar and hornblende phenocrysts have weathered out. Minor carbonate deposits were found on Set I surfaces at joint stations WJ-4, WJ-6, and WJ-7 (Figure 5.8). The joints are continuous and generally tight. Open joints are found at the surface in fracture zones and shears, particularly in "The Fins" in the upstream diversion portal area and on the south bank (GF 6) on the slopes above the proposed downstream cofferdam. Set I parallels most major shears, fracture zones, and alteration zones found at the site. In "The Fins" area, discontinuities primarily parallel Subset Ia; however, in the "Fingerbuster" area these discontinuities parallel Subset Ib joints. The Susitna River is parallel to Subset Ib between the dam centerline and downstream diversion portal area.

Joint Set II is northeast-trending, ranging in strike from 015° to 075° with an average trend of 055° across the site. Most dips are moderate to steep from 60° southeast to 60° northwest with an average dip of 85° northwest. Set II is best developed in the northeast and southeast quadrants where the trend averages 045° with a preferred dip to the northwest. At joint stations WJ-3 and WJ-5, in the upstream diversion portal area, Set II is more strongly developed than Set I, while at joint station WJ-6 in the diorite porphyry approximately 200 feet upstream from WJ-3, no Set II joints were found. It is likely that the face of the outcrop at this station was parallel to Set II joints resulting in no exposure of that set. In the northwest and southwest quadrants, Set II trends more to the east with an average strike of 065° and near-vertical to vertical dips. Set II joints are generally planar to irregular with smooth to slightly rough surfaces. Joint spacings range from 1 inch in fracture zones to 5 feet, averaging 1 to 2 feet. Set II is generally continuous and tight. Open joints were found on the south bank at WJ-1 and at several other outcrops.

Fracture zones are associated with Set II joints in the northeast and southeast quadrants at "The Fins" and in geologic feature GF 3. These zones appear to be discontinuous (see Section 5.2 [c]). The Susitna River runs parallel to subparallel to Set II joints in the upstream diversion portal area. No shears or alteration zones were found associated with Set II joints.

Joint Set III is generally north-south trending, ranging in strike between 335° and 035° with variable dips from 45° east to vertical to 60° west. Set III is a minor set although locally pronounced in the northwest and southwest quadrants. In the northwest quadrant, the average strike and dip are 005° and 80° east. In the southwest, the strike and dip are generally 345° and 80° east (Table 5.2). Where present, the Set III joints range in spacing from less than 1 inch in fracture zones to 5 feet, with an average of 1 to 2 feet. These joints are generally planar to irregular and smooth to rough. Minor carbonate was found at some outcrops in the southwest quadrant.

Moderately to steeply east-dipping Set III joints are likely to be encountered in tunnels near the proposed dam centerline and in the downstream portal area.

Fracture and shear zones parallel to Set III were mapped in structural areas GF 6 and in the "Fingerbuster" (Figure 5.2). At GF 6 above the downstream cofferdam, Set III forms numerous open joints on the cliff face.

Joint Set IV consists of numerous low angle (dipping less than 40°) joints of various orientations, the strongest trend being 090° (Table 5.2). In all quadrants, these joints dip both towards and away from the Susitna River. Set IV joints are planar to irregular, smooth to rough, and discontinuous. Spacing is generally 1 to 2 feet when present. No mineralization or alteration zones are associated with this set. Shear and fracture zones parallel to this set were found in "The Fins" area. These appeared to be due to slumping. Set IV joints probably resulted from stress relief after glacial nloading and/or erosion of the river valley, and therefore should not occur at depth.

In the "Fingerbuster" area (GF 7), the intersection of open joints of Sets I, III, and IV have resulted in large areas of loose, unstable rock, particularly in the proposed location of the main spillway cuts.

At WJ-2 and WJ-4, a strong local joint set striking approximately 335° with a 30° to 70° dip to the southwest was mapped. Minor shears parallel to this set were found near WJ-4. This set may be encountered in tunnels downstream from the centerline.

In summary, shears, fracture zones, and alteration zones at the Watana site tend to parallel Set I and III joints.

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Discontinuous fracture zones were found to parallel Set II joints. No major structures were found associated with Sets II or IV.

The Susitna River appears to be joint-controlled at the Watana damsite. In the upstream area, the river parallels Set II. In the dam centerline area, it is controlled by both Set I and Set II, while downstream from the centerline the river is controlled by shear and fracture zones related to Set I joints.

(iii) Shears, Fracture Zones, and Alteration Zones

This section defines and discusses shears, fracture zones, and alteration zones and combinations of these features which are the shear/fracture zones and shear/alteration zones mapped at the Watana site. Symbols denoting these features on the geologic sections (Figures 5.3 through 5.7) are: shears (S), fracture zones (F), alteration zones (A), shear/alteration zones (S, A), and shear/fracture zones (S, F). For the most part, these features are less than 10 feet wide. Where more than 10 feet wide, both boundaries have been delineated on the geologic map (Figure 5.2) and geologic sections. The individual characteristics of shears, fracture zones, and alteration zones are described below, while Subsection (iv) discusses the specific areas in which these structures occur.

- Shears

Shears are defined as a surface or zone of rock fracture along which there has been measurable displacement or is characterized by breccia, gouge, and/or slickensides indicating relative movement.

Three types of shears are found at the Watana site. The first type, which is found only in the diorite, is called healed shear and/or healed breccia. This type of shear consists of a diorite breccia healed within a matrix of aphanitic to fine grained andesite/diorite. The diorite fragments range from less than 5 percent to 90 percent of the zone and are generally subrounded. The matrix and rock fragments, which are observed in both outcrop and core borings, are fresh and hard to very hard. A photograph of a 1 to 2 foot wide healed sheared zone is shown in the 1980-81 Geotechnical Report[1]. The contacts, although irregular, are tight and unfractured. In outcrops, healed shears and breccia range from less than 1 inch to about 1.5 feet. Up to one foot offsets of these features have been observed where they cross felsic dikes. Two general orientations were found for this type of shear: 305° dipping 45° to 70° northeast, and 300° dipping 65° southwest.

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Healed shears and breccias were found in virtually all boreholes. In all cases, the zone was found to be competent with high RQDs and high core recoveries. The largest healed shear was up to 140 feet thick in COE DH-11. No correlation could be made between the healed shears and breccias noted in the cores and the surface exposures. Therefore, these features were not delineated on the site geologic map. These features are interpreted to be emplacement type shears which formed during the last phases of plutonic activity when the magma was in a semi-solid state.

The second type of shear found at the site is common to all rock types and consists of unhealed breccia and/or gouge. The breccia consists of coarse to fine sand-size rock fragments in a silt or clay matrix. Gouge is generally silt or clay material. Both the breccia and gouge are soft and friable. Thicknesses of these shears vary from less than 0.1 inch up to 10 feet, but are generally less than 1 foot. Carbonate and chlorite mineralization are commonly associated with these shears. Some shears are partially to completely filled with carbonate. Slickensides are found in many shears and occur on both the carbonate and chlorite surfaces. The shears are most often associated with fracture and alteration zones. When found in association with these zones, they have been referred to as shear/fracture and shear/alteration zones. A photograph of a typical shear within a fracture zone is shown on Figure 5.9. These zones will be discussed in more detail in the Fracture Zone and Alteration Zone subsections.

The third type of shear, unlike the two former types, may not be tectonic in origin but may be due to slumping of large blocks. These features are found in "The Fins" area and are discussed in Section 5.2 (c).

- Fracture Zones

Fracture zones are areas of very closely to closely spaced (less than 1 foot) jointed rock where no apparent relative movement has occurred. Fracture zones are common to all rock types and are found in both outcrop and boreholes. Fracture zones in outcrop were found to range from 6 inches up to 30 feet in width but are generally less than 10 feet wide. In the boreholes, fracture zones were found to range from less than 1 foot up to more than 100 feet wide as measured in BH-2. However, for the most part in boreholes and outcrop, the fracture zones are less than 5 feet wide.

Where exposed, they are easily eroded and form topographic lows or gullies, which have become filled with talus. The fracture surfaces are generally iron oxide stained. A coating of white carbonate is also commonly found on the fracture surfaces.

- Alteration Zones

Alteration zones are areas where hydrothermal solutions have caused the chemical breakdown of the feldspars and mafic minerals. The common products of alteration are kaolinitic clay from feldspar, and chlorite from mafic minerals. These zones are found in both the diorite and andesite porphyry, but appear to be less common in the andesite porphyry.

Most of the information regarding alteration zones is from the boreholes. Alteration zones are rarely seen in outcrop because, like the fracture zones, they are relatively easily eroded and tend to form gullies which subsequently become filled with talus. Alteration zones are exposed on the surface on the north bank in "The Fins" and in one outcrop at river level near the dam centerline. The degree of alteration is highly variable ranging from slight, where the feldspars show discoloration, to complete where the feldspars and mafics are completely altered to clay and chlorite. In slightly altered diorite, the rock is bleached to a yellowish green or gray and is generally hard to moderately hard as seen in BH-3 from 933.2 to 948.9 feet (Appendix B, Reference 1). The slightly altered zones have approximately 10 to 25 percent of the feldspars stained or altered to clay. In completely altered diorite, the rock is bleached to whitish gray or very light yellowish gray. The rock fabric is preserved; however, the material is soft and friable. These completely altered zones are uncommon, and when encountered, are generally 1 to 2 feet wide. Most alteration zones found in the boreholes are slightly to moderately altered. These zones are moderately hard with some thin soft zones. A photograph of an alteration zone within "The Fins" is shown on Figure 5.10.

Widths of these alteration zones range up to 10 feet but are generally under 5 feet. An exception is in BH-12 on the south bank which drilled over 300 feet into an alteration zone GF 8 (Figure 5.4). Several shear/alteration zones are exposed in "The Fins" and range up to 10 feet wide.

The carbonate, which is also associated with the alteration zones, occurs as veins or joint filling generally up to 0.5 inch thick. Occasionally, sulphide mineralization and iron oxide staining are also found in these zones.

No increase in joint frequency is evident in association with these alteration zones. Numerous thin (less than2 inches) shears are associated with the alteration zones

(Appendix B, Reference 1). RQDs are generally low, because only fresh to slightly altered rock is considered in taking RQD measurements. Core recovery is generally more than 90 percent within the alteration zones. The transition from fresh to altered rock is gradational, generally occurring over less than 1 foot.

(iv) Significant Geologic Features

The Watana damsite has been divided into several broad areas of significant geologic features which consist of shears, fracture zones, alteration zones, and/or combinations of these features. Two of these areas, initially mapped by the COE (27) are called "The Fins" and "Fingerbuster" (Figure 5.2). Areas or individual structures considered to warrant detailed discussion have been identified on Figure 5.2 by letters GF 1 through GF 8 and are discussed individually below. Seismic line data from this investigation is found in Appendix C. Borehole and seismic data from the 1980-81 investigation are in the 1980-81 Geotechnical Report(1).

- Geologic Feature GF 1 - "The Fins"

Geologic Feature GF 1 is discussed in Section 5.2 - Upstream Cofferdam and Diversion Portals Location.

- Geologic Feature GF 2

GF 2 (Figure 5.2) is approximately 70 to 100 feet wide and consists of northwest-southeast trending fracture zones with minor shears. On the south bank, GF 2 is coincident with a deep, talus-filled gully. Outcrops on either side of the gully are very closely jointed (Set I). Dips are vertical or steeply dipping to the northeast.

On the north bank, GF 2 lies in a deep gully which extends to about Elevation 1850 and probably under an adjacent talus-filled gully to the west. Set I joints form the walls of the gully and are very close to closely spaced and often open. No bedrock was exposed on the gully floor. No sign of hydrothermal alteration was found on the outcrops.

Below Elevation 2200, seismic lines SL81-15X and SL82-5, SL82-10, SL82-11, and SL82-13 (Figure 3.1) indicate low seismic velocity bedrock, 9,000 to 13,000 fps, often overlying a high seismic bedrock velocity, 20,000 to 22,000 fps. The 9,000 fps bedrock along line SL82-10 is up to 300 feet thick. On seismic lines SW-3 and SL82-5, higher bedrock seismic velocities, 17,400 to 18,500 fps, were found over the projection of GF 2, which indicates the feature may be discontinuous to the northwest.

GF 2 is likely to be encountered in the excavation for the intake approach channel, the power intake, and the diversion tunnels (Figures 5.4 and 5.6).

- Geologic Feature GF 3

GF 3 is an area approximately 1,200 to 1,500 feet wide on both the north and south banks and is bounded by geologic features GF 2 and GF 4 (Figure 5.2). The area is characterized by minor shears and fracture zones generally less than 6 feet wide. Outcrop exposure is excellent on the south bank, and although limited on the north bank, a good cross section is exposed (Figure 5.1). Figure 5.2 shows the location of the shears and fracture zones mapped. Most structures trend northwestward with high-angle northeast to vertical dips. Other structures strike northeast and north, parallel to joint Sets II and III.

A 20-foot-wide fracture zone was mapped in a deep gully on the south bank. This is probably continuous beneath the river and aligns with a similar structure on the north bank. This fracture zone probably continues northwestward parallel to GF 2 through the same low seismic velocity zones. A 30-foot-wide bedrock low on SL82-5 lies along the trend of the feature.

A 2.5-foot-wide vertical shear on the south bank was tentatively correlated with a deep, narrow gully along its trend on the north bank. No other structures could be correlated across the river.

On the north bank, a broad talus slope below Elevation 1650 is approximately 400 feet wide and may be the result of intersecting northeast and northwest trending structures in this area.

Seismic line SL82-12, which crosses GF 3 on the south bank at about Elevation 2050, indicates moderately fractured to fresh bedrock across the feature. On the north bank, conditions are similar except at approximately Elevation 1650 where SL82-11 shows highly fractured bedrock (9,000 to 11,200 fps) to depths up to 180 feet, but generally 60 feet, overlying high seismic velocity bed rock (20,000 fps).

The relation of this feature with civil structures, such as the diversion tunnel, power intake structure, penstocks, and powerhouse will require further investigation in the design phase.

- Geologic Feature GF 4

GF 4 consists of two shear/fracture zones (GF 4A and GF 4B), each about 10 feet wide (Figure 5.2). The overall trend of these zones is 315° with a dip of 70° to the east. On the south bank, GF 4A and GF 4B were mapped in a very deep, talus-filled gully. Outcrops in the gullies have very closely to closely spaced joints along joint Sets I, II and III. All joints are heavily carbonate coated. Where mapped, GF 4A was found moderately weathered with possible alteration. Seismic velocities in this area (SL80-3) are lower (15,000 fps) than the usual 18,000 to 20,000 fps velocities measured in less fractured diorite. A bedrock low is noted on SL82-12 where GF 4 projects across.

GF 4A and GF 4B have been projected across the river to correlate with two fracture zones mapped between Elevations 1650 and 1750. These fracture zones are also in a deep gully. GF 4A has been tentatively correlated with the shears, fracture zones, and alteration zones found in borehole BH-3 (Figure 5.3) between borehole depths 414.4 and 622.4 feet. These zones are slightly to moderately altered and generally moderately hard, though locally soft and friable in the shears. RQDs between borehole depths 474 and 530 feet are 0 percent because of the moderate alteration. Throughout the rest of the zone, RQDs are 90 to 100 percent with permeabilities generally 10^{-5} cm/sec. Many of the joints are healed by carbonate. The correlation of the zones in BH-3 with GF 4A has been based on the assumption that the zones are trending northwestward. This assumption is supported by the fact that this fracture zone would have been intersected in either BH-4 or DH-11 if it had had an east-west or a north-south strike.

GF 4B has been correlated with a shear/fracture zone and alteration zone in DH-11 (Figure 5.3) at borehole depth 189.0 to 197.7 feet. The fracture zone is iron oxide stained. The upper three feet of the zone are hydrothermally altered and contain 0.2 feet of clay gouge and breccia. Permeabilities in this zone are high, typically ranging between 10^{-2} cm/sec to 10^{-3} cm/sec. Most joints are coated with sandy silt/clay and minor carbonate.

The GF 4 structure was correlated with lower seismic velocity zones on SL82-5 and SL82-9 on the north bank. On SL82-9, the structure corresponds to a bedrock seismic

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velocity change from 20,000 to 16,500 fps and a small bedrock surface depression. On SL82-5, GF 4A and 4B occur within an area of moderately low seismic velocity (13,400 fps); however, at GF 4B, there is approximately 110 feet of highly fractured, low velocity (9,000 fps) bedrock overlying the higher velocity bedrock. On SL82-14, which is 400-500 feet northwest of and subparallel to SL82-5, there is no strong evidence for GF 4A. GF 4B correlates with a change in slope of the bedrock surface.

The projection of the GF 4A and GF 4B structures would intersect the proposed diversion tunnels (Figure 5.2) at a high angle and would intersect the west end of the powerhouse (Figure 5.3).

- Geologic Feature GF 5

GF 5 is located near the proposed dam centerline and consists of fracture zones and minor shears (Figures 5.2 and 5.4). The area is approximately 60 to 70 feet wide and trends northwest-southeast (310 to 320°). The dip is steep to the northeast. GF 5 on the north bank of the river falls within a deep gully bound on the downstream side by a 75-foot-high diorite cliff. Two northwest trending fracture zones in the gully are as much as 10 feet wide and dip at 75° and 80° to the northeast and southwest, respectively. Although there is little topographic expression of these features higher on the abutment, it has been correlated with several shear and fracture zones intersected in borehole DH-9 (Figure 5.3), and interpreted on SL82-5, SL82-9, and SL82-14. The joints and fractures in DH-9 are generally iron oxide-stained and carbonate-coated. Faint slickensides are observed on some surfaces. The RQDs in DH-9 are low, with an average of 57 percent. Permeabilities are generally between 10^{-1} cm/sec and 10^{-3} cm/sec and decrease with depth. On SW-2, SL82-5, SL82-9, and SL82-14, GF 5 correlates with sharp drops in the bedrock surface and with low seismic velocity bedrock (7,500 to 14,500 fps). On SL82-5, approximately 80 feet of highly fractured bedrock (7,500 fps) overlie 13,400 fps bedrock. No low velocity zones were encountered along SL80-2.

On the south bank, the GF 5 structure is correlated to a 10-foot-wide fracture zone at river level and a series of minor northwest-trending shears between Elevation 1650 and 1850. Farther up the slope, it is correlated with a moderately low (14,000 to 15,000 fps) seismic velocity zone along SL82-12 and SL80-3, and a bedrock depression found in borehole DH-25 and on SL82-12 (Figure 5.7). In this area, overburden thickens from 10 or 15 feet to nearly 80 feet.

On the north bank, GF 5 may likely intersect the diversion and tailrace tunnels, and the excavations for the main spillway.

- Geologic Feature GF 6

GF 6 is characterized by north-south trending shears, fracture zones, and open joints; east-west trending open joints; and northwest trending shears (Figures 5.2 and 5.5). These features are exposed in deep gullies in the high rock cliff face on the south side of the river (Figure 5.11). The north-south shears have up to 2.5 feet of gouge. Open joints along this trend generally dip at about 80° to the east and are up to several feet wide. East-west trending joints dip 70° to 80° north towards the river. The intersection of these joint sets has resulted in block slumping. Details of northwest trending shears in GF 6 are discussed in Section 5.3 (c). It is likely that north-south shears and fracture zones in GF 6 correlate with those in GF 7.

GF 6 lies above the downstream cofferdam. Slumping of blocks in GF 6 may affect the integrity of this abutment.

- Geologic Feature GF 7 - "Fingerbuster"

Geologic Feature GF 7 is discussed in Section 5.5 - Downstream Cofferdam and Portal Locations.

- Geologic Feature GF 8

GF 8 is a wide (approximately 400 feet) northwest trending structure on the south bank of the river which consists primarily of alteration zones but also includes shear and fracture zones (Figure 5.2). This area was delineated during the 1981 field season during the investigation for a possible underground powerhouse location on the south bank.

As a result of the scarcity of bedrock exposure in this area, all geologic interpretation has been based on seismic refraction surveys and drilling. In 1981, an 1,800-foot seismic line (SL81-21) was shot along a northeast-southwest trend across the south bank (Figure 3.1). A zone about 1,100 feet long of low seismic velocity in bedrock was found. Velocities were about 12,000 fps in this zone and 18,000 fps in the adjacent zones on each side. Poor quality rock was confirmed by BH-12 which was drilled to the southeast to intersect this structure

(Figure 5.4). At about Elevation 1700, the boring encountered a nearly continuous zone of altered diorite with minor shears. Alteration is generally slight but includes zones of moderate to severe alteration. Shears are less than 6 inches wide. Joints are generally closely spaced and healed with carbonate. Chlorite is found on some joint surfaces.

The trend and dip of this structure was based on correlation between SL81-21, SW-1, BH-12, and DH-28. DH-28 was drilled vertically to a depth of 125.2 feet in andesite porphyry. The rock in the boring is slightly to moderately altered and moderately hard. Joints are very closely to closely spaced and iron oxide stained throughout. RQDs are generally less than 50 percent and often 0 percent. It is postulated that DH-28 was drilled in a shear/fracture zone related to the GF 8 structure (Figure 5.7). East of DH-28, SW-1 shows zones of alternating high (17,500 to 20,000 fps) and low (12,000 to 13,000 fps) seismic velocity bedrock. No evidence of shearing or alteration was found in BH-8, DH-12, DH-23, or DH-24, or in any outcrops on the south bank (Figure 5.4). This observation served to limit the northward extent of GF 8. In defining the trend of GF 8, it was assumed that this structure would follow the major northwest-southeast structural trend found at the site. The southwest limit of GF 8 was based on the change from low to high bedrock velocity on SL81-21. The southwest contact was assumed to be parallel to the northeast limit. The dip of the structure, based on the seismic line and information from BH-12, is assumed to be about 70° to the southwest (Figure 5.4).

5.2 - Upstream Cofferdam and Diversion Portals Location

(a) Overburden and Ground Water

(i) Introduction

This section discusses the overburden or surficial deposits in the vicinity of the upstream diversion portal and upstream cofferdam location. The extent and type of bedrock and surficial deposits in the upstream diversion area are shown on a geologic map and sections (Figures 5.12 and 5.13). Material types in this area, which consist of talus and alluvium, have been investigated by geologic mapping and seismic refraction surveys (Figure 3.1) and are discussed below.

(ii) Alluvium

The extent of alluvium in the upstream portal and cofferdam area is shown in Figures 5.12 and 5.13. The alluvium occurs primarily at or below river level, however, pockets or thin layers are found above river level. On the north bank, a thin pocket of mixed alluvium and talus was mapped near the proposed diversion tunnel number 1 portal. On the south bank, a layer of alluvial material covers a saddle (possibly an old Susitna River channel) between two bedrock highs.

Alluvium in this area has been divided into two types. Type 1 alluvium occurs at or below the level of the Susitna River and Type 2, which principally occurs on the south bank above river level. Type 1 material is exposed during low flows on a gravel bar on the south bank. The surface of this bar consists of a boulder pavement. However, shallow pits dug in this area show the material to be a sandy gravel, well graded with fine gravel to boulders up to 4 feet in diameter. Grain size, however, is generally limited from 6 to 12 inches. Cobbles are subrounded to rounded. The sand and silt matrix between the gravel fragments make up from 5 to 15 percent of the gravel bar. Cobbles greater than 4 inches are mostly medium grained granitic rocks, while those less than 4 inches are primarily fine grained volcanic, metamorphic and sedimentary rocks. More than 95 percent of the rock fragments are fresh and hard with the remainder being weathered and friable.

Downstream of the proposed cofferdam centerline, the surficial alluvium appears to be finer grained with an increase in the amount of sand. Average gravel size is 2 to 6 inches with 15 to 25 percent coarse to fine sand. Layers and/or lenses of sand up to 1.5 feet thick are found in this area. The sand is uniformly graded and fine grained. Some of this sand appears to be derived from Type 2 alluvium which occurs on the south bank above river level.

Type 2 alluvium is exposed at the river edge and in scattered outcrops further upslope. Upstream of the cofferdam centerline, Type 2 alluvium is primarily well graded, sandy gravel with fragments ranging up to 2 feet but generally from 4 to 6 inches. Approximately 10 to 20 percent of the material is sand. Most fragments are iron oxide stained. About 5 to 10 percent of the fragments, primarily the metamorphic rocks, are severely weathered. Downstream of the cofferdam centerline, the material is exposed at river level where it is washing out beneath the tundra mat and at about Elevation 1500 where it is exposed near two ground water springs and in a seismic line shot hole. In these areas, the materials are disturbed so that the exact lithology is uncertain. At river level, the material is primarily sand with scattered boulders to 4 feet. At the shot hole for SL81-5, 2 feet of talus overlies a yellowish brown sandy gravel alluvium. Fragments range up to 3 inches but are generally 1 inch. Coarse to fine sand comprises 20 to 30 percent of the alluvium. The remaining 5 to 10 percent of the material is non-plastic fines.

The alluvial thicknesses in the upstream diversion area has been estimated from seismic refraction surveys (seismic lines SL81-4, SL81-5, and SL82-15, Figure 3.1). Several interpretations of this seismic data can be made thereby affecting the determination of river alluvium thickness in this area (Appendix J, Reference 1). Different interpretations of the material with velocities in the range of 12,000 to 14,000 fps can be made. These velocities could reflect either fractured/weathered bedrock, or dense/frozen alluvium. River morphology does not readily support the weathered/fractured rock interpretation. Therefore, the latter interpretation has been used in the current interpretation as shown on geologic section UP-3. However, further confirmation of this will be required.

Using this interpretation, alluvium thicknesses beneath the upstream cofferdam area would be a maximum of 90 to 100 feet. To the west side of the river, alluvium is assumed to terminate abruptly against near-vertical bedrock. On the east side of the river, the alluvium thins gradually to 20 feet at river edge and then thins abruptly upslope to about 5 feet on seismic line SL82-15. Above river level on the south bank, alluvial velocities decrease from 5,000 to 2,000 fps, indicating they are unsaturated above river level.

The contact between the alluvium and talus is shown on Figure 5.12. The contact is approximate and is based on: (a) the lowest extent of continuous talus material; and (b) the associated break in the slope which generally occurs between the talus and alluvium. This contact is nearly coincident with the toe planned of the upstream cofferdam.

(iii) Talus

The extent of talus in the portal and cofferdam area is shown on Figures 5.12 and 5.13. Talus occurs on the slopes above the portal locations along the north bank and also on the south bank downstream of the upstream cofferdam location. Talus consists of angular to subangular blocks of diorite with some diorite porphyry. On the north bank, talus ranges from sand-size grains to blocks up to 10 feet in diameter. Average size varies across the area but is generally 1-2 feet. The largest blocks are found at the base of the wide sinuous gully above the proposed diversion tunnel number 2 portal.

On the south bank, downstream of the toe of the cofferdam, talus ranges up to 5 feet in diameter at river level but is generally 6 to 8 inches. Slumps in the talus occur above Elevation 1500 on the south bank (Figure 5.12) where a slump scarp is exposed for approximately 100 feet extending in an approximate east-west direction. The height of the feature is 20 to 30 feet. The toe of the slump corresponds with the talus/alluvium contact and so would partially underlie the downstream toe of the cofferdam. The talus in this area ranges up to 3 feet but generally is from 1 to 2 feet in size.

Talus areas have been divided into two types. Talus 1 is primarily well exposed areas, less than 50 percent vegetated, where the talus is actively or semi-actively moving downslope. These areas are mainly within the gullies in "The Fins," particularly in the area of the diversion tunnel number 2 portal. Talus 2 is densely vegetated areas of inactive talus and more stable slopes. Talus 2 occurs: (a) on the south bank downstream of the cofferdam location; and (b) on the north bank on ridges within "The Fins" above the main area of bedrock outcrops; and (c) along the diversion tunnel route and downstream of the cofferdam location (Figure 5.12).

Thickness of the talus deposits are not known with any certainty, but they would be expected to be variable throughout the area. On the south bank, seismic line SL82-15 (Appendix C) indicates from 5 to 35 feet of 2,000 fps material in a Talus 2 area. Talus thickness at the location of the upstream cofferdam is likely to be about 5 feet.

On the north bank, Talus 1 deposits are generally less than 5 feet thick. An exception to this would be in the talus cones formed at the base of the gullies at river level, particularly in the diversion tunnel number 2 portal area where talus accumulations may be from 10 to 20 feet thick. The extent of Talus 1 below river level is not known, but due to its generally large size and blocky nature, it may be prevalent. Talus in the diversion tunnel number 1 portal area is negligible.

Thickness of Talus 2 deposits on the north bank is also unknown, but based on steepness of the slopes and bedrock outcrop, thickness is estimated to be less than 10 feet.

(iv) Ground Water

Ground water conditions in the upstream diversion area are poorly defined, being based only from mapping observations. However, it is expected that ground water conditions are as described in the 1980-81 Geotechnical Report[1].

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On the north bank, ground water is principally confined to fractures and joints within the bedrock. Ground water seeps were observed at two locations in the diversion area. The greatest flow was observed in the 30-foot-wide gully at the northwest corner of the geologic map (Figure 5.12). Flow was estimated at 10 gallons per minute (gpm) in August, 1982.

A second seep (Figure 5.12), occurs adjacent to a shear zone (geologic feature GF 1G) at about Elevation 1650. Water flow was estimated to be less than 1 gpm.

On the south bank, ground water seeps were found in alluvium in the area of the proposed cofferdam. Two springs at about Elevation 1500 were flowing at about 1 gpm. At the break in slope from the river bank to the gravel bar, two other seeps were observed with ground water flow of about 5 gpm. The seeps on the south abutment may be the result of a perched water table on permafrost.

(b) Bedrock Lithology

The bedrock lithology in the upstream diversion area is primarily diorite to quartz diorite which has been intruded by felsic and mafic dikes. A detailed description of these rock types is in Section 5.1. The extent of these rock types is shown on Figures 5.12 and 5.13.

Bedrock in this area is generally fresh to slightly weathered and very hard to hard. Zones of hydrothermally altered diorite are found upstream of the portal location and are discussed in the following section.

(c) Bedrock Structure

(i) Introduction

This section discusses the structural geology of the upstream cofferdam and diversion portal area of the Watana damsite and how it relates to these proposed structures. This section is presented in two subsections: joints and significant geologic features. Significant geologic features include shears, fracture zones, and alteration zones as defined in Section 5.1 (c).

(ii) Joints

Three of the four joint sets mapped at the site and described in Section 5.1 (c) are found in the upstream and portal area. A plot of the joints in this area are shown on Figure 5.12. Table 5.3 lists the joint characteristics of this area.

Joint Set I, as throughout the damsite, is the most prominent set. Set I joints in this portal area are primarily part of the Ia subset which trends from 285° to 345° and averages 325°. Dips vary from 60° northeast to 30° southwest but are mostly near-vertical to vertical. Joint spacing is variable from less than 1 inch in shear and fracture zones to greater than 5 feet. Average spacing is 1 to 2 feet. Exposures in the deep gullies cross cutting this area show evidence of rapidly increasing joint spacing with depth. Joint surfaces are planar and smooth to slightly rough. Set I joints are parallel to the major shear, fracture, and alteration zones which occur in "The Fins."

Set II joints are generally as prominent as Set I joints in this area. The Set II joints strike northeastward averaging 042° with predominantly near-vertical dips to the northwest. Joint spacing is similar to Set I, generally 1 to 2 feet, and like Set I, increase with depth. Joint surfaces are planar to slightly curved and smooth to slightly rough. Many Set II joints are open with related slumping. Discontinuous fracture zones were found which parallel Set II joints. These are discussed below.

Set III joints are not observed in the upstream portal area.

Set IV joints are low-angle joints with variable orientations. The strongest trend is northeast at 045°. Dips are generally from 10° northwest to 10° southeast. Set IV joints are discontinuous and generally occur only in the upper 30 to 40 feet of rock. These joints are not found in the deeper parts of the gullies which crosscut the upstream portal area. Shears labelled GF 1N on Figure 5.12 are parallel to subparallel to the Set IV joints. These features generally strike from northwest to north and dip eastward toward the Susitna River from 11° to 42°. These features appear to be older bedrock slumps partially healed with carbonate, and are only found above Elevation 1675.

In summary, major shears and alteration zones are parallel to the northwest trending Set I joints. Discontinuous fracture zones are parallel to Set II joints. Spacing of Sets I and II joints increase with depth. Set IV joints are primarily near surface features.

(iii) Significant Geologic Features

The upstream diversion area is located in proximity to the geologic feature referred to as "The Fins"[(27)]. "The Fins" is a series of deep gullies separated by intact rock bands or ribs from 5 to 50 feet wide. For the purpose of this report, "The Fins" has been designated as geologic feature GF 1 to conform to the system of designating significant geologic features (Section 5.1).

"The Fins" (GF 1) is located approximately 2200 feet upstream of the main dam centerline in the area of the proposed upstream cofferdam and diversion portals. The geologic map and sections of the damsite (Figures 5.2, 5.4, and 5.6) shows the relation of this feature to civil arrangements and other geologic features. A more detailed map and sections of "The Fins" structure are shown on Figures 5.12 and 5.13. Two photographs of "The Fins" are included as Figures 5.14 and 5.15. Shears, fracture zones, and alteration zones within "The Fins" have been designated GF 1A through GF 1P for discussion purposes.

Based on more detailed mapping in 1982, a significant reinterpretation of "The Fins" structure has been made. Reconnaissance mapping in 1980 and 1981 indicated the presence of numerous shear fracture zones and alteration zones within this area(1). It was assumed at that time that the deep gullies (Figure 5.14 and 5.15) within "The Fins" were underlain by the major discontinuities. In 1982, these geologic features were mapped in greater detail. This mapping shows that most structural discontinuties crosscut the gullies rather than lie within them.

"The Fins" is an area of major shears, fracture zones, and alteration zones of various orientations. The strongest trend of these discontinuities is northwest-southeast, parallel to Set I, and northeast-southwest parallel to Set II. Minor shears were found trending at various orientations.

- <u>Northwest Trending Structures</u>

  Northwest trending structures consist of shears, fracture zones and alteration zones. These features strike from 310° to 345° and generally have high-angle to vertical dips. Three major shear/alteration zones (GF 1B, 1C and 1E) were mapped upstream of the location for the diversion tunnel number 2 portal. These zones consist of hydrothermally altered diorite from 5 to 10 feet wide. The rock in these zones is yellowish orange, severely altered and medium hard to soft and friable. Very close to close spaced shears are found parallel to the alteration zone. Shears range from less than 1 inch up to 1 foot. Gouge is generally a slightly to moderately plastic sandy clay. Blocks of less altered and unsheared diorite are often found within the alteration zones.

Carbonate veins ranging from 0.5 to 8 inches occur within the alteration zones. These veins both parallel and cross cut the zones. Carbonate veins are fractured, but no offsets were noted. Figure 5.10 is a photograph of GF 1C near river level, showing a carbonate vein within an alteration zone. Above this outcrop at about Elevation 1550, a 4 inch wide light gray, fine to medium grained felsic dike cross cuts the alteration zone. The dike is fresh to slightly weathered and very closely fractured. The dike is truncated by a 2- to 3-inch-wide shear. Of these three alteration zones, only GF 1C is likely to be encountered in a portal excavation (Figure 5.13).

The area of the diversion portal excavations is characterized by a series of parallel to subparallel shears and fracture zones (GF 1F to 1J, and GF 1L). These structures generally trend from 325° to 340° which is subparallel to the strike of the alteration zones. Dips vary within the same zone, but are usually greater than 80°. Widths of these zones range from 1 to 10 feet and are also variable within the same zones as seen with GF 1G and GF 1I. GF 1G increases in width with depth from 1 to 2 feet at Elevation 1700 to 6 feet at the diversion tunnel number 1 portal area at Elevation 1500. Conversely, GF 1I decreases in width with depth, varying from about 5 feet where it crosses above the diversion tunnel routes, to 1.5 feet at river level in the cofferdam area. It should be anticipated that other shear and fracture zones may vary in width laterally and vertically. Shears such as GF 1G, GF 1I and GF 1J are primarily zones of very closely spaced joints which include thinner zones (less than 1 foot) of breccia and gouge. The shear planes generally form the boundary of the zone.

GF 1L, which consists of two parallel fracture zones, 10 feet and 1.5 feet wide, is presently the major source of talus for the large sinuous gully that it crosses at about Elevation 1800. Talus is derived from the area of intersection of GF 1L and GF 1J. This area is highly fractured with many open joints and loose rock. GF 1L forms a topographic low which cross cuts the main gullies at a high angle. This feature aligns with a deep gully and fracture zone on the south bank. This feature as well as those mentioned above, are expected to be encountered in the tunnels. They intersect the tunnel alignment favorably at an acute angle. These structures also pass beneath the cofferdam location.

- Northeast Trending Structures

Northeast trending structures in the upstream portal area were mapped to the southwest of the proposed excavation area. These four features (GF 1M) are fracture zones less than 6 feet wide with dips ranging from 62° southeast to vertical. These features tend to form gullies and/or bedrock faces parallel to the trend of the valley. GF 1M structures were mapped only in the southwest portion of the map area (Figure 5.12). Although bedrock is continuously exposed along the projected trend of these features, no trace of the GF 1M structures was found northeast of GF 1L so it is assumed that they are discontinuous. It is unlikely that these features would be encountered in the portal excavations, however, similar structures to the northwest may be encountered in the diversion tunnels.

- Miscellaneous Structures

In addition to the northeast and northwest trending structures discussed above, there are numerous minor shears mapped in "The Fins" area. Two north-south trending shears, GF 1F were mapped upstream of the diversion portal area. The shears are 1 and 3 feet wide and dip west at approximately 60°. Slickensides on a carbonate coating indicate an oblique sense of movement. No shears of this orientation were found in the diversion portal area.

A series of low angle shears (GF 1N, Figures 5.12 and 5.13) were mapped primarily in an area above Elevation 1675 along the proposed diversion tunnel alignment. These features strike northeast and northwest, and dip from 11° to 42° southeast and northeast, respectively. Dips are toward the river. These structures consist primarily of highly fractured rock from less than 1 foot to 6 feet in width. The structural planes are generally curved to irregular in shape. Unlike most fracture zones, the fractured rock in the GF 1N structures is tight, hard, and partially healed with carbonate cement. A shear at Elevation 1800, which dips at 42° east, has offset a felsic dike by 16 inches. There is no gouge or breccia associated with this shear. However, there is a 3 foot fracture zone on either side of the shear plane. The amount of offset could not be determined on the remainder of the GF 1N shears; however, many joints are discontinuous across the structure, indicating movement. The exception to this are the Set I joints which crosscut the shears with no offset.

The continuity of the GF 1N shears is uncertain; none could be traced for more than about 10 to 30 feet due to talus and vegetative cover. None were mapped below Elevation 1675 feet or upstream of the diversion tunnel number 2 alignment. These features dip towards the portal cut (Secion UP-2, Figure 5.13) and although partially healed, may become unstable during excavation.

- Extent of "The Fins"

The overall trend of "The Fins" is 300° to 310°. The extension of this feature to the northwest is inferred from seismic refraction lines SL81-15, SL81-15X, and SW-3 which show low seismic velocities (10,000 to 12,700 fps) in bedrock as well as low bedrock elevation along the projection of "The Fins" (Figure 5.4). In contrast, the bedrock seismic velocity southwest of this feature is greater than 17,000 fps (Appendix C, Reference 1).

Beyond the seismic lines, "The Fins" has been inferred to trend along a topographic low (Figure 6.7). Altered rock found in COE boreholes DR-18, DR-19, and DR-20 in the Watana Relict Channel may also have drilled into this feature (Figure 3.2). The topographic low projects to Tsusena Creek, where, along the northwest bank, an altered and sheared outcrop of granodiorite is exposed. This outcrop exposure is approximately 325 feet wide, and is characterized by northwest, north-south, and east-west trending shears.

The continuation of "The Fins" to the southeast beyond the south bank of the Susitna River is uncertain. On the south bank across from "The Fins", there is a topographic low in Quarry Site L[1], as well as shears and fracture zones which align with the GF 1 structures. Seismic line SL82-15 (Figure 3.1), which crosses the trend of "The Fins", shows a bedrock depression and low velocity bedrock (7,700 fps) (Appendix C). This area is the inferred location of "The Fins." Beyond this area, no outcrops or topographic trends could be correlated to this feature.

5.3 - Downstream Cofferdam and Portals Location

(a) Overburden and Ground Water

(i) Introduction

This section discusses the overburden/surficial deposits in the vicinity of the proposed downstream diversion portals, tailrace portal, and spillway flip-bucket. The extent and type of bedrock and surficial deposits in this area are shown on a geologic map and sections (Figures 5.16 and 5.17). Sections are drawn through proposed locations for diversion tunnel number 2, tailrace tunnel, spillway flip-Bucket and along the centerline of the downstream cofferdam. This area has been investigated by geologic mapping, seismic refraction surveys, and borings. Borehole and seismic survey line locations are shown on Figure 3.1.

(ii) Alluvium

The extent of alluvium in this area is shown on Figures 5.16 and 5.17. Alluvium occurs beneath the river and also locally along the river banks. On the north bank, an alluvial terrace extends upstream from the diversion tunnel number 1 portal area to beyond the downstream cofferdam location. This terrace extends up to about Elevation 1485. Based on the extensive talus upslope from this terrace, it is likely that this alluvium overlies and/or is interbedded with talus material. Downstream from the terrace, minor amounts of alluvial material are mixed in with talus which extends to river level. On the south bank, alluvium occurs downstream of the bedrock cliffs (Figure 5.16).

Alluvium exposures on the north bank at the cofferdam location consist of a gravel to sandy gravel with subrounded to rounded coarser fragments, generally from 3 inches to 2 feet. The matrix is composed primarily of sand with lesser amounts of silt. The composition of fragments is primarily granitic rock with lesser amounts of volcanic and metasedimentary rocks. Three borings (DH-1, 2 and 3) drilled by the COE in the river approximately 400 feet upstream of the cofferdam location (Figure 3.1), encountered rounded gravel, cobbles, and boulders up to 3 feet in diameter. These materials are uncemented in a sand matrix. Rock fragments were fresh and hard, and consisted of granitic and metamorphic rocks. Boring DH-3 encountered a 15 foot layer of gravelly sand while localized traces of clay were found on some fragments in borings DH-2 and DH-3(27).

Alluvial thickness in the downstream cofferdam and portal location has been estimated from borings DH-1, 2 and 3, and seismic refraction lines SL82-4 (Appendix C) and DM-C (12) (Figure 3.1). In the vicinity of the downstream cofferdam (Section DP-4, Figure 5.17) alluvial thickness reaches a maximum of about 90 feet in a bedrock trough on the south side of the river. This area coincides with a shear and fracture zone (GF 7J) described in Section 5.2 (c). Alluvial thickness decreases towards the north side of the river, generally from 40 to 60 feet beneath the river. On the north bank, the alluvium which probably is interlayered with talus, is about 20 to 30 feet thick. Downstream from the cofferdam location in the spillway area, no alluvium is exposed on the north bank due to abundant talus and the presence of bedrock outcrops at the river edge, however, beneath the river channel, alluvial thickness is expected to be the same as in the cofferdam area.

(iii) Talus

The extent of talus in the downstream cofferdam and portal area is shown on the geologic map and sections (Figures 5.16 and 5.17). Talus occurs along the slopes of the north and south banks. alus consists of angular to subangular fragments of diorite and quartz diorite. Fragments range from sand-size up to about 5 feet, with most blocks from 1 to 3 feet.

Talus has been divided into two types. Talus 1 is areas of active to semi-active talus. These areas have thin vegetation with more than 50% of the talus exposed. Talus 2 is areas of inactive talus and more stable slopes where the vegetation is thick and generally less than 50% of the talus is exposed (Figure 5.16).

Talus 1 occurs on the north bank primarily in the area of extensive open joints and loose unstable rock as shown on Figure 5.16 and 5.18. Three gullies within this area are actively funneling talus material. The causes of the active talus are the numerous shears in this area (Section 5.3 [c]). An area of active and semi-active talus occurs further upstream between Elevation 1750 and 1575. The source of this talus is another area of open joints and loose, unstable rock resulting from intersecting shears and fracture zones. Minor amounts of Talus 1 occur on the south bank in gullies above the downstream cofferdam location. Talus 2 occurs throughout most of the downstream cofferdam and portal area.

Talus thickness has been defined based on the numerous seismic lines (SL82-3, SL82-4, SL82-6, SL82-7, and SL82-8) which were run in this area (Figure 3.1). Seismic velocities up to 3,500 fps were considered to be talus in the damsite area (Table 5.1). Based on this, talus thickness were found to range from 0 up to 35 feet. The thickest talus, generally 20 to 35 feet, was found along SL82-4 in the location of the tailrace and diversion tunnel number 2 outlet areas; along SL82-8 in the spillway flip-bucket area; and near the intersection of SL82-6 and SL82-3 above the two diversion tunnel routes.

(iv) Ground Water

The details of the ground water conditions in the downstream cofferdam and portal area are not well known. It is likely that ground water will be restricted to the fractures and joints within the bedrock and in the alluvium beneath the river. Ground water was only observed at one location in this area. This was a small spring on the north bank upstream of the cofferdam location at about

Elevation 1525. Flow was less than 10 gpm. A general description of overall damsite ground water regime is presented in Section 5.6.

(b) Bedrock Lithology

The bedrock lithology in the downstream cofferdam and portals location is primarily diorite and quartz diorite which have been intruded by felsic dikes. Andesite porphyry also occurs in a small portion of this area. A detailed description of these rock types and the nature of the andesite porphyry/diorite contact is discussed in Section 5.1. The extent of these rock types is shown on Figure 5.16.

Bedrock in this area is generally fresh to slightly weathered and very hard to hard. However, the area has numerous shears, fracture zones, and alteration zones that lower the bedrock quality. These structures are discussed in Section 5.3 (c).

(c) Bedrock Structure

(i) Introduction

This section discusses the structural geology of the downstream cofferdam and portals area of the Watana damsite and its relation to these proposed site facilities. This section is presented in two subsections: joints and significant geologic features. Significant geologic features include shears, fracture zones, and alteration zones as defined in Section 5.1 (c).

(ii) Joints

Joints in the downstream cofferdam and portals area were found to belong to all four joint sets found at the Watana damsite (Section 5.1 [c]). A plot of joints in the downstream cofferdam and portal area is shown on Figure 5.16. Table 5.4 lists the joint characteristics of this area.

Joint Set I is the second most prominent set in the area. Joints trend northwestward ranging from 285° to 305° and averaging 290°. Dips are variable from 45° northeast to 60° southwest but are generally 85° southwest. Set I joints in this area are part of the Ib subset and are subparallel to parallel to the major shears, fracture zones, and alteration zones. Joint spacing varies from 1 inch in fracture zones to 3 feet and is generally 1 to 2 feet. Joint surfaces are planar and smooth with carbonate coating locally. Set I joints often form the outcrop faces and are often open. Open Set I joints are found at GF 6 and in the area of the proposed spillway cuts (Figure 5.2).

Joint Set II is weakly developed in the downstream portal area, unlike the upstream portal area. This set strikes northwestward at 065° and is generally vertical. Joint spacing is usually 1 to 2 feet where the set is present. Surfaces are planar to slightly curved and smooth. No shears or alteration zones were found related to this set, however, minor fracture zones are parallel to it.

Set III joints are the most common joints in this area. Their range is highly variable, but the major trend is northward at 005° with high angle dips (80°) to the east. The joints are planar and smooth with a 1 to 2 foot spacing. Minor carbonate and hydrothermal alteration are found locally. Many of the Set III joints are open and form large areas of unstable rock where they occur with open Set I and Set IV joints as described above. Set III joints parallel shears, fracture zones, and alteration zones.

Set IV joints are low-angle with strikes from 055° to 110°, but average east at 090°. Dips are generally southward at 40°. These dips are towards the Susitna River, subparallel to parallel to the slopes of the gorge. This set is often discontinuous and where present, spaced at 2 to 3 feet. Surfaces are planar and smooth.

In summary, Sets I and III are the most prominent joints and are parallel to the major shears, fracture zones, and alteration zones. The occurrence of open joints of Sets I, III and IV result in unstable rock masses in the area of the spillway cuts and above the downstream cofferdam.

(iii) Significant Geologic Features

The downstream cofferdam and portal area is located within two geologic features: GF 6 and GF 7. These features are identified on the damsite geologic map (Figure 5.2) and the detailed map and sections of the downstream cofferdam and portals location (Figures 5.16 and 5.17). Geologic feature GF 7 was originally designated as the "Fingerbuster" by the COE in 1978; however, in order to conform to the system of designating significant geologic features begun in the 1980-81 Geotechnical Report (1) it has been designated GF 7. GF 7 and "Fingerbuster" are used interchangeably.

- Geologic Feature GF 6

Geologic feature GF 6 is located on the south bank of the river in the vicinity of the downstream cofferdam. This feature is an area of extensive open joints and also includes minor shears and fracture zones. The loose blocks associated with this structure may affect the integrity of the south abutment of the downstream cofferdam. This feature is described in detail in Section 5.1(c).

- Geologic Features GF 7-"Fingerbuster"

The "Fingerbuster" is primarily located downstream of the main dam centerline. The feature consists of shears, fracture zones and alteration zones which have been designated GF 7A through GF 7R. The relation of these geologic features to the civil arrangements are shown on Figures 5.16 and 5.17. Photographs of various features in the "Fingerbuster" area are shown on Figures 5.18, 5.19 and 5.20.

Based on the detailed mapping in 1982, a more refined interpretation of the "Fingerbuster" has been developed over that presented in the 1980-81 Geotechnical Report. Reconnaissance mapping by the COE in 1978 (27) and Acres in 1980-81 (1) showed the presence of shear, fracture zones and alteration zones within this area. However, the extent of these features could not be determined. In 1982 these geologic features were mapped in greater detail and their extent is shown or inferred on Figure 5.16.

The "Fingerbuster" structures are best exposed on the north bank of the Susitna River from river level to Elevation 1725 downstream of the proposed diversion tunnels. Exposures show two strong trends of discontinuities: northwest-southeast and north-south. The northwest-southeast trend is parallel to Set I joints and is the major trend of the structure. The north-south trend is parallel to the Set III joints.

- Northwest Trending Structures

The northwest trending structures consist primarily of shears and associated alteration zones. The strike of these structures is generally between 295° and 305° with variable high angle to vertical dips. Within the diorite these structures are frequently hydrothermally altered with gouge and breccia up to 2 feet thick. This altered and gouge material is yellowish orange, moderately to severely altered, soft and friable. The rock immediately surrounding these shears is generally fresh to slightly weathered and hard. Joint spacings range from very close to moderately close. Figure 5.19 is a photograph of shear and fracture zone GF 7R. Two 6 inch shears are surrounded by a fracture zone of very close to closely spaced joints, most of which are open. This zone is one of the sources of talus in the north-south gully which it crosses at about Elevation 1850.

The extent of these northwest trending shears could not be traced accurately beyond the area of the spillway. Within the area, most shears were traced across outcrops. Where not exposed, the shears tend to form topographic lows. Weathering of the soft shear material generally results in the formation of a bedrock scarp uphill from the shear and a talus pile below it (GF 7K on Section DP-1, Figure 5.17). Upstream from the spillway area, outcrops become fewer and talus more abundant. Shears are projected into this area based on their trend and lower seismic velocities (Figure 3.1). Seismic line SL82-8 indicates highly fractured bedrock (seismic velocity of 7,000 fps) overlying moderately fractured bedrock (13,500 fps). Similar conditions are encountered to the east along SL82-7 and SL82-6. However, on SL82-3 which crosscuts the trend of these structures, bedrock velocities are 22,000 fps with no overlying intermediate layer. Similarly seismic line SL82-4, which subparallels the trend, also shows high velocities (18,200 fps) along its length. Based on the work performed in this area to date, it has been assumed that most of these shears extend at least as far east as the proposed area of diversion tunnel number 1. The anomalous high seismic velocities denoted in SL82-3 and SL82-4 are currently unexplained. WCC suggest the higher velocities may be apparent velocities due to seismic waves refracted along ribs of more intact bedrock parallel to the north trending shears (see Appendix C). Additional subsurface work in this area will be required.

It is likely that the northwest-southeast shears extend to the south bank (discussed below). Geologic feature GF 7J has been correlated from the north bank, beneath the river, to the south bank. This feature crosscuts both diorite and andesite porphyry, and projects beneath the proposed dam foundation on the south abutment.

On the north bank in the andesite porphyry, GF 7J lies in a deep, vegetated gully trending at 290° (Figure 5.2). Exposures in the gully are very closely spaced, vertical fractures trending approximately 290° with thin zones of breccia and gouge. The andesite porphyry on the gully walls is slightly to moderately weathered/altered. Figure 5.20 shows the slightly altered shear/fracture GF 7J exposed at river level on the north bank. GF 7J has been projected across the river to correlate with features exposed along the base of the cliffs in area GF 6 (Figure 5.2). GF 7J is inferred to dip at 75° to the north to vertical, based on the slope of the cliff face and dips of shears behind and at the base of the cliff.

GF 7J has also been correlated with a shear zone intersected from 97.8 to 104.0 feet in DH-1 (Figure 5.5). This zone is slightly to moderately altered, with shears less than 6 inches wide. The rock is moderately hard, but soft in shear zones. RQDs are generally less than 40 percent in DH-1 with permeabilities about 10^{-3} cm/sec. Shearing may also exist in DH-3 where core loss of 6.7 feet occurred near the top of rock between 94.0 and 104.7 feet.

GF 7J also projects to the southeast from the river bank where it is exposed in a steep-walled, 10- to 15-foot-wide gully at the andesite porphyry/diorite contact at Elevation 1750. The rock in the zone itself has a granular nearly schistose character typical of cataclastic rocks. The rock has been healed and resheared. No exposures of GF 7J were found beyond this point, however, it has been tentatively correlated to a 10,000 fps zone on seismic line SW-1 (Figures 3.1 and 5.4). This correlation is questionable, since the zone was not intersected by BH-8, which lies between these features.

Related to the northwest trending structures are areas of open joints and loose, unstable rock. The most significant of these areas occurs in the area of the proposed excavation for the spillway flip-bucket (Figure 5.16). This area extends from river level to about Elevation 1850. Large blocks of detached rock are slumping along the intersection of Sets I, III and IV joints. Set IV is oriented subparallel to the Susitna River and dipping towards the river between 30° to 50° (Figure 5.8). Set IV joints dips into the proposed spillway flip-bucket excavation, which may require additional rock support. Above Elevation 1850, this area has a step-like appearance caused by a series of west to northwest trending ridges and gullies from 10 to 20 feet wide. Spruce trees growing along these ridges show rotation, indicating recent movement. The "steps" lie along the trend of Set Ib joint and the northwest trending shears. These features appear to be a series of near-surface bedrock slumps. This zone may extend up to Elevation 2200 where it was correlated with a low seismic velocity zone on SW-2.

- <u>North Trending Structures</u>

The larger, continuous north trending structures in the "Fingerbuster" are labelled GF 7L, M, N, O, P and Q (Figure 5.16). These structures are primarily fracture zones with associated minor shears, with the exception of GF 7Q, which is a major shear zone. These structures strike from 335° to 005° with dips generally vertical.

The zones range up to 30 feet in width; however, most are less than 5 feet wide. Shears, where they occur in these zones, generally consist of up to 6 inches of breccia and gouge. An exception to this is GF 7Q which is discussed below. The north trending shears likely extend beneath the Susitna River and correlate with similar structures on the south bank in GF 6.

GF 7Q is the most significant of the north trending features. On the north bank, this structure is partially exposed in a 40-foot-wide gully filled with deep talus. The andesite porphyry/diorite contact is coincident with this structure to about Elevation 2000. A highly fractured outcrop of diorite breccia in an andesite matrix within this zone is moderately to severely weathered. Joints are very closely to closely spaced, trending 330° (Set I) and 0° (Set III), and dipping steeply to vertical. Slickensides on the gully walls indicate a vertical displacement. Another outcrop at Elevation 1850 on the east side of the gully is very fine to medium grained diorite which has been intruded by thin veins of andesite containing diorite fragments.

BH-2 was drilled across GF 7Q to determine its location at depth. A shear/fracture zone was intersected between borehole depths of 71.2 and 177.1 feet, which was also coincident with the andesite porphyry/diorite contact at approximately 126 feet (Figure 5.6). The rock in this zone contains major shears and zones of alteration. RQDs and core recoveries were generally less than 50 percent and often 0 percent. A gully that branches from the main shear to the northwest is inferred to be another shear and fracture zone (Figure 5.2).

The extension of GF 7Q to the south is based on a strong north-south topographic lineament which extends to Elevation 1800 on the south bank. No outcrops were found in this gully. This feature, which is downstream from the main dam structure, has been considered significant in design. Every effort has been made to avoid placing major civil structures in this area. Excavations for portals and tunnels may encounter the north trending structures; however, since these features are small and intersect the civil structures at a high angle, they should not significantly affect design.

- Extent of "Fingerbuster"

The main "Fingerbuster" trend is northwest-southeast. To the southeast the "Fingerbuster" shears have been tentatively correlated with shears in BH-6 and DH-21 (Figures 5.3 and 5.4). Few outcrops are found on the south bank along the projection of the structure. Shears are found where bedrock is exposed. Seismic lines SL81-20 and SL81-21 indicate a bedrock low along the trend, however, bedrock seismic velocity is high (18,000 fps) indicating good quality rock. To the northwest, no bedrock outcrops are found between the north bank of the Susitna River and Tsusena Creek: however, an area of sheared and altered diorite similar in trend to the "Fingerbuster" was found to the northwest of Tsusena Creek (Figure 4.1) and may be the continuation of the "Fingerbuster" structure.

5.4 - Spillway and Intake Areas

(a) Introduction

This section discusses the geology of the surficial deposits and bedrock in the area of the main spillway and intake structures on the north bank of the Susitna River. The general arrangement of these structures in relation to the surficial deposits and bedrock geology is shown on the damsite maps (Figures 5.1 and 5.2). Additional detail of the spillway flip-bucket area is shown on the downstream portal area map and sections (Figures 5.16 and 5.17) and discussed in Sections 5.1 and 5.3.

(b) Overburden and Ground Water

Surficial deposits in this area have been investigated by geologic mapping, seismic refraction surveys, and boreholes. The material types encountered consist of alluvium, talus and till (Figure 5.1). Their extent and lithology are discussed individually below.

- Alluvium

Alluvial deposits are located primarily in the river channel downstream from the spillway flip-bucket. In boreholes DH-1, DH-2, and DH-3 in the river (Figure 3.1) upstream from this area, the alluvium consists of a gravel to sandy gravel with subrounded to rounded fragments generally from 3 inches to 2 feet in diameter in a sand matrix with minor silt. Alluvial thickness is expected to be similar to that in the main damsite, generally less than 50 to 70 feet (see Section 5.3). Additional thin alluvial materials are found locally above Elevation 2000.

- Talus

Talus occurs on the lower slopes of the gorge generally below Elevation 1950, and so will likely only be encountered in the areas of the lower spillway and spillway flip-bucket excavations. Talus consists of angular boulders of diorite and quartz diorite generally from 1 to 2 feet in diameter. Thickness is variable, ranging from 0 to 30 feet (Section DP-3, Figure 5.17). The seismic velocity of this talus material ranges from 1,200 to 3,000 fps (Appendix C) (see Section 5.3).

- Till

Till, overlain by undifferentiated surficial deposits, occurs on the upper slopes of the gorge generally above Elevation 1950 (Figure 5.1). Minor amounts of alluvium and outwash deposits are found locally. In the intake area these deposits thicken northwestward from about 10 feet at Elevation 2000 to about 50 feet at the power intake at Elevation 2225.

Along the spillway, overburden is thickest, about 40 feet at the outlet facilities intake at Elevation 2150 but are thinner along the axis. At Elevation 2200 near the dam centerline, overburden thickness ranges from 0 to 10 feet. Between dam centerline and Elevation 1950, overburden thickness is generally 20 feet along the spillway.

(c) Bedrock Lithology

Bedrock in the spillway and intake areas ranges from diorite to quartz diorite with minor amounts of granodiorite. These rock types have been intruded by minor felsic and mafic dikes. Andesite porphyry volcanic flows occur to the north and west of this area. The andesite porphyry/diorite contact crosses the Susitna River about 600 feet downstream of the spillway flip-bucket and about 200 feet west of the spillway at Elevation 2200. Detailed descriptions of bedrock lithology are presented in Section 5.1.

Bedrock quality is variable throughout the spillway and intake area. In the intake area, seismic lines SL81-15 and SL82-10 (Figure 3.1) show areas of poor quality bedrock with seismic velocities of 9,000 to 12,700 fps (Appendix C), primarily in the proposed intake channel. Bedrock quality appears better at the proposed power intake structure with velocities of 15,400 to 18,500 fps (SW-3 and SL82-5).

Seismic line SL82-5 extends along the axis of the spillway to about Elevation 2000 (Figure 3.1). The seismic line shows moderately good bedrock (seismic velocity 13,400 fps) to about Elevation 2150. Below this elevation to the end of the line at Elevation 1990 is a zone up to 120 feet thick of poor quality bedrock (seismic velocity 7,500 to 9,000 fps). This zone extends to below the downstream limit of the proposed spillway excavation at about Elevation 1500 (Section DP-3, Figure 5.17). The low seismic velocity bedrock is likely due to shears, fracture zones and alteration zones which are discussed below.

(d) Bedrock Structure

(i) Significant Geologic Features

The spillway and intake areas cross most of the geologic features defined in the damsite area. These features are identified below but are discussed in detail in Section 5.1 and shown on Figure 5.2.

The intake channel is cross cut nearly along its axis by geologic feature GF 2, a zone of fractu[illegible]ing and minor shearing about 70 to 100 feet wide (Sec[illegible]n W-2, Figure 5.4). The feature passes through an area of the present power intake channel intersecting it at a high angle. Minor shears related to the GF 3 feature may also be present in this area.

The upper spillway lies in the GF 3 feature which consists of minor shears and fracture zones within moderately good bedrock. Discontinuities in this area trend primarily northwest and north-east. Between Elevation 2200 and 2050, the proposed spillway crosses the GF 4 and GF 5 structures, which consist of northwest trending fracture zones with associated shears and alteration zones. The GF 4 fracture zones dip at high angles to the northeast while GF 5 is vertical. The decrease in bedrock quality discussed above begins at these features. Below Elevation 1,850, the spillway passes through the "Fingerbuster" (GF 7) feature (see Section 5.3).

5.5 - Ancilliary Civil Structures Location

(a) Introduction

The additional geotechnical investigations, consisting of seismic refraction, soil borings and geologic mapping, which were undertaken during 1982 serve to better define geotechnical conditions in the areas of some of the proposed ancilliary facilities. The data presented in the following sections refines that information presented in the 1980-81 Geotechnical Report (1).

(b) Emergency Spillway

A total of eight seismic lines and one borehole cross or intersect the alignment and approach channel of the proposed of the emergency spillway. Overburden depths in this area range between 15 and 60 feet, a decrease from the 15 to 100 feet originally estimated. The average overburden depth in the inlet and fuse plug areas averages approximately 40 feet, decreased from the initial estimate of 50 to 75 feet. The estimated bedrock surface is shown on Figure 6.7.

(c) Camp Areas

Overburden thickness in the areas of the proposed construction camp and permanent village sites (Figures 1.2 and 6.7) are expected to be in excess of 100 feet, with the exception of the area north of the permanent village site near Tsusena Creek, where bedrock is estimated to drop off to greater than 200 feet below the surface. Foundation construction for the camp construction will be in the gravels and sands of the glacial outwash and ice disintegration deposits which cover the areas (Units A thru C - Section 6). The permanent village, at current site, is on shallow deposits of Units A through F over the lacustrine Unit B. While there is no boring information on ground water levels in these areas, it is expected that the water table will occur perched on top of the sporadic permafrost areas and on the top of the aquiclude lacustrine unit G (Section 6.3). Deeper aquifers may also exist at depth beneath Unit G.

(d) Access Roads

As described in the 1980-81 Geotechnical Report (1), access roads in the relict channel and borrow site areas will encounter the full range of glacial and alluvial materials. In general, selective route alignment should allow avoidance of a majority of the boggy and fine-grained materials. Damsite access and construction roads will have to be routed to conform to the natural bedrock shelves which occur at various elevations in the damsite, and will be cut into talus and alluvial deposits down to bedrock. Significant rock excavation will be necessary where the roads cross areas of steep topography, and in particular, where roads cross the "Fingerbuster" or enter the damsite at the lower elevations. Any roads built on the south abutment above the break in the slope (Elevation 1900) and below Elevation 2300, will encounter significant frozen and supersaturated glacial and alluvial overburden.

5.6 - Ground Water Regime

The 1982 studies consisted of instrumentation readings of the pneumatic piezometers installed in the damsite during 1980-81. These readings continued to support those findings and conclusions set forth in the 1980-81 Geotechnical Report (1). The geologic mapping revealed additional springs on slopes at overburden/bedrock contacts (Figure 5.1).

Instrumentation reading of BH-3 and BH-6 were made throughout the year on approximately monthly basis. BH-3 showed consistent reading of the ground water level within the upper 10 feet of the surface. The previously reported 280 foot reading, presented in Section 6 of the 1980-81 Geotechnical Report for this boring was erroneous. Water levels in BH-6 continued to show seasonal fluctuates between 103 feet to 150 feet below ground surface with the lower water level being recorded in the late winter and spring and the higher water table in late summer and fall.

Runoff is noted along the toe of talus slopes on both abutments resulting in icing of these areas during the winter. In addition, the perched ground water table on the permafrost on the south abutment results in numerous springs above Elevation 1900. BH-12, which experienced artesian conditions when drilled, continued to flow at 2 - 3 gpm throughout the year.

Further investigations and instrumentation will be required in subsequent phases of study to accurately define the ground water condition in the damsite area.

5.7 - Permafrost Regime

The interpretation of the permafrost regime at the damsite remains unchanged as presented in the 1980-81 Geotechnical Report (1). While only sporadic overburden permafrost has been detected on the upper north abutment, extensive permafrost exists on the south abutment. BH-6 continues to show near-zero permafrost at depths of about 80 to 170 feet beneath the Susitna River (Figure 5.21), while DH-21, on the south abutment near river level, has thick ice in the casing year-round at depth of less than 20 feet. All the borings on the south abutment show permafrost, based on temperature measurements and very low rock permeabilities in fractured zones.

The lack of concentration of thermistor instrumentation on the south abutment precludes determination of annual frost conditions. On the upper north abutment however, the one borehole (BH-3) shows vertical annual frost penetration of about 8 feet, with a mean low temperature below the zone of annual amplitude (about 70 feet deep) of 1.3°C. BH-6 appears to be located just about on the zero isotherm at the damsite, with annual freezing and thawing to full depth of annual amplitude, about 80 feet.

The borings on the upper south abutment all show permafrost from 0 to 25 feet with the active zone usually around 10 to 15 feet thick. The depth of zero annual amplitude ranges between 15 and 45 feet.

The deeper holes, both in and out of permafrost, pick up a uniform indication of geothermal gradient at about 130 feet vertically below ground surface as described in the 1980-81 Geotechnical Report (1).

The south abutment is expected to be frozen to depths of between 100 to 250 feet and possibly greater. Some of the bedrock and alluvium adjacent to the river is expected to be frozen (0 to -1°C) to depths of 30 to 100 feet, but permafrost is not expected to exist in the alluvium under the river. The right abutment may have scattered permafrost below Elevation 1800 to 1900.

ACRES

TABLE 5.1: WATANA DAMSITE AND VICINITY SEISMIC VELOCITY CORRELATIONS

INFERRED MATERIAL	WATANA DAMSITE	WATANA RELICT CHANNEL/ BORROW SITE D	FOG LAKES RELICT CHANNEL	WATANA BORROW SITES C, E, F, I, J
Shallow, loose dry sands, gravels, topsoil	1000-1500 fps (1)	1100-1600	1100-2000	1000-1500
Moist granular, well drained materials including loose ablation tills and outwash; slope wash, talus	1500-3500	1600-3350	2000-3000	1500-2000
Moist terraces, gravels occur predominately as surface terraces of shallow fill material in relict channels, stream valleys. May include drained till, frozen soil and lacustrine materials in damsite	3400-4600	3350-5200	3000-4600	2000-5000
Lacustrine materials (tills in damsite) - relative uniform	5200 (upper left	4100-5200	---	---
- frozen	7500-8000 abutment only)	5200-6000	---	---
Water	4600-4800	4600-4800	4600-4800	4600-4800
Granular alluvium, saturated, outwash, sand and gravel stream and river deposits without high percentage of boulders or high density. May include some tills.	4600-6100	5250-6600	4200-5000	5000-7500
Saturated dense alluvium, bouldery or frozen alluvium, most tills include dense talus and boulder fields; very coarse, deeply buried alluvium. Higher velocity zones frozen if not very dense.	(7000-8000 at river level and on south abutment only) (12000-14000 in riverbed near "The Fins")	6600-10800	4300-9000	7500-9500
Anomalous velocity zones. Outcrops and borings in damsite show moderately fractured bedrock which would normally be expected to have velocities above 10,000 fps. Material in Fog Lakes Relict Channel assumed to be frozen or well consolidated till. Assumed to be bedrock for borrow sites to provide conservative estimates of material quantities.	6000-9000 (right abutment above El 1500 only)		8000-11500 (thick channel fills)	9650-10000

TABLE 5.1

(Cont'd)

INFERRED MATERIAL	WATANA DAMSITE	WATANA RELICT CHANNEL/ BORROW SITE D	FOG LAKES RELICT CHANNEL	WATANA BORROW SITES C, E, F, I, J
Ice (on surface)	11000	11000	11000	11000
Highly sheared, weathered or altered bedrock- very poor quality	7000-10600	8000-12500	8000-10500	10300-11750
Sheared, fractured, weathered or altered bedrock - moderately competent except poor quality on south abutment in 11000-12000 fps zones in Watana damsite.	10600-13500	13000-14000	10500-14000	12300-13300
Bedrock, surface weathering or stress relief jointing to moderate depths, generaly very competent.	13500-16200	14000-16000	14100-16000	13970-15500
Bedrock, fresh, extremely competent, minimal fracturing or jointing.	16200-22200	16000-23500	16000-23000	16000-17000

NOTES: (1) Seismic velocity in feet per second (fps)

(2) Velocity ranges given match specific velocities in seismic refraction survey reports (Reference Numbers 12, 25, 39, 41, 43), and are intended as a presentation of the interpretation of material types by AAI. Stated ranges are not intended to definitively predict material conditions or nature at a particular location or for a particular velocity.

TABLE 5.2: WATANA DAMSITE
JOINT CHARACTERISTICS*

JOINT SET	SITE QUADRANT	STRIKE RANGE	STRIKE AVERAGE**	DIP RANGE	DIP AVERAGE**	SPACING*** RANGE	SPACING*** AVERAGE	SURFACE CONDITIONS TEXTURE	SURFACE CONDITIONS COATING	REMARKS
I****	All	265°-335°	300°	55°NE-65°SW	75°NE	1"-15'	2'	Planar, smooth to locally rough, continuous		Parallel to major shears, fracture zones, and alteration zones.
	NE	280°-345°	330° 310°	55°NE-70°SW	80°NE 80°NE	2"-10'	2'	Same as above	Carbonate and alteration, locally. Major carbonate at WJ-6	
	SE	270°-350°	320°	60°NE-70°SW	80°NE	2"-10'	2'	Same as above		
	SW	270°-340°	325° 295°	60°NE-70°SW	90° 75°NE	1"-15'	2'	Same as above	Major carbonate at WJ-7	
	NW	265°-335°	325° 295°	45°NE-60°SW	85°SW 75°NE	1"-15'	2'	Same as above	Minor carbonate and alteration, locally. Major carbonate at WJ-4	
II	All	015°-075°	055°	60°NW-60°SE	85°NW	1"-5'	1-2'			Parallel to fracture zones in NE quadrant; no shears or alteration zones.
	NE	015°-065°	040°	60°NW-60°SE	80°NW	1"-10'+	1-2'	Planar to irregular, smooth to slightly rough	Minor carbonate	
	SE	025°-080°	050°	65°NW-60°SE	85°NW	1"-10'+	1-2'	Same as above	Same as above	
	SW	040°-080°	065°	70°NW-70°SE	85°NW	1"-10'+	1-2	Planar, smooth to rough	Same as above	
	NW	050°-070°	065°	60°NW-70°SE	90°	1"-10'+	1-2'	Same as above	Same as above	

* Surface data only
** Major joint concentration
*** Where set is present
**** Includes Subsets Ia and Ib (see Section 5.1)

TABLE 5.2

(Cont'd)

JOINT SET	SITE QUADRANT	STRIKE RANGE	STRIKE AVERAGE**	DIP RANGE	DIP AVERAGE**	SPACING*** RANGE	SPACING*** AVERAGE	SURFACE CONDITIONS TEXTURE	SURFACE CONDITIONS COATING	REMARKS
III	All	335°-035°	350°	45°E-60°W	75°E	0.5"-5'	1-2'	Planar to slightly curved, smooth to slightly rough		Parallel to minor shears, fracture zones, and alteration zones.
	NE	325°-025°	350°	55°E-60°W	60°E	2"-10'	1-2'	Same as above	Minor carbonate and alteration, locally	Weakly developed.
	SE	---	---	---	---	---	---	---	---	Not observed.
	SW	340°-020°	345°	60°E-80°W	80°E	0.5"-10'	1-2'	Planar to irregular smooth to rough	Minor carbonate and alteration, locally	Strongly developed.
	NW	335°-035°	005°	45°E-60°W	80°E	0.5"-10'	1-2'	Same as above.	Same as above	Same as above.
IV	All	Variable		Shallow to Moderate				Planar to irregular		Probably stress relief, near surface.
	NE		075°		15°S 10°N	2"-5'+	1-2'	Same as above.	---	Same as above.
	SE		090° 310°		25°S 40°NE	2"-5'+	1-2'	Same as above.	---	Same as above.
	SW		000° 090°		05°E 25°N	6"-10' 6"-10'	2' 2'	Same as above.	---	Same as above.
	NW		090°	10°N-10°S	---	2"-5'+	2-3'	Same as above.	---	Same as above.

* Surface data only
** Major joint concentration
*** Where set is present
**** Includes Subsets Ia and Ib, (see Section 5.1)

TABLE 5.3: WATANA DAMSITE UPSTREAM COFFERDAM AND PORTAL AREA JOINT CHARACTERISTICS*

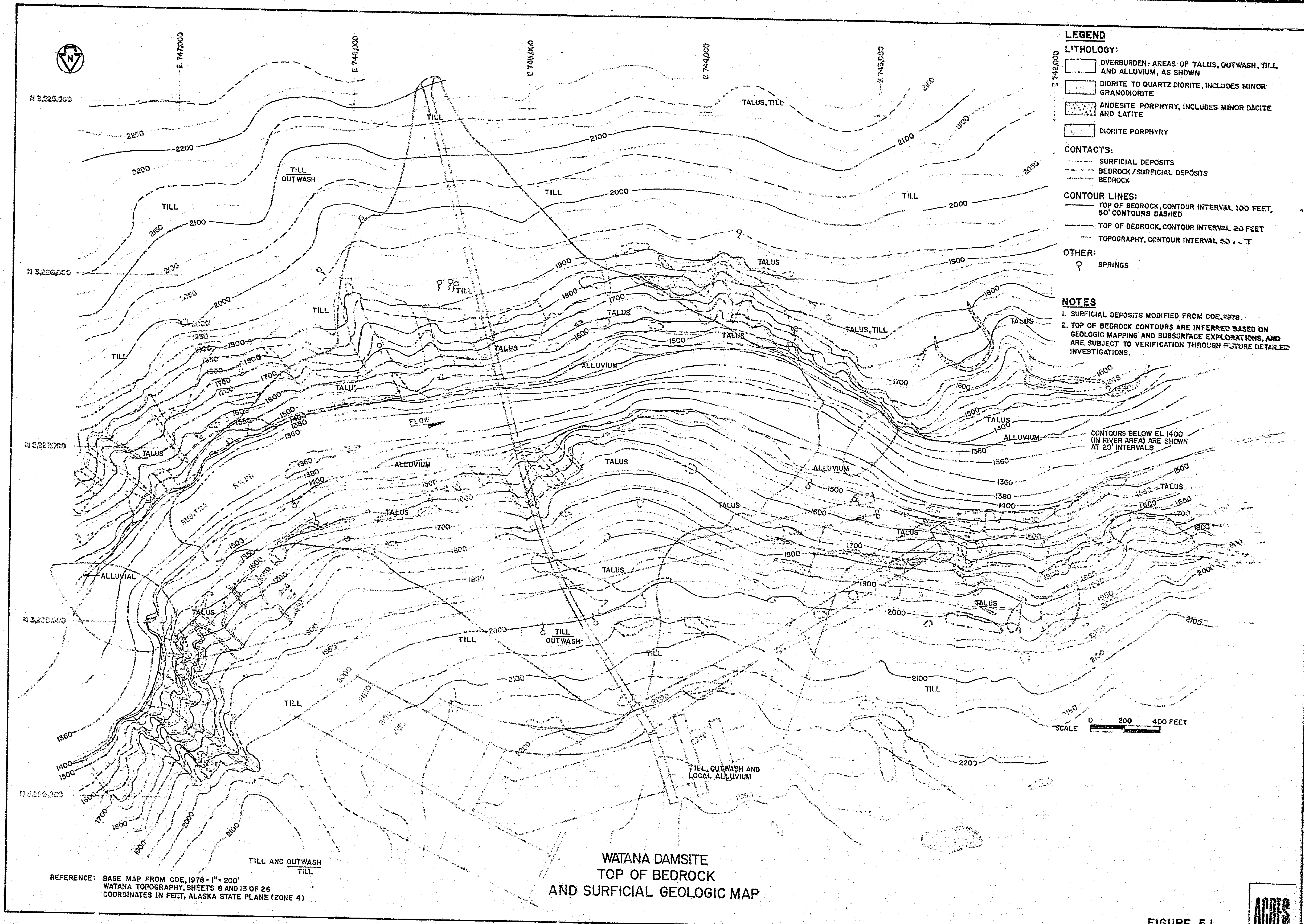
JOINT SET	STRIKE		DIP		SPACING***		SURFACE CONDITIONS		REMARKS
	RANGE	AVERAGE**	RANGE	AVERAGE**	RANGE	AVERAGE	TEXTURE	COATING	
I	285°-345°	325°	60°NE-60°SW	90°	0.5"-5'+	1-2'	Planar, smooth to slightly rough	Alteration, locally.	Parallel to major shears, fracture zones, and alteration zones.
II	020°-060°	042°	65°NW-60°SE	85°NW	0.5"-4'	1-2'	Planar to slightly curved, smooth to slightly rough	---	Parallel to minor fracture zones; many open; slumping
III	---	---	---	---	---	---	---	---	Not Observed.
IV	Variable	045°	20°NW-30°SE	10°NW 10°SE	0.5"-5'+	2'	Planar to slightly curved, smooth	---	Discontinuous; probably stress relief.

* Surface data only
** Major joint concentration
*** Where set is present

TABLE 5.4: WATANA DAMSITE DOWNSTREAM COFFERDAM AND PORTAL AREA JOINT CHARACTERISTICS*

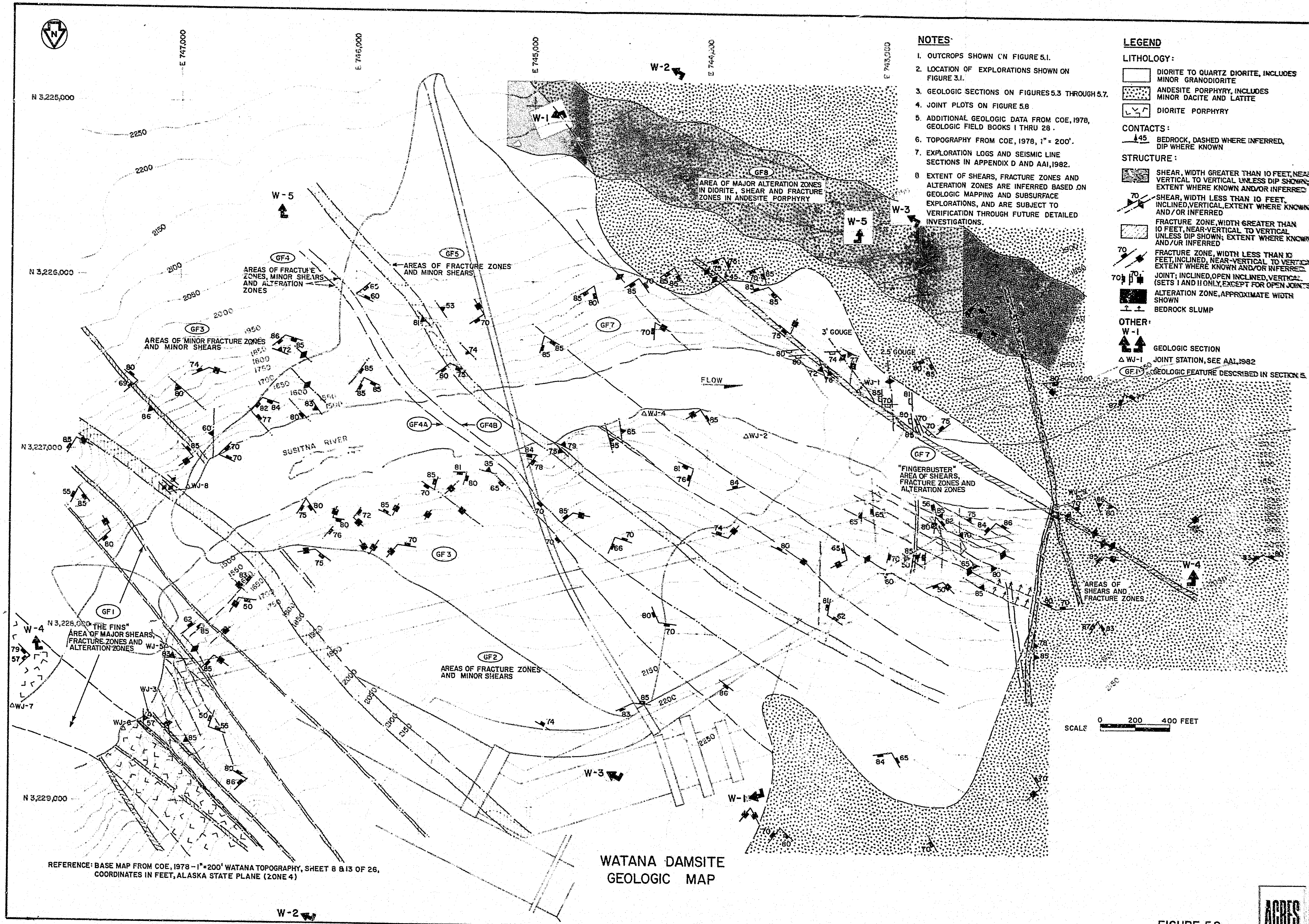
JOINT SET	STRIKE		DIP		SPACING***		SURFACE CONDITIONS		REMARKS
	RANGE	AVERAGE**	RANGE	AVERAGE**	RANGE	AVERAGE	TEXTURE	COATING	
I	285°-305°	290°	45°NE-60°SW	85°SW	1"-3'	1-2'	Planar, smooth	Carbonate and alteration, locally	Subparallel to parallel to shears, fracture zones and alteration zones.
II	050°-070°	065°	70°NW-70°SE	90°	1"-10'+	1-2'	Planar to slightly curved, smooth	---	No shears or alteration zones, but minor fracture zones. Weakly developed.
III	325°-025°	005°	55°E-60°W	80°E	1"-10'	1-2'	Planar, smooth	Minor carbonate and alteration, locally	Parallel to shears, fracture zones and alteration zones. Many open.
IV	055°-110°	090°	30°S-55°S	40°S	4"-5'+	2-3'	Planar, smooth	---	Dips toward river, parallel to slope, discontinuous.

* Surface data only
** Major joint concentration
*** Where set is present



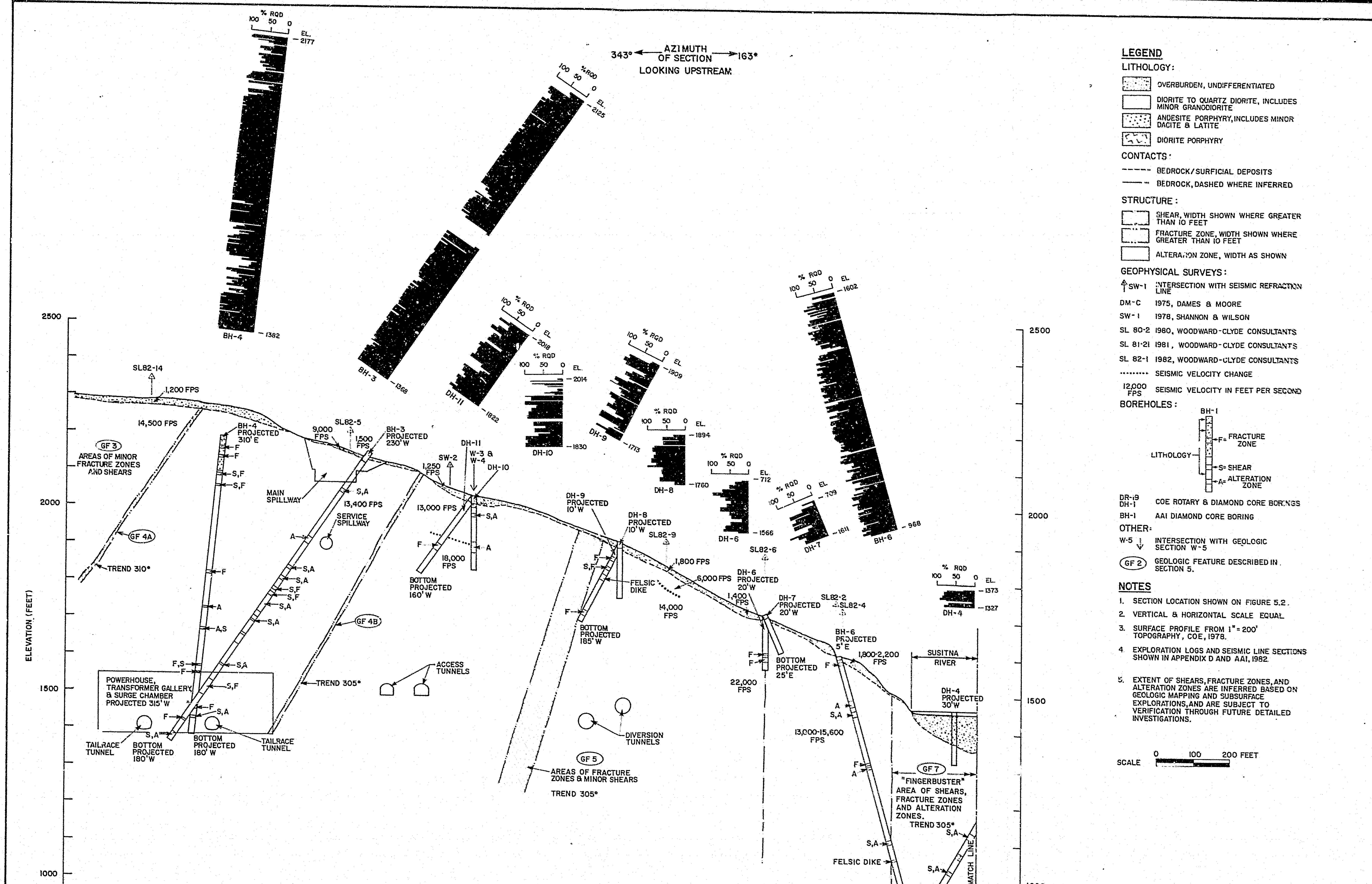
WATANA DAMSITE
TOP OF BEDROCK
AND SURFICIAL GEOLOGIC MAP

FIGURE 5.1



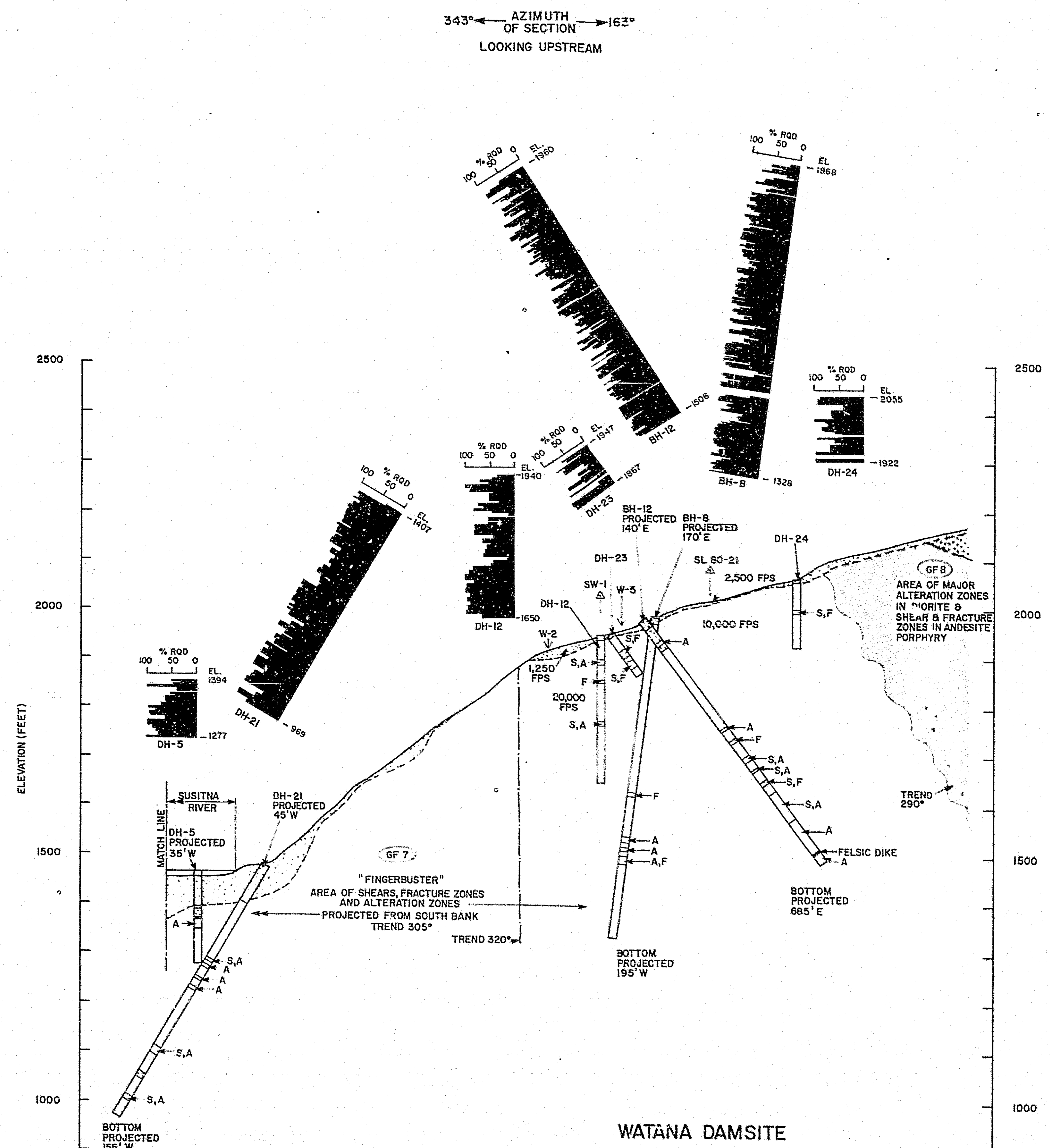
WATANA DAMSITE
GEOLOGIC MAP

FIGURE 5.2



WATANA DAMSITE
GEOLOGIC SECTION W-1
SHEET 1 OF 2

FIGURE 5.3



LEGEND

LITHOLOGY:

- OVERBURDEN, UNDIFFERENTIATED
- DIORITE TO QUARTZ DIORITE, INCLUDES MINOR GRANODIORITE
- ANDESITE PORPHYRY, INCLUDES MINOR DACITE & LATITE
- DIORITE PORPHYRY

CONTACTS:

- BEDROCK/SURFICIAL DEPOSITS
- BEDROCK, DASHED WHERE INFERRED

STRUCTURE:

- SHEAR, WIDTH SHOWN WHERE GREATER THAN 10 FEET
- FRACTURE ZONE, WIDTH SHOWN WHERE GREATER THAN 10 FEET
- ALTERATION ZONE, WIDTH AS SHOWN

GEOPHYSICAL SURVEYS:

- SW-1 INTERSECTION WITH SEISMIC REFRACTION LINE
- DM-C 1975, DAMES & MOORE
- SW-1 1978, SHANNON & WILSON
- SL 80-2 1980, WOODWARD-CLYDE CONSULTANTS
- SL 81-21 1981, WOODWARD-CLYDE CONSULTANTS
- SL 82-1 1982, WOODWARD-CLYDE CONSULTANTS
- SEISMIC VELOCITY CHANGE
- 12,000 FPS SEISMIC VELOCITY IN FEET PER SECOND

BOREHOLES:

BH-1
LITHOLOGY
F= FRACTURE ZONE
S= SHEAR
A= ALTERATION ZONE

- DR-19 DH-1 COE ROTARY & DIAMOND CORE BORINGS
- BH-1 AAI DIAMOND CORE BORING

OTHER:

- W-5 INTERSECTION WITH GEOLOGIC SECTION W-5
- GF 2 GEOLOGIC FEATURE DESCRIBED IN SECTION 5.

NOTES

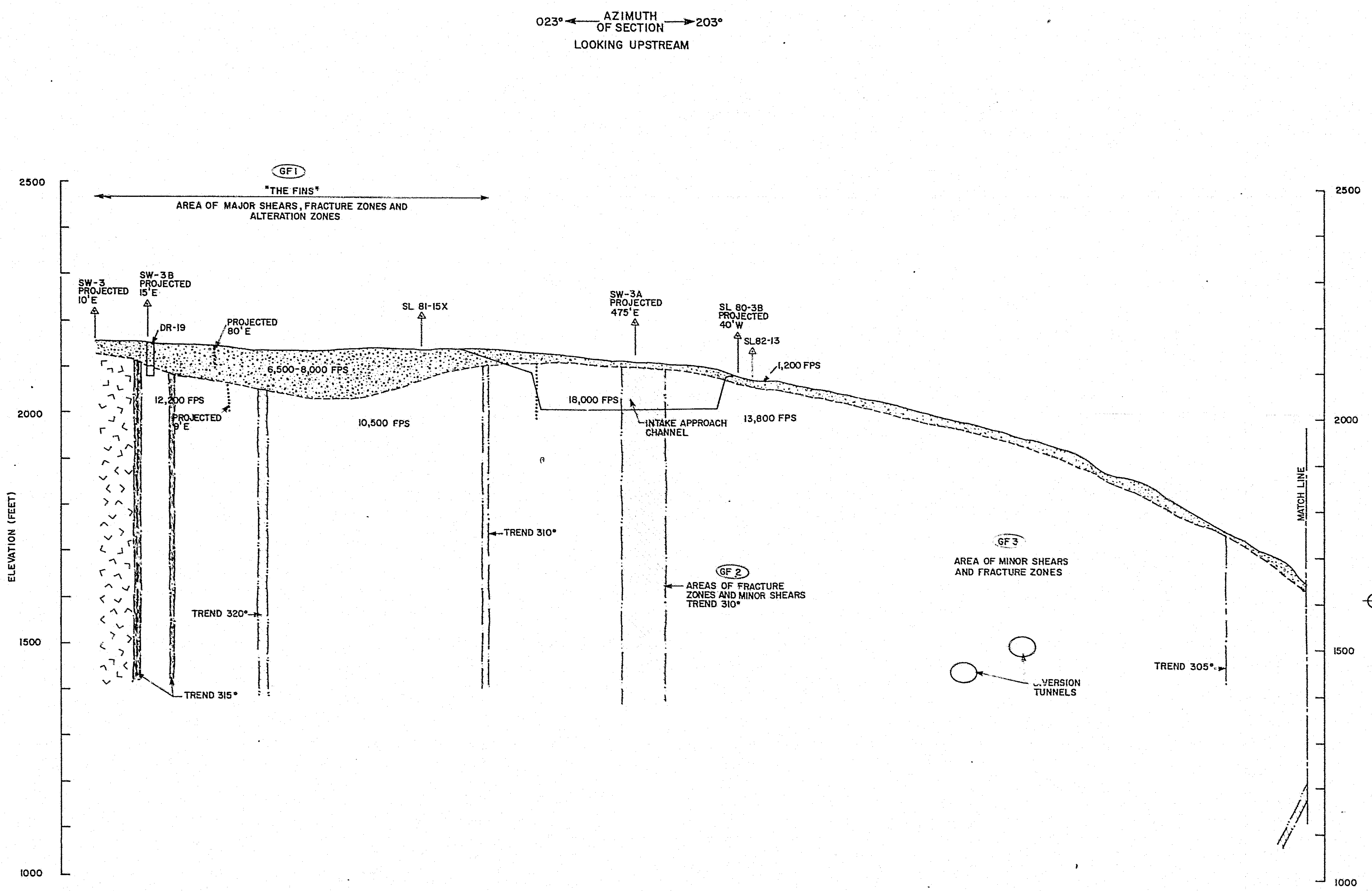
1. SECTION LOCATION SHOWN ON FIGURE 5.2.
2. VERTICAL & HORIZONTAL SCALE EQUAL.
3. SURFACE PROFILE FROM 1" = 200' TOPOGRAPHY, COE, 1978.
4. EXPLORATION LOGS AND SEISMIC LINE SECTIONS SHOWN IN APPENDIX D AND AAI, 1982.
5. EXTENT OF SHEARS, FRACTURE ZONES, AND ALTERATION ZONES ARE INFERRED BASED ON GEOLOGIC MAPPING AND SUBSURFACE EXPLORATIONS, AND ARE SUBJECT TO VERIFICATION THROUGH FUTURE DETAILED INVESTIGATIONS.

SCALE 0 100 200 FEET

WATANA DAMSITE
GEOLOGIC SECTION W-1
SHEET 2 OF 2

ACRES

FIGURE 5.3



LEGEND

LITHOLOGY:

- OVERBURDEN, UNDIFFERENTIATED
- DIORITE TO QUARTZ DIORITE, INCLUDES MINOR GRANODIORITE
- ANDESITE PORPHYRY, INCLUDES MINOR DACITE & LATITE
- DIORITE PORPHYRY

CONTACTS:

- BEDROCK/SURFICIAL DEPOSITS
- BEDROCK, DASHED WHERE INFERRED

STRUCTURE:

- SHEAR, WIDTH SHOWN WHERE GREATER THAN 10 FEET
- FRACTURE ZONE, WIDTH SHOWN WHERE GREATER THAN 10 FEET
- ALTERATION ZONE, WIDTH AS SHOWN

GEOPHYSICAL SURVEYS:

- SW-1 INTERSECTION WITH SEISMIC REFRACTION LINE
- DM-C 1975, DAMES & MOORE
- SW-1 1978, SHANNON & WILSON
- SL 80-2 1980, WOODWARD-CLYDE CONSULTANTS
- SL 81-21 1981, WOODWARD-CLYDE CONSULTANTS
- SL 82-1 1982, WOODWARD-CLYDE CONSULTANTS
- .... SEISMIC VELOCITY CHANGE
- 12,000 FPS SEISMIC VELOCITY IN FEET PER SECOND

BOREHOLES:

BH-1

LITHOLOGY — F= FRACTURE ZONE — S= SHEAR — A= ALTERATION ZONE

- DR-19 DH-1 COE ROTARY & DIAMOND CORE BORINGS
- BH-1 AAI DIAMOND CORE BORING

OTHER:

- W-5 INTERSECTION WITH GEOLOGIC SECTION W-5
- GF 2 GEOLOGIC FEATURE DESCRIBED IN SECTION 5.

NOTES

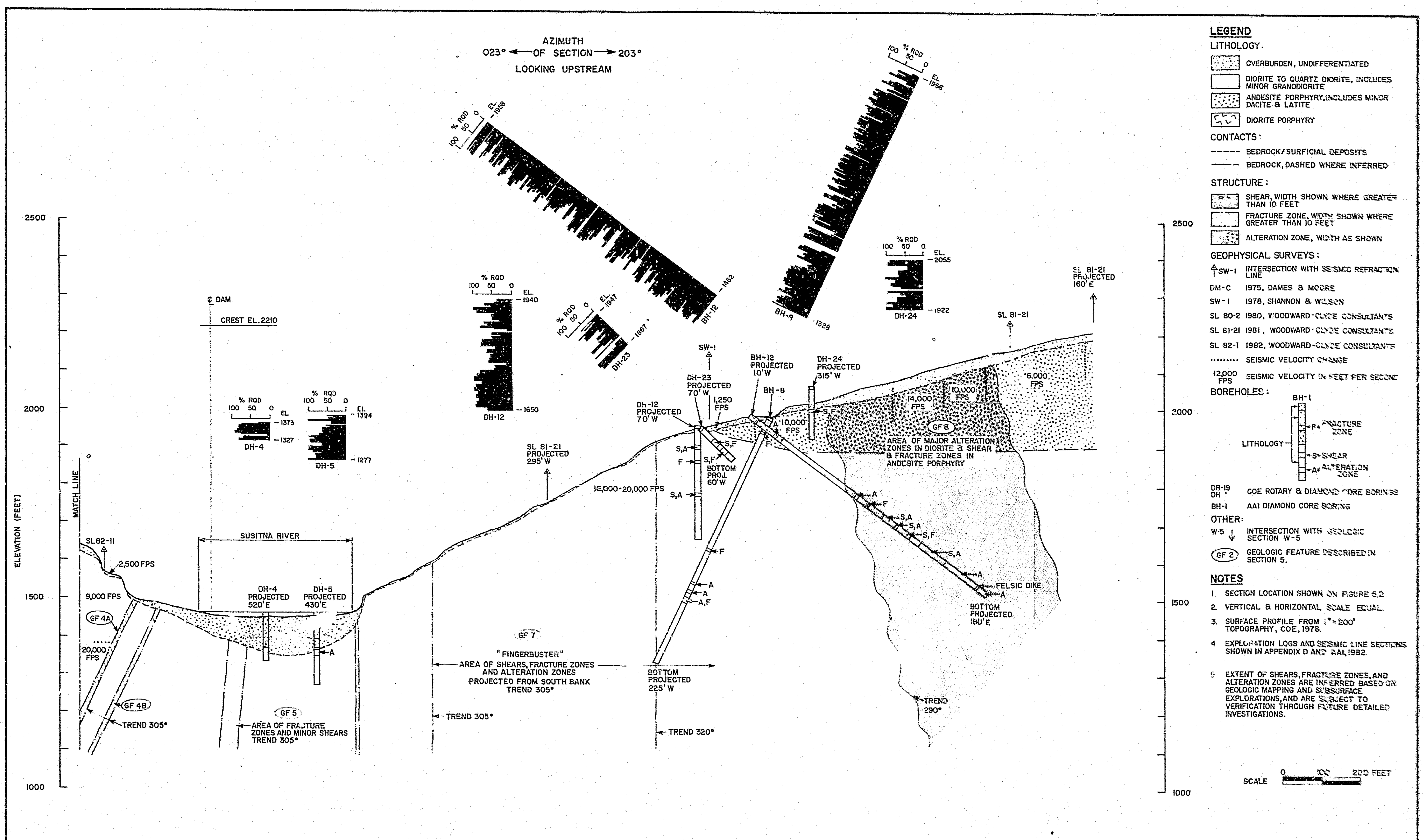
1. SECTION LOCATION SHOWN ON FIGURE 5.2
2. VERTICAL & HORIZONTAL SCALE EQUAL.
3. SURFACE PROFILE FROM 1" = 200' TOPOGRAPHY, COE, 1978.
4. EXPLORATION LOGS AND SEISMIC LINE SECTIONS SHOWN IN APPENDIX D AND AAI, 1982
5. EXTENT OF SHEARS, FRACTURE ZONES, AND ALTERATION ZONES ARE INFERRED BASED ON GEOLOGIC MAPPING AND SUBSURFACE EXPLORATIONS, AND ARE SUBJECT TO VERIFICATION THROUGH FUTURE DETAILED INVESTIGATIONS.

SCALE 0 100 200 FEET

WATANA DAMSITE
GEOLOGIC SECTION W-2
SHEET 1 OF 2

ACRES

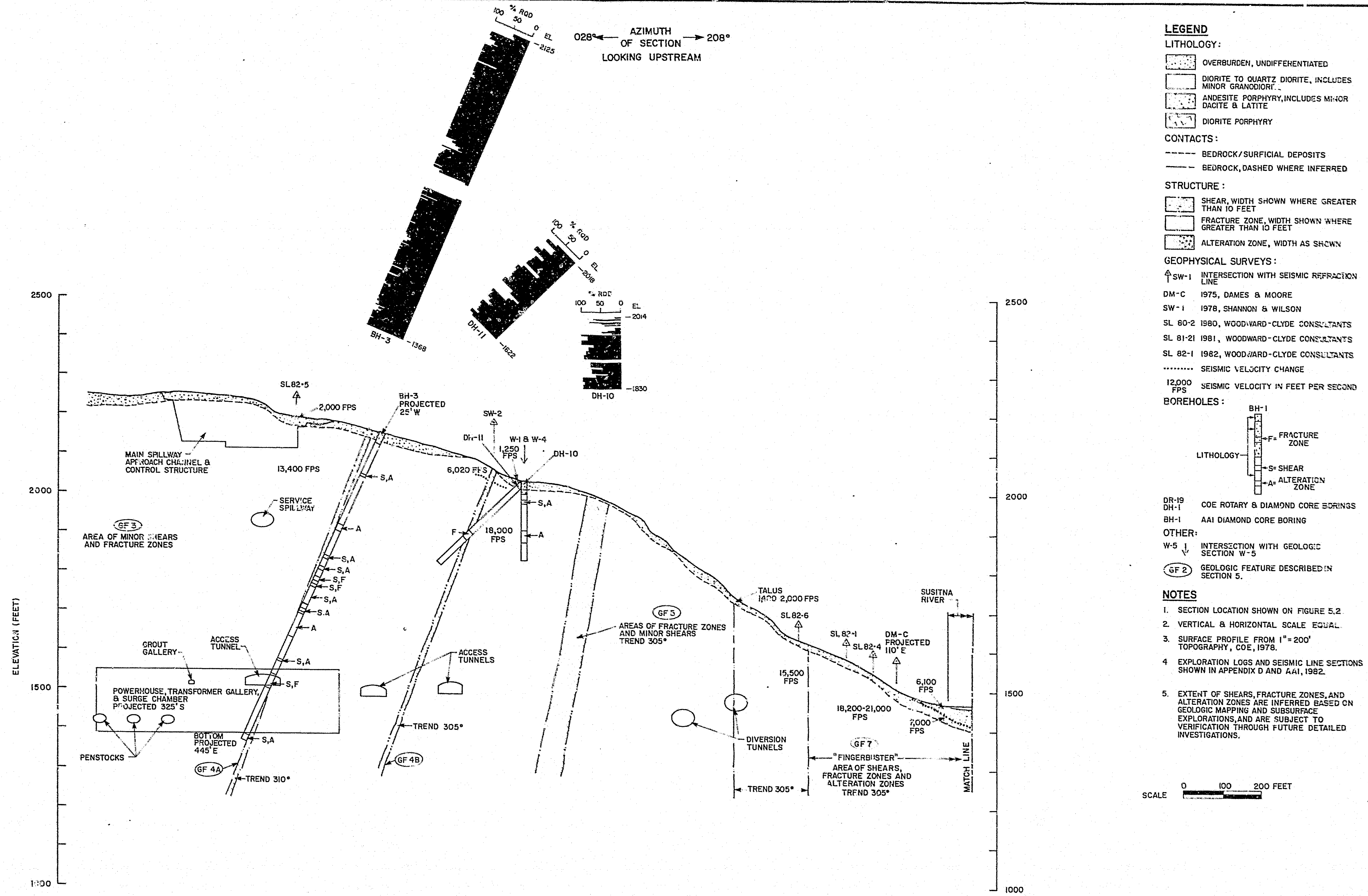
FIGURE 5.4



WATANA DAMSITE
GEOLOGIC SECTION W-2
SHEET 2 OF 2

ACRES

FIGURE 5.4



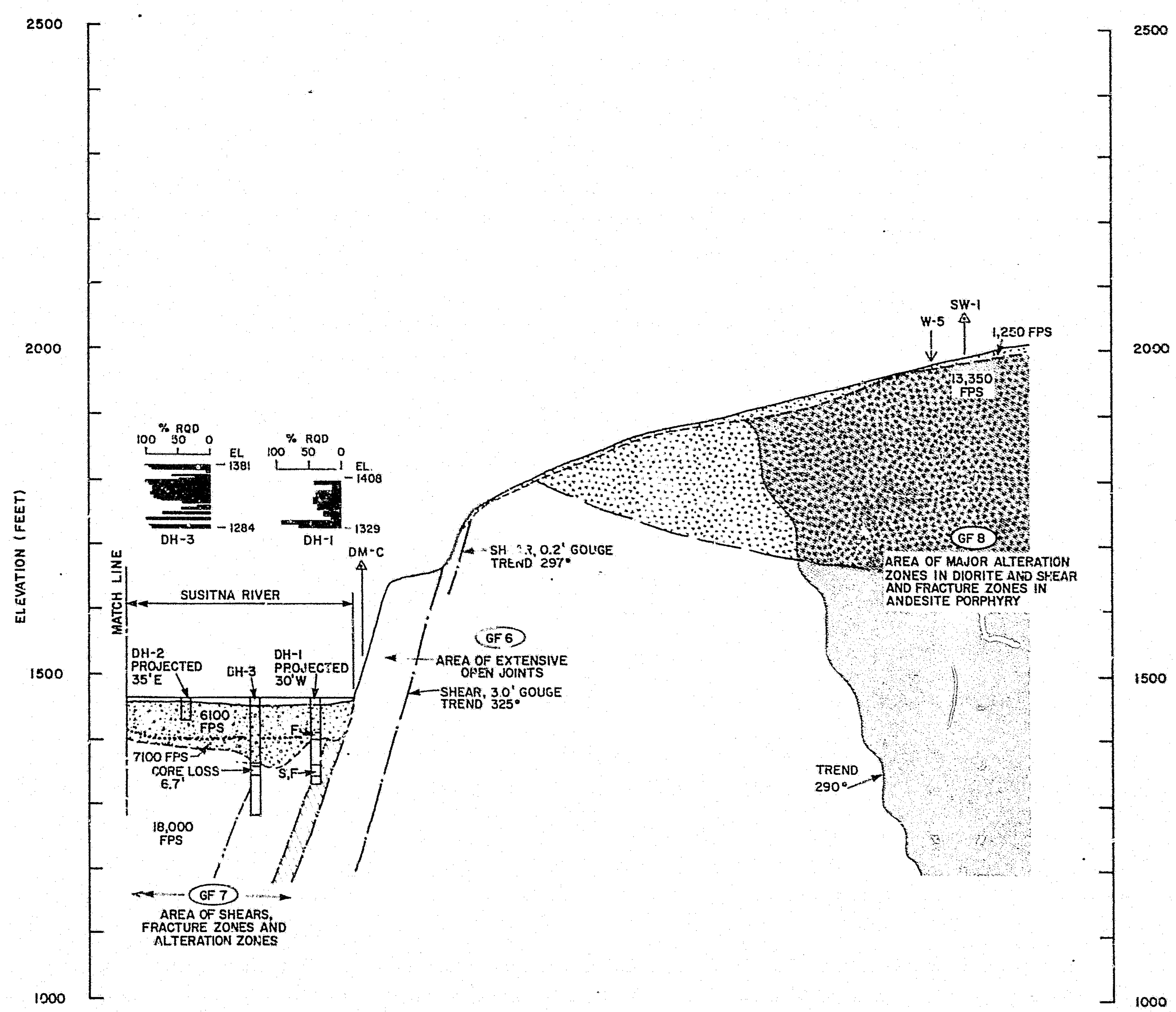
WATANA DAMSITE
GEOLOGIC SECTION W-3
SHEET 1 OF 2

ACRES

FIGURE 5.5

028° ← AZIMUTH OF SECTION → 208°

LOOKING UPSTREAM



LEGEND

LITHOLOGY:

- OVERBURDEN, UNDIFFERENTIATED
- DIORITE TO QUARTZ DIORITE, INCLUDES MINOR GRANODIORITE
- ANDESITE PORPHYRY, INCLUDES MINOR DACITE & LATITE
- DIORITE PORPHYRY

CONTACTS:

- BEDROCK/SURFICIAL DEPOSITS
- BEDROCK, DASHED WHERE INFERRED

STRUCTURE:

- SHEAR, WIDTH SHOWN WHERE GREATER THAN 10 FEET
- FRACTURE ZONE, WIDTH SHOWN WHERE GREATER THAN 10 FEET
- ALTERATION ZONE, WIDTH AS SHOWN

GEOPHYSICAL SURVEYS:

SW-1 INTERSECTION WITH SEISMIC REFRACTION LINE

DM-C 1975, DAMES & MOORE

SW-1 1978, SHANNON & WILSON

SL 80-2 1980, WOODWARD-CLYDE CONSULTANTS

SL 81-21 1981, WOODWARD-CLYDE CONSULTANTS

SL 82-1 1982, WOODWARD-CLYDE CONSULTANTS

SEISMIC VELOCITY CHANGE

12,000 FPS SEISMIC VELOCITY IN FEET PER SECOND

BOREHOLES:

BH-1

LITHOLOGY

F= FRACTURE ZONE

S= SHEAR

A= ALTERATION ZONE

DR-19 DH-1 COE ROTARY & DIAMOND CORE BORINGS

BH-1 AAI DIAMOND CORE BORING

OTHER:

W-5 INTERSECTION WITH GEOLOGIC SECTION W-5

GF 2 GEOLOGIC FEATURE DESCRIBED IN SECTION 5.

NOTES

1. SECTION LOCATION SHOWN ON FIGURE 5.2.
2. VERTICAL & HORIZONTAL SCALE EQUAL.
3. SURFACE PROFILE FROM 1" = 200' TOPOGRAPHY, COE, 1978.
4. EXPLORATION LOGS AND SEISMIC LINE SECTIONS SHOWN IN APPENDIX D AND AAI, 1982.
5. EXTENT OF SHEARS, FRACTURE ZONES, AND ALTERATION ZONES ARE INFERRED BASED ON GEOLOGIC MAPPING AND SUBSURFACE EXPLORATIONS, AND ARE SUBJECT TO VERIFICATION THROUGH FUTURE DETAILED INVESTIGATIONS.

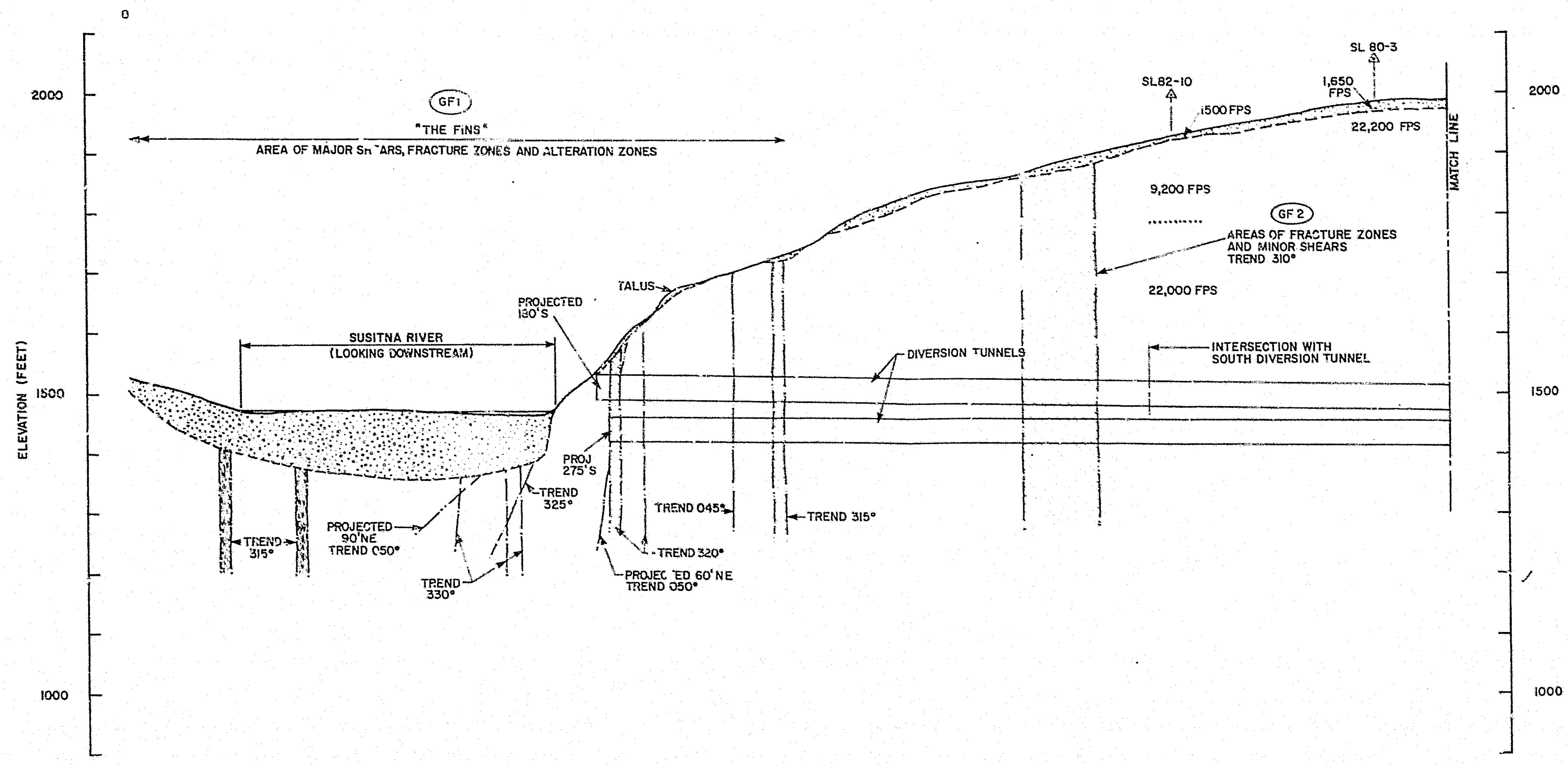
SCALE 0 100 200 FEET

WATANA DAMSITE
GEOLOGIC SECTION W-3
SHEET 2 OF 2

FIGURE 5.5

ACRES

086° ← AZIMUTH OF SECTION → 266°
LOOKING SOUTH



LEGEND

LITHOLOGY:

- OVERBURDEN, UNDIFFERENTIATED
- DIORITE TO QUARTZ DIORITE, INCLUDES MINOR GRANODIORITE
- ANDESITE PORPHYRY, INCLUDES MINOR DACITE & LATITE
- DIORITE PORPHYRY

CONTACTS:

- BEDROCK/SURFICIAL DEPOSITS
- BEDROCK, DASHED WHERE INFERRED

STRUCTURE:

- SHEAR, WIDTH SHOWN WHERE GREATER THAN 10 FEET
- FRACTURE ZONE, WIDTH SHOWN WHERE GREATER THAN 10 FEET
- ALTERATION ZONE, WIDTH AS SHOWN

GEOPHYSICAL SURVEYS:

- SW-1 INTERSECTION WITH SEISMIC REFRACTION LINE
- DM-C 1975, DAMES & MOORE
- SW-1 1978, SHANNON & WILSON
- SL 80-2 1980, WOODWARD-CLYDE CONSULTANTS
- SL 81-21 1981, WOODWARD-CLYDE CONSULTANTS
- SL 82-1 1982, WOODWARD-CLYDE CONSULTANTS
- .... SEISMIC VELOCITY CHANGE
- 12,000 FPS SEISMIC VELOCITY IN FEET PER SECOND

BOREHOLES:

BH-1
LITHOLOGY
F= FRACTURE ZONE
S= SHEAR
A= ALTERATION ZONE

- DR-19 DH-1 COE ROTARY & DIAMOND CORE BORINGS
- BH-1 AAI DIAMOND CORE BORING

OTHER:

- W-5 INTERSECTION WITH GEOLOGIC SECTION W-5
- GF 2 GEOLOGIC FEATURE DESCRIBED IN SECTION 5.

NOTES

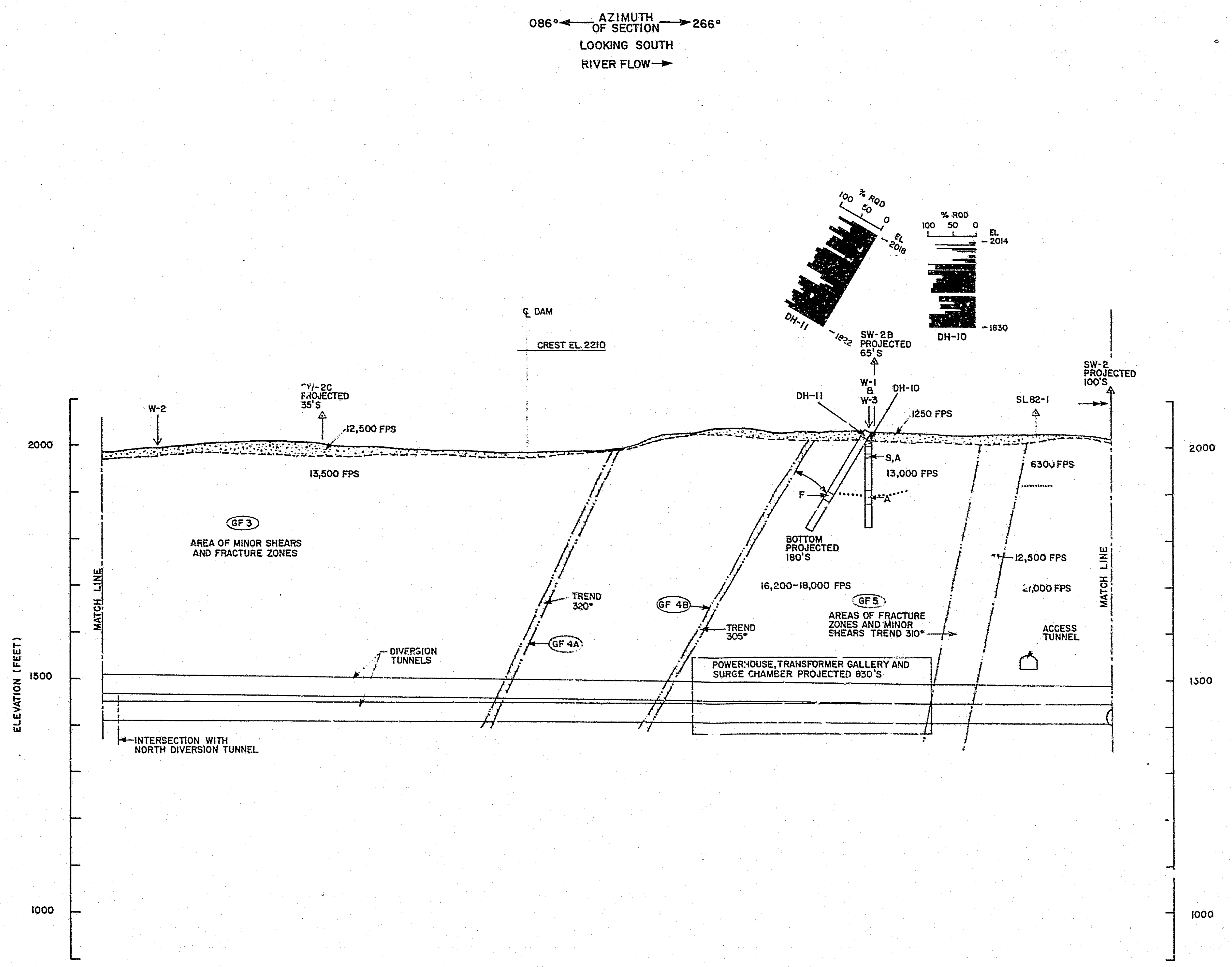
1. SECTION LOCATION SHOWN ON FIGURE 5.2.
2. VERTICAL & HORIZONTAL SCALE EQUAL.
3. SURFACE PROFILE FROM 1" = 200' TOPOGRAPHY, COE, 1978.
4. EXPLORATION LOGS AND SEISMIC LINE SECTIONS SHOWN IN APPENDIX D AND AAI, 1982.
5. EXTENT OF SHEARS, FRACTURE ZONES, AND ALTERATION ZONES ARE INFERRED BASED ON GEOLOGIC MAPPING AND SUBSURFACE EXPLORATIONS, AND ARE SUBJECT TO VERIFICATION THROUGH FUTURE DETAILED INVESTIGATIONS.

SCALE 0 100 200 FEET

WATANA DAMSITE
GEOLOGIC SECTION W-4
SHEET 1 OF 3

ACRES

FIGURE 5.6



LEGEND

LITHOLOGY:

- OVERBURDEN, UNDIFFERENTIATED
- DIORITE TO QUARTZ DIORITE, INCLUDES MINOR GRANODIORITE
- ANDESITE PORPHYRY, INCLUDES MINOR DACITE & LATITE
- DIORITE PORPHYRY

CONTACTS:

- BEDROCK/SURFICIAL DEPOSITS
- BEDROCK, DASHED WHERE INFERRED

STRUCTURE:

- SHEAR, WIDTH SHOWN WHERE GREATER THAN 10 FEET
- FRACTURE ZONE, WIDTH SHOWN WHERE GREATER THAN 10 FEET
- ALTERATION ZONE, WIDTH AS SHOWN

GEOPHYSICAL SURVEYS:

- SW-1 INTERSECTION WITH SEISMIC REFRACTION LINE
- DM-C 1975, DAMES & MOORE
- SW-1 1978, SHANNON & WILSON
- SL 80-2 1980, WOODWARD-CLYDE CONSULTANTS
- SL 81-21 1981, WOODWARD-CLYDE CONSULTANTS
- SL 82-1 1982, WOODWARD-CLYDE CONSULTANTS
- SEISMIC VELOCITY CHANGE
- 12,000 FPS SEISMIC VELOCITY IN FEET PER SECOND

BOREHOLES:

BH-1
LITHOLOGY
F= FRACTURE ZONE
S= SHEAR
A= ALTERATION ZONE

- DR-1S DH-1 COE ROTARY & DIAMOND CORE BORINGS
- BH-1 AAI DIAMOND CORE BORING

OTHER:

- W-5 INTERSECTION WITH GEOLOGIC SECTION W-5
- GF 2 GEOLOGIC FEATURE DESCRIBED IN SECTION 5.

NOTES

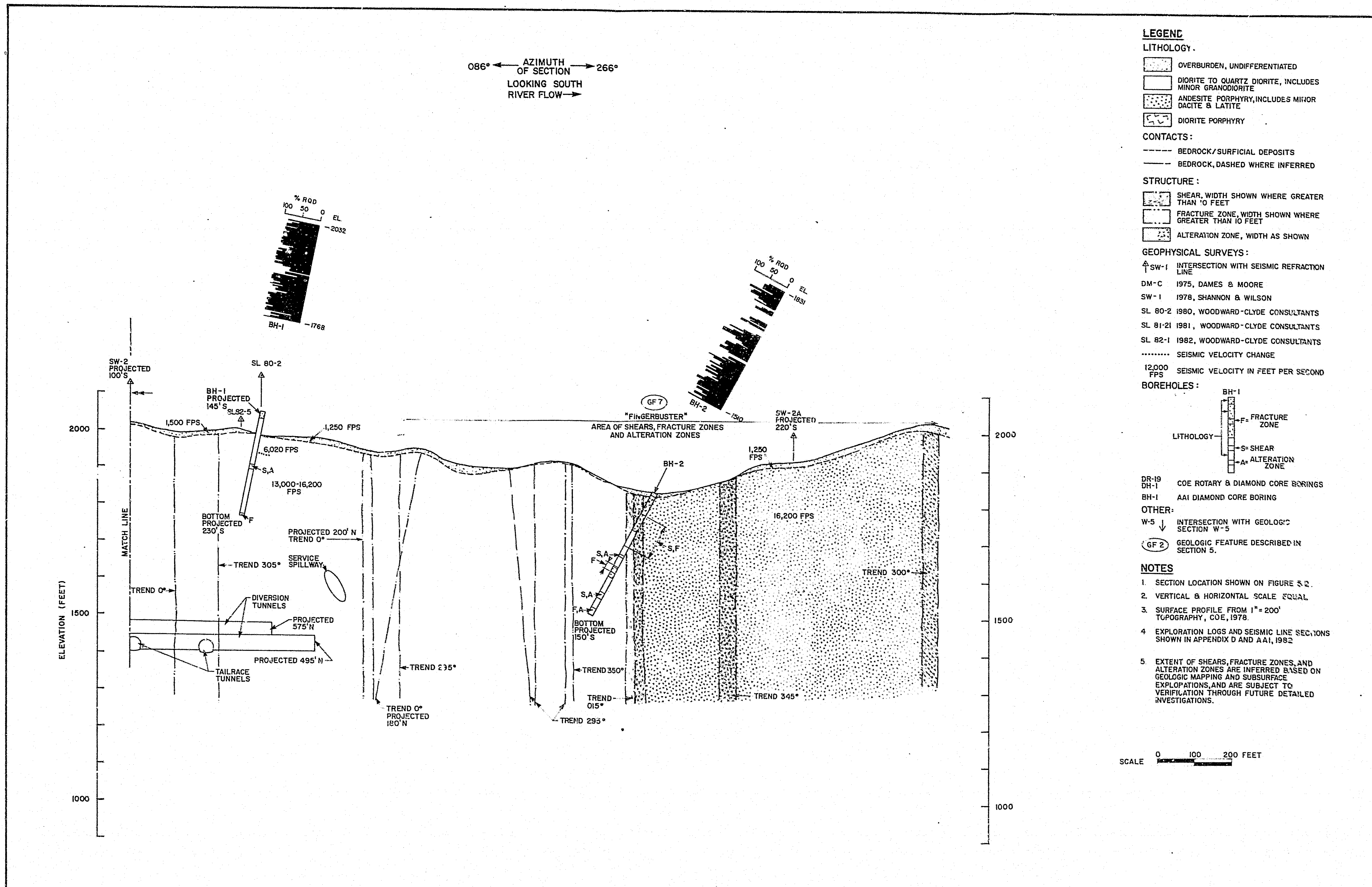
1. SECTION LOCATION SHOWN ON FIGURE 5.2.
2. VERTICAL & HORIZONTAL SCALE EQUAL.
3. SURFACE PROFILE FROM 1"=200' TOPOGRAPHY, COE, 1978.
4. EXPLORATION LOGS AND SEISMIC LINE SECTIONS SHOWN IN APPENDIX D AND AAI, 1982.
5. EXTENT OF SHEARS, FRACTURE ZONES, AND ALTERATION ZONES ARE INFERRED BASED ON GEOLOGIC MAPPING AND SUBSURFACE EXPLORATIONS, AND ARE SUBJECT TO VERIFICATION THROUGH FUTURE DETAILED INVESTIGATIONS.

SCALE 0 100 200 FEET

WATANA DAMSITE
GEOLOGIC SECTION W-4
SHEET 2 OF 3

ACRES

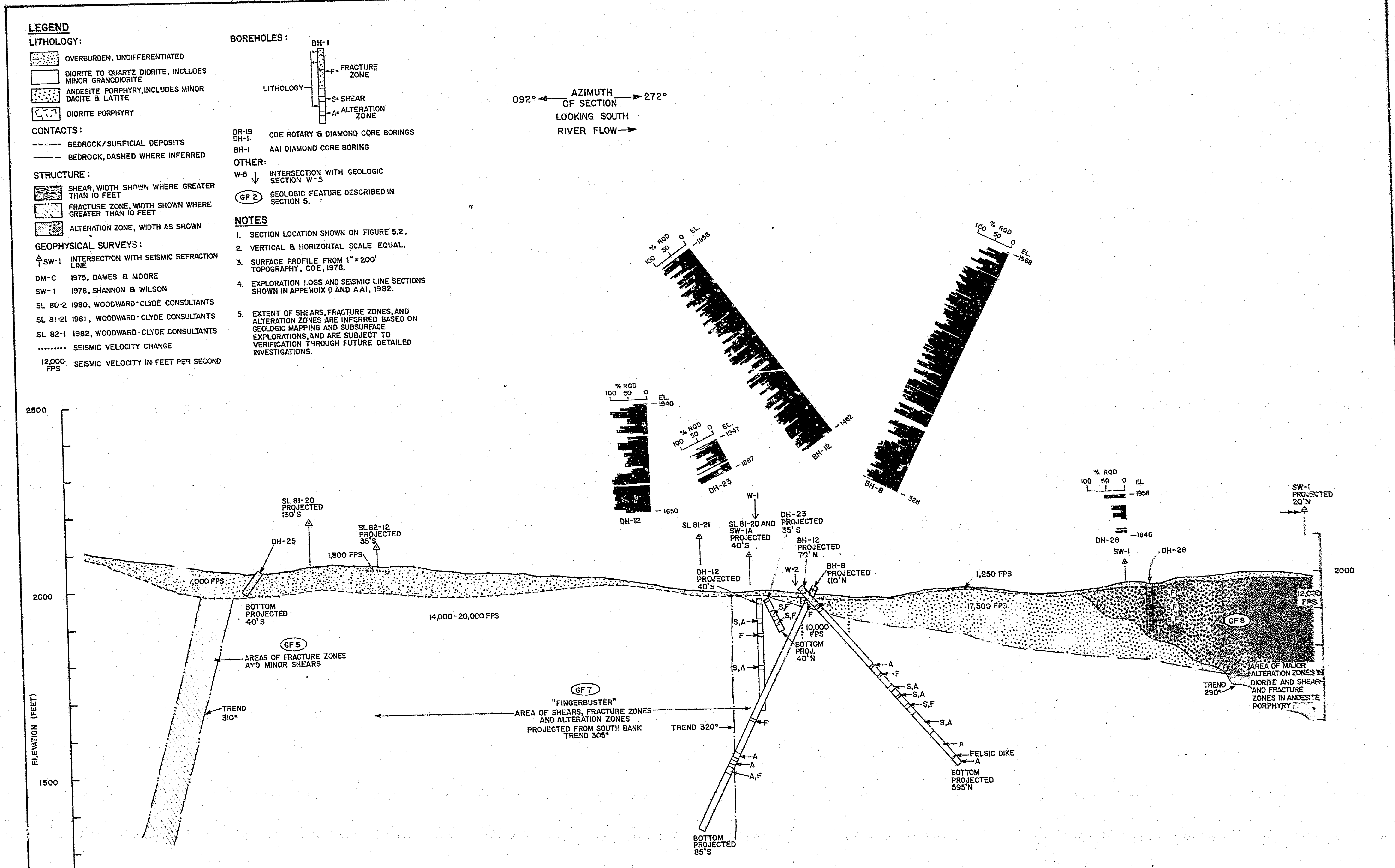
FIGURE 5.6



WATANA DAMSITE
GEOLOGIC SECTION W-4
SHEET 3 OF 3

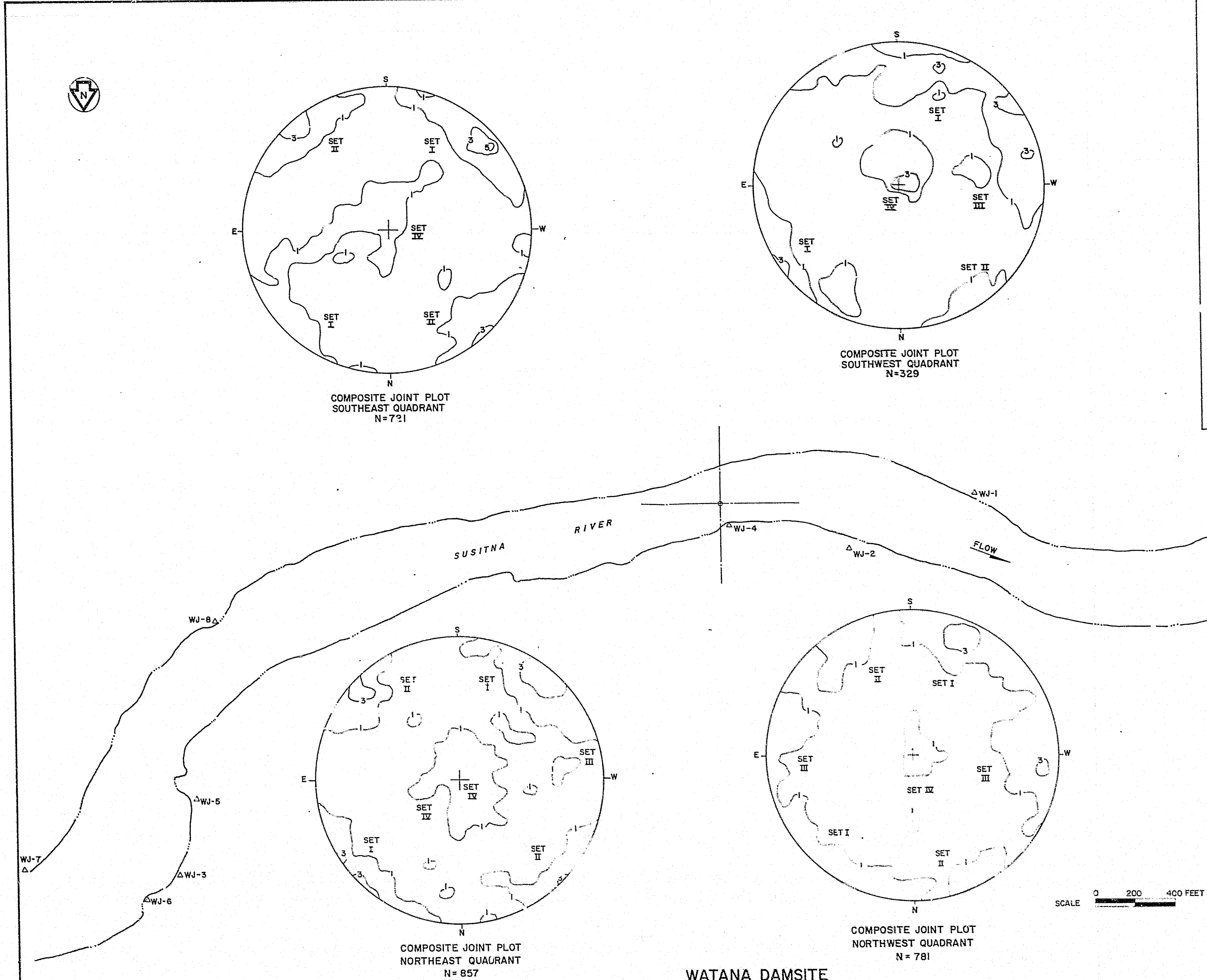
ACRES

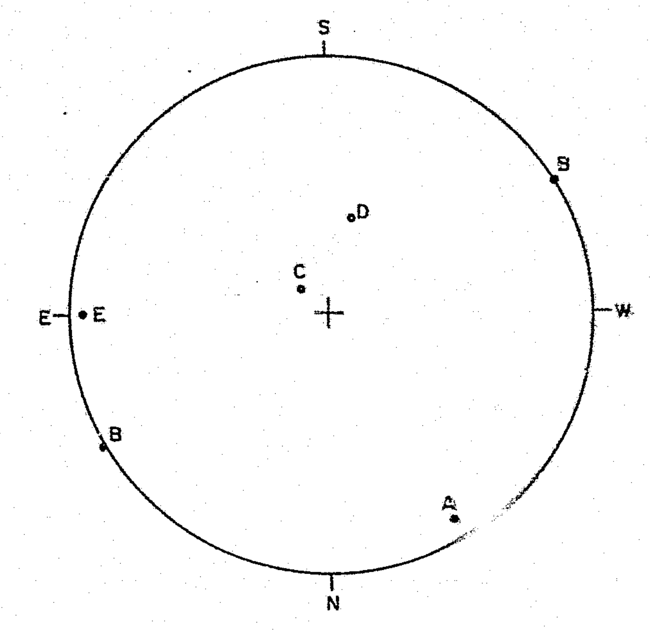
FIGURE 5.6



WATANA DAMSITE
GEOLOGIC SECTION W-5

FIGURE 5.7





POINT	STRIKE	DIP
A	060°	80° SE
B	330°	90°
C	045°	10° NW
D	285°	30° NE
E	0°	80° W

NOTE: PLOTTING BY PROJECTION OF PERPENDICULARS TO JOINT PLANES ON SURFACE OF LOWER HEMISPHERE. POINTS ARE PLOTTED ON AN EQUAL-AREA NET.

JOINT PLOTTING METHOD

NOTES

1. CONTOURS ARE PERCENT OF JOINTS PER 1% OF AREA. CONTOURS SHOWN – 1, 3, & 5%.
2. N EQUALS NUMBER OF DATA POINTS.
3. COMPOSITE PLOTS INCORPORATE ALL JOINT DATA FROM THEIR RESPECTIVE QUADRANTS.
4. JOINT PLOTS FOR JOINT STATIONS (WJ-1,2,3,4,5,6,7,8 & S) IN AAI, 1982.

WATANA DAMSITE
COMPOSITE JOINT PLOTS

ACRES

FIGURE 5.8

GF IP

VIEW LOOKING NORTH ALONG STRIKE
OF SHEAR; DIP 57° WEST
RIVER LEVEL - NORTH BANK
"THE FINS" AREA

NOTE:

1. GEOLOGIC FEATURE DESCRIBED IN SECTION 5.

WATANA DAMSITE
TYPICAL SHEAR

ACRES

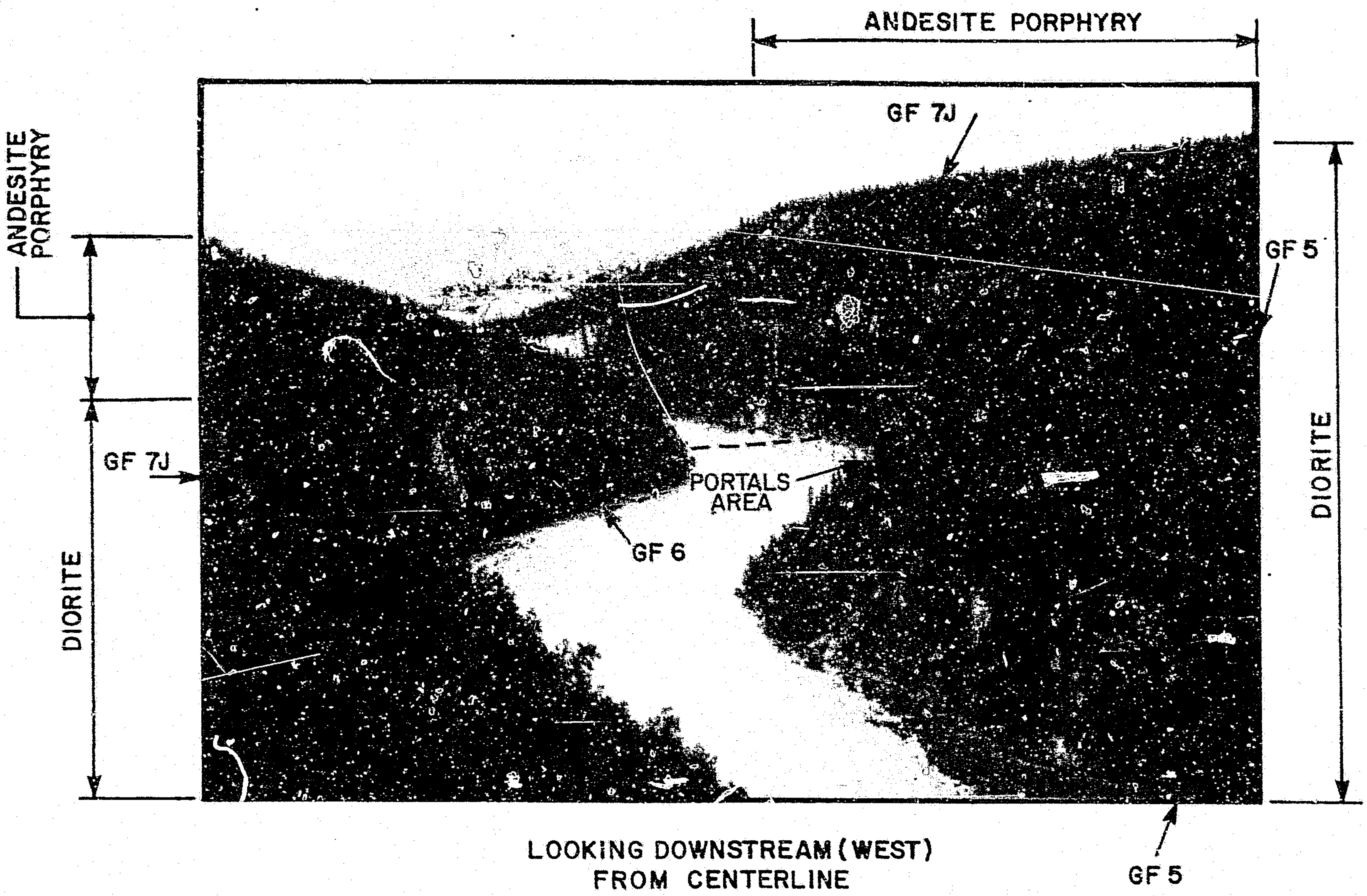
FIGURE 5.9

NORTH SIDE OF GF 10 SHEAR/ALTERATION ZONE
RIVER LEVEL-NORTH BANK "THE FINS" AREA

WATANA DAMSITE
SHEAR / ALTERATION ZONE
"THE FINS" AREA

ACRES

FIGURE 5.10



LOOKING DOWNSTREAM (WEST)
FROM CENTERLINE

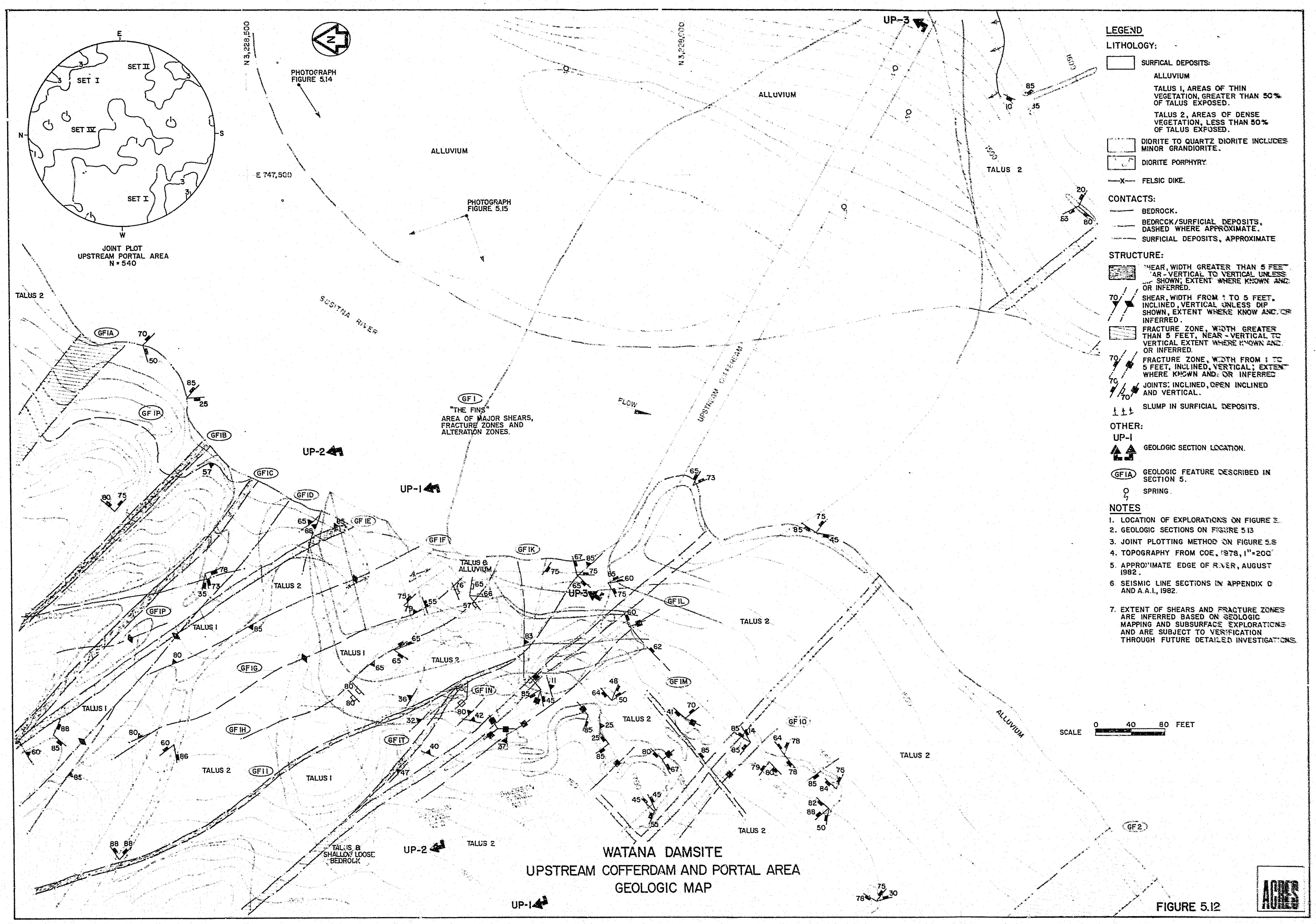
NOTES:

1. GEOLOGIC FEATURES DESCRIBED IN SECTION 5.
2. DASHED LINE IS ANDESITE PORPHYRY / DIORITE CONTACT.

WATANA DAMSITE
GEOLOGIC FEATURES DOWNSTREAM OF CENTERLINE

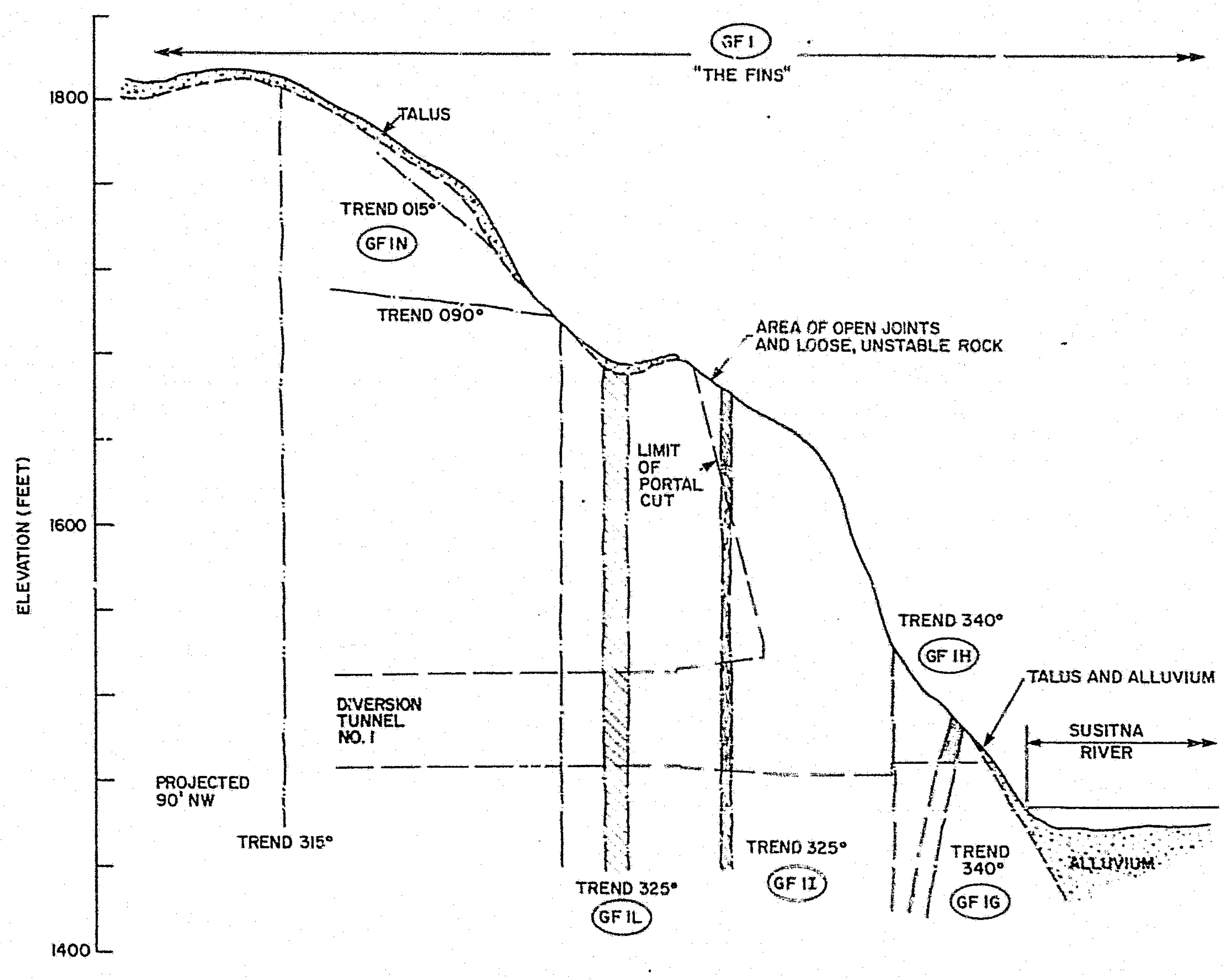
ACRES

FIGURE 5.11

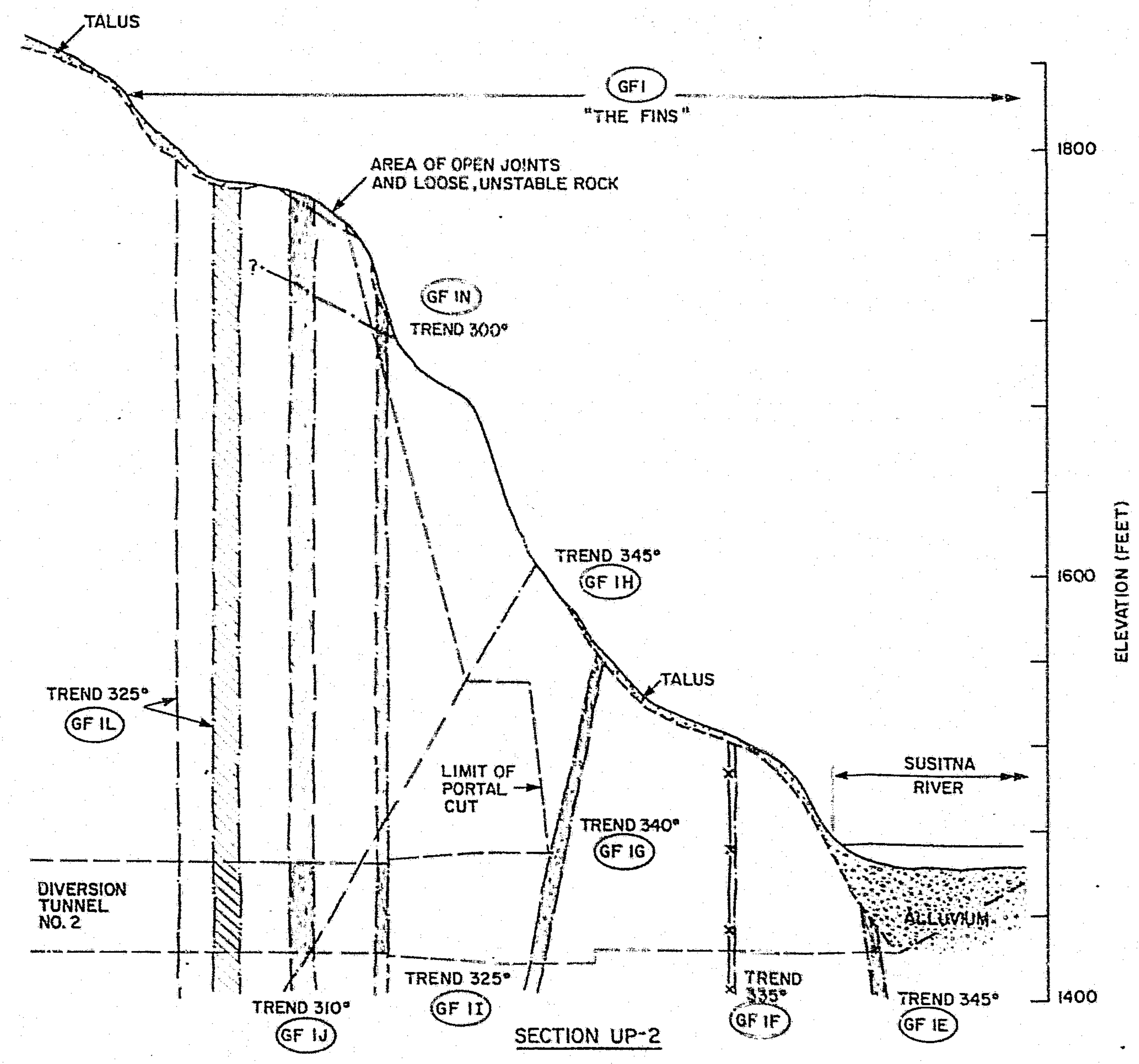


WATANA DAMSITE
UPSTREAM COFFERDAM AND PORTAL AREA
GEOLOGIC MAP

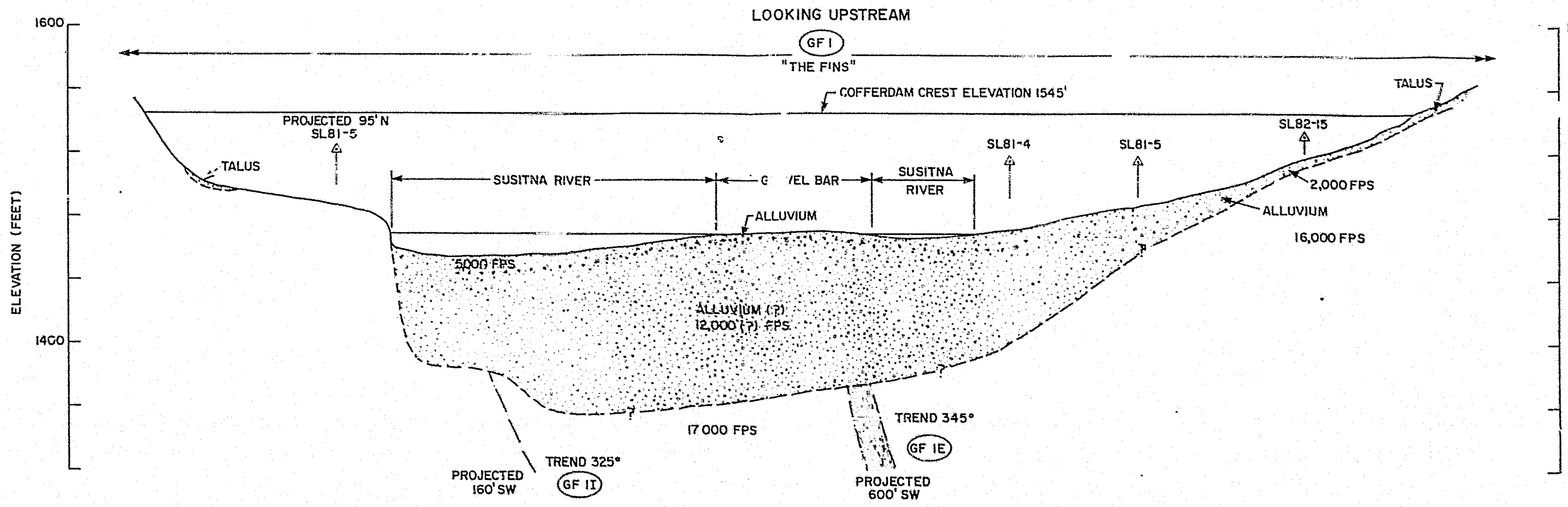
FIGURE 5.12



SECTION UP-1



SECTION UP-2



SECTION UP3

LEGEND

LITHOLOGY:

- SURFICIAL DEPOSITS: ALLUVIUM AND TALUS.
- DIORITE TO QUARTZ DIORITE, INCLUDES MINOR GRANODIORITE.
- FELSIC DIKE.

CONTACT:

- BEDROCK / SURFICIAL DEPOSITS, APPROXIMATE

STRUCTURE:

- SHEAR, WIDTH SHOWN WHERE GREATER THAN 5 FEET.
- FRACTURE ZONE, WIDTH SHOWN WHERE GREATER THAN 5 FEET.

GEOPHYSICAL SURVEYS:

- SL81-5 INTERSECTION WITH SEISMIC REFRA... LINE
- SL81-4 1981, WOODWARD-CLYDE CONSUL...
- SL82-15 1982, WOODWARD-CLYDE CONSULTANTS.
- ····· SEISMIC VELOCITY CHANGE.
- 5000 FPS SEISMIC VELOCITY IN FEET PER SECOND.

OTHER:

- GF IE GEOLOGIC FEATURE DESCRIBED IN SECTION 5

NOTES:

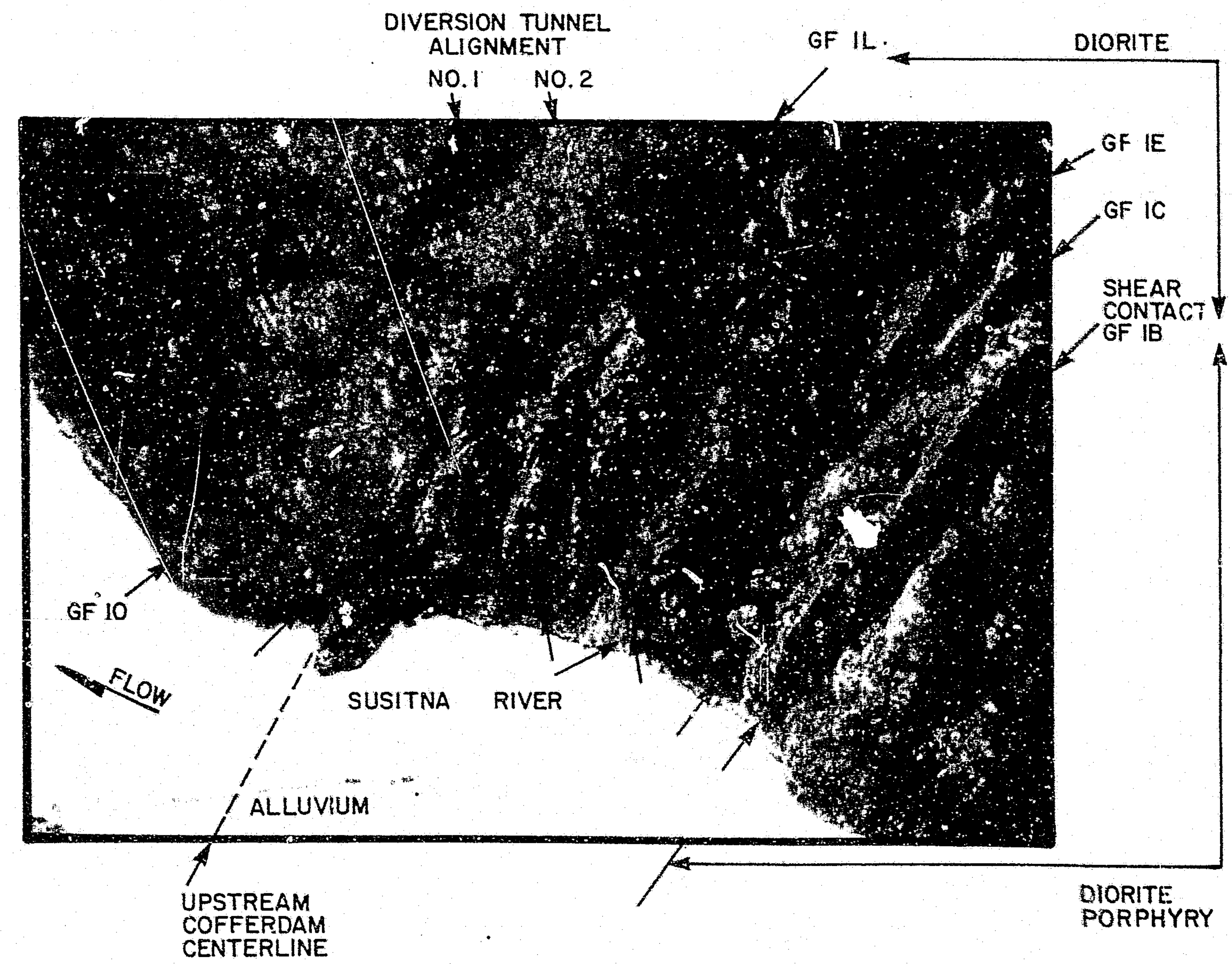
1. SECTION LOCATIONS SHOWN ON FIGURE 5.12.
2. VERTICAL AND HORIZONTAL SCALES EQUAL.
3. SURFACE PROFILE FROM 1"=200' TOPOGRAPHY COE, 1978.
4. SEISMIC LINE SECTIONS SHOWN IN APPENDIX D AND A.A.I., 1982.
5. EXTENT OF SHEARS, FRACTURE ZONES AND ALTERATION ZONES ARE INFERRED, BASED ON GEOLOGIC MAPPING AND SUBSURFACE EXPLORATIONS AND ARE SUBJECT TO VERIFICATION THROUGH FUTURE DETAILED INVESTIGATIONS.

SCALE 0 40 80 FEET

WATANA DAMSITE
UPSTREAM COFFERDAM AND DIVERSION PORTAL AREA
GEOLOGIC SECTIONS

ACRES

FIGURE 5.13



OBLIQUE AERIAL VIEW
LOOKING SOUTHWEST

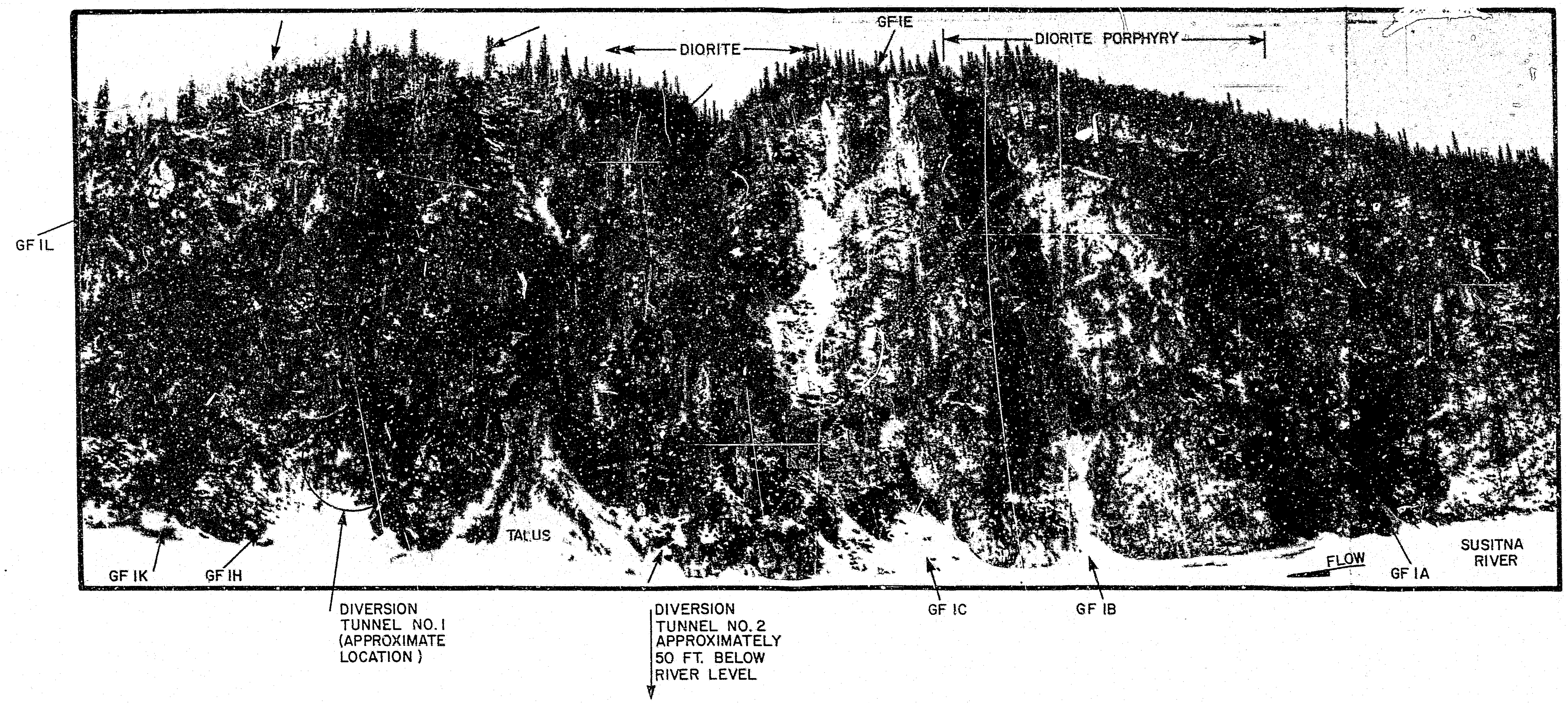
NOTES.

1. GEOLOGIC FEATURES DESCRIBED IN SECTION 5.
2. LOCATION OF PHOTOGRAPH SHOWN ON FIGURE 5.12
3. PHOTOGRAPH TAKEN SEPTEMBER, 1982.

WATANA DAMSITE
AERIAL VIEW OF UPSTREAM PORTAL AREA

ACRES

FIGURE 5.14



VIEW LOOKING WEST

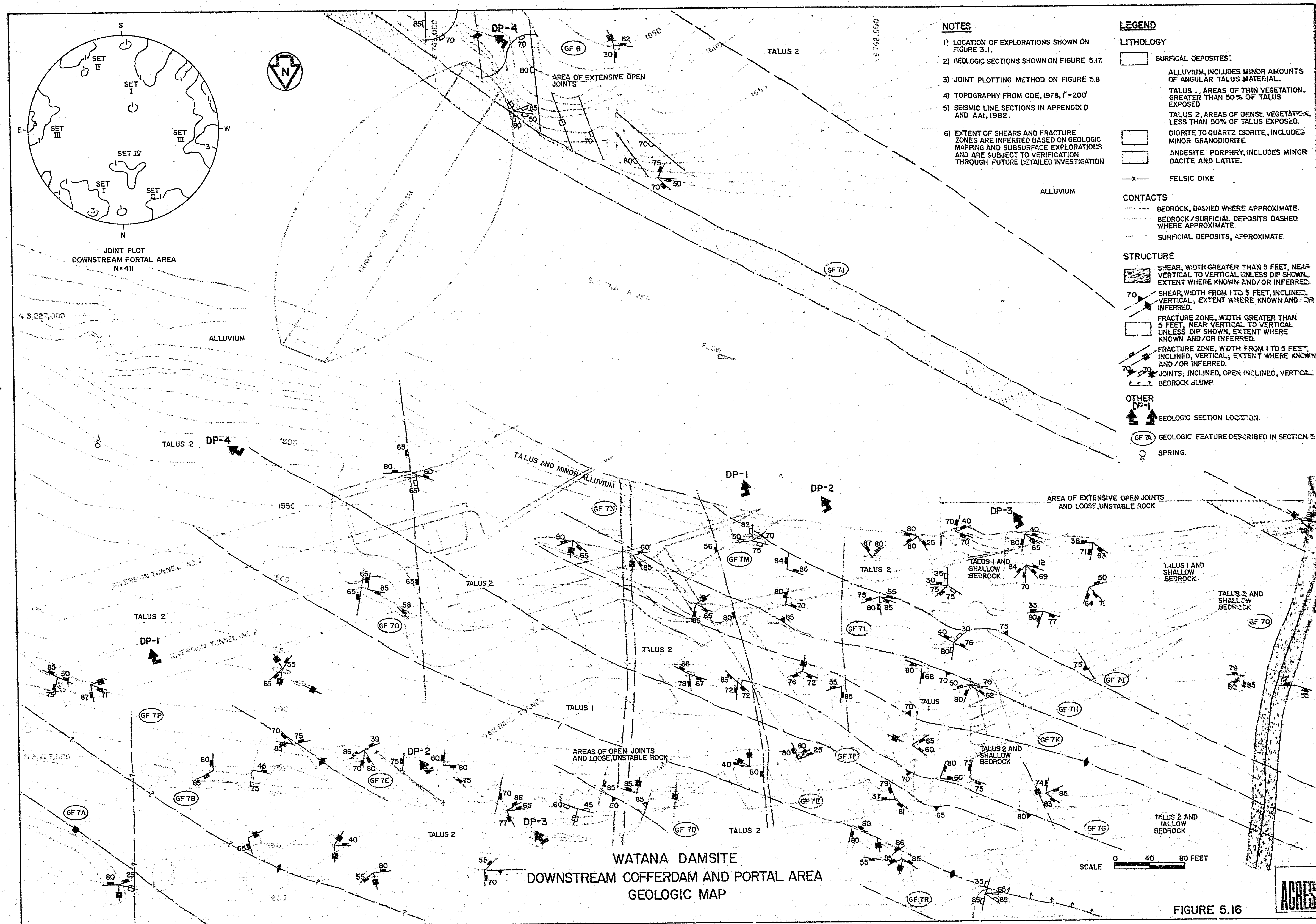
NOTES:

1. GEOLOGIC FEATURES DESCRIBED IN SECTION 5.
2. LOCATION OF PHOTOGRAPH ON FIGURE 5.12
3. PHOTOGRAPH FROM COE, 1978.

WATANA DAMSITE
PHOTOMOSAIC OF UPSTREAM PORTAL AREA

ACRES

FIGURE 5.15



WATANA DAMSITE
DOWNSTREAM COFFERDAM AND PORTAL AREA
GEOLOGIC MAP

FIGURE 5.16

LEGEND

LITHOLOGY:

- SURFICIAL DEPOSITS: ALLUVIUM AND TALUS.
- DIORITE TO QUARTZ DIORITE, INCLUDES MINOR GRANODIORITE.
- —X— FELSIC DIKE.

CONTACT:

- ----- BEDROCK/SURFICIAL DEPOSITS, APPROXIMATE.

STRUCTURE:

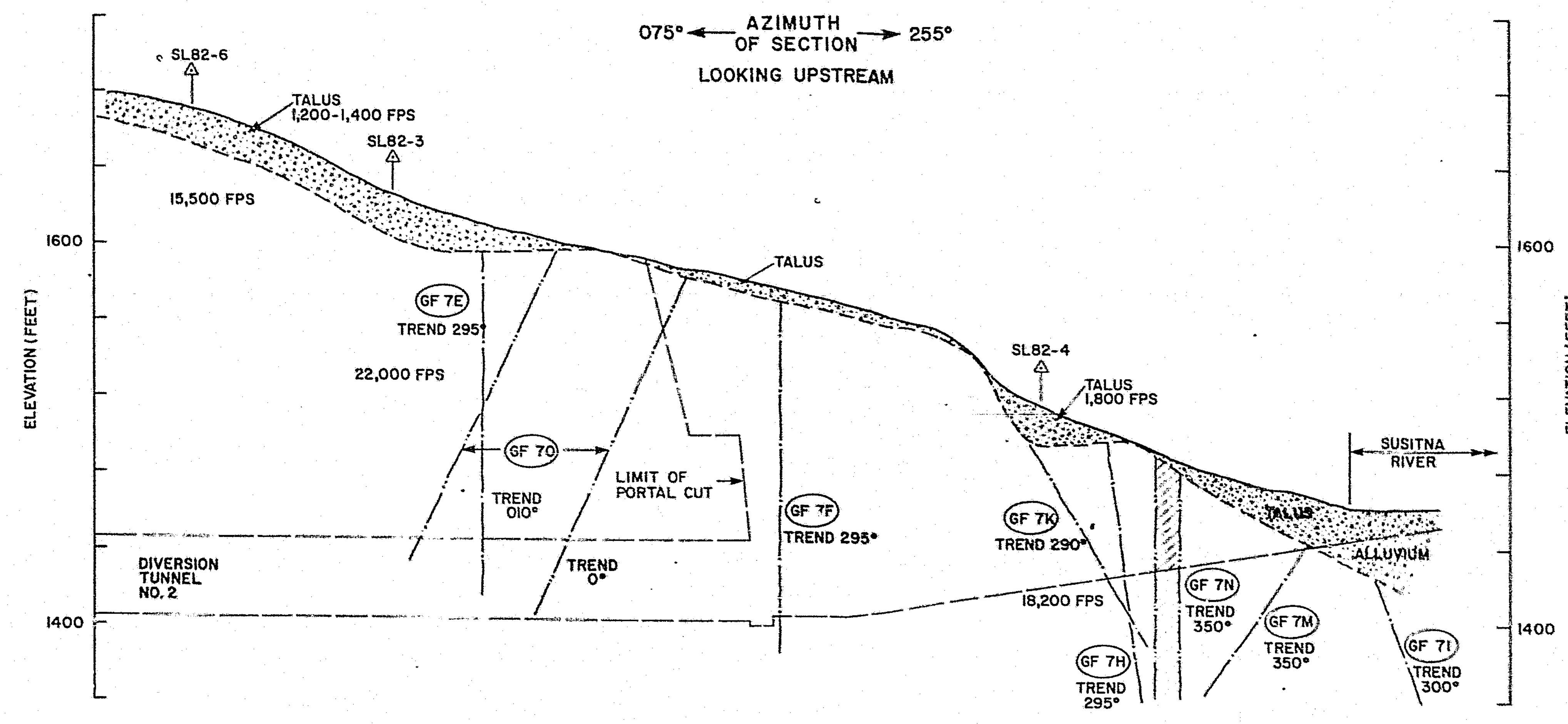
- SHEAR, WIDTH SHOWN WHERE GREATER THAN 5 FEET.
- FRACTURE ZONE, WIDTH SHOWN WHERE GREATER THAN 5 FEET.

GEOPHYSICAL SURVEYS:

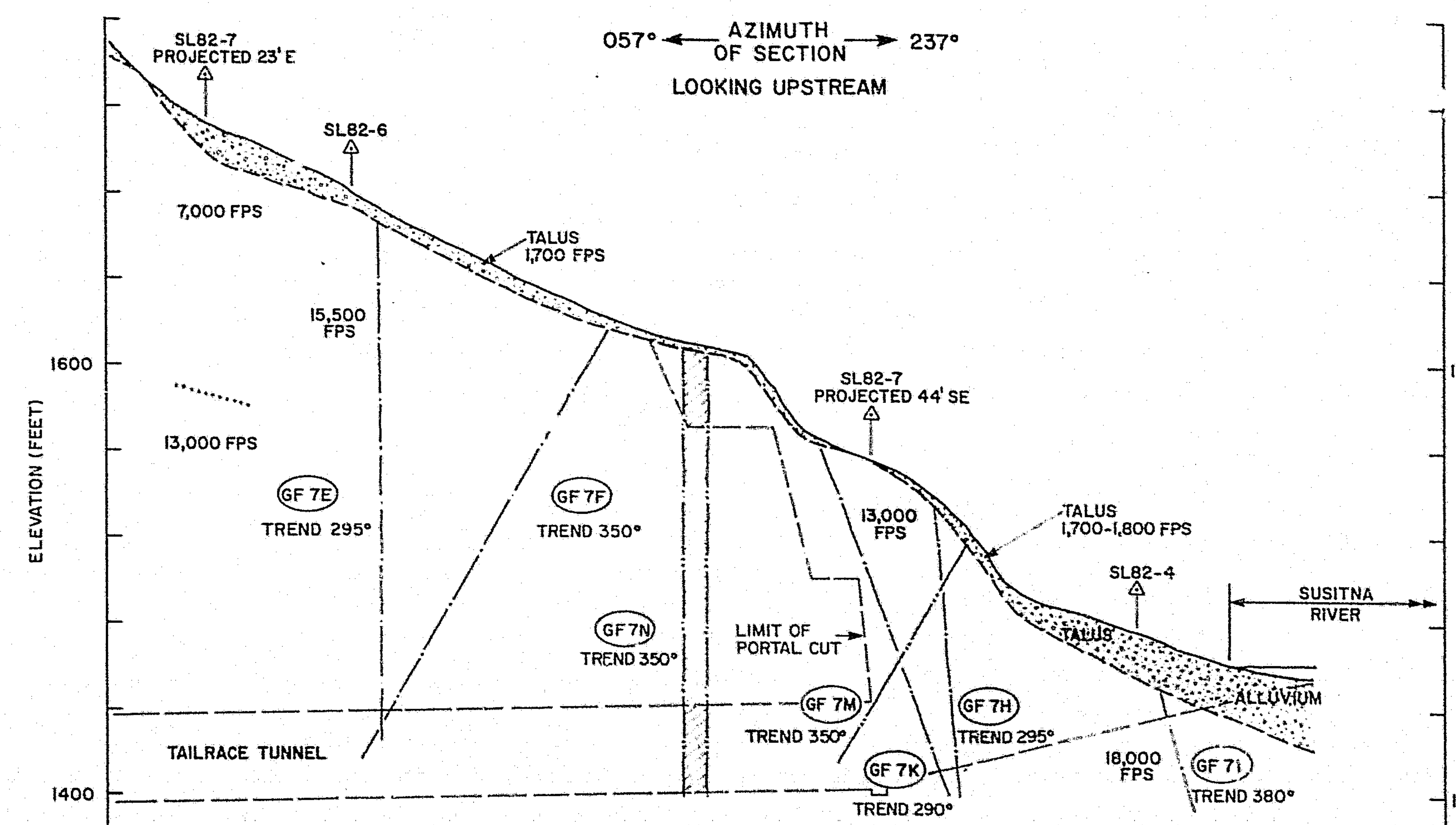
- SL82-I INTERSECTION WITH SEISMIC REFRACTION LINE.
- SL82-I 1982, WOODWARD-CLYDE CONSULTANTS.
- .... SEISMIC VELOCITY CHANGE.
- 5,000 FPS SEISMIC VELOCITY IN FEET PER SECOND.

OTHER:

- (GF 7E) GEOLOGIC FEATURE DESCRIBED IN SECTION 5.



SECTION DP-1



SECTION DP-2

NOTES:

1. SECTION LOCATIONS SHOWN ON FIGURE 5.16.
2. VERTICAL AND HORIZONTAL SCALES EQUAL.
3. SURFACE PROFILE FROM 1"=200' TOPOGRAPHY COE, 1978.
4. SEISMIC LINE SECTIONS SHOWN IN APPENDIX D.
5. EXTENT OF SHEARS, FRACTURE ZONES AND ALTERATION ZONES ARE INFERRED, BASED ON GEOLOGIC MAPPING AND SUBSURFACE EXPLORATIONS AND ARE SUBJECT TO VERIFICATION THROUGH FUTURE DETAILED INVESTIGATIONS.

SCALE 0 40 80 FEET

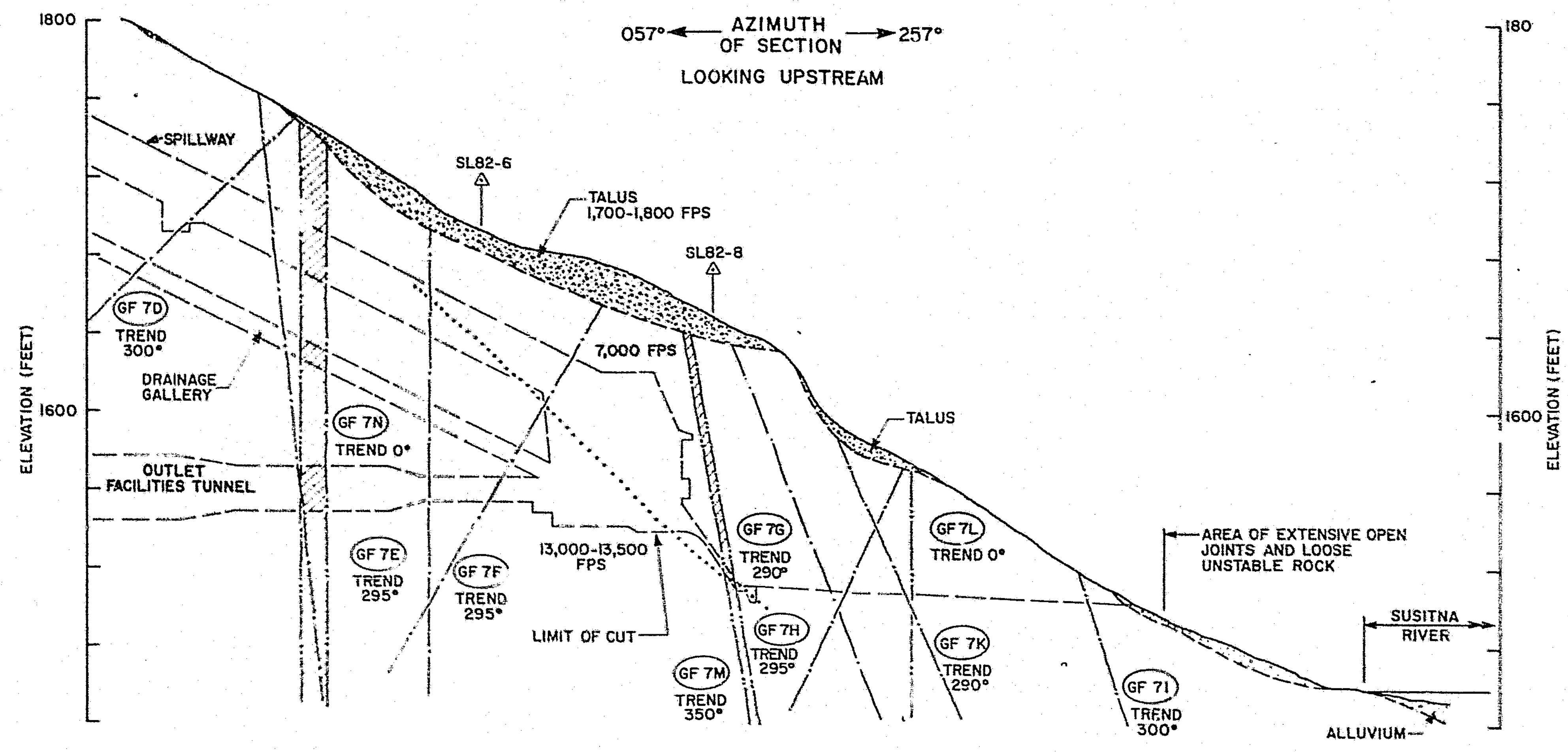
WATANA DAMSITE
DOWNSTREAM COFFERDAM AND PORTAL AREA GEOLOGIC SECTIONS
SHEET 1 OF 2

ACRES

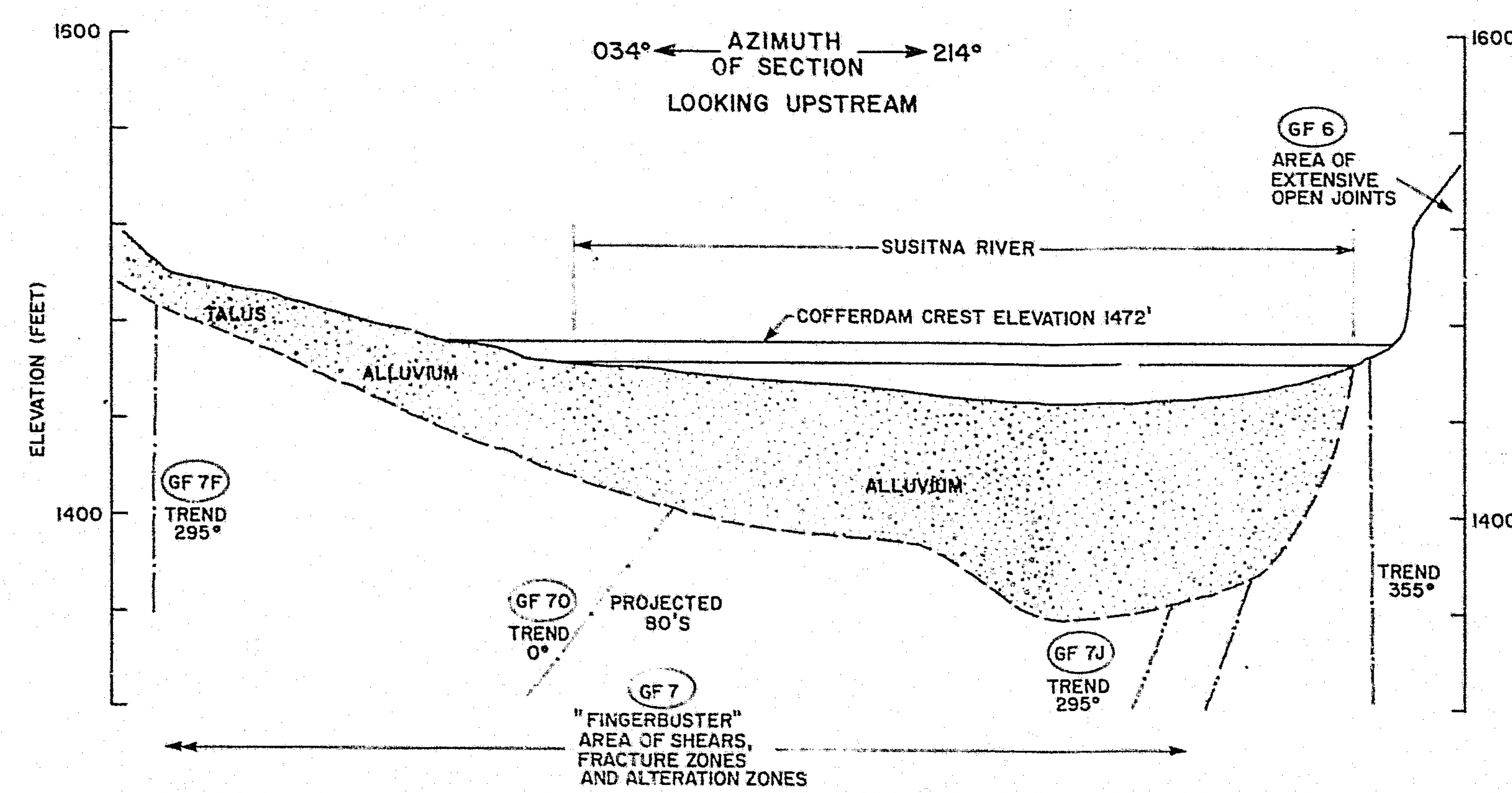
FIGURE 5.17

NOTE:

1. EXPLANATION FOR SYMBOLS ON SHEET 1.



SECTION DP-3



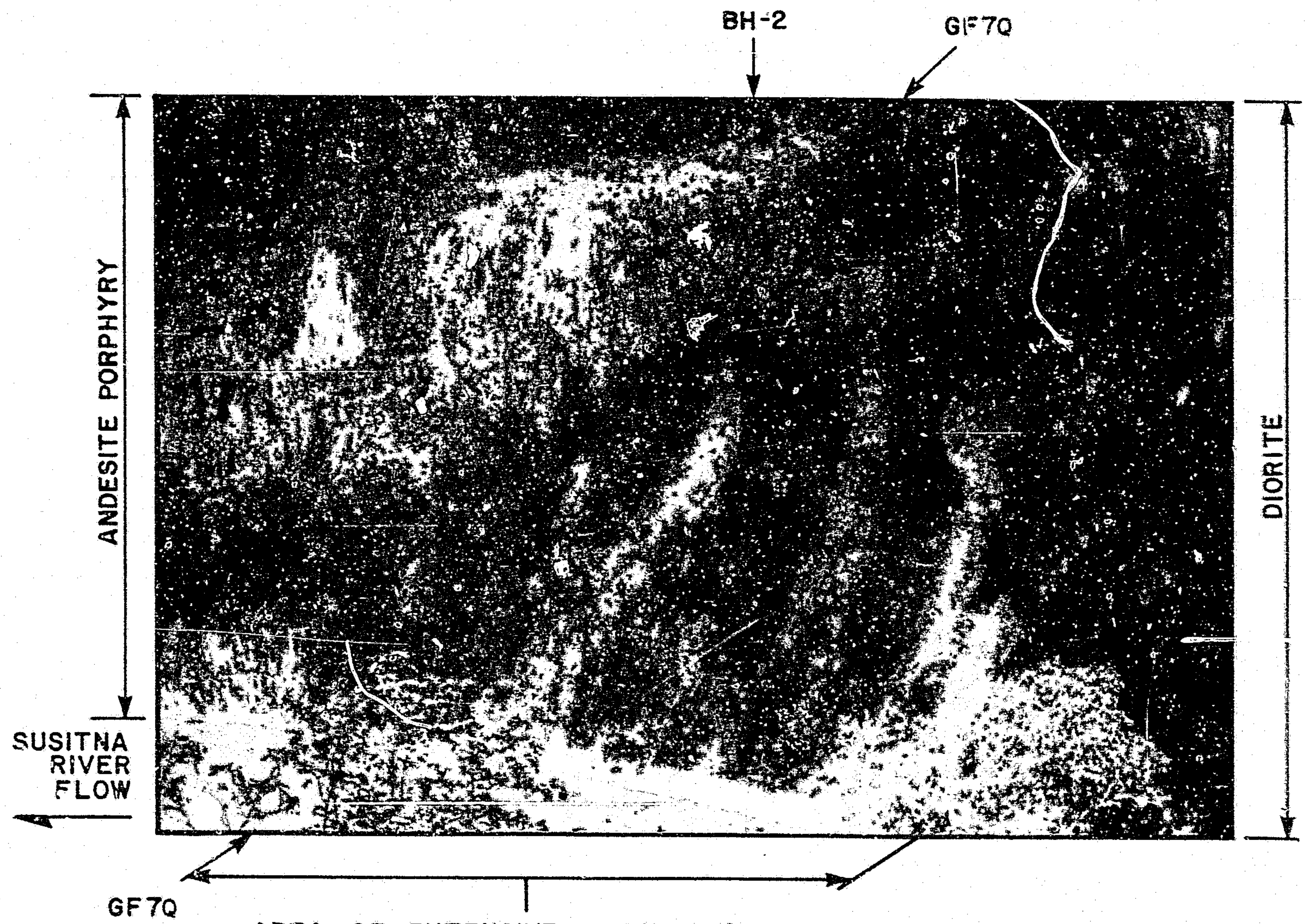
SECTION DP-4

SCALE 0 40 80 FEET

WATANA DAMSITE
DOWNSTREAM COFFERDAM AND PORTAL
AREA GEOLOGIC SECTIONS
SHEET 2 OF 2

FIGURE 5.17

ACRES



NOTES:

1. GEOLOGIC FEATURES IN "FINGERBUSTER" AREA DESCRIBED IN SECTION 5.
2. ANDESITE PORPHYRY / DIORITE CONTACT ALONG GF7Q SHEAR.
3. SHEARS WITHIN GF7 TREND FROM UPPER LEFT TO LOWER RIGHT.

WATANA DAMSITE
"FINGERBUSTER" AREA
NORTH BANK

ACRES

FIGURE 5.18

GF 7R

JOINT SET IV

JOINT SET IV

GF 7R

VIEW LOOKING NORTHWEST ALONG STRIKE OF ZONE.
NORTH BANK-ELEVATION 1850 FT.

NOTES:

1. GEOLOGIC FEATURE DESCRIBED IN SECTION 5.
2. JOINT SET IV DIPS TOWARDS SUSITNA RIVER.
3. JOINT SET I PARALLEL TO GF 7R

WATANA DAMSITE
TYPICAL SHEAR / FRACTURE ZONE
"FINGERBUSTER" AREA

ACRES

FIGURE 5.19

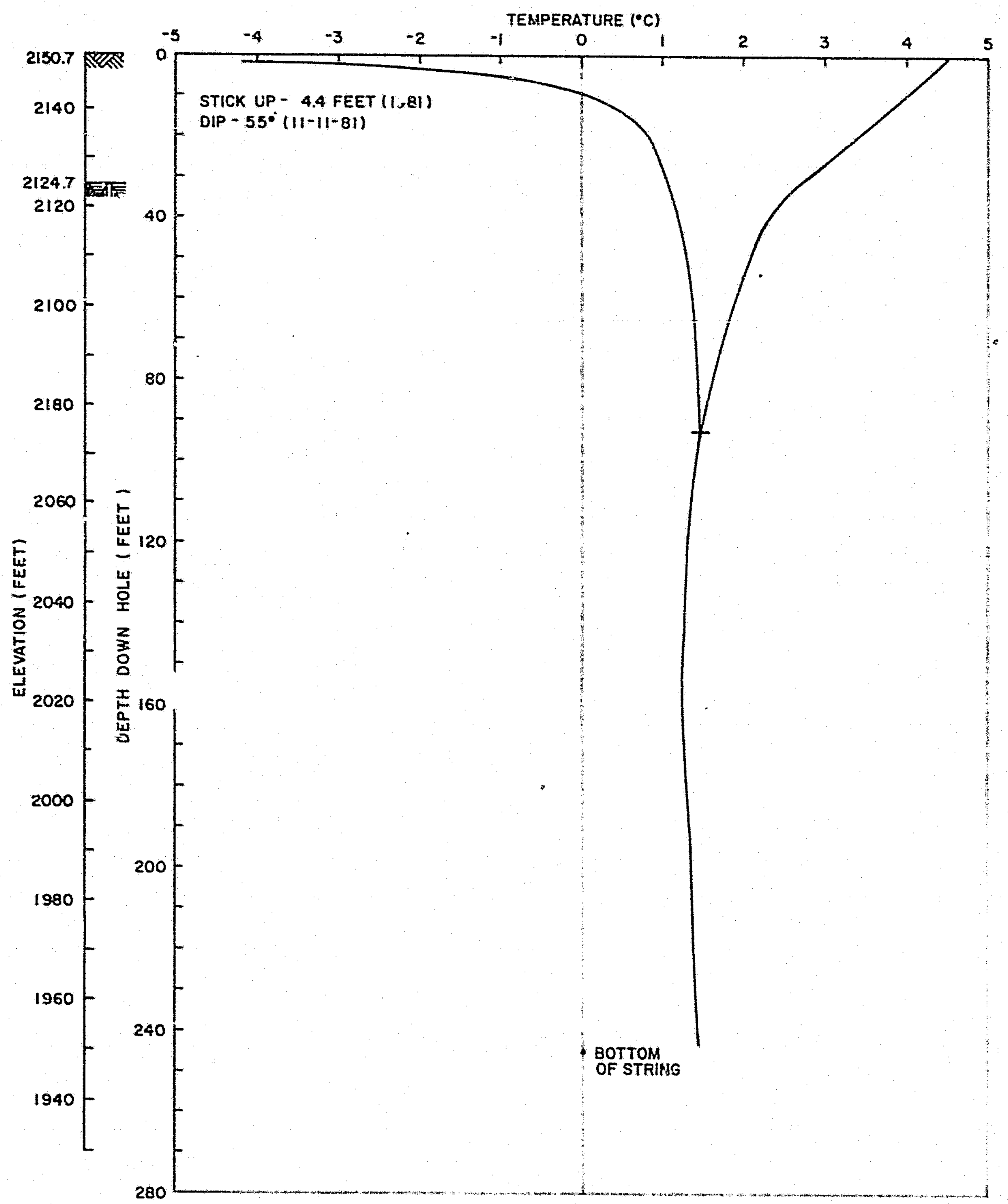
VIEW LOOKING NORTHWEST
ALONG STRIKE OF SHEAR
RIVER LEVEL - NORTH BANK

NOTE:
GEOLOGIC FEATURES IN THE "FINGERBUSTER" (GF 7) AREA ARE DESCRIBED IN SECTION 5.

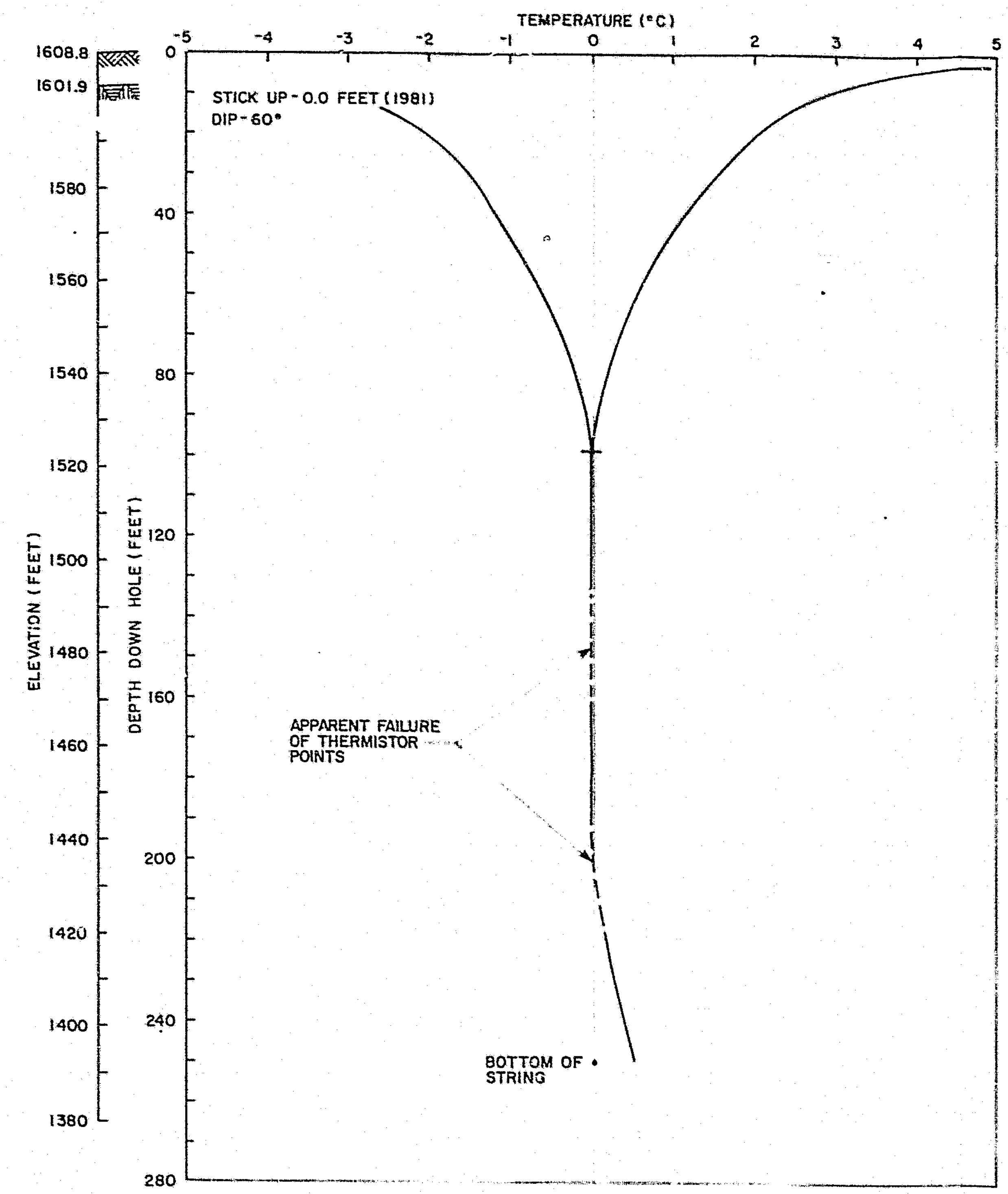
WATANA DAMSITE
GEOLOGIC FEATURE GF 7J
"FINGERBUSTER" AREA

FIGURE 5.20

ACRES



BH-3



BH-6

LEGEND

LITHOLOGY:

GROUND SURFACE

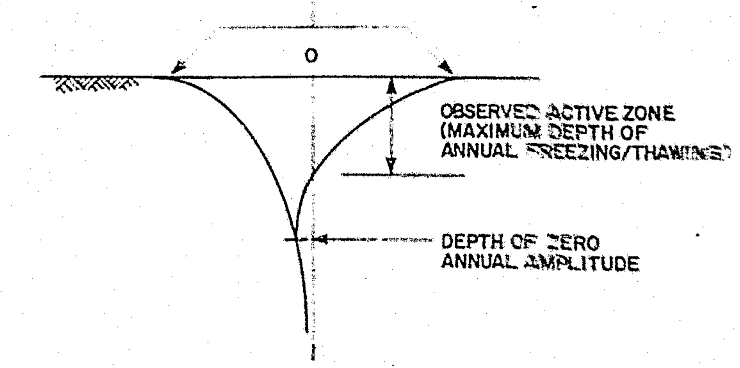
TOP OF ROCK

BOREHOLES:

AP	AUGER BORING	CORPS OF ENGINEERS (1978)
DH	DIAMOND CORE BORING	
DR	ROTARY DRILL HOLE	
AH	AUGER HOLE	ACRES AMERICAN INCORPORATED (1980 - 1982)
BH	BORE HOLE	

DATA SYMBOLS:

ENVELOPE SHOWING RANGE OF OBSERVED TEMPERATURES



NOTES

1. LOCATION OF BORINGS SHOWN ON FIGURES 3.1 AND 3.2.
2. THERMISTOR STRINGS MANUFACTURED BY INSTRUMENTATION SERVICES IN FAIRBANKS, ALASKA
3. BORINGS BH-3, BH-6 ARE PERMANENT MULTI-POINT THERMISTOR STRINGS WITH TWO THERMISTORS AT EACH READING POINT. DATA FOR TWO POINTS IS AVERAGED. ALL OTHER BORINGS ARE PVC PIPE, CAPPED AND FILLED WITH ANTIFREEZE (ETHYLENE GLYCOL) MIXTURE READINGS TAKEN WITH A THERMISTOR CABLE FITTED WITH REDUNDANT (SINGLE PRIOR TO 1981) THERMISTOR.
4. THERMISTOR READOUT BOXES MANUFACTURED BY KEITHLEY [illegible] AND FLUKE, USED FOR 1980 THROUGH 1982 READINGS.
5. TOP OF ROCK ELEVATIONS SHOWN ONLY WHEN ENCOUNTERED.
6. BORINGS ARE VERTICAL UNLESS A DIP IS SHOWN.

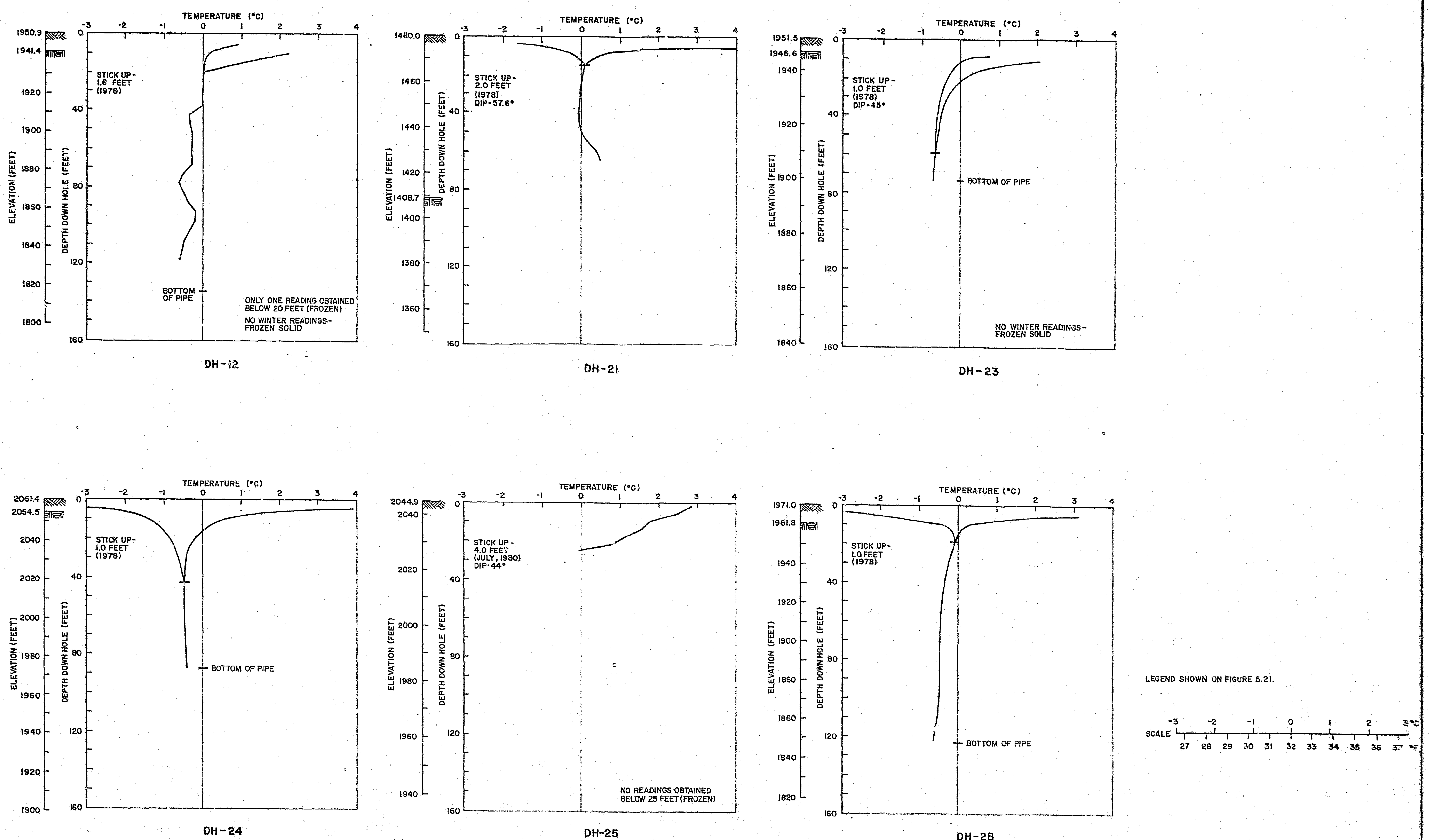
SCALE

°C	-3		-2		-1		0		1		2		3
°F	27	28	29	30	31		32	33	34	35	36	37	

WATANA DAMSITE
THERMISTOR DATA
SHEET 1 OF 2

ACRES

FIGURE 5.21



WATANA DAMSITE
THERMISTOR DATA
SHEET 2 OF 2

ACRES

FIGURE 5.21

6 - RESULTS OF GEOTECHNICAL INVESTIGATIONS - WATANA RELICT CHANNEL

6.1 - Introduction

During the course of investigations carried out by the COE and Acres, subsequent studies in 1980-81 confirmed the existence of a possible buried relict channel running from the Susitna River gorge from immediately upstream of the proposed damsite to Tsusena Creek, a distance of approximately 1.5 miles.

The major potential problems associated with the relict channel are:

- breaching of the reservoir rim resulting in catostrophic failure of the reservoir; and

- subsurface seepage resulting in potential downstream piping and/or lose of energy.

Breaching of the reservoir rim can be caused by saturation of the unconsolidated sediments within the channel resulting in surface settlement or by liquefaction during an earthquake.

Excessive subsurface seepage can be caused by highly permeable unit(s) within the channel that would provide a continuous flow path between the reservoir and Tsusena Creek.

As a result of these potential problems, a geotechnical program was undertaken during 1980-81 (1) to obtain a better understanding of the channel configuration and geology. However, due to excessive depths of the channel (>400 feet), difficulties of drilling through bouldery material and logistical and cost constaints, no information regarding the deep stratigraphy of the channel was obtained during 1980-81.

Therefore, Acres undertook supplemental investigations to include drilling, field mapping, laboratory testing, instrumentation installation and seismic refraction surveys during the summer 1982 season (Figure 3.2). Additional deep drilling and seismic investigations were also planned to complement the summer investigations during FY 83. The objective of these investigations was to refine the stratigraphy of the Watana Relict Channel/Borrow Site D area; determine material properties of the strata; and provide information on the permafrost and hydrogeological conditions. Results of these investigations are presented in the following section. A surficial geologic map of the area is shown on Figure 6.1. Figure 6.2 is a generalized stratigraphic column for the Watana Relict Channel/Borrow Site D area. The correlation of this stratigraphy across the area is shown on Figure 6.3 and 6.4, with photographs of these materials in Figure 6.5. Contour maps of the various stratigraphic units is in Figure 6.6. The information presented here supersedes that information presented in Section 6.2 of the 1980-81 Geotechnical Report (1).

6.2 - Location and Configuration

The Watana Relict Channel, as defined in this report, is located between the present course of the Susitna River and Tsusena Creek, and fills an area from the emergency spillway location (Figure 1.2) to Deadman Creek. Borrow Site D is located in the southeast quarter of the channel and overlies the major portion of the inlet area near the Susitna River.

The location of the channel is shown by the top-of-rock map presented in Figure 6.7.

The ground surface in the relict channel area is hummocky with a drainage divide trending generally north to northeast through the area which closely corresponds with seismic lines DM-A and DM-B (Figure 3.2).

The maximum overburden thickness in the thalweg channel is approximately 450 feet (Figure 6.4). The distance between the proposed reservoir and Tsusena Creek along the shortest distance through the channel is approximately 6,200 feet and about 7,700 along the thalweg section (Figure 6.7).

The thalweg course is somewhat irregular, diverting from the Susitna valley downsteam of Deadman Creek at a point near seismic line SL82-22. The channel trends with an uphill gradient parallel to the Susitna River to a point near AH-D30 (see Figures 3.2 and 6.7).

From AH-D30, the channel diverts northwesterly, with a steep downward gradient, to a bedrock low located northwest of DR-22 (Figure 6.7). Bottom elevation of this pool has been estimated from seismic refraction data and borehole DR-22. Beyond the pool, the channel runs through a narrow gorge rising to an elevation of approximately 1,800 feet from where it continues to its confluence with Tsusena Creek (Figure 6.7).

Minor tributaries to the Watana Relict Channel are found near Tsusena Creek. These tributaries flow in a southwesterly direction, and may be partially joint controlled (Figure 5.8 and Section 5.1 [c]). A buried waterfall appears to exist in one tributary, immediately adjacent to Tsusena Creek.

Details of the paleo-drainage regime, and the sequence of events leading to the formation of the relict channel are given in Section 5.4.

6.3 - Stratigraphy of the Watana Relict Channel/Borrow Site D

Twelve stratigraphic units have been delineated in the Watana Relict Channel/Borrow Site D area (Figure 6.2). These units (denoted as Units A through K) are differentiated by their physical properties, as identified in the field, and their material characteristics. Cross sections and a fence diagram of the relict channel are shown in Figure 6.3 and 6.4. Photographs of the typical units and top of unit maps are presented in Figure 6.5 and 6.6. Surficial distribution of those units is indicated on Figure 6.1.

Field identification of these units was based on drilling, in-hole testing, mapping of outcrop exposures, and geomorphology. Distinguishing properties include color, grain size, roundness of particles, compaction, imbrication, composition, lithology, sorting, weathering and striations. Material properties obtained from laboratory tests on samples from drilling and bulk samples taken from exposures along Tsusena and Deadman Creek included grain size, moisture content, Atterberg Limits and composition of sample wash residue. Typical stratigraphic unit gradations and standard penetration test data for these units are shown in Figures 6.8 through 6.10.

The unit breakdown has been based on specific modes of deposition (i.e. glacial advance, retreat, ablation, etc.). Due to the complexity of glacial and paraglacial depositional environments, wide variations in material properties and physical characteristics within specific units are encountered. However, for the most part, these variations are indicative of localized facies changes and/or local anomalies within the unit and have, therefore, been classified within the overall unit.

Detailed discussion of material properties of Units A through F are presented in Section 8.2. The following is a brief description of stratigraphic units used in delineating the stratigraphy in Borrow Site D and the relict channel. As additional information is collected, refinement of the unit breakdown is likely. Table 6.1 and 6.2 list the interpreted depth to the top of stratigraphic units and the unit thickness.

(a) Unit A/B - Surficial Deposits

Unit A/B is the uppermost unit found in the area, and consists primarily of frost-heave cobbles and boulders, organic silts, peat and muck. This unit forms a thin, discontinuous veneer (0-7 feet thick) that has been subjected to post-glacial erosion, frost heaving and vegetative decomposition. Its composition is variable. In undrained lowland areas, Unit A/B consists of peats and organic silts, while in drained low areas, it often consists of large boulders and cobbles which have been raised to the surface by frost action. Such boulder fields are found frequently across the site, and were likely formed within a paraglacial environment where the fine material has been washed away. In higher areas underlain by shallow bedrock, the unit is generally thin or absent.

(b) Unit C - Ice Disintegration Deposits

Unit C is an ice disintegration deposit forming a discontinuous mantle across the Watana Relict Channel/Borrow Site D area. This unit is geomorphically expressed as a knob and kettle topography, typical of ice disintegration terrain. Local knobs of Unit C generally range from 5 to 40 feet thick. The unit is found most frequently in the northern portion of the area, where it forms moraine-type ridges, while it is often absent in the southern portion of the area toward the Susitna River (Figure 6.1). Being near surface, Unit C is easily identified in the field and on air photos by its hummocky topography.

The unit is composed of tan to brown silty sand with subangular gravel and cobbles throughout (Figures 6.5 and 6.8). The unit is generally poorly sorted, although local areas of sorting are present due to flowing water during ice melting. Some pebbles and cobbles are weakly striated. The degree of compaction is variable though generally, density tends to increase with depth.

(c) Unit D - Alluvium

Unit D is an alluvium found locally as confined channels within the upper surface of Units E/F (Figure 6.6) (Section 6.3 [f] and Figures 6.1 and 6.3). It is occasionally found near the ground surface where Unit C has been eroded by present day drainage. It is most extensively found within the Watana Relict Channel area, and is less common in Borrow Site D.

The unit is composed of stratified sand, silt, gravel and cobbles in sorted layers (Figure 6.5). Particles are generally rounded to subrounded, with coarse material generally found in a matrix of sand and silt. Thickness of the unit varies from 0 to greater than 40 feet.

(d) Unit D' - Lacustrine Deposits

Unit D' is a discontinuous lacustrine unit found locally across the Watana Relict Channel/Borrow Site D area. These lacustrine deposits have been observed in thickness from 0 to 21 feet, and are principally found within low areas of the upper surface of Unit E/F (Section 6.3[f]). They are occasionally overlain by Unit D but can also be found directly under Unit C. No surficial exposures of the unit have been found.

The unit is generally composed of a gray laminated clay which occasionally shows evidence of rhythmic deposition and varves (Figure 6 5). Local facies changes to silt and fine sand, which also show laminations and evidence of lacustrine deposition.

(e) Unit M - Basal Till

Unit M is a basal till, found in the Borrow Site D adjacent to the Susitna River valley (Figure 6.1). Unit M lies stratigraphically between Units C and E/F, and ranges in observed thickness from 0 to 80 feet.

The unit appears as a very dense gray clay matrix containing angular striated gravel and cobbles (Figure 6.5). The unit appears similar to Unit G' in drilling samples. Examination of washed sample residue indicates however, that the coarse fraction contains much more mafic rock types than does Unit G' (Section 6.3[g]). No evidence of Unit M was found in the Watana Relict Channel area or in the northern portions of Borrow Site D.

(f) Units E/F - Outwash

Units E/F form a thick mantle of outwash overlying most of the Watana Relict Channel/Borrow Site D area. This relatively continuous mantle contains an upper, low energy facies (Unit E), and a stratigraphic lower high energy facies (Unit F). Together, these units form a mantle of outwash averaging 40 feet thick (Figure 6.6). These units are generally uniform in thickness in Borrow Site D, and thicken to a maximum of 130 feet in the Watana Relict Channel area. They are exposed extensively at the surface (Figure 6.1), in areas not overlain by ice disintegration deposits, Unit C.

The upper facies (Unit E) is composed primarily of an olive brown silt and fine sand matrix containing subangular to subrounded gravel and cobbles throughout (Figure 6.5). Localized lenses of clean sand, gravel or clay are occasionally found. Size and content of coarse material increase progressively with depth through the gradational facies change from Unit E to Unit F. The higher energy facies (Unit F) is composed of a very dense brown to tan sandy, gravelly silt matrix containing numerous cobbles and boulders. Boulder and cobble content increase toward the lower portions of the unit, with a boulder zone frequently found at the base of the unit separating it from the underlying Unit G or G'.

(g) Unit G - Glaciolacustrine and Waterlain Till

Unit G is a relatively continuous strata of glaciolacustrine and waterlain deposits found throughout the Watana Relict Channel/Borrow Site D area. These deposits have been designated Unit G and, together with Unit G' (see Section 6.3[h]), form a stratigraphic marker horizon across the area, identified by their high clay content and gray color. Unit G ranges in thickness from 0 to 74 feet (Figure 6.6).

Gray to blue gray uniform, laminated clay (rock flour) comprises most of the unit, with rhythmic interbeds of fine silt (Figure 6.5). Strong varving has developed in the clay at many locations. Localized striated gravels and coarse sand are often found. At some locations, ice lenses up to six inches thick have been encountered. A gradational facies change locally occurs between Unit G and G' as denoted by increasing amounts of striated gravels and poorly developed laminations. In these areas, the unit appears to have been deposited as a waterlain till (see Section 6.4).

(h) Unit G' - Basal Till

Unit G' is basal till found in localized areas of the Watana Relict Channel and Borrow Site D. This unit forms a thick deposit trending northwest-southeast across the borrow area (Figures 6.1 and 6.3), and is also found as isolated patches in other portions of the area (Figures 6.1 and 6.4).

ACRES

The unit consists of subangular to angular gravel and cobbles set in a matrix of gray to blue-gray, very dense clay (Figure 6.5). Gravels and cobbles, largely granites and diorite, are generally striated. Elongated cobbles often show imbricate structure within the matrix material. The matrix may contain varying amounts of silt and sand as well as clay. An upward gradation into waterlain and/or lacustrine facies occurs where Unit G' is overlain by Unit G.

(i) Unit H - Alluvium

Unit H is a localized alluvial and fluvial deposit, confined to channels in the upper surface of Unit I (Section 6.3[j] and Figure 6.6). This discontinous unit is found in both the Watana Relict Channel and Borrow Site D area, although it is thickest in the Watana Relict Channel.

Stratified, sorted sand, gravel and cobbles make up most of Unit H. Particles are generally rounded, and often show some evidence of weathering to include limonite and hematite staining (Figure 6.5). Alternating strata of sand and silts are found within interstitial spaces between cobbles. Organic matter, including wood, are occasionally found in the unit. The unit ranges in thickness from 0 to 41 feet.

(j) Unit I - Outwash

Unit I is a stratum of outwash generally found directly below Unit G' or Unit H. This outwash is absent in many areas of the site, particularly in those areas of Borrow Site D where bedrock is at a high elevation (Figures 6.3 and 6.4). Thicknesses of the unit ranges from 0 to 75 feet, reaching maximum thickness in the Watana Relict Channel area.

Subrounded gravel and cobbles in a very dense silty sand matrix make up most of the unit. The unit is weathered in most samples, showing red-brown hematite and limonite staining on particles, giving the unit a characteristic rusty color. Coarse fractions make up most of the unit. Some clasts show striations with some portions of the unit appearing as a till. A lacustrine facies, composed of silt, sand or clay, is often found in the lower center of the unit (Figure 6.2).

(k) Unit J - Till

Unit J is a discontinuous stratum of till found mainly in the area of the Watana Relict Channel, but occasionally in the Borrow Site D area (Figure 6.3). The unit varies in thickness from 0 to 62 feet.

The appearance of Unit J is similar to that of Unit I, being a rusty brown color and very dense. It contains a large amount of angular and subangular gravels and cobbles that show some evidence of striations. Sampling of this unit is difficult due to its high density and rocky matrix. No exposures of the unit were found in the area.

(l) Unit J' - Lacustrine and/or Stratified Deposits

Unit J' was deposited from both flowing and standing water. The unit is generally confined to the Watana Relict Channel area, although it is occasionally encountered in borings in the Borrow Site D area (Figures 6.3 and 6.4). It appears as filling in the low topographic areas of the upper surface of Unit J (Section 6.3[j]).

This unit is composed of either stratified sands, silts and gravels; or lacustrine sands and silts. Gravel fragments are generally rounded with maximum detected thickness of 48 feet.

(m) Unit K - Alluvium

Unit K is the oldest and deepest unconsolidated deposit found in the Watana Relict Channel area and consists of an alluvium. These deposits have only been found along the main thalweg of the relict channel and its related tributaries (Figures 6.3 and 6.4), principally in the southeastern portions of the relict channel near the Susitna River.

The alluvium is composed primarily of rounded boulders and cobbles. Matrix material appears scarce or absent, and high drill water losses were encountered by the COE during the 1978 investigations. Little else is known of this unit due to its depth and difficult drilling conditions.

6.4 - Geologic History of the Watana Relict Channel/Borrow Site D Area

Based on the stratigraphy encountered during the geotechnical investigations, a sequence of geologic events during which the various units were deposited has been reconstructed. A proposed sequence of events was presented in the 1980-81 Geotechnical Report (1). Further investigations during 1982 verified much of the 80-81 interpretation; however, modifications and refinements were made to several stratigraphic units and the geologic events associated with their deposition. The geologic history, presented below, has been based on all investigations carried out to date by Acres and the COE (27). This geologic sequence is summarized in Figure 6.2. Additional drilling and testing proposed in the Watana Relict Channel for the winter of 1982-83 has been designed to confirm and augment this interpretation. The information presented in this Section supersedes that which was presented in Section 6.2 of the 1980-81 Geotechnical Report (1).

(a) Formation of the Relict Channel

Some indication of the early Quaternary geologic history of the area can be obtained from the topography of the bedrock surface, presented in Figure 6.7. This map has been based on extensive seismic refraction surveys and limited borings in the Watana Relict Channel and Borrow Site D area. This map provides some indication as to the possible paleo-drainage regime in the area.

It appears that the former main drainage of the Susitna River flowed from east to west along the north edge of the present Susitna River valley. At a point near SL82-22 it turned slightly northwest, cutting a channel generally parallel to the present river channel to a point near SL82-19 where it diverted northwesterly (see Figure 6.7). It then flowed with a steep gradient toward the present Tsusena Creek, at which point it turned southwest, roughly along the present course of Tsusena Creek. This paleo-drainage channel has been designated the "Watana Relict Channel"; the term referring to the portion of the channel now filled with overburden, between the Susitna River and Tsusena Creek.

A valley in the bedrock found along SL82-22 indicates the point at which the channel diverted from the Susitna Valley into the Relict Channel. Seismic lines DM-A, SL81-14, SL82-16, SL82-18, SL80-20, SL81-13, and SL82-17 (Figure 3.2) all cross the former course of the Susitna River (Figures 6.3 and 6.4). Drilling performed by the COE shows that the alluvium Unit K, likely represents the fluvial deposits of this former drainage regime. The cobbles and boulders within Unit K indicate the high energy deposition and steep gradient of the relict channel.

A change in morphology is found in the lower portion of Tsusena Creek, downstream of the point of entrance of the relict channel. Here, the valley wall slopes become more gentle indicating a more mature drainage system than that of the upper reaches north of the relict channel. This more mature drainage supports the postulation that this portion of Tsusena Creek may have been the downstream portion of the formed relict channel where it re-entered the current flow regime of the Susitna.

Other paleo-drainage channels are also evident in the bedrock drainage in the area of Deadman Creek (Figure 6.7). Several channels, now primarily filled with Units E and F (Figure 8.2), appear to have been smaller tributaries flowing into and parallel to Deadman Creek. The relationship of these smaller channels to the Watana Relict Channel is not clear.

The Watana Relict Channel appears to have incised to a depth of approximate Elevation 1800 before glaciation resulted in diversion of the river to its present location.

(b) Early Glaciation

Following the incision of the Watana Relict Channel, a major advance of ice moved through the area filling in the relict channel and smoothing the topography. This advance, which has been delineated as Glaciation J, was likely a major advance that resulted in the deposition of the basal till Unit J (Figure 6.2). Based on the distribution of this till (Figures 6.3 and 6.4), the glaciation appears to have covered most of Borrow Site D and the Watana Relict Channel area. The degree of weathering displayed by particles of Unit J confirm the relative older age of this till to other tills in the immediate area.

As the glaciation retreated, a paraglacial environment of ponded lakes and braided streams developed in the area as evidenced by the deposition of Unit J', an alluvial and lacustrine deposit (Section 6.3). As expected in such a depositional environment, this unit is not present everywhere, but rather confined to localized topographic lows where water collected and flowed.

As Glaciation J continued, meltwaters deposited outwash Unit I (Figure 6.2) on top of Units J and/or J'. A minor readvance of the ice margin into this area may have occurred during this period as parts of Unit I have a till-like facies. Melting and retreat of Glaciation J continued to deposit the remainder of the outwash to Unit I.

It was probably during this time that the Susitna River cut a course somewhat parallel to its present course below Elevation 1800. The Watana Relict Channel was probably dammed by active or stagnant ice during the retreat of Glaciation J, while the river cut down along major joint sets (Section 5.1) through the plutonic body at the damsite to an elevation below the base of the Watana Relict Channel (Elevation 1800).

(c) Early Interglacial Period

Following deposition of Unit I, the area experienced an interglacial stade. Erosion took place with stream channels cutting into the upper surface of Unit I. These channels became filled with Unit H alluvium. Evidence of an interglacial environment is given by organics and wood specimens found in the upper horizon of Units I and H. Some organics are also found in portions of Unit G. Drainage in the Watana Relict Channel area was likely to the south into the Susitna River and east and west into the present areas of Deadman and Tsusena Creeks. Drainage tributaries cut into the underlying unconsolidated materials and bedrock (Figure 6.7).

(d) Middle Glaciation

At the close of the interglacial period, a new ice front advanced across the area. This glacial advance, referred to as Glaciation G', is represented by the basal till, Unit G'. The dense na ·e and structure of this till indicates a thick ice mass. As melting occurred, a proglacial environment was developed. Drainage appears to have been blocked one or more times, resulting in the formation of glacial lake(s) at or near the ice margin. Thick deposits of glacially derived materials in Unit G are extensive throughout the area indicating the extensive size of the lake(s). Varves are common within Unit G. Coarse sands, gravels and ice rafted particles within this lacustrine unit indicate the close proximity of the ice margin during deposition.

A transition between Unit G and G' contains features of both a till and of a lacustrine or waterlain till deposit. The basal till Unit G' is found only in localized patches, whereas Unit G glaciolacustrine material is extensive throughout the area (Figure 6.3). This complex depositional relationship may be explained by either: (1) parts of Unit G' were removed and reworked by water as the lake formed, or (2) the ice mass was not grounded everywhere as it moved across the area, with G' only being deposited where the ice was grounded.

As the ice mass retreated the glacial lake(s) drained. During this time, water may have eroded some of the upper surface of Unit G (Figure 6.6) and deposited the thick outwash of Unit F. During this period, the ice margin was probably nearby, as evidenced by the large subangular particles found in Unit F (Figure 6.5). As the ice receeded, energy of the flowing meltwater decreased resulting in the deposition of the finer facies Unit E.

Units E and F represent the same event, but differ in the degree energy environment of deposition.

(e) Middle Interglacial

After retreat of the ice and deposition of Units E and F, the Watana Relict Channel/Borrow Site D area was again subjected to an interglacial period. During this time, erosion took place resulting in surface streamflows and inception of lakes in lowland areas. Unit D alluvium was deposited during this period. Based on the distribution of Unit D, the topography of the area at that time appeared to be similar to that of the present. This indicates that major drainage patterns of the time followed similar courses to those of Deadman Creek, Tsusena Creek and the Susitna River. Areas of standing water and lakes were also present during this time, as evidenced by Unit D'.

(f) Localized Glaciation

Concurrent with the interglacial period during which Units D and D' were deposited, a localized advance of ice occurred in the southeastern portion of Borrow Site D. This advance deposited a compact basal till, Unit M. Based on the apparent distribution of Unit M (Figure 6.1), it appears the advance was confined to the southeastern portion of the area, since no deposits of Unit M have been identified elsewhere in the area. This ice advance was likely either a valley type glaciation moving through the Deadman/Susitna confluence area, or alternatively a tongue of ice from an advance originating in the south which moved no further into the area.

The deposition of Units D, D' and M appear to be concurrent, with the alluvial and lacustrine Units D and D' being deposited during the time the localized glaciation depicted by Unit M moved across a portion of the area. Units D and D' represent the the periglacial deposition environment. Both units continued to be deposited during and after the retreat of the local glaciation, resulting in parts of Unit M being covered by these units.

(g) Last Glaciation

At the close of the interglacial period represented by Units D and D', the Borrow Site D/Watana Relict Channel area was again glaciated. The glaciation overrode surficial Units E and F, and minor areas of Units D and D'. This glaciation re-worked the upper horizons of these units as it moved across the area. Later the ice became stagnated in the area, with ablation and melting exceeding accumulations at the source area. The stagnated ice mass wasted in-place resulting in the deposition of the ice disintegration Unit C (Figures 6.1 and 6.4).

Since: (a) the material of Unit C was largely derived from the underlying Units E and F; and (b) the ice was not extremely active, deposits of Unit C closely resemble Units E and F in composition. Due to this compositional similarities, it is difficult to clearly delineate the basal till contact of Unit C with the underlying Units E and F.

As the ice mass wasted downward, meltwater resulted, locally reworking Unit D. Ice melting resulted in the hummocky knob-and-kettle features which form much of the present topography.

(h) Post-Glacial Events

Recent geologic events in the area are confined to post-glacial erosion and frost heaving, and are represented by Unit A/B (Figure 6.2). Major post-glacial erosion occurred through resurrection of the Tsusena and Deadman Creek drainage channels, and the continued down cutting of these streams through bedrock (Figure 6.2). Erosion by surficial drainage has occurred, forming the present drainage channels found in the Watana Relict Channel area, and forming the minor tributaries to the Susitna River. Frost heaving has raised coarse material to the surface. This material has, in some places, rolled into low areas, where it has been reworked by post-glacial erosion, forming the boulder fields frequently in the flat channels found across the area.

(i) Summary

The Quaternary historical sequence presented above closely corresponds with other geologic studies performed in the Susitna River Basin. Work on this project by Woodward-Clyde Consultants (40) independently came to the conclusion that the area had experienced a similar sequence of four glacial advances.

These include: pre-Wisconsinian >100,000 years before present (y.b.p.); Early Wisconsinian, 75,000 to 40,000 y.b.p.; Late Wisconsinian, 25,000 to 9,000 y.b.p.; and Holocene, <9,000 y.b.p.

The scenario presented in this section are substantiated by the field data. However, further detailed information will be necessary to verify several areas of the interpretation. Principal areas requiring further evaluation are:

- Bedrock elevations in the vicinity of SL81-14, in the area of the apparent bedrock depression; and

- Extent and continuity of several of the deeper units, particularly Unit K.

Acres believes the Hammer drilling program set forth this winter will greatly assist in further refinement of this interpretation.

6.5 - Ground water

The ground water regime in the relict channel is complex and poorly understood due to the presence of intermittent permafrost, aquicludes, perched water tables, and confined aquifers. Instrumentation installed during this program have not had adequate time to fully stabilize to provide any additional data relative to the ground water regime. Initial readings indicate that some of the instruments may have malfunctioned. Further verification of this will be required in FY83.

Based on drilling it appears that possible artesian or confined water tables exist in Units H and J' while several other units appear to be unsaturated.

A perched water table condition exists, at least locally, on top of the impervious Unit G, and possibly on top of M, I, and J. Limited permeability testing (Section 6.7 [c]) indicate the range of average permeability in the more gravelly materials is about 10^{-3} cm/sec, while the tills and lacustrine deposits can be estimated at about 10^{-4} to 10^{-5} cm/sec.

Systematic instrumentation of the various units will be necessary to determine the actual conditions in the relict channel area, but in general terms it appears most areas have a shallow water table, and the pervious units, with the possible exception of Unit K, may be under natural hydrostatic heads equal to or greater than planned reservoir level.

6.6 - Permafrost Regime

The permafrost and ground temperature regime as described in the 1980-81 Geotechnical Report (1) remains relatively unchanged. Re-evaluation of the earlier drill logs and of the ground temperature envelopes from the thermistor installations (Figure 6.11) has led to the conclusion that most of the identified permafrost does not include solid phase water, but rather reflects mixed-phase or freezing temperature water. Very few of the borings noted as encountering permafrost in drilling (as detected by thermometer or visible ice) have frozen back to zero or freezing temperatures upon stabilization. It is believed that the permafrost encountered in the Watana Relict Channel/Borrow Site D area is so close to 0°C that there is not enough latent heat capacity to refreeze after disturbance.

The active zone averages about 10 to 15 feet, reaching a 22 foot maximum recorded depth. The zero annual temperature amplitude point ranges from 8 to 80 feet, but generally average between 25 to 40 feet in depth. Maximum depth of permafrost, continuous from the surface (based on boring logs) was about 40 feet, in Unit G. Isolated permafrost has been detected as deep as 240 feet (DR-22), but the deepest permafrost depth indicated by instrumentation is about 70 feet. It appears that most of the visible ice is confined to the annual frost zone in Units C, D, E and F; and to Units G, G' and H in permafrost zones. Unit G is the only place where significant ice lenses have been detected, ranging up to 6 inches in thickness, and locally comprising up to 50 percent of sample volume.

Average ground temperature at depth with the exception of several frozen shallow holes, run from +0.5°C to about +1.5°C, with the mean lowest temperature at depth probably being around +1°C. Additional discussion on the shallow permafrost regime is provided in Section 8.2.

6.8 - Engineering Impacts

(a) Introduction

As stated in Section 6.1 the principal impacts of the relict channel on project design is the potential of breaching the reservoir rim and excessive seepage resulting in either downstream piping and loss of energy. Although the 1982 work has not totally eliminated these concerns, it did provide additional information in evaluating these potential problems. The results and preliminary conclusions derived from this program are presented below. The FY83 winter drilling program has been designed to provide the additional data to confirm the conclusions set forth here.

(b) Reservoir Rim Stability

Breaching of the reservoir rim may occur by either settlement and/or slumping under static or dynamic conditions. Static failure may be either progressive or catastrophic. Several conditions must exist for slides to develop. These are:

- Widespread relatively pervious loose unconsolidated material;
- Widespread permafrost in granular material; and/or
- Slide surface with gradients sufficient to cause movement.

A slide occuring in the Watana Relict Channel is considered unlikely due to the following:

(a) A low potential slide gradient exists in the narrow thalweg section near "The Fins" due to the rise in the bedrock surface in this area (Figure 6.7). A slide further upstream near Deadman Creek would require an extremely large quantity of material moving on a low gradient to result in a breaching of the reservoir. Similarly, a failure on the Tsusena Creek side of the channel would likewise be on a low gradient and would involve a large volume of material.

(b) The density of the sediments within the relict channel are shown by the Standard Penetration Tests (SPT) in Figures 6.9 and 6.10. As noted in Figure 6.9, all SPT for units below C are in excess of 60 per foot, indicating a relatively dense compact material. This is supported by field observations which show that the majority of units exposed on bank cuts are, for the most part, free standing.

(c) As stated in Section 6.7, only localized permafrost exists within the relict channel.

(d) Although only preliminary data is available, the permeability of the upper units appear to be relatively low (10^{-3} to 10^{-5} cm/sec) (Section 6.6).

(e) Work performed during 1982 failed to show any continuous uniform unconsolidated material in the relict channel.

In conclusion, although work performed to date does not fully eliminate the potential for static failure within the relict channel, the likelihood of such a catastrophic event occurring appears to be small considering: (a) the materials within the channel are relatively competent; (b) no widespread permafrost; and (c) low surface gradients.

An alternative method for rim failure may be caused by dynamic shaking by an earthquake resulting in liquefaction of the channel sediments. Liquefaction generally occurs in loose, unconsolidated, well sorted, saturated materials. Earthquake shaking results in the decrease of the shearing resistance of a cohesionless soil and is associated with a sudden, but temporary increase of the pore fluid pressure. The liquefied material is then temporarily transformed into a fluid mass that could settle and/or flow.

To initiate a major liquefaction failure within the Watana Relict Channel, requires the existence of a relatively continuous liquefiable material throughout the area.

Although a few sorted sands and silts occur in various units such as Unit D, D', E/F, H, and J' (Figure 6.8), these materials occur only as discontinuous lenses. In addition, the high SPT (Figures 6.9 and 6.10) indicate that the material below Unit C are relatively dense compact material.

Unit C has the majority of the blow counts below 20 per foot. This unit, however, is not a critical unit to the reservoir rim stability as it is relatively freely drained on the surface and makes up only a portion of the rim.

Results of work performed in 1982 show that there are no large scale liquefiable materials in the upper 250 feet of the relict channel. However, additional drilling and testing will be required during FY83 to further characterize the units at depth and provide further evidence against the potential for liquefaction.

(c) Leakage Potential

During the 1982 summer drilling program six falling head permeability tests were performed in cased boreholes. Four of these were in Units E/F, one in Unit G', and one in Unit I. The calculated results, utilizing standard open-casing falling head calculations gave permeability between $1x10^{-3}$ and $5x10^{-4}$ cm/sec (Table 6.3). These tests were performed in those portions of the borehole which appeared to have very coarse gradations, or where drill fluid was lost. Therefore these results represent the high permeability range within these units.

For the purposes of estimating the maximum probable flow which could leak out of the reservoir under full head, the following assumptions were made, all of which represent worst possible cases.

- That a continuous flow path exists from inlet to outlet on each unit;
- That units are not blocked or occluded at inlet or outlet;
- That the average gradient is 9 percent (Elevation 2200 pool to Elevation 1675 at Tsusena Creek, over minimum flow path of about 6,000 feet);
- That the inlet section can provide all the flow that the critical "weir" section (along seismic line DM-A, Reference 1, Figure 6.34) can pass; and
- That average permeability over the entire cross section is 10^{-3} cm/sec.

Under these assumptions, for the known channel width of about 14,000 feet and average depth of 200 feet, the loss at full pool would be about 9 cfs. To significantly affect project power economics the permeability, on the average, would have to be about 10^{-2} cm/sec. Therefore, unless one or more of the permeable units (such as H, J', K) are found in subsequent drilling to extend continuously, in significant cross sections, and are exposed to the reservoir, the chance of flows exceeding 10 cfs is highly unlikely. This amount is not considered significant to project operation.

(d) Potential for Failure by Piping

Major leakage through the relict channel could result in piping along Tsusena Creek that would cause erosion and progressive failure working back up the channel. Although the geologic model to date does not indicate piping to be a problem, further geotechnical studies planned for the winter of 1983 are intended to determine permeabilities of the lower stratigraphic units in the relict channel. If, subsequent to this program, piping is considered a potential problem, then discharge points along Tsusena Creek will likely be controlled by the placement of properly graded materials to form a filter blanket over the zones of emergence.

TABLE 6.1: WATANA RELICT CHANNEL/BORROW SITE D INTERPRETED DEPTHS TO TOP OF STRATIGRAPHIC UNITS AT BORINGS

BORING NUMBER	STRATIGRAPHIC UNIT A/B	C	M	D	D'	E/F	G	G'	H	I	J'	J	K	BEDROCK
DR-13	Not noted	-	-	-	-	0	15	-	78	>84				
DR-14	"	0	-	20	>75									
DR-15	"	0	-	15	22	36	-	55	-	-	-	-	-	286
DR-16	"	-	-	-	-	0	31	-	-	47	-	-	-	67
DR-17	Not interpreted - too shallow													
DR-18	"	-	-	-	-	0	20	88	-	110	-	170	-	231
DR-19	"	-	-	-	-	-	-	-	-	0	-	36	-	55
DR-20	"	-	-	-	-	0	20.5	-	53	90	-	167	-	210
DR-22	"	-	-	-	-	0	56	-	90	131	183	231	293	454
DR-26	"	0	-	-	-	19	45	-	56	67	>94.8			
DR-27	"	-	-	-	-	0	21	>44						
AH-D1	0	-	-	-	-	4.5	>20							
AH-D2	0	0.5	-	-	-	3	>29							
AH-D3	Not interpreted													
AH-D4	Not interpreted													
AH-D5	0	1.5	-	7.5	-	10	>48.3							
AH-D6	0	5	-	7.5	-	22	>50							
AH-D7	0	.5	-	-	-	15	>48.3							
AH-D8	0	4.5	-	9.5	-	15	>50.3							
AH-D9	0	1.5	-	4.5	-	6	40	-	50	52	-	58	-	64
AH-D10	0	1.5	-	-	-	7.5	>50							
AH-D11	0	3	-	20	-	25	>54.8							
AH-D12	0	-	-	-	-	4	>60							

TABLE 6.1
(Cont'd)

STRATIGRAPHIC UNIT

BORING NUMBER	A/B	C	M	D	D'	E/F	G	G'	H	I	J'	J	K	BEDROCK
AH-D13	0	0.6	-	-	15	20	>50							
AH-D14	0	0.5	-	-	-	14	>75							
AH-D15	0	-	-	-	-	2.5	34.5	-	72	>84				
AH-D16	0	3	29	43.5	58.5	67	111.5	-	-	147	-	156	-	170.5
AH-D17	0	2	-	-	-	40	76	90	103	107	184	187	207	215
AH-D18	0	3.5	-	-	25	46	97.5	131	>189.3					
AH-D19	0	6	15	-	-	70	166.5	-	-	194	>215			
AH-D20	0	3	-	-	-	24	65	105	-	114	-	-	-	136
AH-D21	0	3	-	-	-	18	63.5	101	108	115	-	137	-	174
AH-D22	0	-	-	-	-	-	-	-	-	-	-	-	-	6
AH-D23	0	5.2	-	26	-	38.5	92.5	>160						
AH-D24	0	-	-	-	-	4	-	-	-	-	-	-	-	30
AH-D25	-	-	-	10	-	-	-	7	-	28	-	71	>90	
AH-D26	0	4.2	-	-	-	15.5	75	-	-	83.3	-	-	-	96
AH-D27	0	5	-	20	59.5	63	157	-	-	177.5	>195			
AH-D28	0	3	19	-	-	98	123	-	196.5	210.5	>234			
AH-D29	0	4	-	14	-	18	149	>158						
AH-D30	0	6	-	-	-	18	-	69.5	>100					

Notes:
(1) Stratigraphic column shown on Figure 6.2
(2) Top of Unit Maps on Figure 6.6
(3) Unit thicknesses shown in Table 6.2
(4) All borings vertical, numbers shown are true depths.
(5) Due to lack of samples and core photos, pre-1982 hole interpretations are less certain than for AH-D15 through AH-D30.

LEGEND:

6	Depth to unit from ground surface
-	Boring passed through stratigraphic sequence without detecting indicated unit.
>69.5	Boring terminated in previous unit - depth shown represents minimum possible depth of next unit contact at that location
(blank)	Boring did not penetrate, or could not be sampled at depth necessary to detect presence of unit.

TABLE 6.2: WATANA RELICT CHANNEL/BORROW SITE D
INTERPRETED STRATIGRAPHIC UNIT THICKNESS IN BORINGS

BORING NUMBER	STRATIGRAPHIC UNIT A/B	C	M	D	D'	E/F	G	G'	H	I	J'	J	K	BEDROCK ENCOUNTERED
DR-13	Not noted	-	-	-	-	15	63	-	6+					No
DR-14	"	20	-	55+										No
DR-15	"	15	-	7	14	19	-	231	-	-	-	-	-	Yes
DR-16	"	-	-	-	-	31	16	-	-	20	-	-	-	Yes
DR-17	Not interpreted													
DR-18	"	-	-	-	-	20	68	22	-	60	-	61	-	Yes
DR-19	Not noted	-	-	-	-	-	-	-	-	36	-	19	-	Yes
DR-20	"	-	-	-	-	20.5	32.5	-	37	77	-	43	-	Yes
DR-22	"	-	-	-	-	56	34	-	41	52	48	62	161	Yes
DR-26	"	19	-	-	-	26	11	-	11	27.8+				No
DR-27	"	-	-	-	-	21	23+							No
AH-D1	4.5	-	-	-	-	15.5+								No
AH-D2	0.5	2.5	-	-	-	26+								No
AH-D3	Not interpreted													No
DH-D4	"													No
AH-D5	1.5	6	-	2.5	-	38.3+								No
AH-D6	5	2.5	-	14.5	-	28+								No
AH-D7	.5	14.5	-	-	-	33.3+								No
AH-D8	4.5	5	-	5.5	-	35.3+								No
AH-D9	1.5	3	-	1.5	-	34	10	-	2	6	-	6	-	Yes
AH-D10	1.5	6	-	-	-	42.5+								No

TABLE 6.2

(Cont'd)

STRATIGRAPHIC UNIT

BORING NUMBER	A/B	C	M	D	D'	E/F	G	G'	H	I	J'	J	K	BEDROCK
AH-D11	3	17	-	5	-	29.8+								No
AH-D12	4	-	-	-	-	56+								No
AH-D13	.6	14.4	-	-	5	30+								No
AH-D14	.5	13.5	-	-	-	61+								No
AH-D15	2.5	-	-	-	-	32	37.5	-	12+					No
AH-D16	3	26	14.5	15	8.5	44.5	35.5	-	-	9	-	14.5	-	Yes
AH-D17	2	38	-	-	-	36	14	13	4	77	3	20	8	Yes
AH-D18	3.5	21.5	-	-	21	51.5	33.5	58.3+						No
AH-D19	6	9	55	-	-	96.5	27.5	-	-	19+				No
AH-D20	3	21	-	-	-	41	40	9	-	22	-	-	-	Yes
AH-D21	3	15	-	-	-	45.5	37.5	7	7	22	-	37	-	Yes
AH-D22	6	-	-	-	-	-	-	-	-	-	-	-	-	Yes
AH-D23	5.2	20.8	-	12.5	-	54	67.5+							No
AH-D24	4	-	-	-	-	26	-	-	-	-	-	-	-	Yes
AH-D25	-	-	-	7	-	-	-	21	-	43	-	19+		No
AH-D26	4.2	11.3	-	-	-	59.5	8.3	-	-	12.7	-	-	-	Yes
AH-D27	5	15	-	39.5	3.5	94	20.5	-	-	17.5+				No
AH-D28	3	16	79	-	-	25	73.5	-	14	23.5+				No
AH-D29	4	10	-	4	-	131	9+							No
AH-D30	6	12	-	-	-	51.5	-	30.5+						No

Notes:
(1) Stratigraphic column shown on Figure 6.2
(2) Borrow material isopach maps shown on Figure 8.2
(3) All borings vertical, numbers shown are are vertical thickness.
(4) Due to lack of samples and core photos for comparison, pre-1982 hole interpretations are less certain than for AH-D15 thru AH-D30.

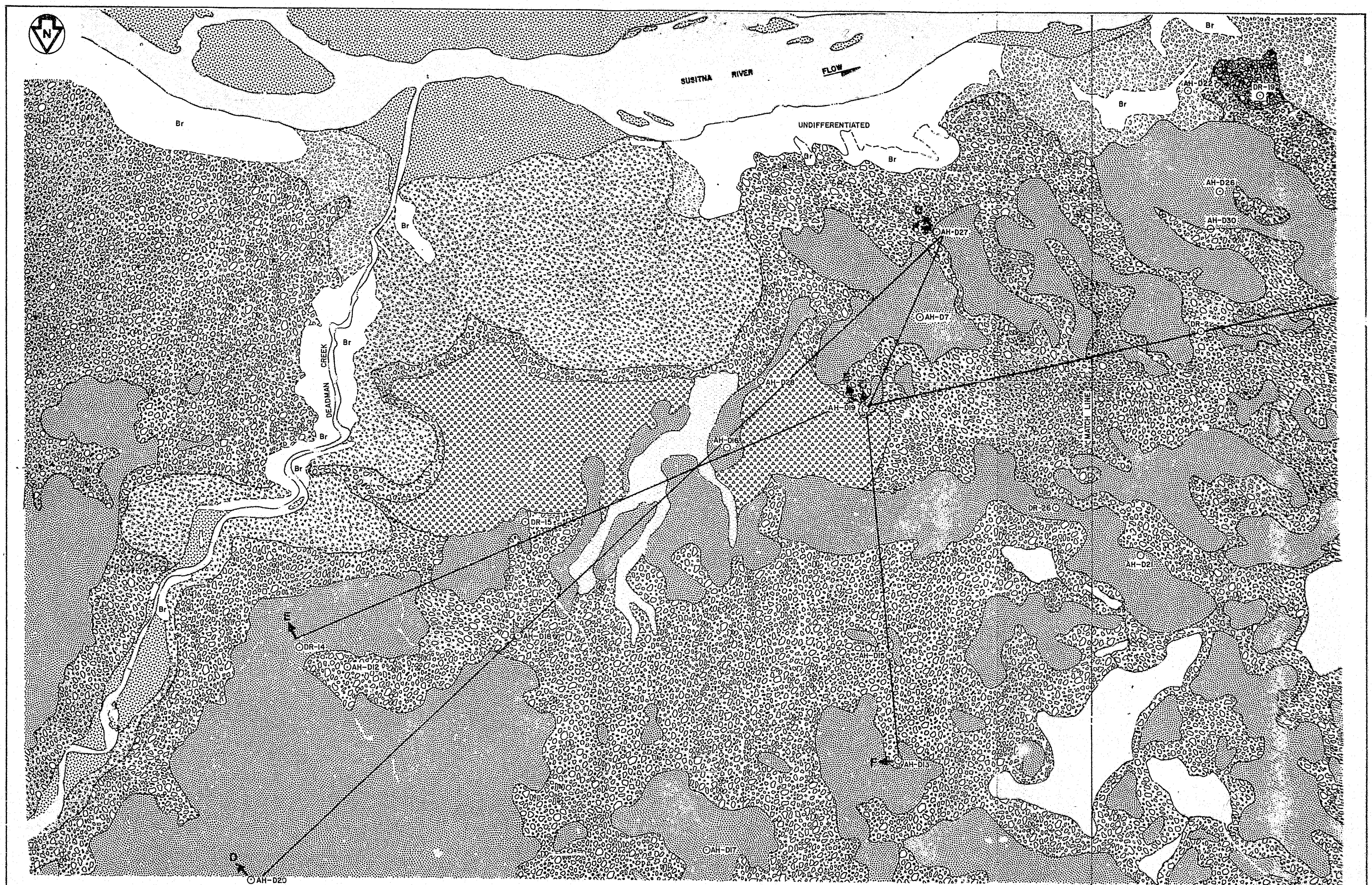
LEGEND:

6	Thickness of unit where encountered in boring
-	Boring passed through stratigraphic sequence without detecting indicated unit.
30.5+	Boring terminated in unit; thickness shown represents partial thickness.
(blank)	Boring did not penetrate or could not be sampled at depth necessary to detect presence of unit.

TABLE 6.3: WATANA RELICT CHANNEL/BORROW SITE D BOREHOLE PERMEABILITY TEST RESULTS

	HOLE NUMBER					
	AH-D18	AH-D18	AH-D20	AH-D21	AH-D23	AH-D27
Test Type	Falling Head	Falling Head	Falling Head	Falling Head	Falling Head	Falling Head
Depth (ft)	91.7	144.0	122.5	54.0	38.8	140.0-145.0
Stratigraphic Unit	E/F	G'	I	F	E	F
Intake Point	HW Casing Flush w/ Bottom of Hole	HW Casing Flush w/ Bottom of Hole	HW Casing Flush w/ Bottom of Hole	HW Casing Flush w/ Bottom of Hole	HW Casing Flush w/ Bottom of Hole	5 ft Section, NX Core Hole
Average Permeability	$5x10^{-4}$	$2x10^{-3}$	$2x10^{-4}$	$2x10^{-3}$	$1x10^{-3}$	$4x10^{-3}$
Range of Permeability (cm/sec)	$4.5x10^{-5}$ to $5.3x10^{-3}$	$2.5x10^{-4}$ to $2.8x10^{-4}$	$4.3x10^{-5}$ to $5.7x10^{-5}$	$1.3x10^{-4}$ to $1.9x10^{-2}$	$6.6x10^{-4}$ to $1.7x10^{-3}$	0 to $1.2x10^{-3}$
Duration of test	2 hrs	2 hrs	2 hrs	2 hrs	1-1/2 hrs	1 hr

Reference (32)

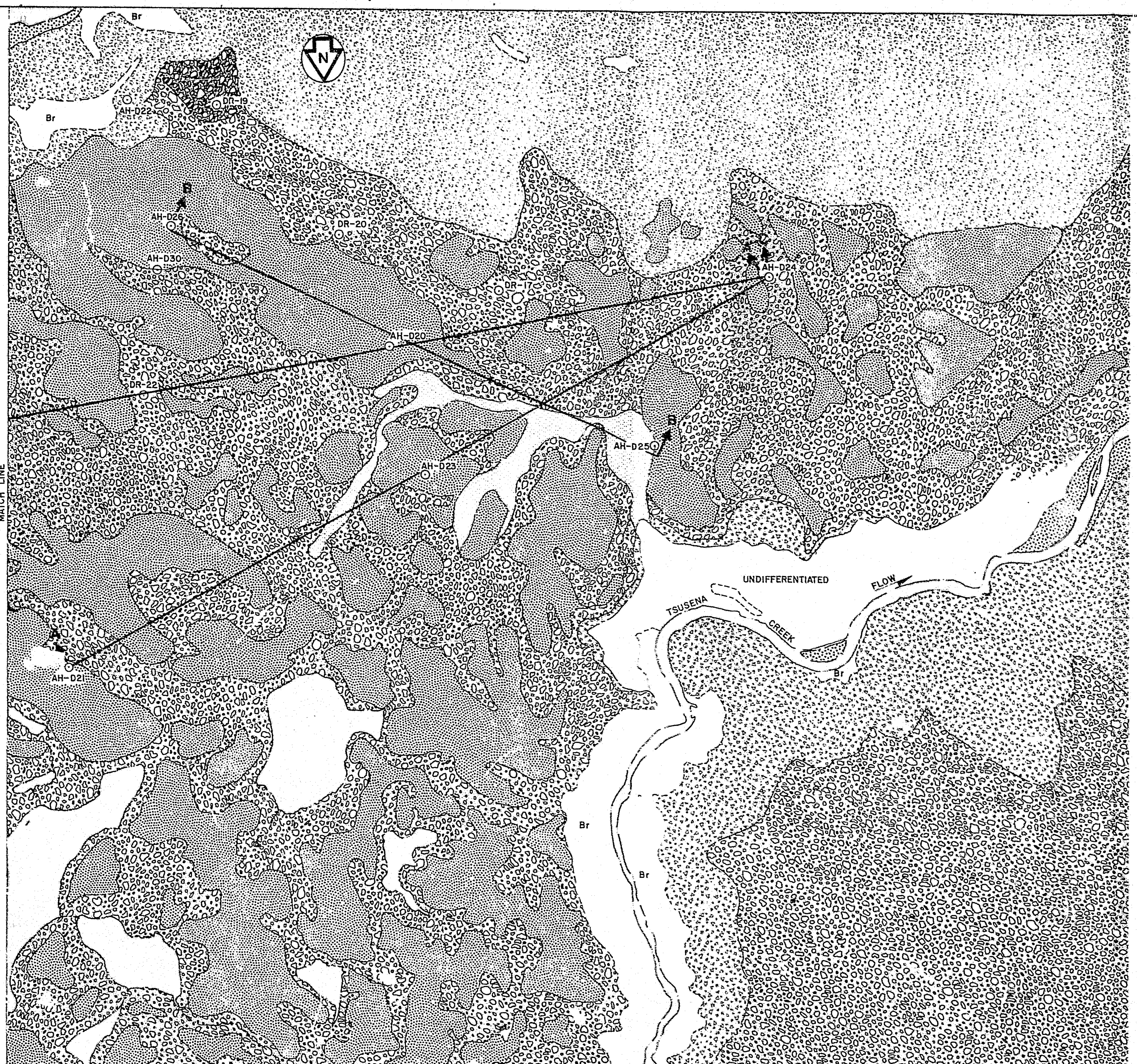


WATANA
BORROW SITE D/RELICT CHANNEL
SURFICIAL GEOLOGIC MAP
SHEET 1 OF 2

SCALE 0 400 800 FEET

FIGURE 6.1

ACRES



LEGEND:

AL	RECENT RIVER ALLUVIUM
A/B	SURFICIAL DEPOSITS
C	ICE DISINTEGRATION DEPOSITS
M	BASAL TILL
D	ALLUVIUM
E/F	OUTWASH
G	BASAL TILL
I	EARLY OUTWASH
Br	BEDROCK
⊙ DR-17	BOREHOLE, COE
⊙ AH-D21	BOREHOLE, AAI
A A	CROSS SECTION LOCATION

NOTES:

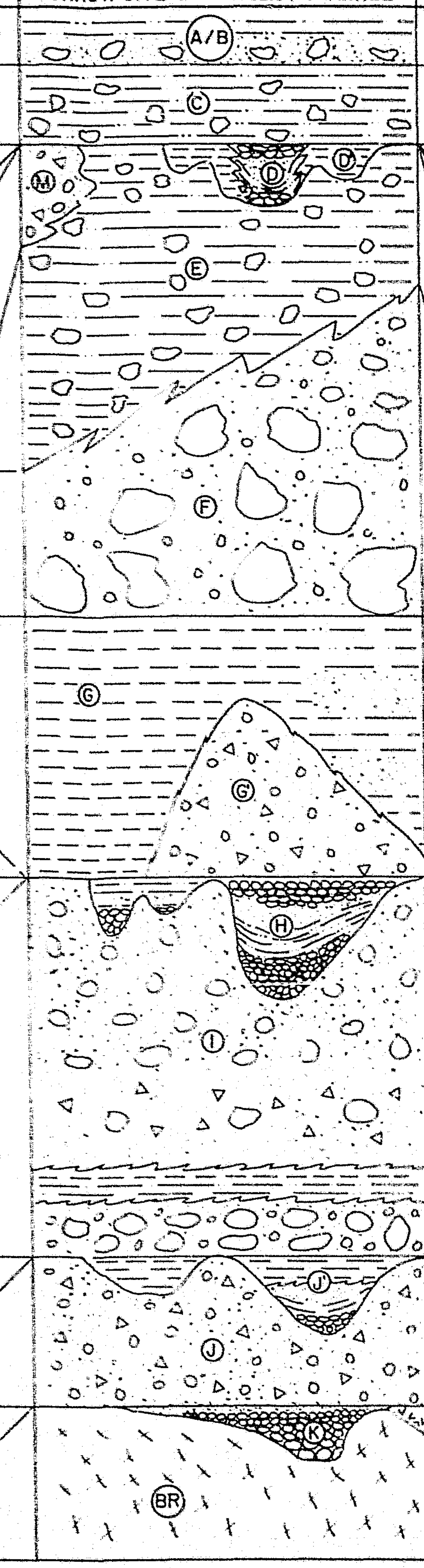
1. FOR CROSS SECTIONS SEE FIGURE 6.4.
2. MAPPING BASED ON AIR PHOTO INTERPRETATION, RECONNAISSANCE LEVEL GEOLOGIC MAPPING, AND LIMITED SUBSURFACE EXPLORATION AND IS SUBJECT TO VERIFICATION.

SCALE 0 400 800 FEET

WATANA
BORROW SITE D/RELICT CHANNEL
SURFICIAL GEOLOGIC MAP
SHEET 2 OF 2

FIGURE 6.1

ACRES



UNIT	TYPE OF DEPOSIT	GEOLOGIC EVENT	STRATIGRAPHIC COLUMN BORROW SITE D RELICT CHANNEL	THICKNESS	DESCRIPTION	REMARKS
A/B	SURFICIAL DEPOSITS	POST GLACIAL EROSION & FROST HEAVING.		RANGE 0.7 FT. AVG. 3 FT.	ORGANICS, PEAT, SILT & BOULDERS RAISED BY FROST ACTION.	SURFICIAL BOULDER FIELDS, SWAMPS & BOGS.
C	ICE DISINTEGRATION	ABLATION OF LAST GLACIAL ADVANCE & MELTING OF ICE LENSES.		RANGE 0-38 FT. AVG. 9 FT.	TAN-BROWN SAND WITH SOME COBBLES & GRAVEL. LOOSE TO DENSE, CONTAINS LESS SILT THAN OUTWASH UNITS E & F.	HUMMOCKY TOPOGRAPHY, KNOB & KETTLE FEATURES, NO OVERCONSOLIDATION.
		MAJOR GLACIAL ADVANCE				UPPER LIMIT OF OVERCONSOLIDATION
D	ALLUVIUM	INTERGLACIAL, ICE FRONT A LONG DISTANCE FROM DEPOSITIONAL AREA.		RANGE 0-40 FT.	GRAY STRATIFIED SAND, GRAVEL & COBBLES. VERY DENSE.	CONFINED TO TOPOGRAPHIC LOW AREAS ON TOP OF UNIT "E" & RELATED FLOW CHANNELS.
D'	LACUSTRINE	LOCALIZED PONDING OF LAKES DURING INTERGLACIAL.		RANGE 0-21 FT.	GRAY/ BROWN LAMINATED CLAY & SILT, VERY DENSE.	LIMITED EXTENT, NOT FOUND IN ALL BORINGS. LAMINATIONS PRESENT. GENERALLY THIN
		RETREAT OF GLACIATION "M"				
M	BASAL TILL	VALLEY TYPE GLACIAL ADVANCE CONFINED TO FORMER SUSITNA VALLEY.		RANGE 0-79 FT.	GRAY CLAY WITH ANGULAR TO SUBANGULAR GRAVEL & COBBLE, VERY DENSE. COARSE FRACTION MAINLY PHYLLITE & ARGILLITE.	FOUND NEAR SUSITNA VALLEY. PEBBLES & COBBLES SUBANGULAR & STRIATED. APPEARANCE SIMILAR TO "G" BUT MUCH HIGHER PERCENTAGE OF PHYLLITE & ARGILLITE FRAGMENTS.
E	OUTWASH	GLACIAL MELTING & RETREAT; ICE FRONT AT A DISTANCE FROM SITE.			BROWN TO GRAY-BROWN SILTY SAND WITH GRAVEL & COBBLES. PARTICLES SUBANGULAR TO SUBROUNDED.	SUBANGULAR TO SUBROUNDED PARTICLES. FEWER COBBLES & BOULDERS THAN UNIT "F" BELOW. PARTIALLY SORTED.
F	OUTWASH	GLACIAL RETREAT; ICE FRONT NEAR SITE		RANGE E/F 0-131 FT. AVG. 37 FT.	BROWN SILTY SAND WITH GRAVEL & MANY COBBLES & BOULDERS, POORLY SORTED. SIZE OF COARSE FRACTION INCREASES WITH DEPTH. OFTEN CONTAINS A ZONE OF COBBLES & BOULDERS AT BASE OF UNIT.	LARGE COBBLES & BOULDERS INDICATES HIGH ENERGY ENVIRONMENT WITH ICE FRONT NEARBY. LARGE BOULDER ZONE AT BASE GRADING TO SMALLER FRAGMENTS TOWARD THE TOP OF UNIT INDICATES RECEDING ICE.
		DRAINING OF LAKE "G" GLACIAL RETREAT BEGINS				
G	GLACIOLACUSTRINE & WATERLAIN TILL	LAKES & FLOATING ICE. ICE MASS PARTIALLY DETACHED (FLOATING).		RANGE 0-74 FT.	GRAY CLAY, LAMINATED, VERY DENSE. CONTAINS SILTY OR SANDY INTERLAMINATIONS WHICH ARE MORE PREVALENT IN RELICT CHANNEL AREA. OCCASIONALLY VARVED.	ORGANICS FOUND IN LAMINATIONS OF UNIT "G". WOOD FOUND IN UPPER HORIZONS OF UNIT "G". LACUSTRINE LAMINATIONS & VARVES PRESENT TOGETHER WITH STRIATED PEBBLES & SAND AS WELL.
		BASAL MELTING, ICE THICKENING				
G'	BASAL TILL	MAJOR GLACIAL ADVANCE.		RANGE 0-231 FT.	GRAY CLAY WITH ANGULAR & SUBANGULAR GRAVEL & COBBLES. UNSORTED, VERY DENSE.	STRIATIONS ON COARSE FRACTION, LITTLE OXIDATION, BASAL TILL STRUCTURE INCLUDING POOR SORTING, HIGH DENSITY & IMBRICATION OF ELONGATED FRAGMENTS.
H	ALLUVIUM	INTERGLACIAL, ICE FRONT REMOVED FROM SITE.		RANGE 0-41 FT.	BROWN GRAVEL, SAND & SILT, STRATIFIED, SORTED. VERY DENSE. CONFINED TO VALLEY AREAS IN THE AT-THE-TIME TOPOGRAPHY OF THE UPPER SURFACE OF UNIT "I".	ROUNDED PARTICLES, SORTED. ORGANICS FOUND IN UNIT "H".
I	OUTWASH (TILL ?)	GLACIAL MELTING & RETREAT, ICE FRONT NEARBY PARAGLACIAL ENVIRONMENT. MINOR GLACIAL RE-ADVANCE. GLACIAL MELTING & RETREAT CONTINUES.		RANGE 0-77 FT.	BROWN TO RED-BROWN SAND & SILT WITH GRAVEL & COBBLES. OXIDATION ON SURFACES OF PARTICLES. VERY ROCKY, OVERCONSOLIDATED. MAY BE AN OUTWASH RE-WORKED BY A MINOR READVANCE OF ICE.	ORGANICS FOUND IN UPPER HORIZON OF UNIT "I", INCLUDING WOOD. OXIDATION (LIMONITE & HEMATITE) INDICATES WEATHERING & OLDER AGE. OCCASIONALLY DISPLAYS SOME CHARACTERISTICS OF A TILL INCLUDING REMNANT STRIATIONS ON PEBBLES & ANGULAR FRAGMENTS. LACUSTRINE SAND, SILT OR CLAY OFTEN FOUND IN MIDDLE OF UNIT.
		RETREAT OF GLACIATION "J"				
J'	LACUSTRINE & /OR STRATIFIED DEPOSITS	BASAL MELTING & PONDING; FLOWING WATER.		RANGE 0-48 FT.	BROWN SAND, SILT, GRAVEL & CLAY, LAMINATED & /OR STRATIFIED. SAND OCCASIONALLY OXIDIZED.	LIMITED EXTENT, OFTEN APPEARS SORTED, FRAGMENTS ROUNDED
J	TILL	MAJOR GLACIAL ADVANCE.		RANGE 0-62 FT.	BROWN SILT WITH MANY COBBLES & MUCH GRAVEL. VERY DENSE, OXIDIZED. PARTICLES ANGULAR & SUBANGULAR.	STRIATED PEBBLES, SUBANGULAR PARTICLES, HIGH DEGREE OF OVERCONSOLIDATION
K	ALLUVIUM	OLDEST UNCONSOLIDATED DEPOSITS FOUND IN WATANA RELICT CHANNEL AREA.		RANGE 0-161 FT.	BOULDERS, COBBLES, SAND & GRAVEL, ROUNDED.	FOUND ONLY LOCALLY ALONG CHANNEL COURSES (THALWEGS) CUT INTO BEDROCK.
BR	BEDROCK				PRIMARILY DIORITE & GRANODIORITE WITH OCCASIONAL INCLUSIONS OF ARGILLITE. ANDESITE FOUND IN WESTERN PORTION OF AREA.	DRILLED > 10' INTO BEDROCK TO VERIFY.

NOTE: STRATIGRAPHIC COLUMN DIAGRAMMATIC & NOT TO SCALE.

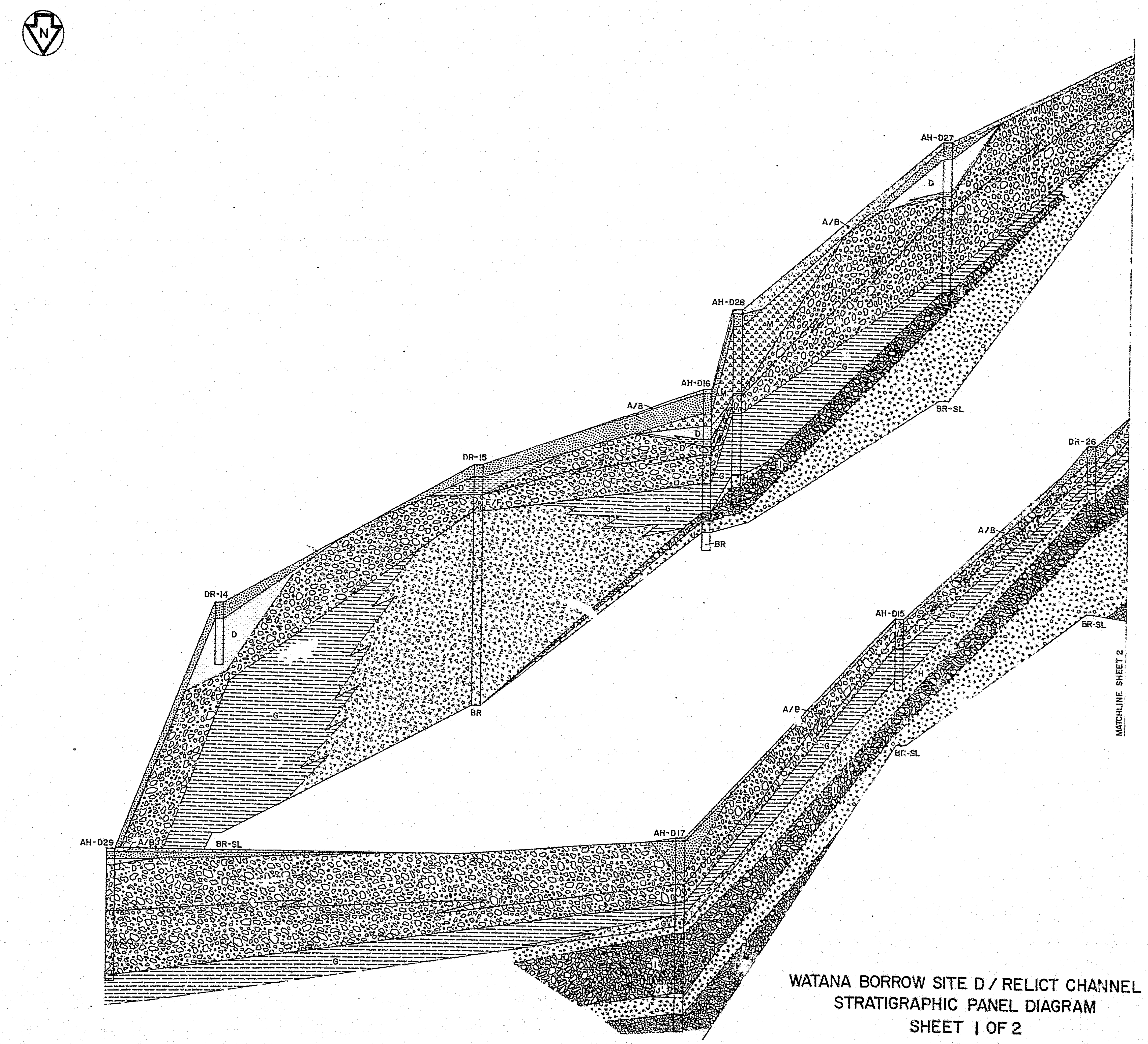
GENERALIZED STRATIGRAPHIC COLUMN
WATANA RELICT CHANNEL AND BORROW
SITE D AREA

ACRES

FIGURE 6.2

NOTES:

1. FOR DETAILED STRATIGRAPHY SEE FIGURE 6.2.
2. FOR LEGEND SEE SHEET 2.
3. EXTENT OF STRATA AND CONTACTS ARE INFERRED BASED ON INTERPRETATION OF SUBSURFACE EXPLORATIONS AND ARE SUBJECT TO VERIFICATION BY FUTURE INVESTIGATIONS.



APPROXIMATE SCALES

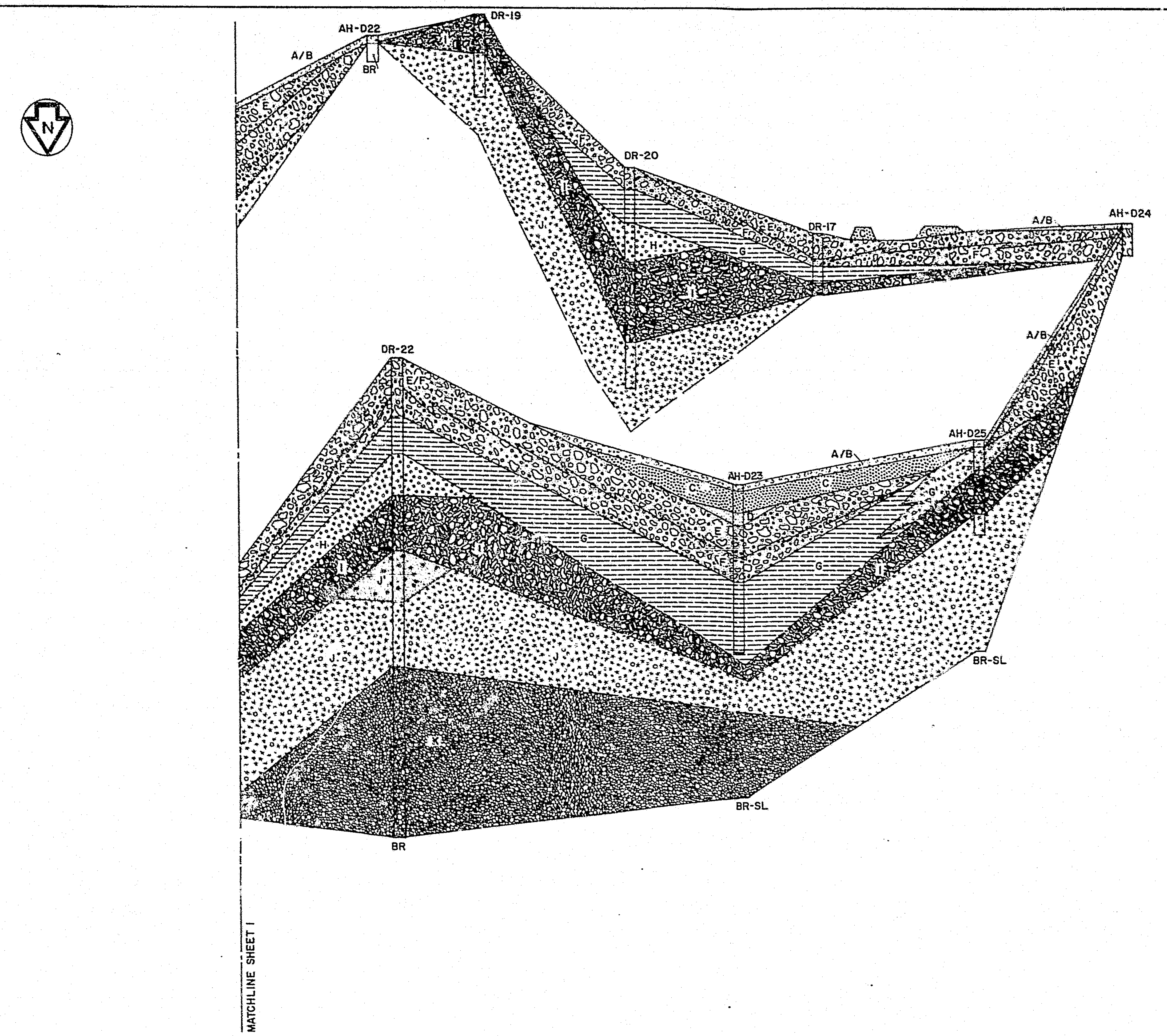
HORIZ. 0 400 800 FEET

VERT. 0 50 100 FEET

WATANA BORROW SITE D / RELICT CHANNEL
STRATIGRAPHIC PANEL DIAGRAM
SHEET 1 OF 2

ACRES

FIGURE 6.3



LEGEND:

A/B	SURFICIAL DEPOSITS
C	ICE DESINTIGRATION DEPOSITS
M	BASAL TILL
D	ALLUVIUM
D'	LACUSTRINE
E F	OUTWASH
G	LACUSTRINE
G'	BASAL TILL
H	ALLUVIUM
I	OUTWASH
J	ALLUVIUM / LACUSTRINE
J'	TILL
K	ALLUVIUM
Br	BEDROCK

NOTES:

1. FOR DETAILED STRATIGRAPHY SEE FIGURE 6.2.
2. EXTENT OF STRATA AND CONTACTS ARE INFERRED BASED ON INTERPRETATION OF SUBSURFACE EXPLORATIONS AND ARE SUBJECT TO VERIFICATION BY FUTURE INVESTIGATIONS.

APPROXIMATE SCALES

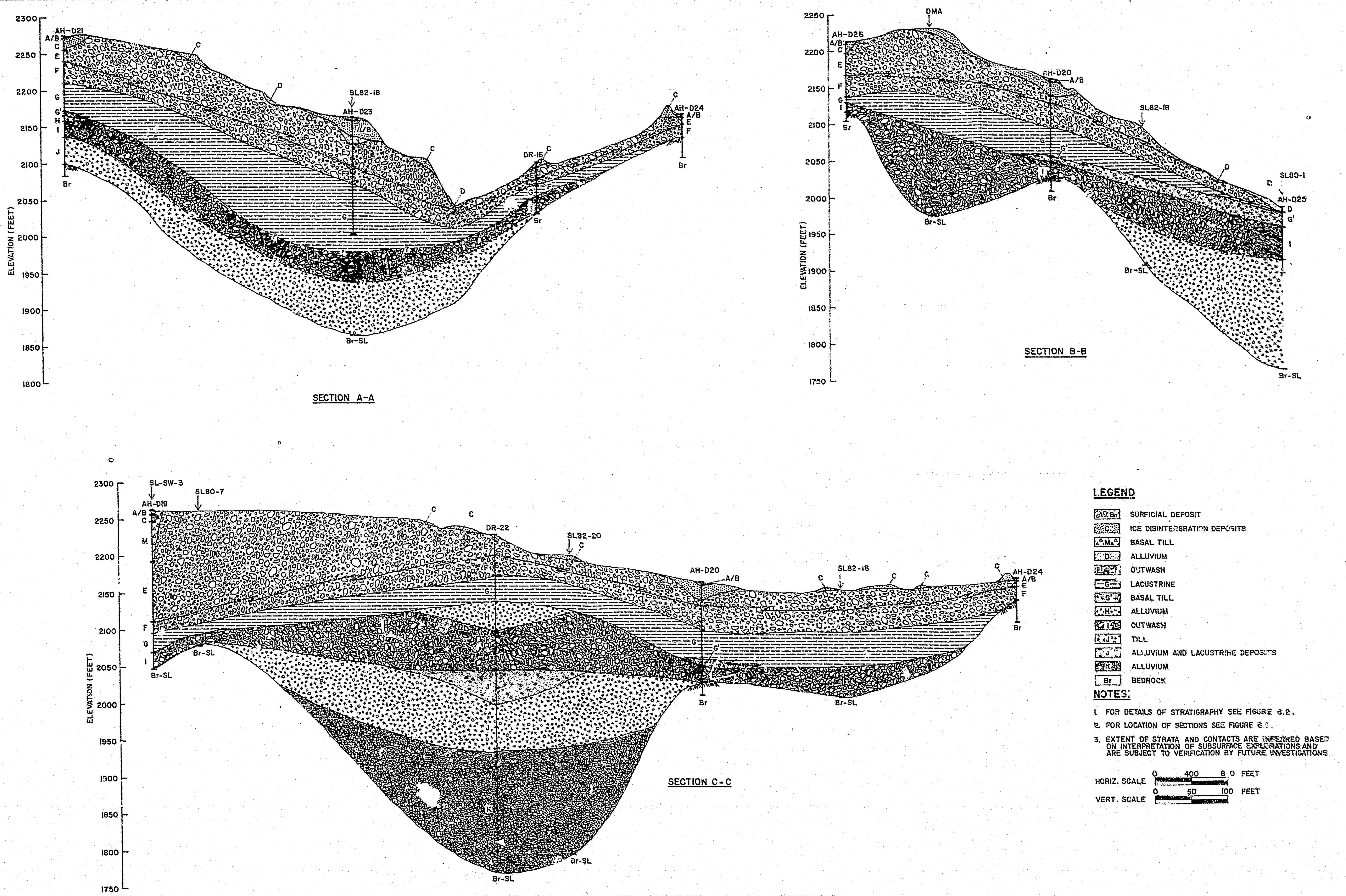
HORIZ. 0 400 800 FEET

VERT. 0 50 100 FEET

WATANA BORROW SITE D / RELICT CHANNEL
STRATIGRAPHIC PANEL DIAGRAM
SHEET 2 OF 2

FIGURE 6.3

ACRES



WATANA RELICT CHANNEL CROSS SECTIONS
SHEET 1 OF 3

FIGURE 6.4

LEGEND:

A/B	SURFICIAL DEPOSIT
C	ICE DISINTEGRATION DEPOSITS
M	BASAL TILL
D	ALLUVIUM
D	LACUSTRINE
E/F	OUTWASH
G	LACUSTRINE
G	BASAL TILL
H	ALLUVIUM
I	OUTWASH
J	TILL
Br	BEDROCK

SECTION D-D

NOTES:

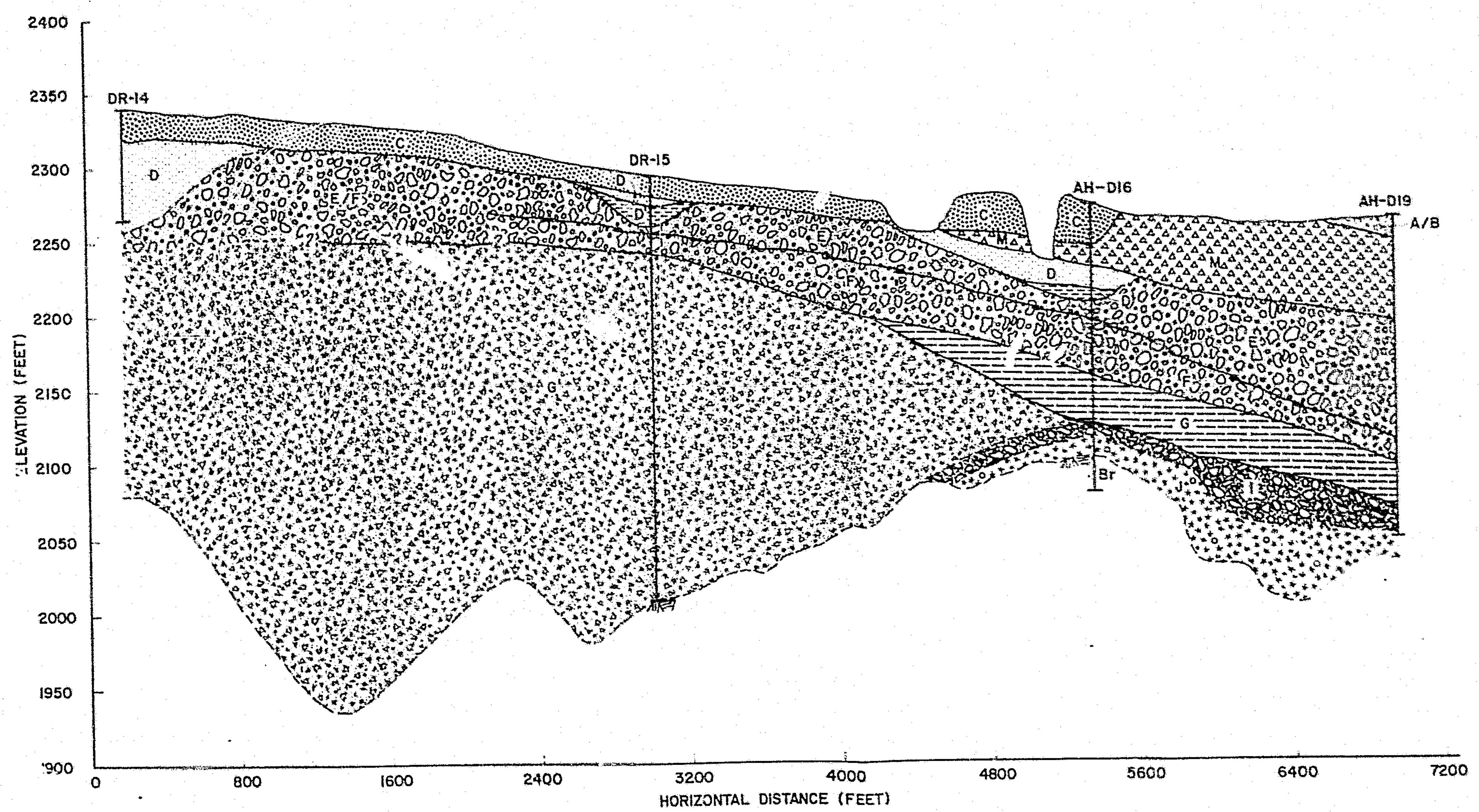
1. FOR DETAILS OF STRATIGRAPHY SEE FIGURE 6.2.
2. FOR LOCATION OF SECTIONS SEE FIGURE 6.1
3. EXTENT OF STRATA AND CONTACTS ARE INFERRED BASED ON INTERPRETATION OF SUBSURFACE EXPLORATIONS AND ARE SUBJECT TO VERIFICATION BY FUTURE INVESTIGATIONS.

HORIZ. SCALE 0 400 800 FEET

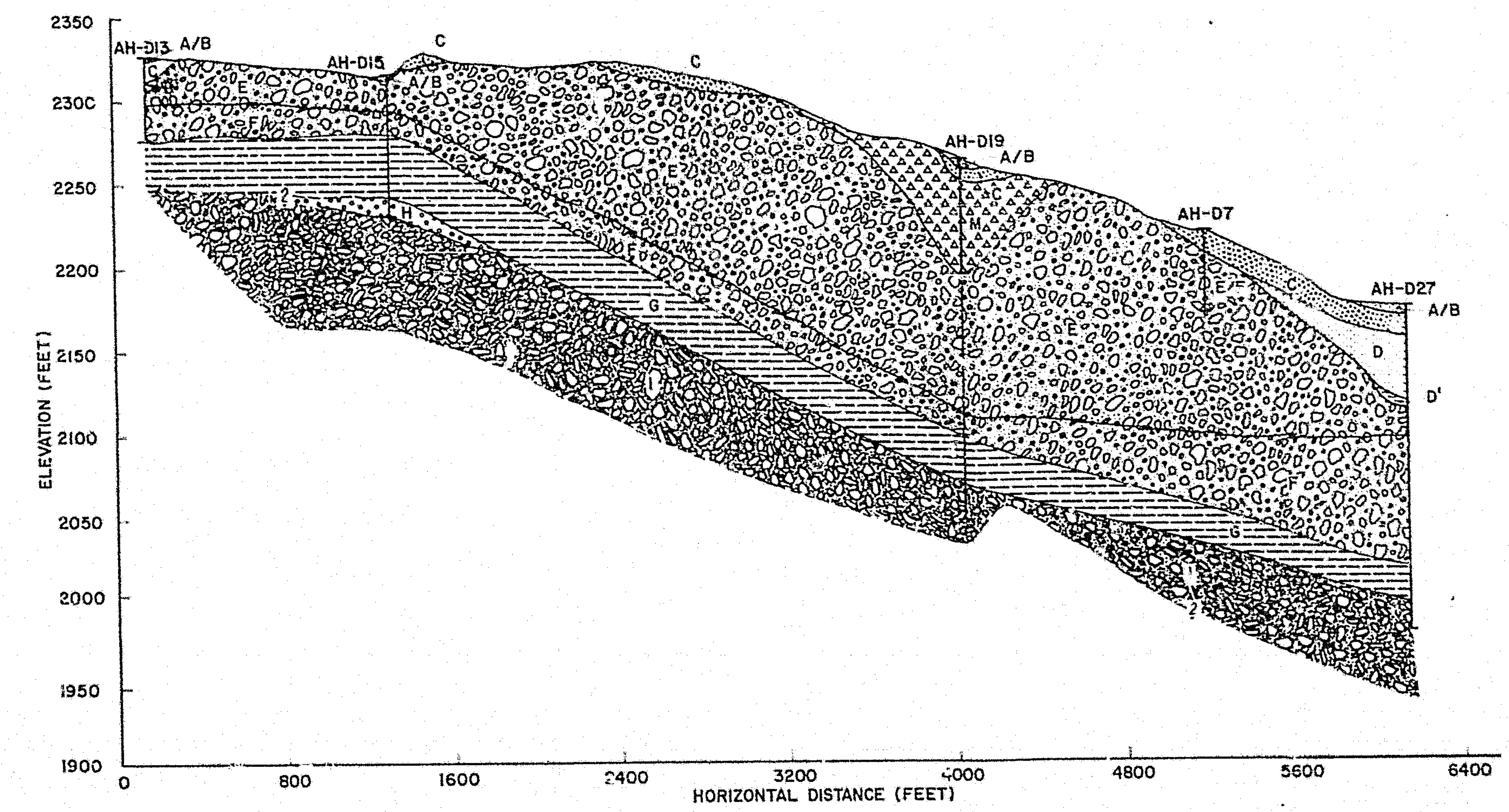
VERT. SCALE 0 50 100 FEET

WATANA
BORROW SITE D
CROSS SECTION
SHEET 2 OF 3

FIGURE 6.4



SECTION E-E



SECTION F-F

LEGEND:

- A/B — SURFICIAL DEPOSIT
- C — ICE DISINTEGRATION DEPOSITS
- M — BASAL TILL
- D — ALLUVIUM
- D' — LACUSTRINE
- E/F — OUTWASH
- G — LACUSTRINE
- G' — BASAL TILL
- H — ALLUVIUM
- I — OUTWASH
- J — TILL
- Br — BEDROCK

NOTES:

1. FOR DETAILS OF STRATIGRAPHY SEE FIGURE 6.2
2. FOR LOCATION OF SECTIONS SEE FIGURE 6.[illegible]
3. EXTENT OF STRATA AND CONTACTS ARE INFERRED BASED ON INTERPRETATION OF SUBSURFACE EXPLORATIONS AND ARE SUBJECT TO VERIFICATION BY FUTURE INVESTIGATIONS.

HORIZ. SCALE 0 400 800 FEET

VERT. SCALE 0 50 100 FEET

WATANA
BORROW SITE D
CROSS SECTIONS
SHEET 3 OF 3

ACRES

FIGURE 6.4

UNIT C

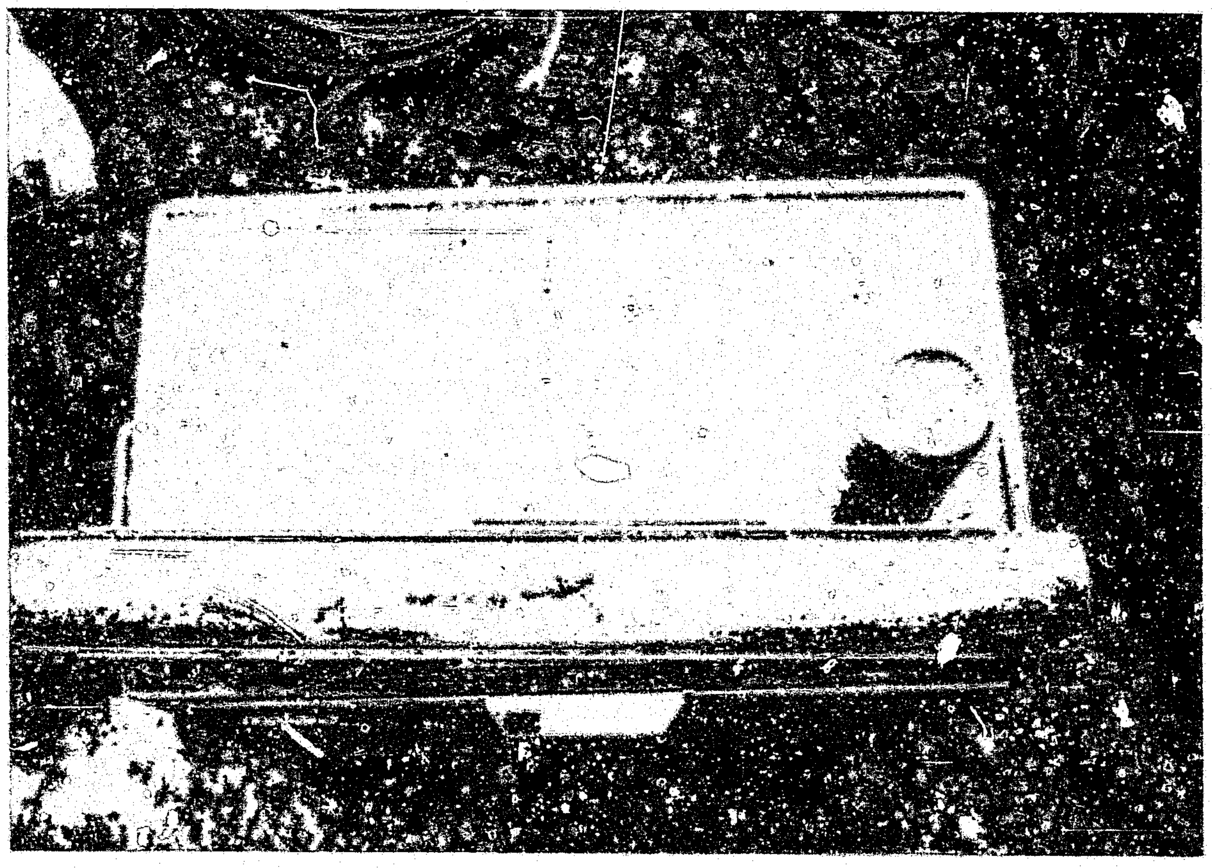
UNIT M

WATANA RELICT CHANNEL/BORROW SITE D
TYPICAL MATERIAL PHOTOS
SHEET 1 OF 7

FIGURE 6.5

ACRES

UNIT D

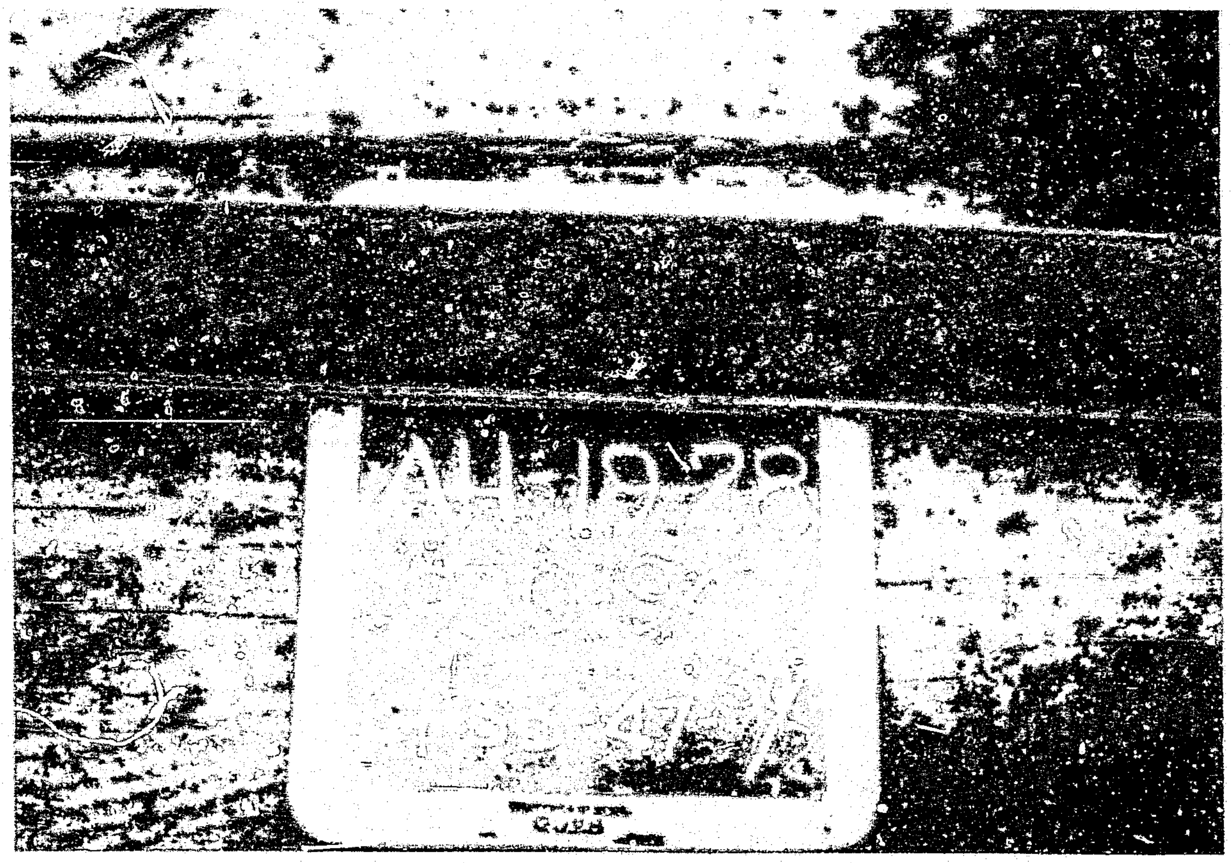


UNIT D'

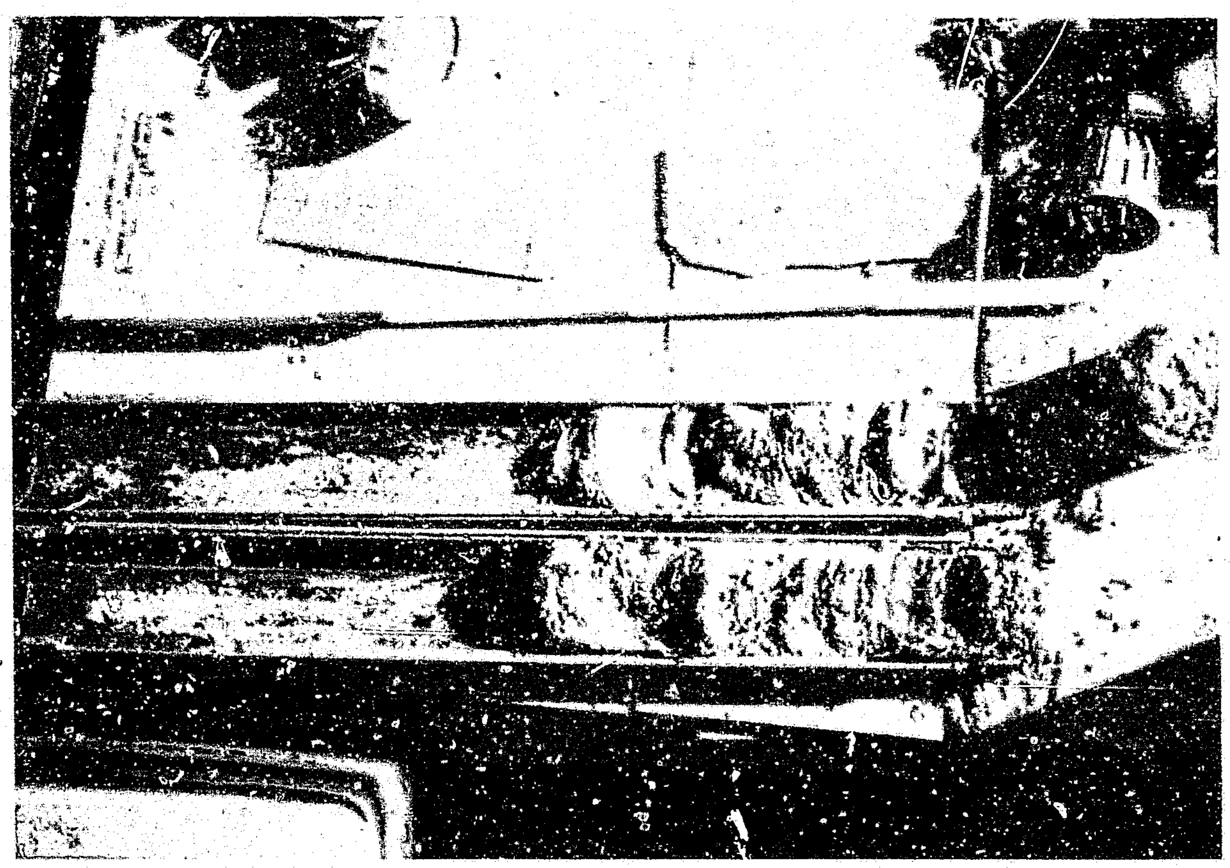
WATANA RELICT CHANNEL/BORROW SITE D
TYPICAL MATERIAL PHOTOS
SHEET 2 OF 7

FIGURE 6.5

ACRES



UNIT E/F

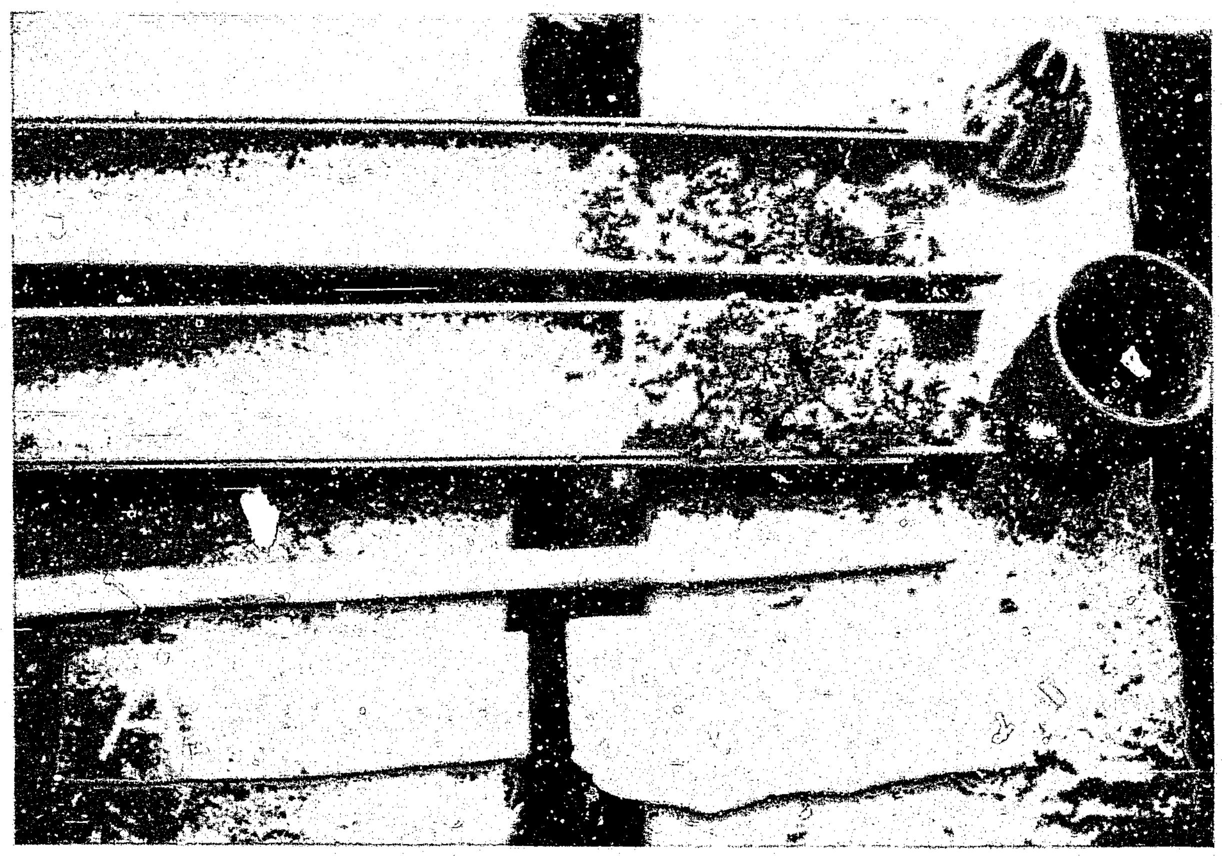


UNIT G

WATANA RELICT CHANNEL/BORROW SITE D
TYPICAL MATERIAL PHOTOS
SHEET 3 OF 7

FIGURE 6.5

ACRES



UNIT I

WATANA RELICT CHANNEL / BORROW SITE D
TYPICAL MATERIAL PHOTOS
SHEET 4 OF 7

FIGURE 6.5

ACRES

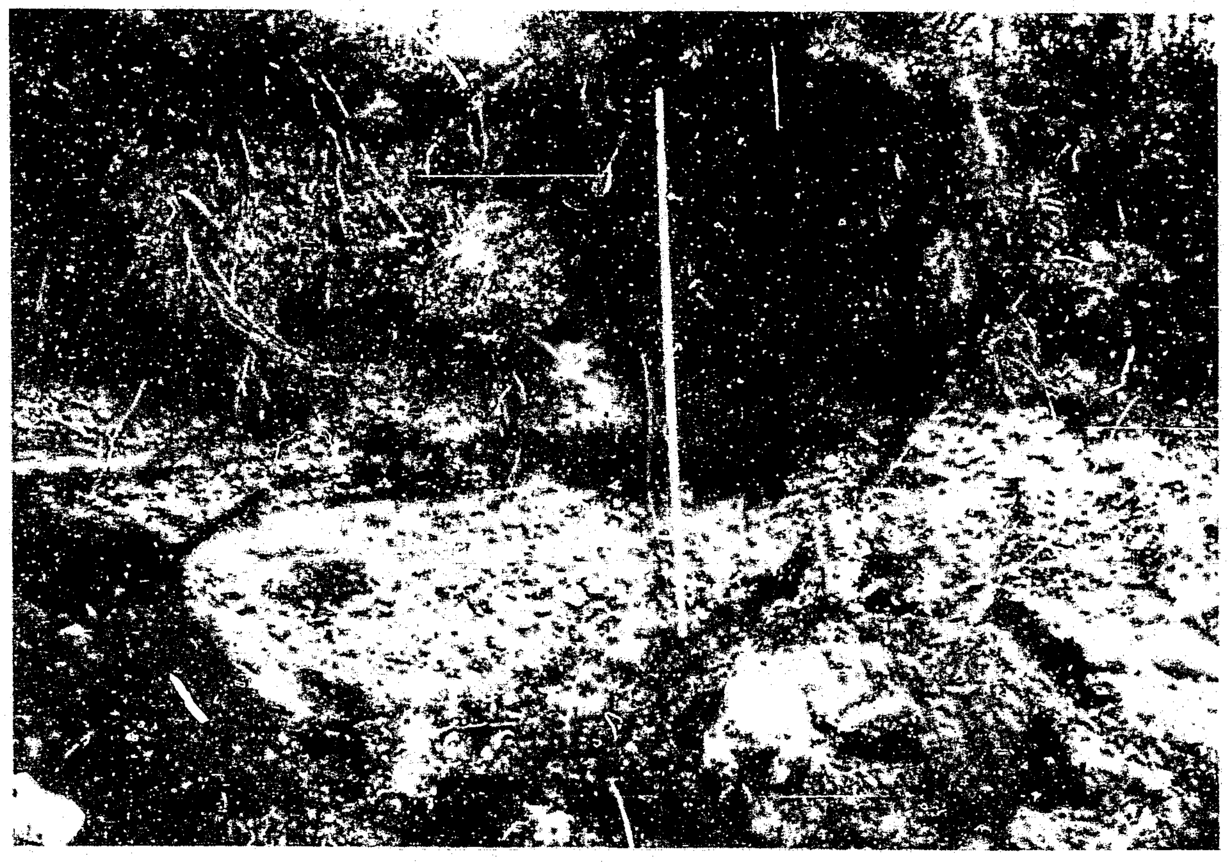
UNIT F

UNIT G'

WATANA RELICT CHANNEL/BORROW SITE D
TYPICAL MATERIAL PHOTOS
SHEET 5 OF 7

FIGURE 6.5

ACRES



UNIT D

UNIT E

WATANA RELICT CHANNEL/BORROW SITE D
TYPICAL MATERIAL PHOTOS
SHEET 6 OF 7

FIGURE 6.5

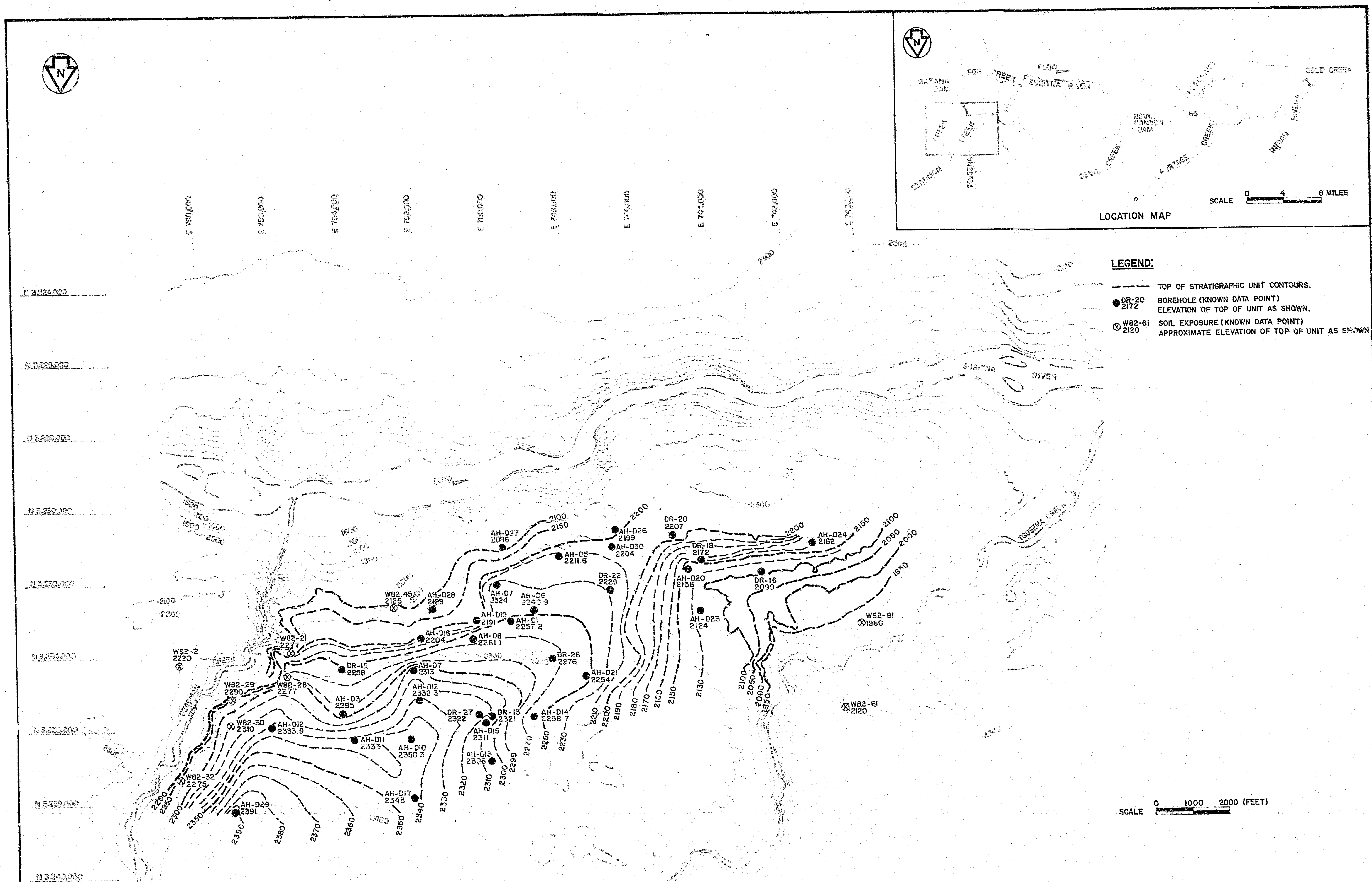
ACRES

UNIT H

WATANA RELICT CHANNEL / BORROW SITE D
TYPICAL MATERIAL PHOTOS
SHEET 7 OF 7

FIGURE 6.5

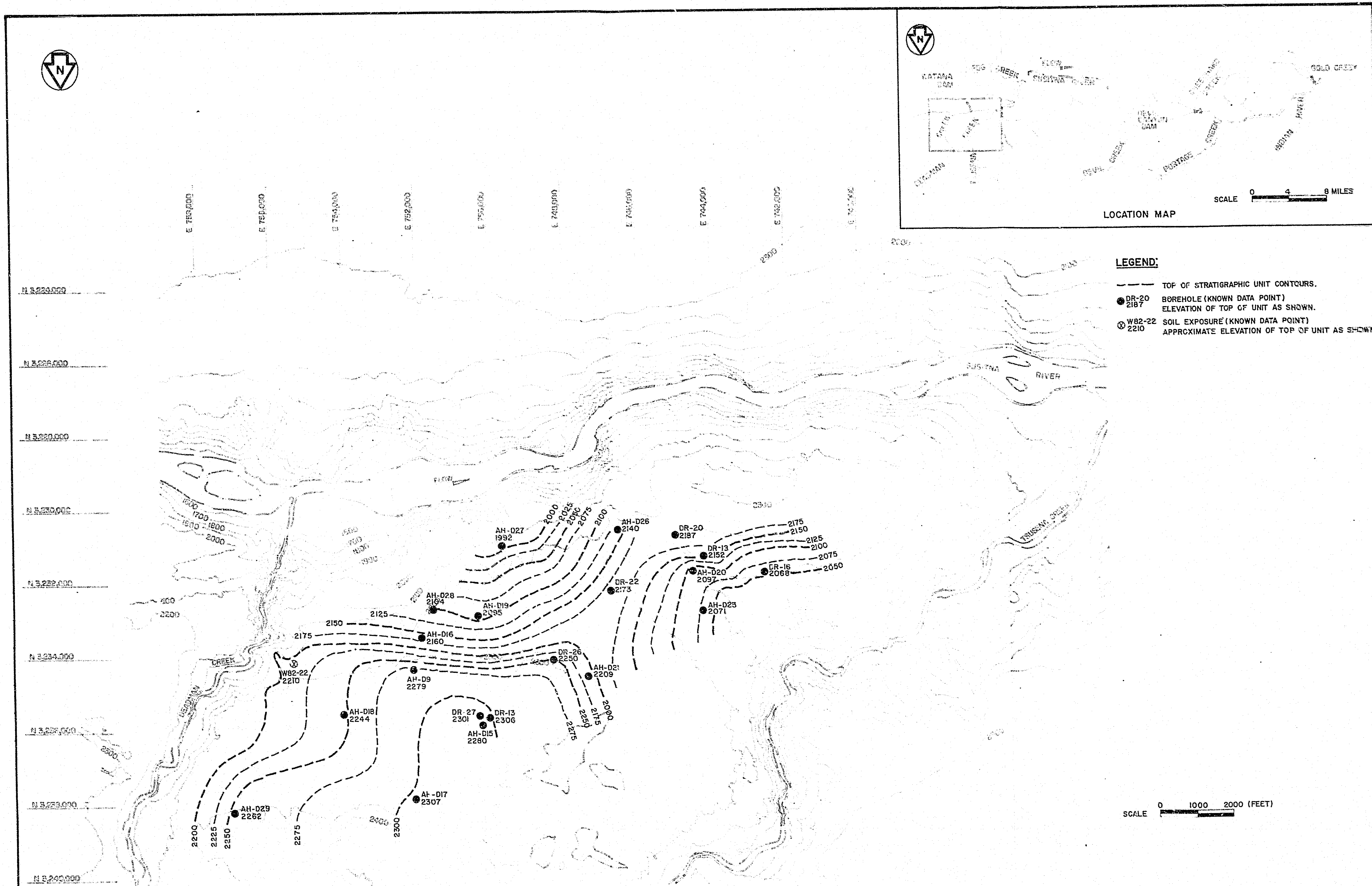
ACRES



WATANA
BORROW SITE D/RELICT CHANNEL
TOP OF STRATIGRAPHIC UNIT E/F CONTOURS
SHEET 1 OF 3

FIGURE 6.6

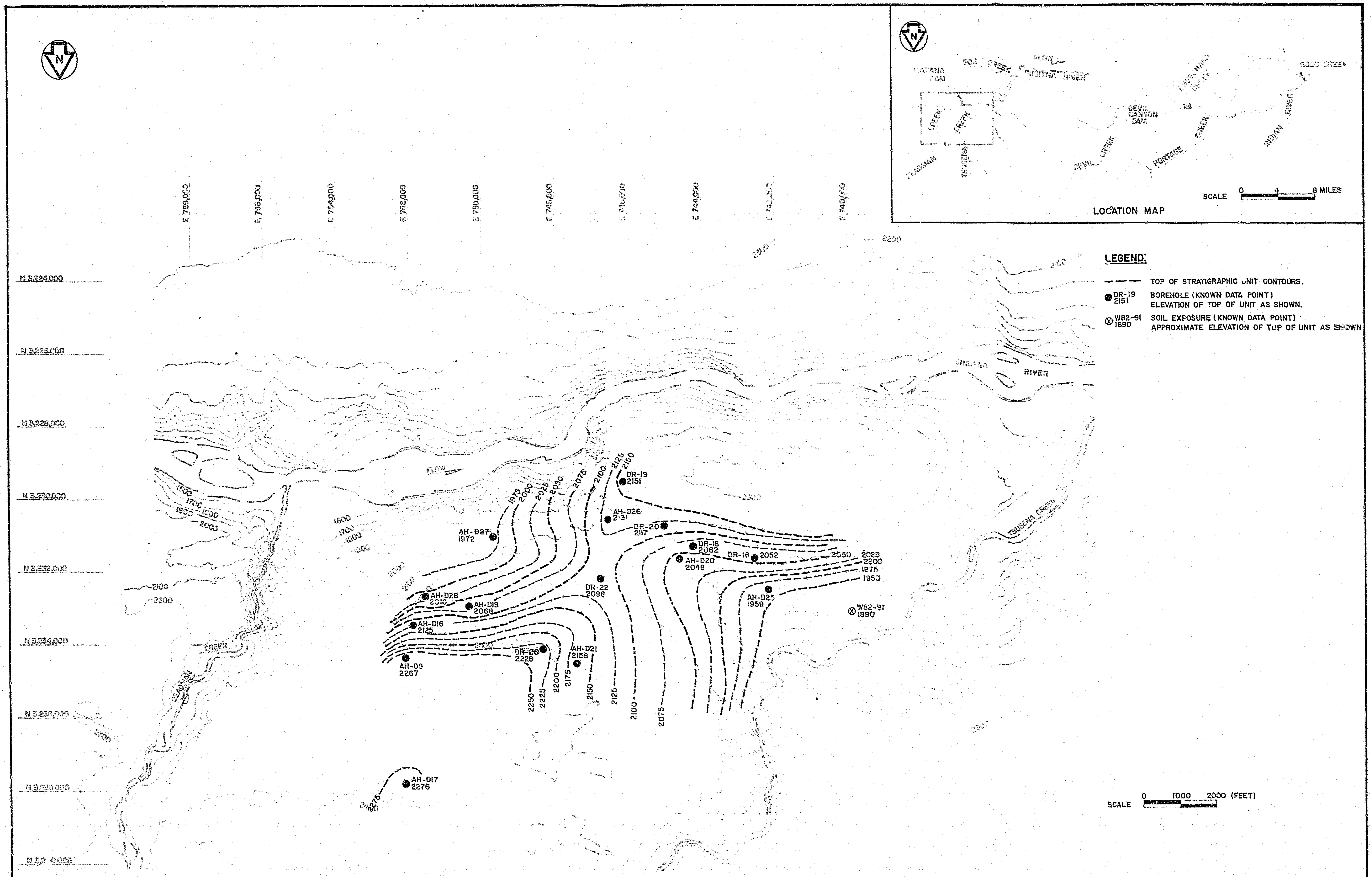
ACRES



WATANA
BORROW SITE D/RELICT CHANNEL
TOP OF STRATIGRAPHIC UNIT G CONTOURS
SHEET 2 OF 3

ACRES

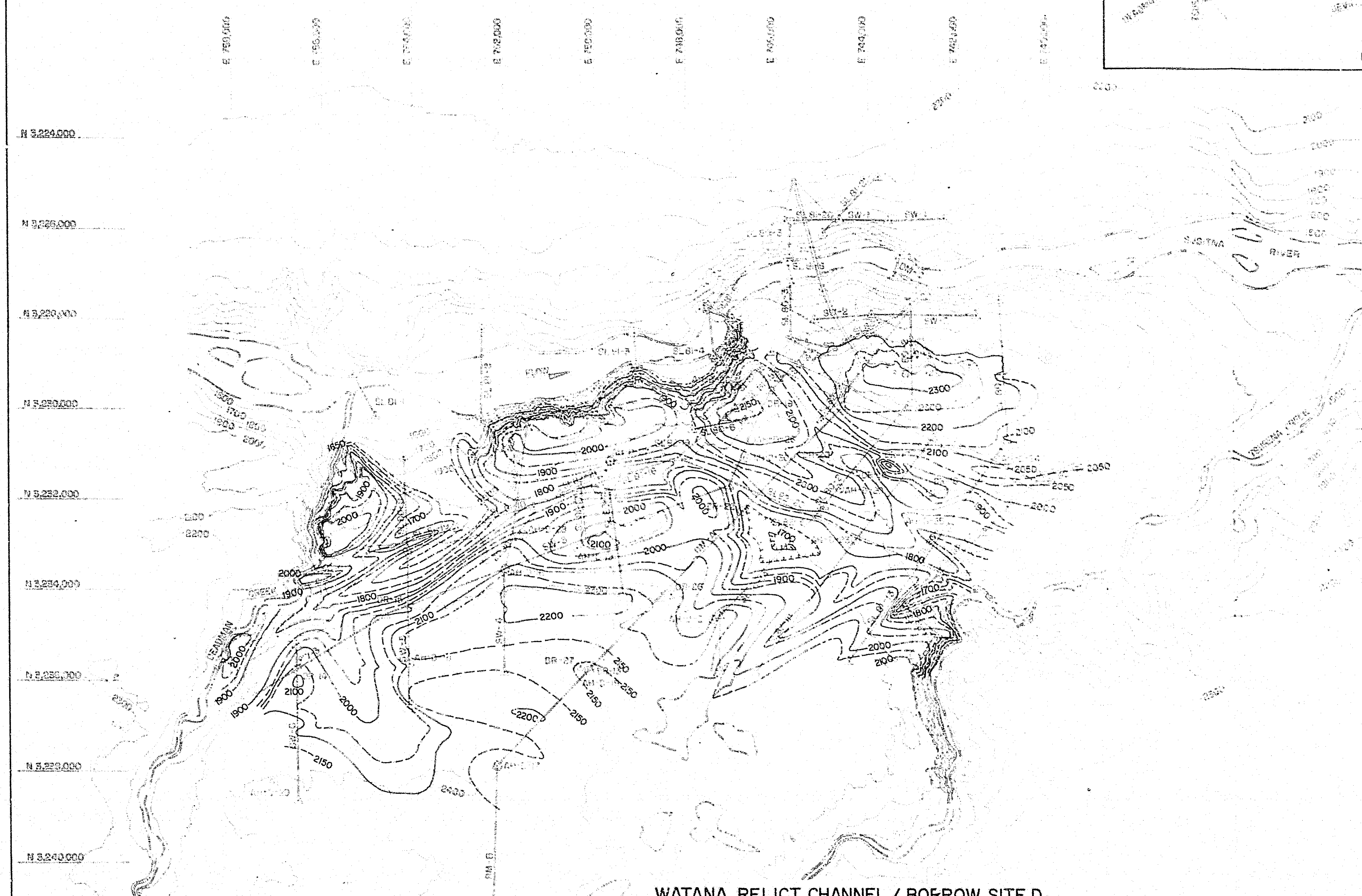
FIGURE 6.6

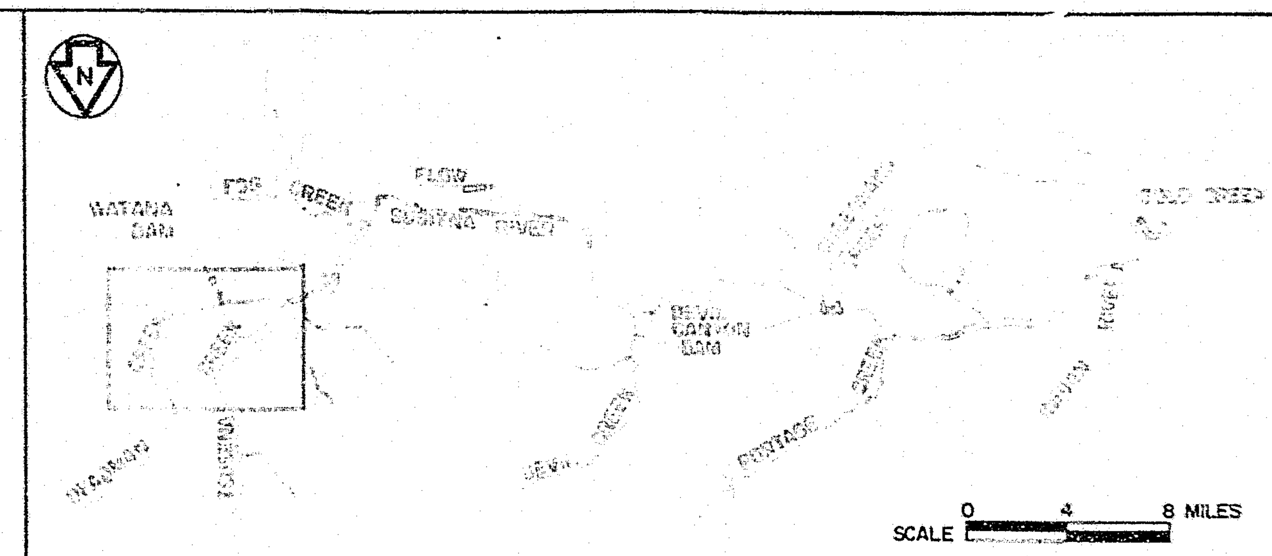


WATANA
BORROW SITE D/RELICT CHANNEL
TOP OF STRATIGRAPHIC UNIT I CONTOURS
SHEET 3 OF 3

FIGURE 6.6

ACRES





LOCATION MAP

LEGEND

LITHOLOGY:

BEDROCK OUTCROP, UNDIFFERENTIATED

CONTACT:

BEDROCK / SURFICIAL DEPOSITS APPROXIMATE

CONTOUR LINES:

TOP OF BEDROCK, CONTOUR INTERVAL 50 FEET

50 FOOT CONTOURS DASHED

TOPOGRAPHY, CONTOUR INTERVAL 100 FEET

NOTES:

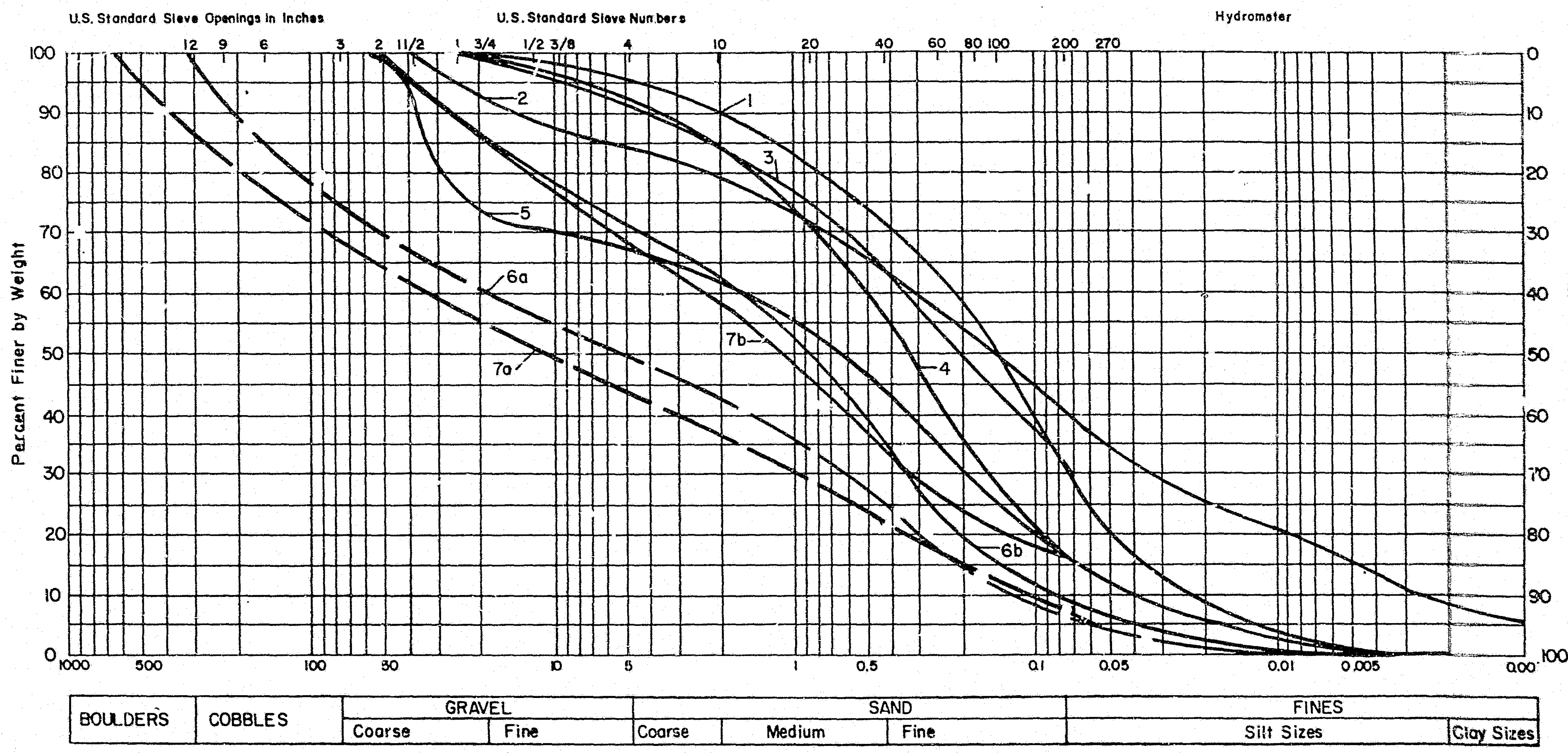
1. BASE MAP FROM 1978, COE - 1" = 200' DAMSITE TOPOGRAPHY SHEETS 1 THROUGH 26 OF 26.
2. EXPLORATION LOGS AND SEISMIC LINE SECTIONS SHOWN IN APPENDICES A AND [illegible] AND AAI, 1982.
3. DETAILED TOP OF BEDROCK IN DAMSITE AREA SHOWN ON FIGURE 5.1.
4. SUPERCEDES FIGURE 6.35, AAI, 1982.

SCALE 0 1000 2000 FEET

WATANA RELICT CHANNEL / BORROW SITE D
TOP OF BEDROCK

ACRES

FIGURE 6.7



1.	AH-D23	SAMPLE 23-7b	17.0 - 19.0 FT.	SM		BULK EXPOSURE SAMPLES			
2.	AH-D19	SAMPLE 19-7	14.0 - 16.0 FT.	SC	6a.	W82-74			GP-GM
3.	DR-14	SAMPLE 1	0-20 FT.	SM	6b.	W82-74		(W/2" MAX. PARTICLE SIZE)	SM
4.	AH-D23	SAMPLE 23-3	8.5-10.5 FT.	SM	7a.	W82-2	PIT 1, 1A, 1B		GP-GM
5.	DR-15	SAMPLE 1	0-15 FT.	SM	7b.	W82-2	PIT 1, 1A, 1B	(W/2" MAX. PARTICLE SIZE)	SM

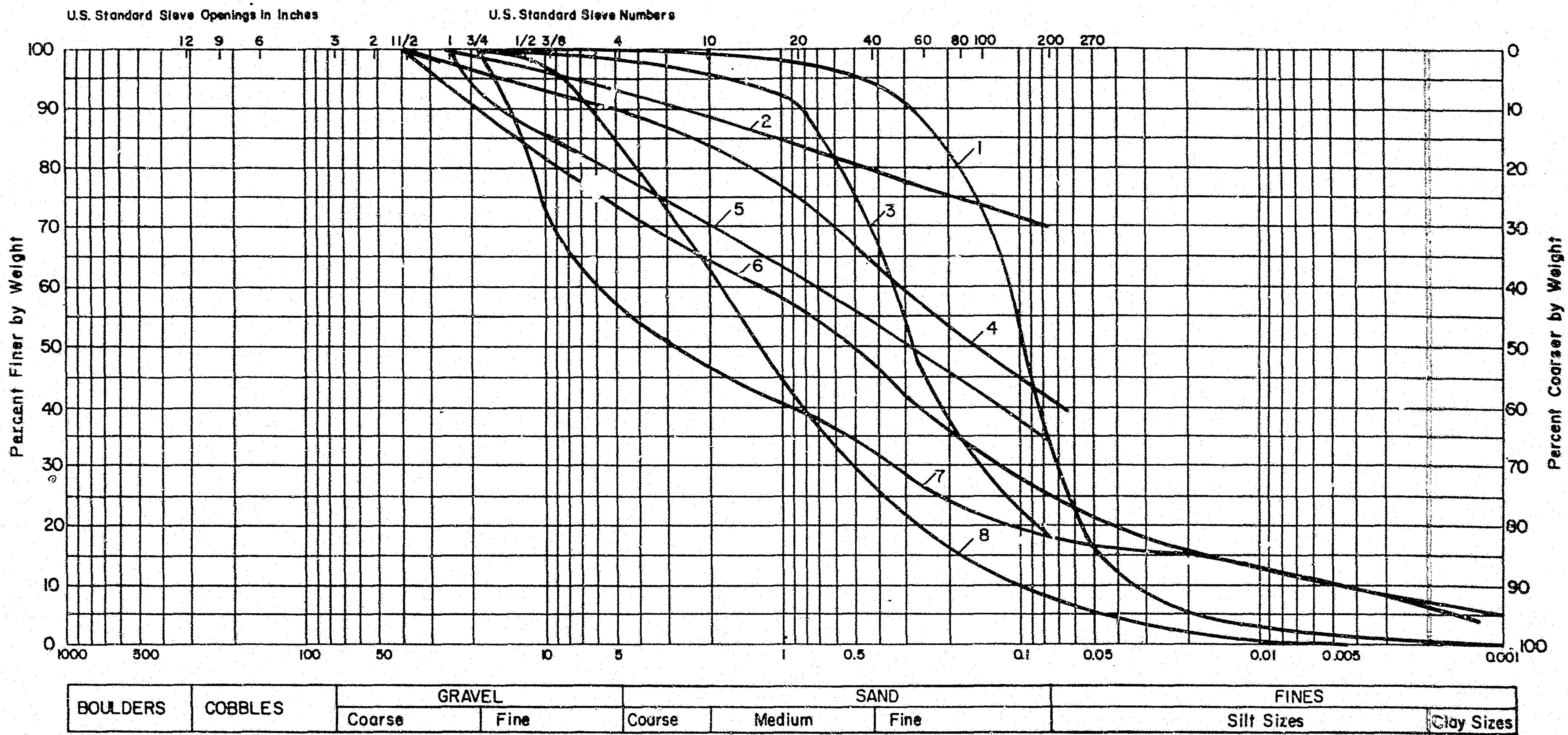
WATANA RELICT CHANNEL / BORROW SITE D

TYPICAL GRADATION CURVES STRATIGRAPHIC UNIT C

SHEET 1 OF 10

FIGURE 6.8

ACRES

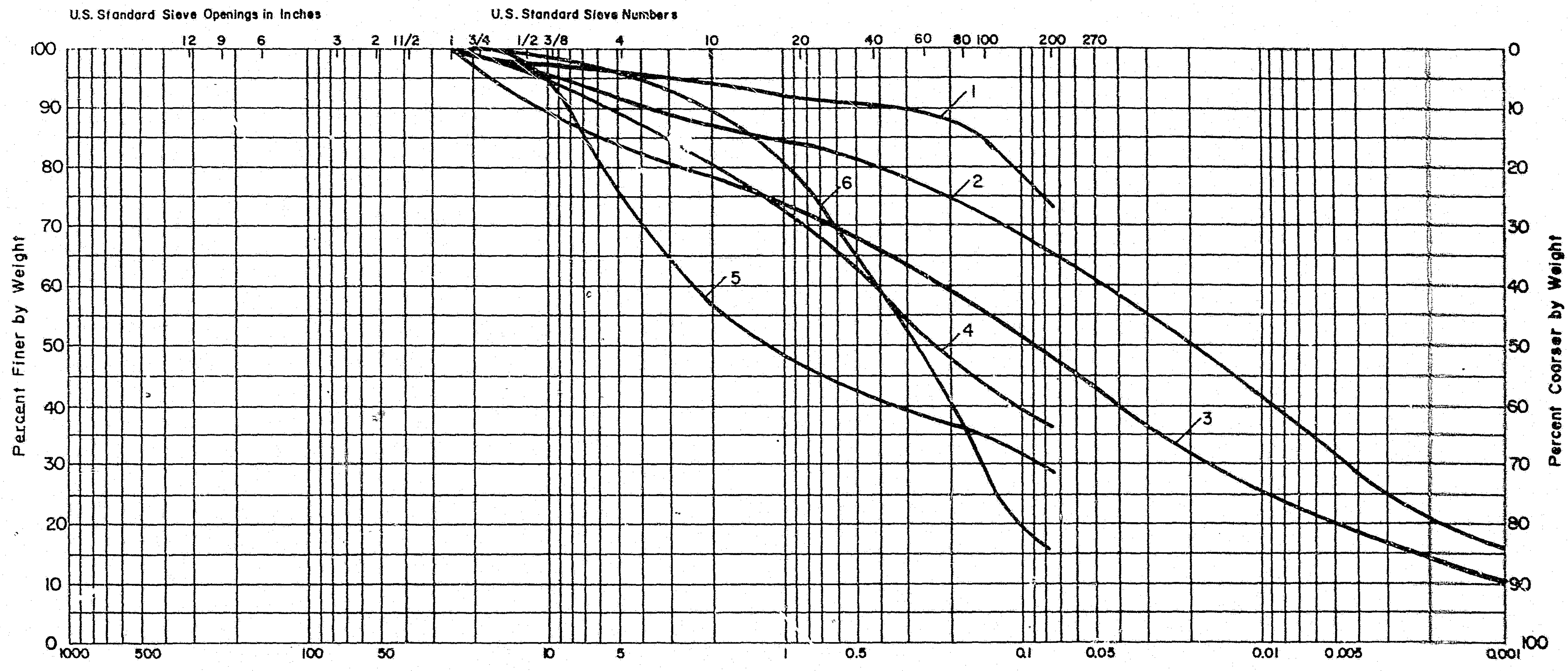


1.	AH-D16 B	SAMPLE 16B-29a	54.9–55.5 FT.	M
2.	AH-D27	SAMPLE 27-12	54.0–54.4 FT.	CL
3.	AH-D23	SAMPLE 23-11	29.0–31.0 FT.	SM
4.	AH-D29	SAMPLE 29-7	16.0–18.0 FT.	SM
5.	AH-D27	SAMPLE 27-10	44.0–48.0 FT.	SC
6.	AH-D27	SAMPLE 27-5	28.0–29.3 FT.	SC-SM
7.	DR-15	SAMPLE 2	17.0–22.0 FT.	GM-GC
8.	DR-14	SAMPLE 6	61.0–63.0 FT.	SW-SM

WATANA RELICT CHANNEL / BORROW SITE D
TYPICAL GRADATION CURVES STRATIGRAPHIC UNIT D
SHEET 2 OF 10

FIGURE 6 . 8

ACRES



BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

1. AH-D16B SAMPLE 16B-34 64.3-64.9 FT. ML
2. AH-D18 SAMPLE 18-9 25.0-27.0 FT. CL-CH
3. AH-D18 SAMPLE 18-15 37.0-38.4 FT. CL-SC
4. AH-D27 SAMPLE 27-13 60.0-61.2 FT. SM-SC
5. AH-D16 B SAMPLE 16B-36B 67.8-68.8 FT SM
6. DR-15 SAMPLE 4 26.3-36.0 FT. SC

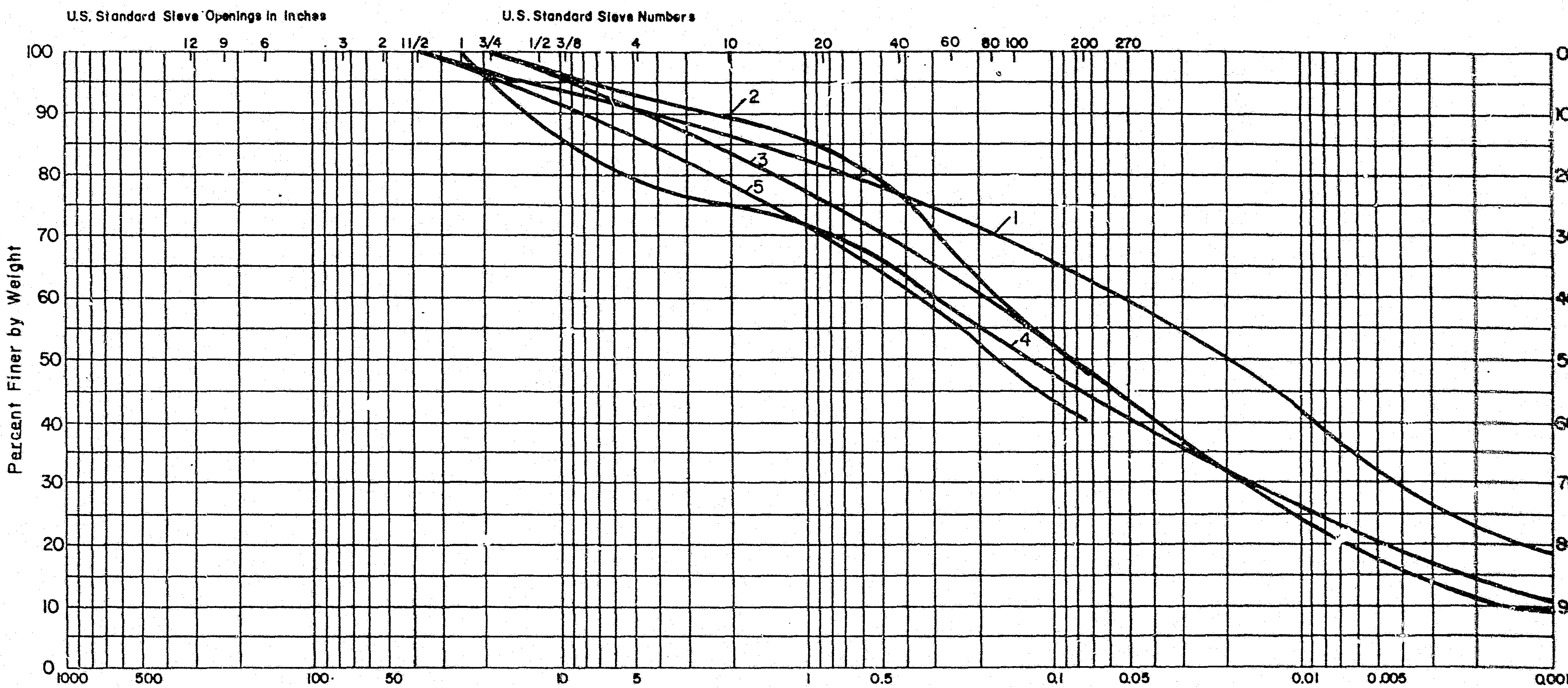
WATANA RELICT CHANNEL / BORROW SITE D

TYPICAL GRADATION CURVES STRATIGRAPHIC UNIT D'

SHEET 3 OF 10

FIGURE 6.8

ACRES



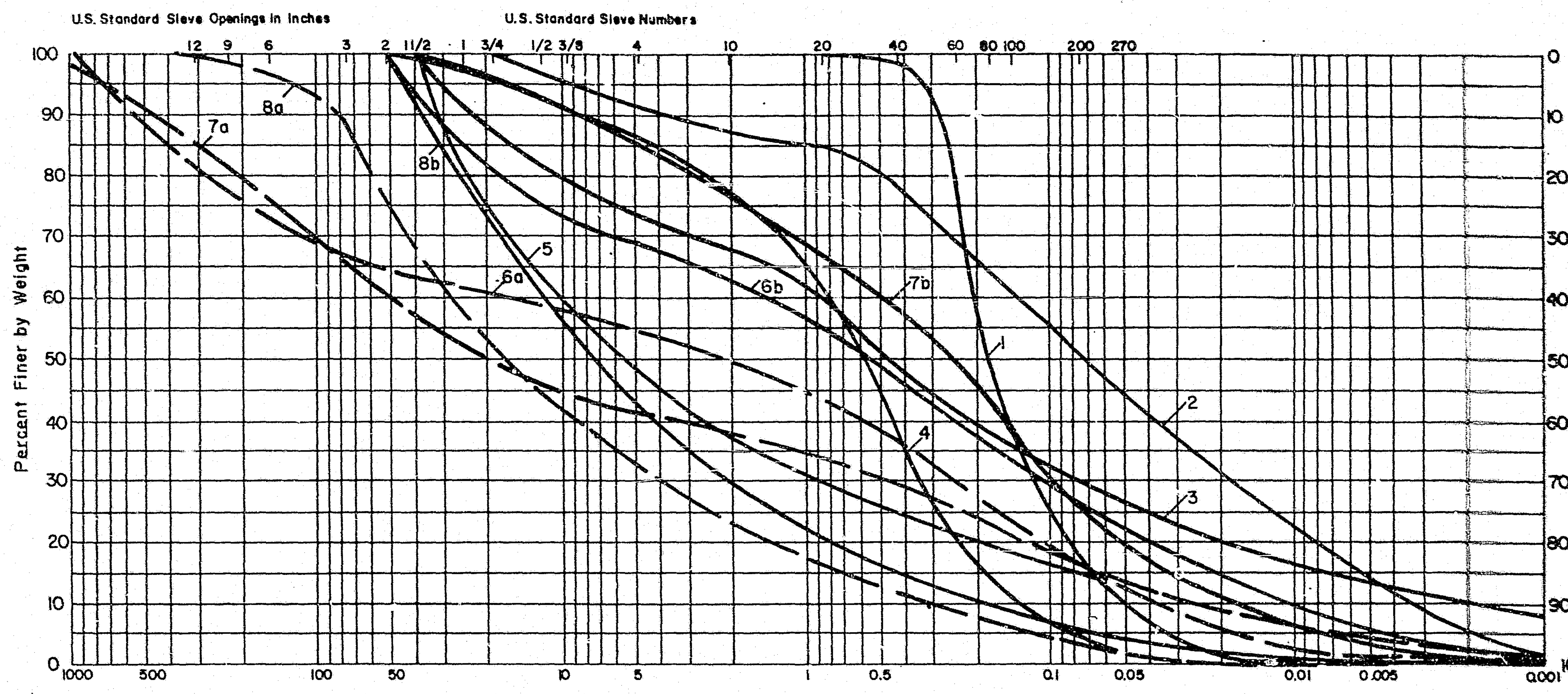
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

1. AH-D28 SAMPLE 28-12b 24.0-26.0 FT. CL
2. AH-D16 SAMPLE 16-14b 30.2-31.0 FT. CL-SC
3. AH-D28 SAMPLE 28-9b 18.0-20.0 FT. SC-CL
4. AH-D28 SAMPLE 28-17 36.0-38.0 FT. SC-CL
5. AH-D19 SAMPLE 19-12b 34.3-35.8 FT. SM-SC

WATANA RELICT CHANNEL/BORROW SITE D
TYPICAL GRADATION CURVES STRATIGRAPHIC UNIT M
SHEET 4 OF 10

FIGURE 6.8

ACRES



BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

1.	AH-D20	SAMPLE 20-20	44.0–46.0 FT.	SM
2.	AH-D15	SAMPLE 15-7	15.0–17.0 FT.	SM
3.	AH-D26	SAMPLE 26-6	27.0–28.4 FT.	SC
4.	AH-D16B	SAMPLE 16B-38	71.3–72.9 FT.	SP
5.	AH-D24	SAMPLE 24-5	14.0–16.0 FT.	SM-SC

BULK EXPOSURE SAMPLES

6a.	W82-26	PIT 4		GM
6b.	W82-26	PIT 4	(W/2" MAX. PARTICLE SIZE)	SM
7a.	W82-44	PIT 2		GM
7b.	W82-44	PIT 2	(W/2" MAX. PARTICLE SIZE)	SM
8a.	W82-91			GW
8b.	W82-91		(W/2" MAX. PARTICLE SIZE)	GW-GM

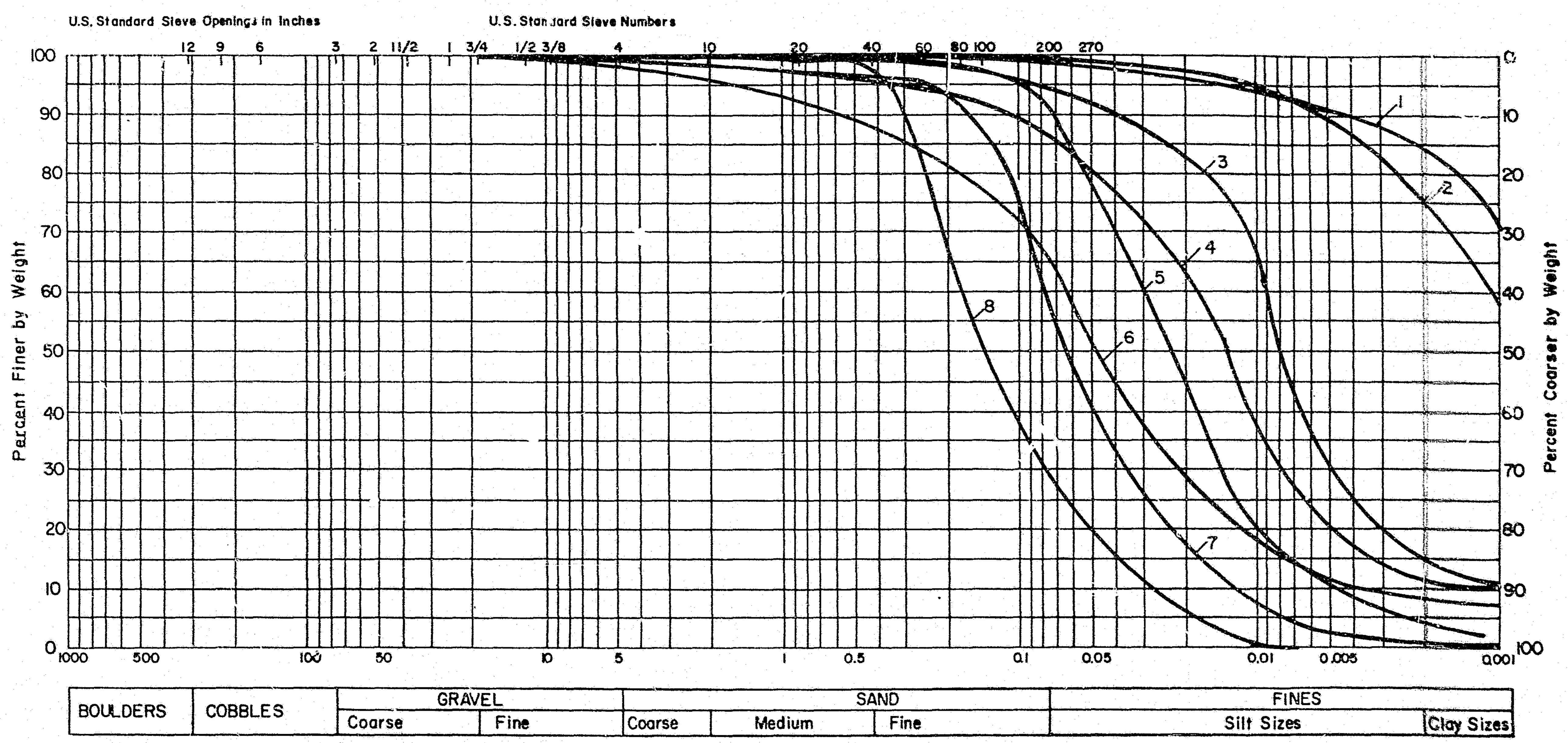
WATANA RELICT CHANNEL / BORROW SITE D

TYPICAL GRADATION CURVES STRATIGRAPHIC UNIT E/F

SHEET 5 OF 10

FIGURE 6.8

ACRES



1.	AH-D28	SAMPLE 28-48	148.5-150.5 FT.	CH
2.	AH-D28	SAMPLE 28-47	143.5-145.5 FT.	CH
3.	AH-D19	SAMPLE 19-46	169.0-169.4 FT.	CL-ML
4.	AH-D23	SAMPLE 23-50	146.0-147.2 FT.	ML
5.	DR-20	SAMPLE 4b	50.0-51.5 FT.	ML-CL
6.	AH-D18	SAMPLE 18-26A	98.0-100.0 FT.	ML-CL
7.	AH-D23	SAMPLE 23-46	132.2-133.0 FT.	ML
8.	DR-18	SAMPLE 4a	63.0-64.5 FT.	SM

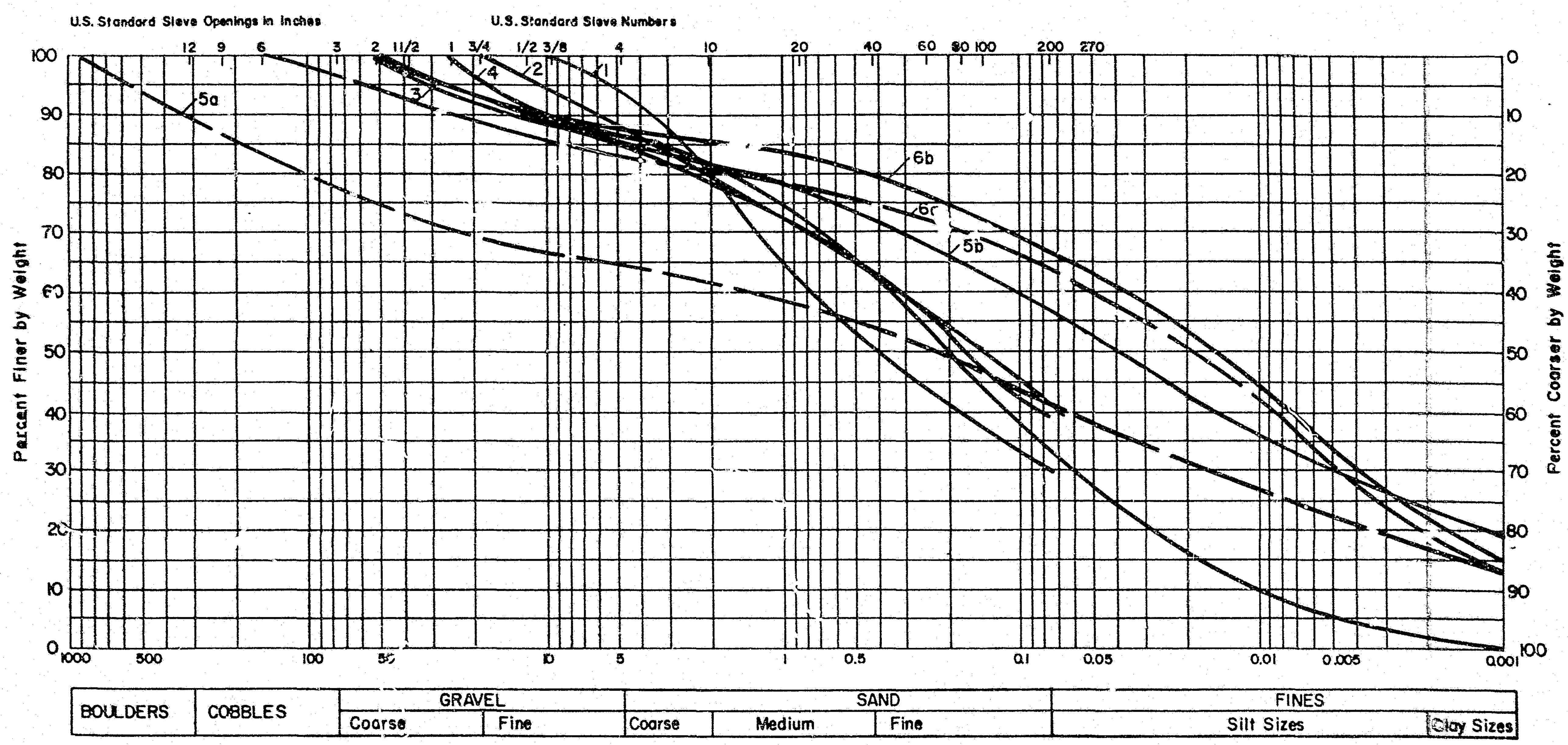
WATANA RELICT CHANNEL / BORROW SITE D

TYPICAL GRADATION CURVES STRATIGRAPHIC UNIT G

SHEET 6 OF 10

FIGURE 6.8

ACRES



1. AH-D18 SAMPLE 18-55 172.0–173.0 FT. SM-SC
2. AH-D17 SAMPLE 17-39 102.0–102.8 FT. SM-SC
3. AH-D17 SAMPLE 17-35 94.0–95.2 FT. SC

BULK EXPOSURE SAMPLES

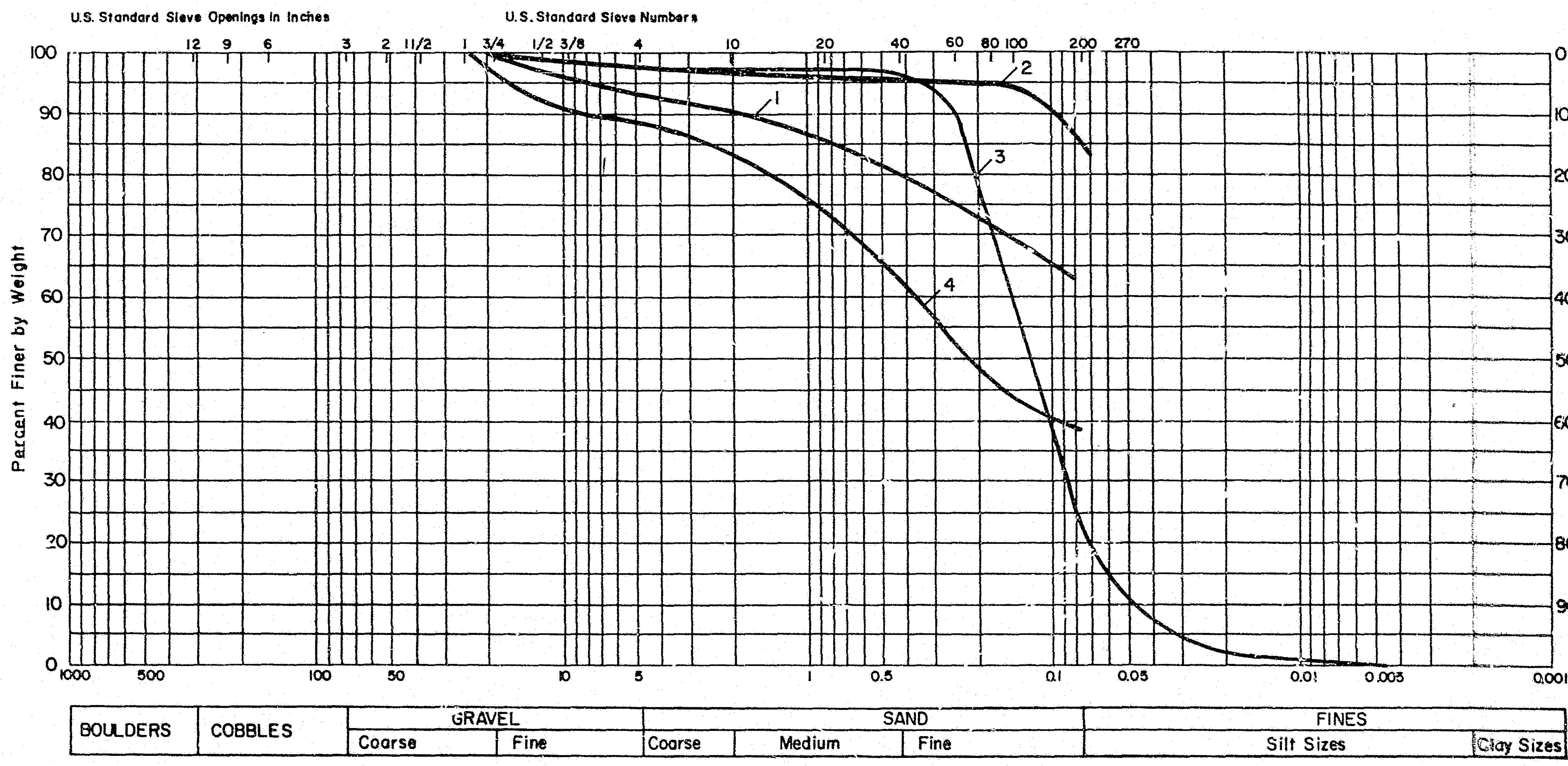
4. W82-73 SM-SC
5a. W82-2 PIT 5,6,7 SC
5b. W82-2 PIT 5,6,7 (W/ 2" MAX. PARTICLE SIZE) CL
6a. W82-45 PIT 2 CL-ML
6b. W82-45 PIT 2 (W/ 2" MAX. PARTICLE SIZE) CL-ML

WATANA RELICT CHANNEL / BORROW SITE D

TYPICAL GRADATION CURVES STRATIGRAPHIC UNIT G'

SHEET 7 OF 10

FIGURE 6.8



1. AH-D28 SAMPLE 28-57 206.0-206.7 FT. CL
2. AH-D21 SAMPLE 21-44 108.0-108.8 FT. ML
3. DR-22 SAMPLE 6 117.2-118.5 FT. SM
4. DR-22 SAMPLE 5 97.0-98.5 FT. SM

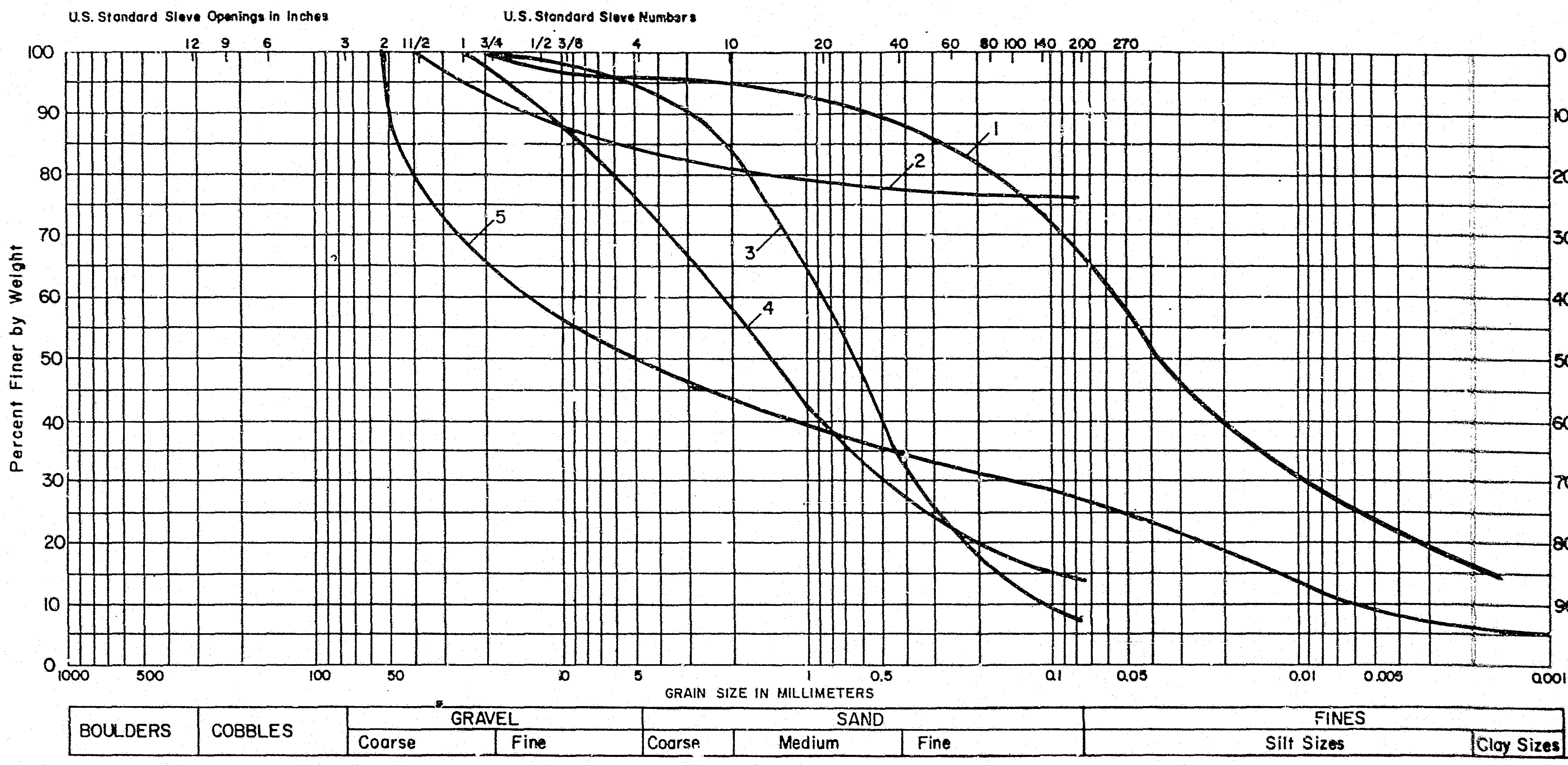
WATANA RELICT CHANNEL / BORROW SITE D

TYPICAL GRADATION CURVES STRATIGRAPHIC UNIT H

SHEET 8 OF 10

FIGURE 6.8

ACRES



1. DR-18	SAMPLE 8a	158.3-159.6 FT.	ML-CL
2. AH-D25	SAMPLE 25-19	53.0-54.0 FT.	ML-CL
3. AH-D25	SAMPLE 25-22	68.0-69.1 FT.	SW
4. AH-D21	SAMPLE 21-49	130.0-131.0 FT.	SM-SW
5. AH-D25	SAMPLE 25-11	32.0-32.7 FT.	GM-SM

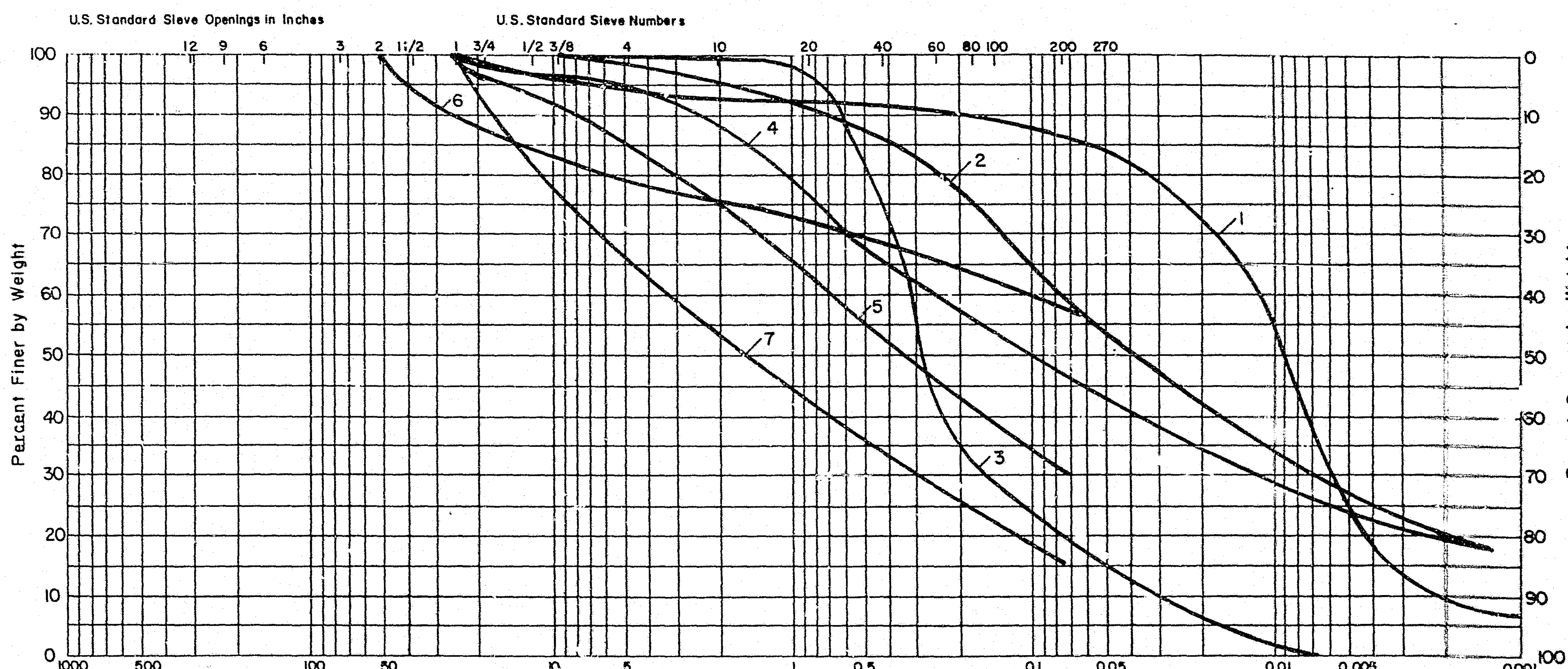
WATANA RELICT CHANNEL / BORROW SITE D

TYPICAL GRADATION CURVES STRATIGRAPHIC UNIT I

SHEET 9 OF 10

FIGURE 6.8

ACRES



BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

1. AH-D16B SAMPLE 16B-73 163.0-164.1 FT. ML-MH
2. DR-18 SAMPLE 9 199.1-200.0 FT. ML
3. DR-22 SAMPLE 9 198.3-199.5 FT. SM (J')
4. DR-20 SAMPLE 9 189.5-195.1 FT. ML
5. DR-22 SAMPLE 11 238.4-238.8 FT. SM-SC
6. AH-D16B SAMPLE 16B-72 159.0-161.0 FT. SC-SM
7. AH-D21 SAMPLE 25-55 158.5-158.7 FT. SM

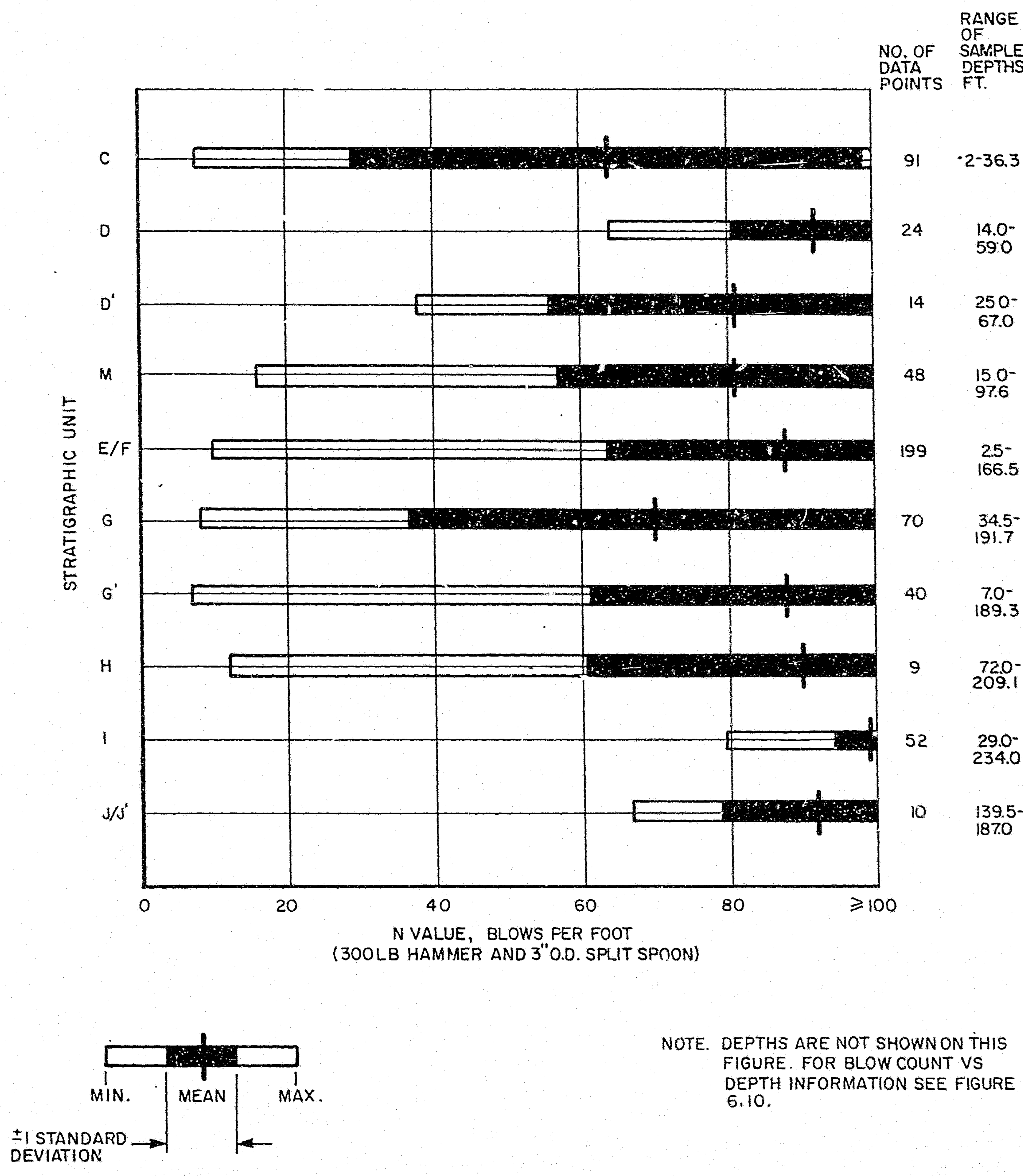
WATANA RELICT CHANNEL / BORROW SITE D

TYPICAL GRADATION CURVES STRATIGRAPHIC UNIT J/J'

SHEET 10 OF 10

FIGURE 6.8

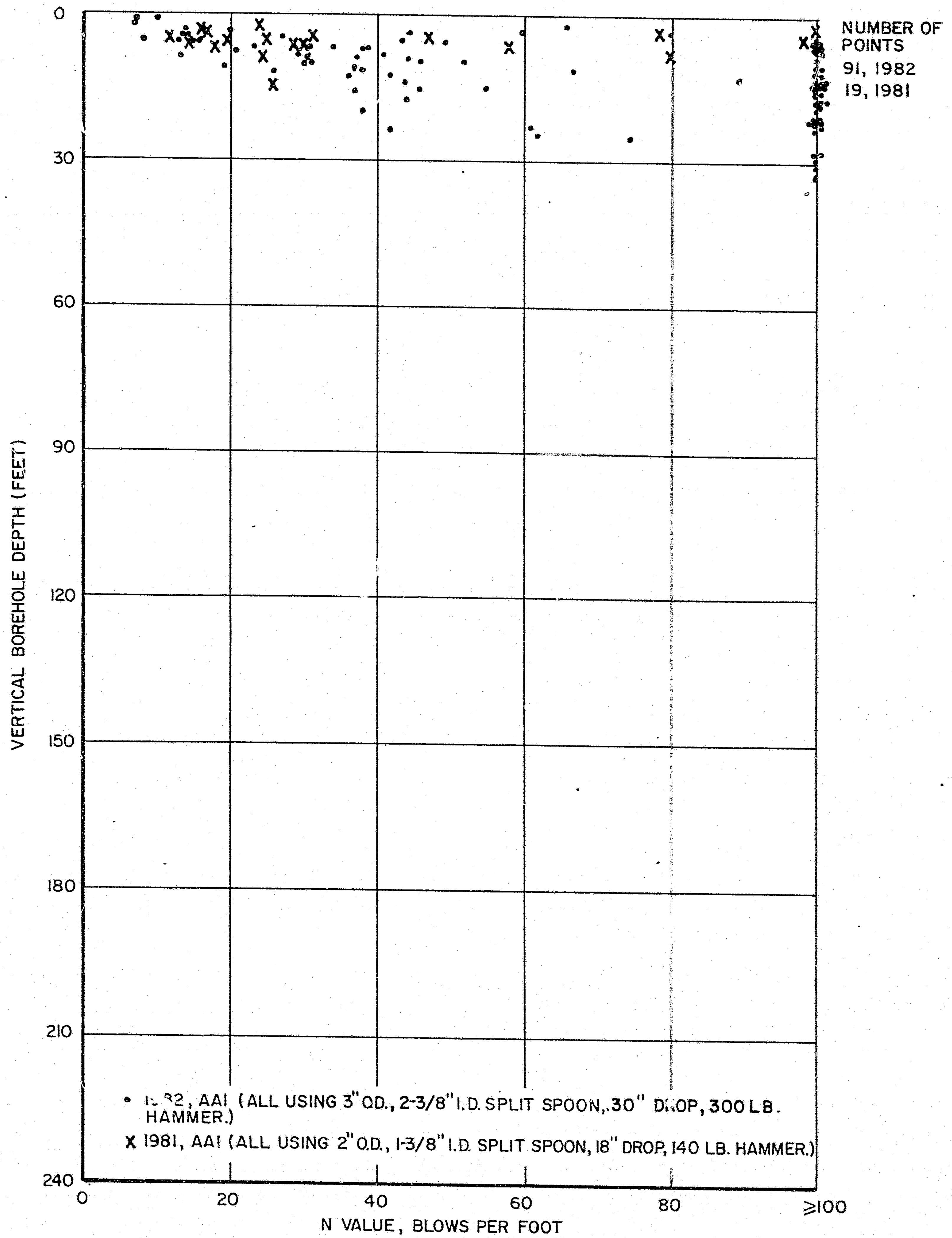
ACRES



WATANA RELICT CHANNEL/BORROW SITE D
COMPOSITE DRIVE SAMPLE BLOW COUNT DATA

ACRES

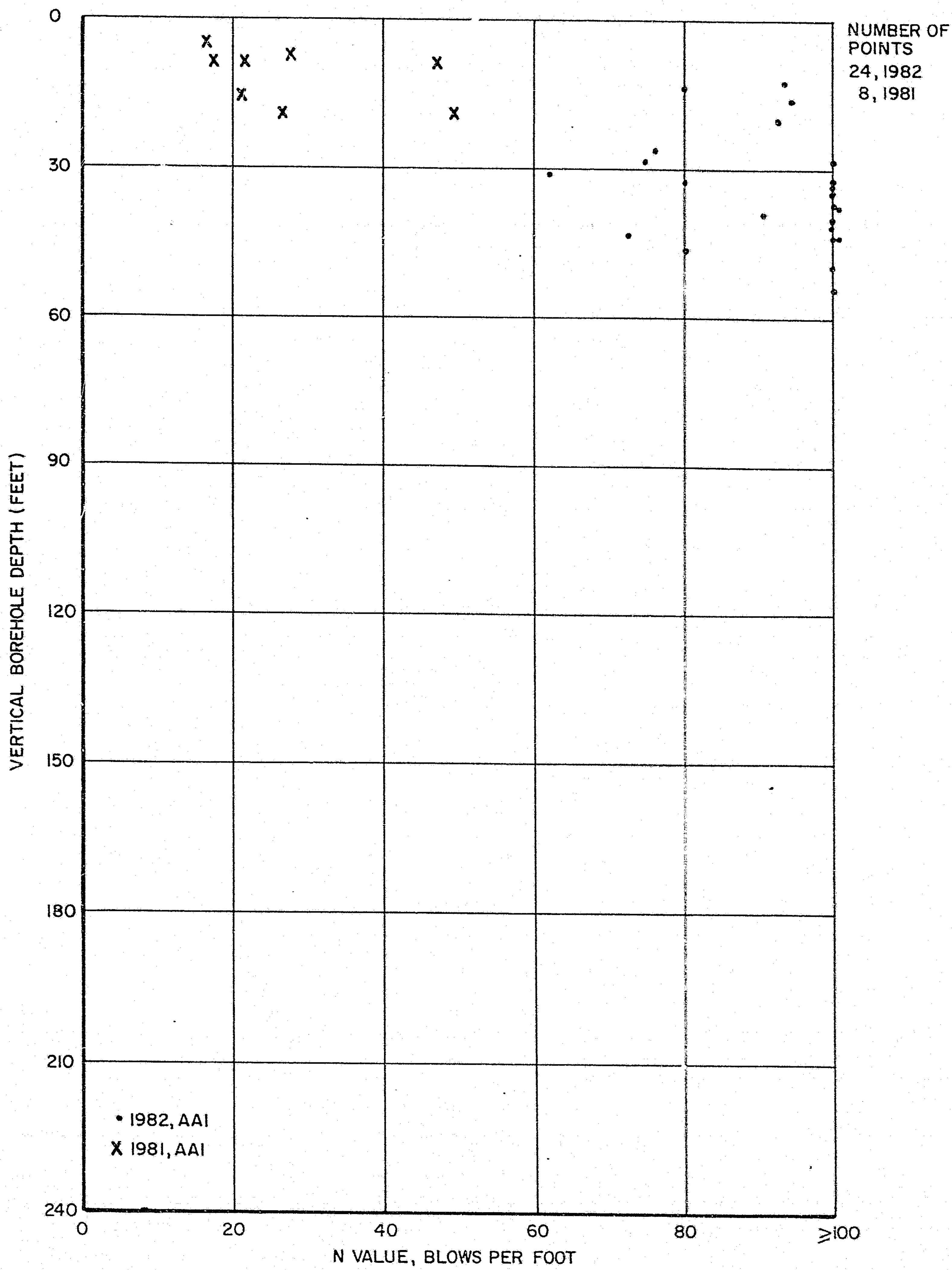
FIGURE 6.9



WATANA RELICT CHANNEL / BORROW SITE D
DRIVE SAMPLE BLOW COUNT DATA
UNIT C
SHEET 1 OF 10

FIGURE 6.10

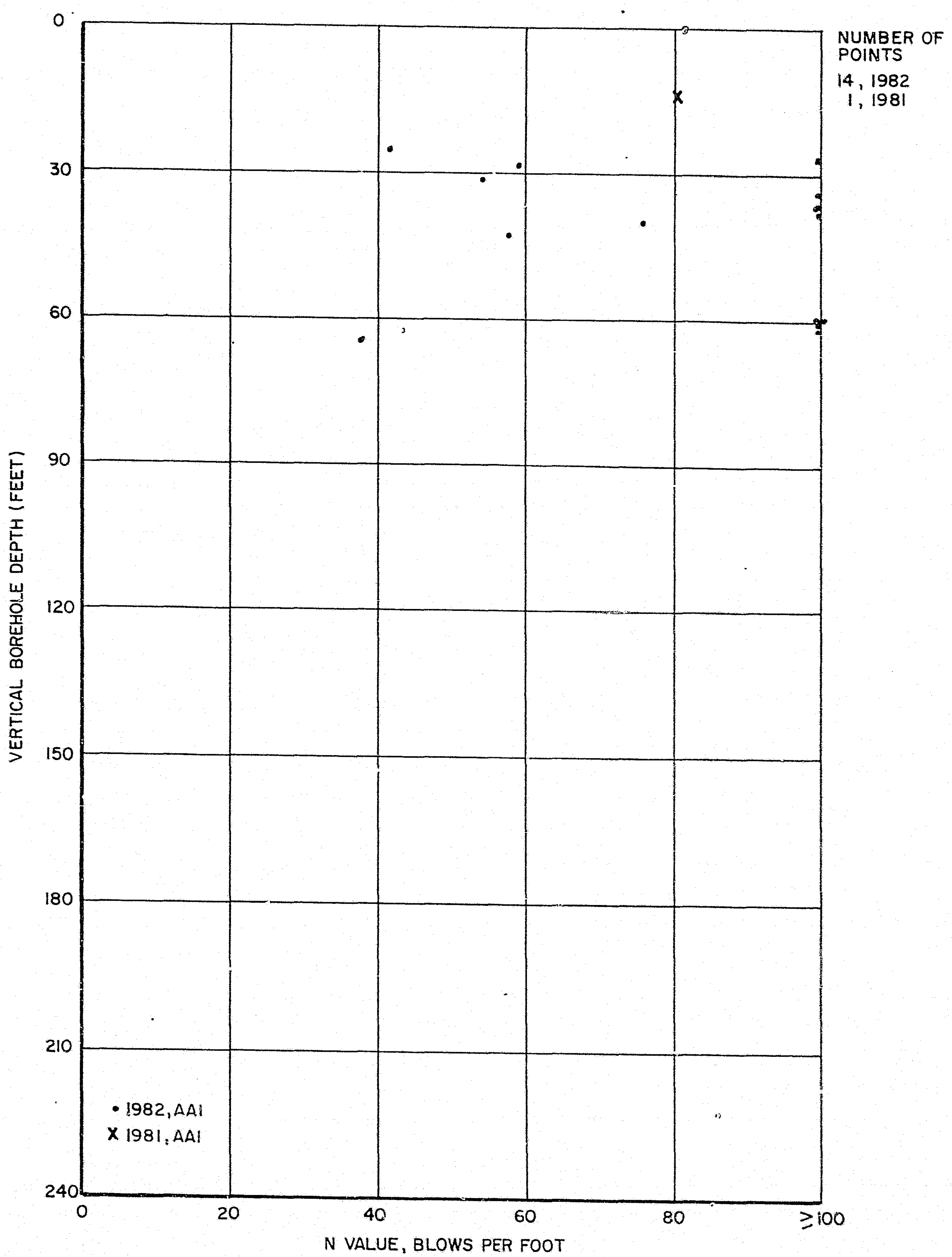
ACRES



WATANA RELICT CHANNEL / BORROW SITE D
DRIVE SAMPLE BLOW COUNT DATA
UNIT D
SHEET 2 OF 10

FIGURE 6.10

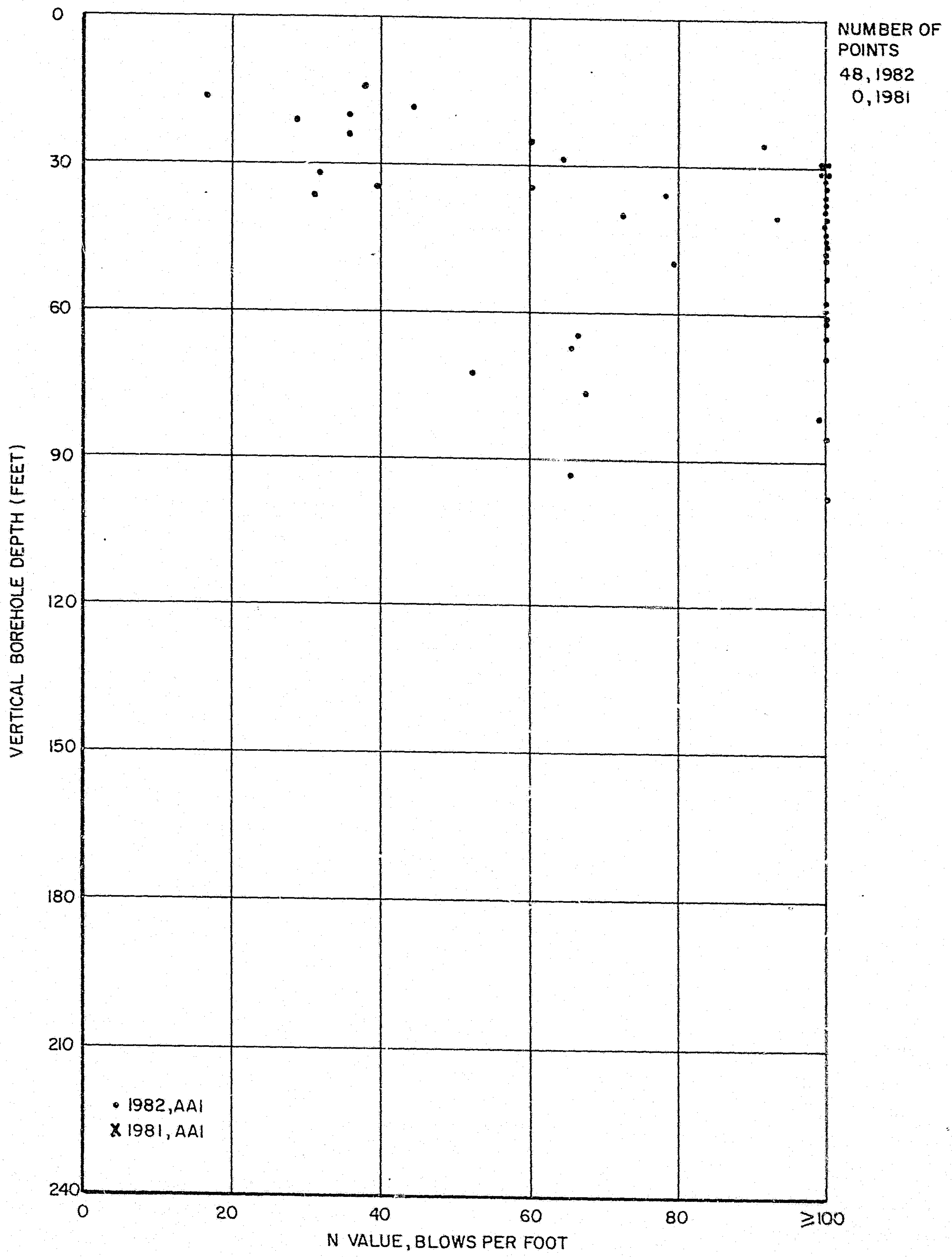
ACRES



WATANA RELICT CHANNEL / BORROW SITE D
DRIVE SAMPLE BLOW COUNT DATA
UNIT D'
SHEET 3 OF 10

FIGURE 6.10

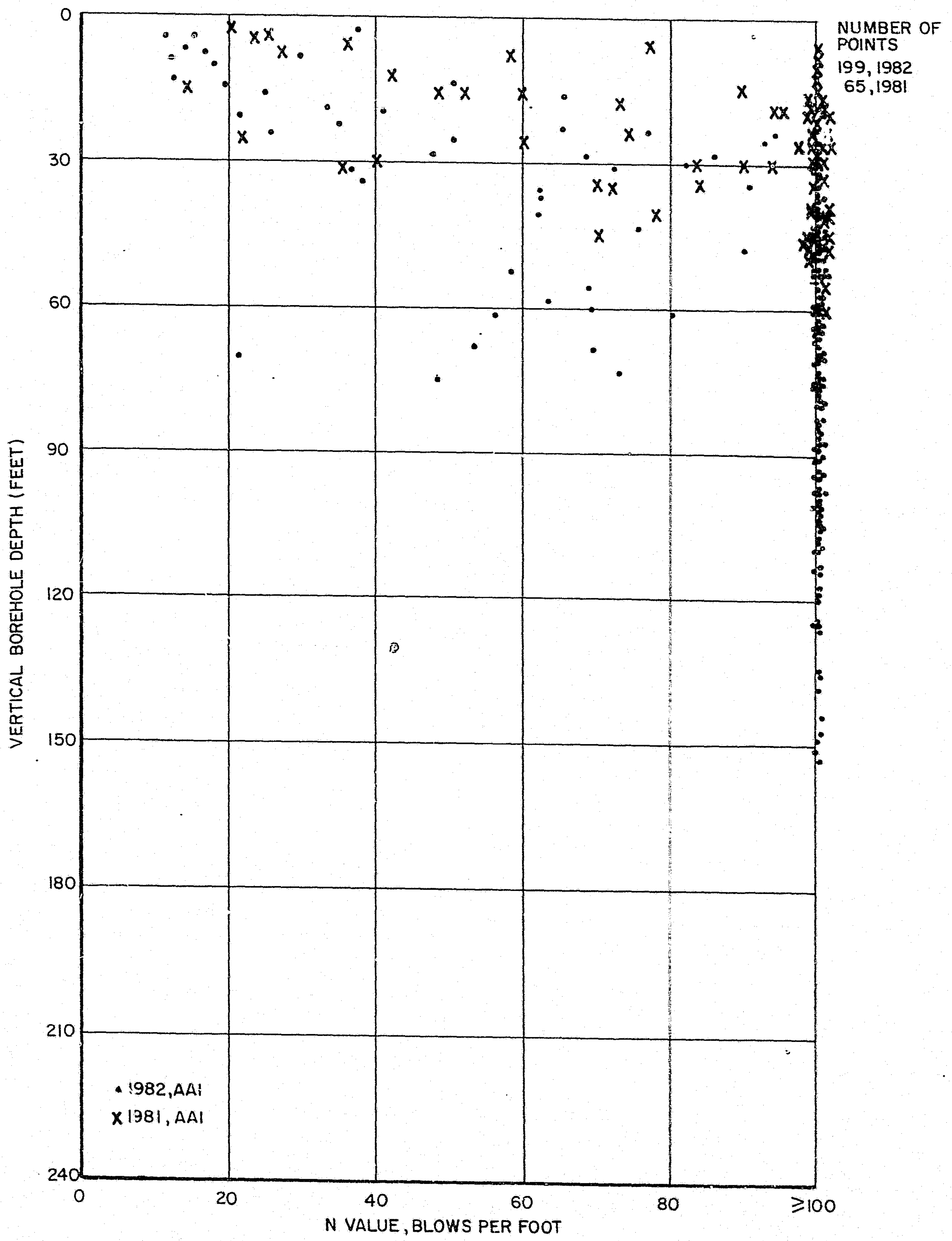
ACRES



WATANA RELICT CHANNEL / BORROW SITE D
DRIVE SAMPLE BLOW COUNT DATA
UNIT M
SHEET 4 OF 10

FIGURE 6.10

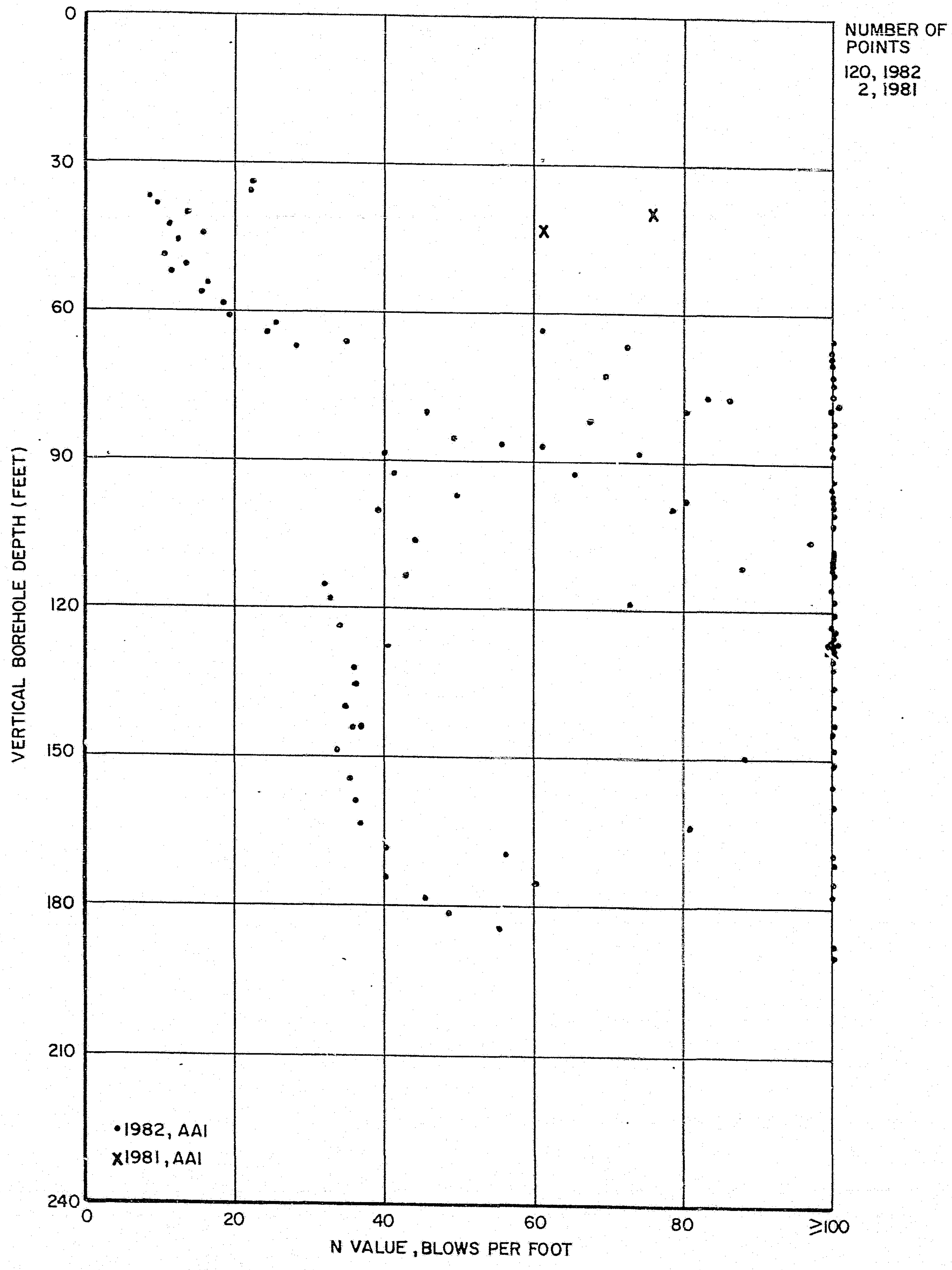
ACRES



WATANA RELICT CHANNEL / BORROW SITE D
DRIVE SAMPLE BLOW COUNT DATA
UNIT E/F
SHEET 5 OF 10

ACRES

FIGURE 6.10



WATANA RELICT CHANNEL / BORROW SITE D

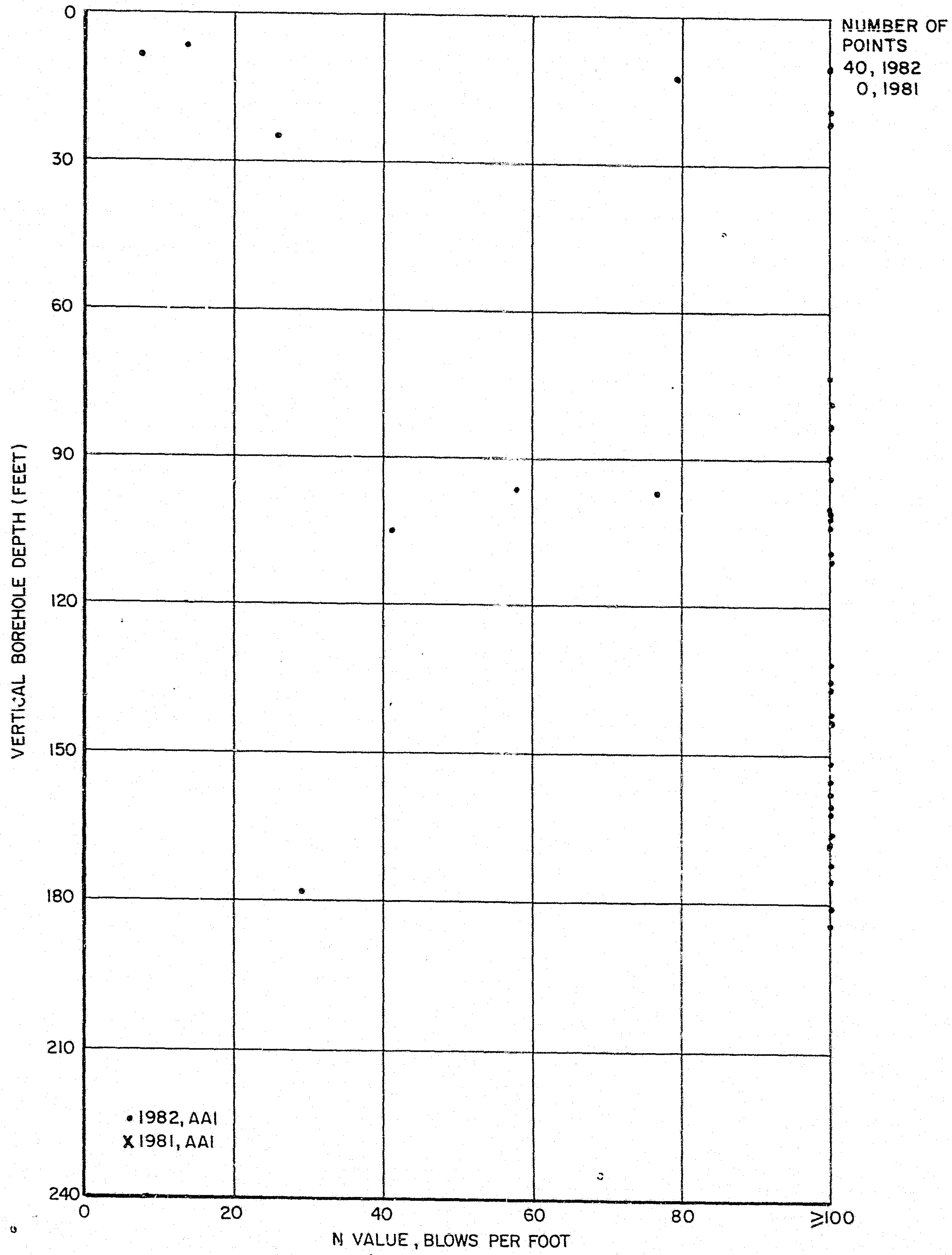
DRIVE SAMPLE BLOW COUNT DATA

UNIT G

SHEET 6 OF 10

ACRES

FIGURE 6.10



WATANA RELICT CHANNEL / BORROW SITE D

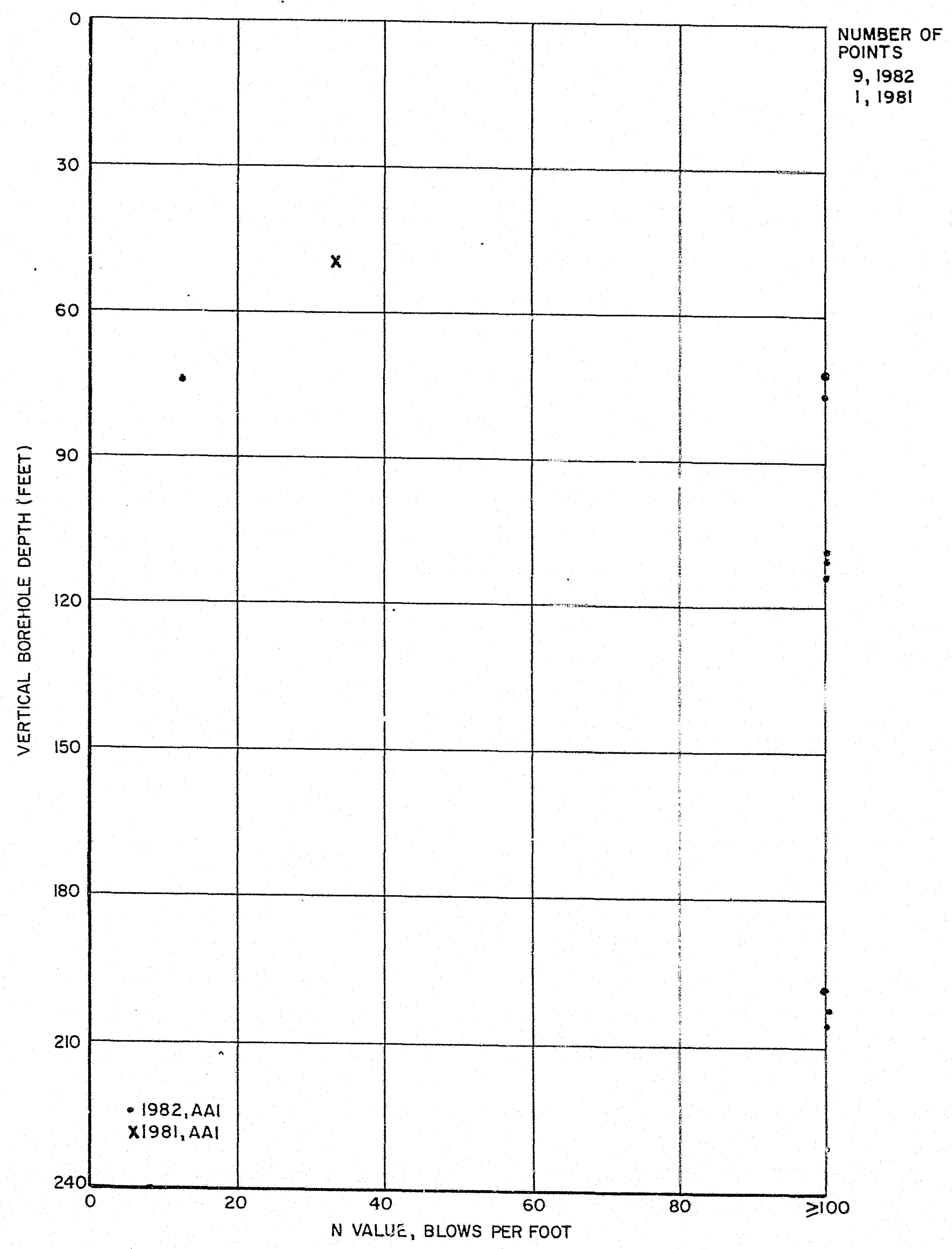
DRIVE SAMPLE BLOW COUNT DATA

UNIT G'

SHEET 7 OF 10

FIGURE 6.10

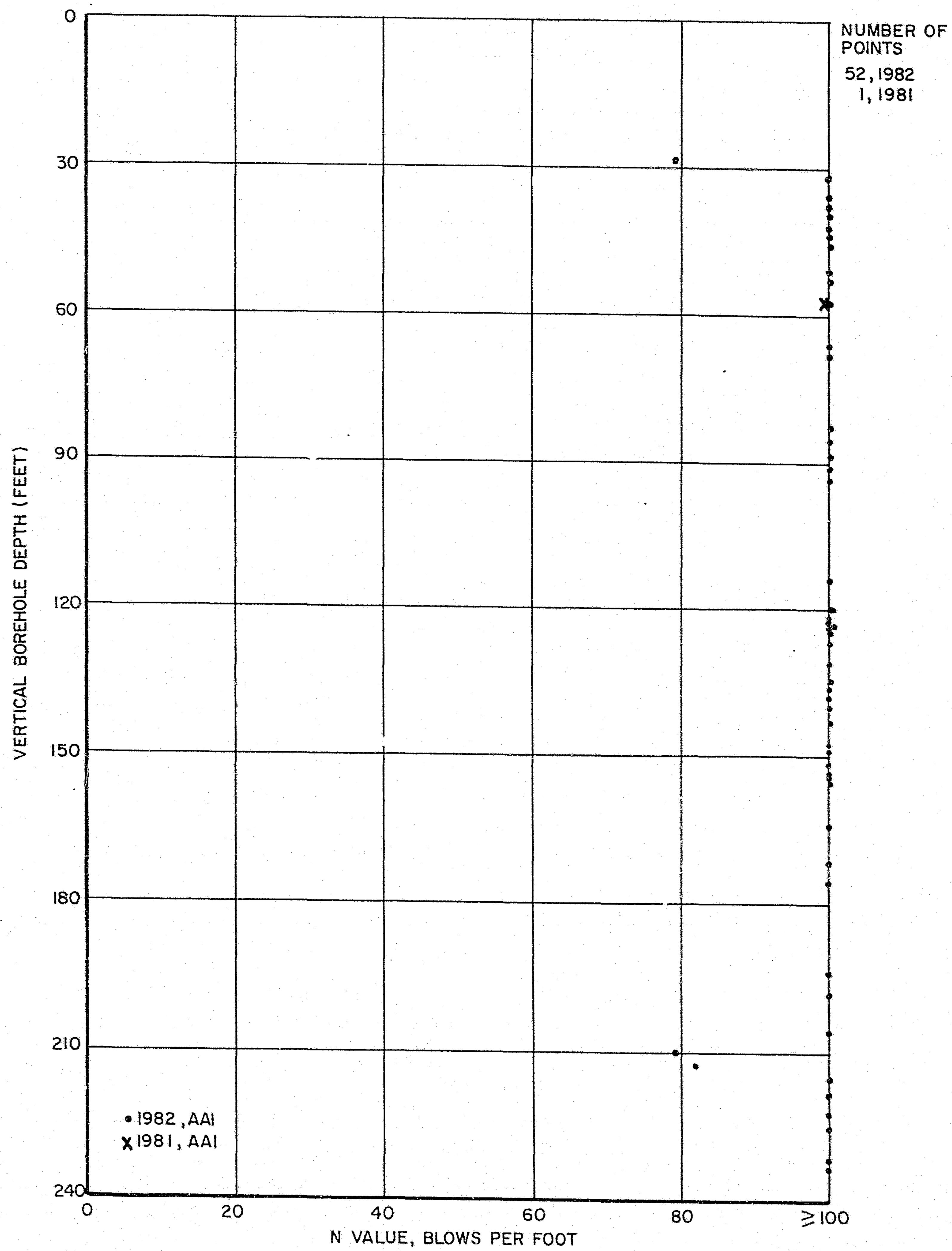
ACRES



WATANA RELICT CHANNEL / BORROW SITE D
DRIVE SAMPLE BLOW COUNT DATA
UNIT H
SHEET 8 OF 10

ACRES

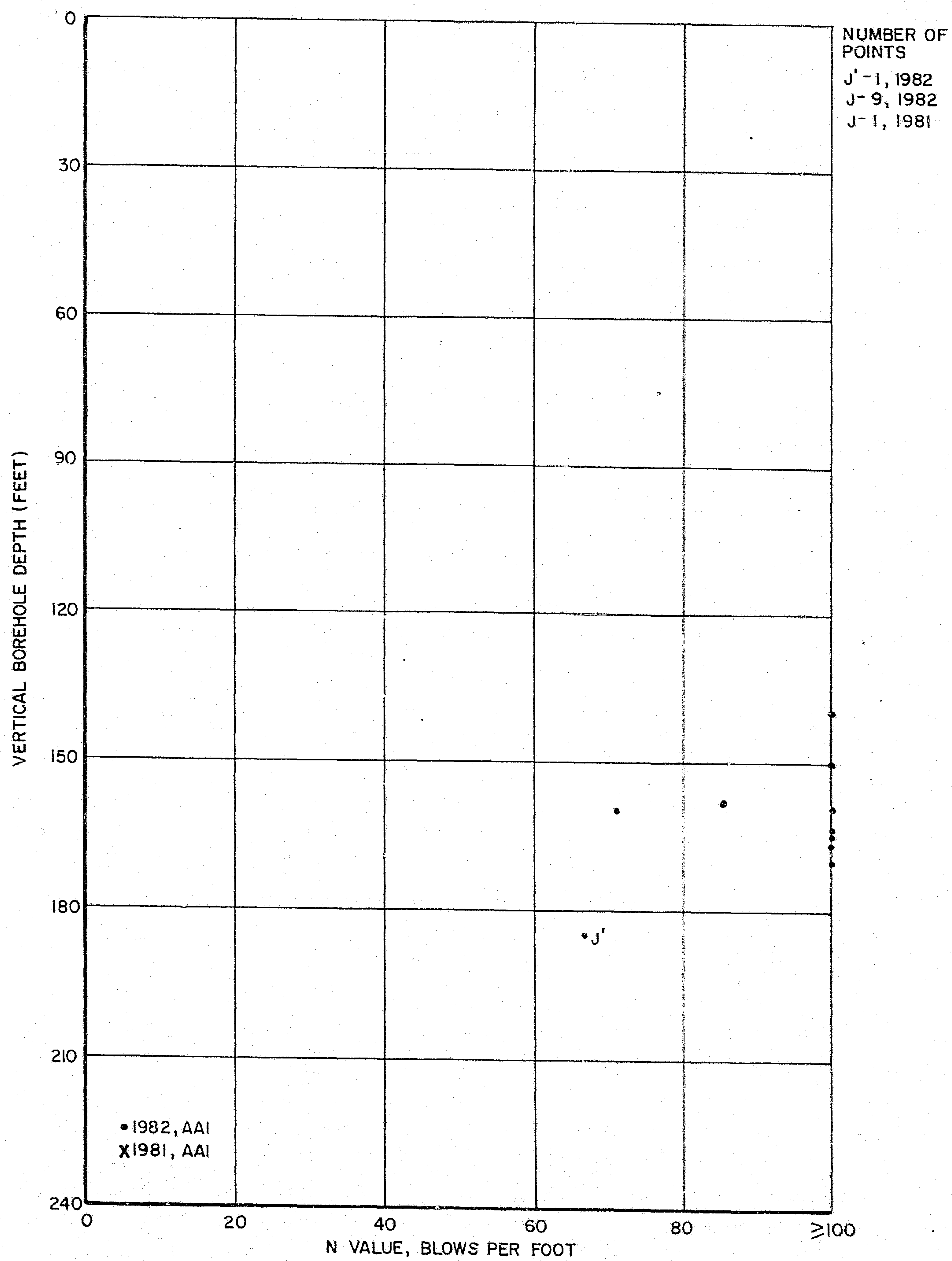
FIGURE 6.10



WATANA RELICT CHANNEL / BORROW SITE D
DRIVE SAMPLE BLOW COUNT DATA
UNIT I
SHEET 9 OF 10

FIGURE 6.10

ACRES



WATANA RELICT CHANNEL / BORROW SITE D

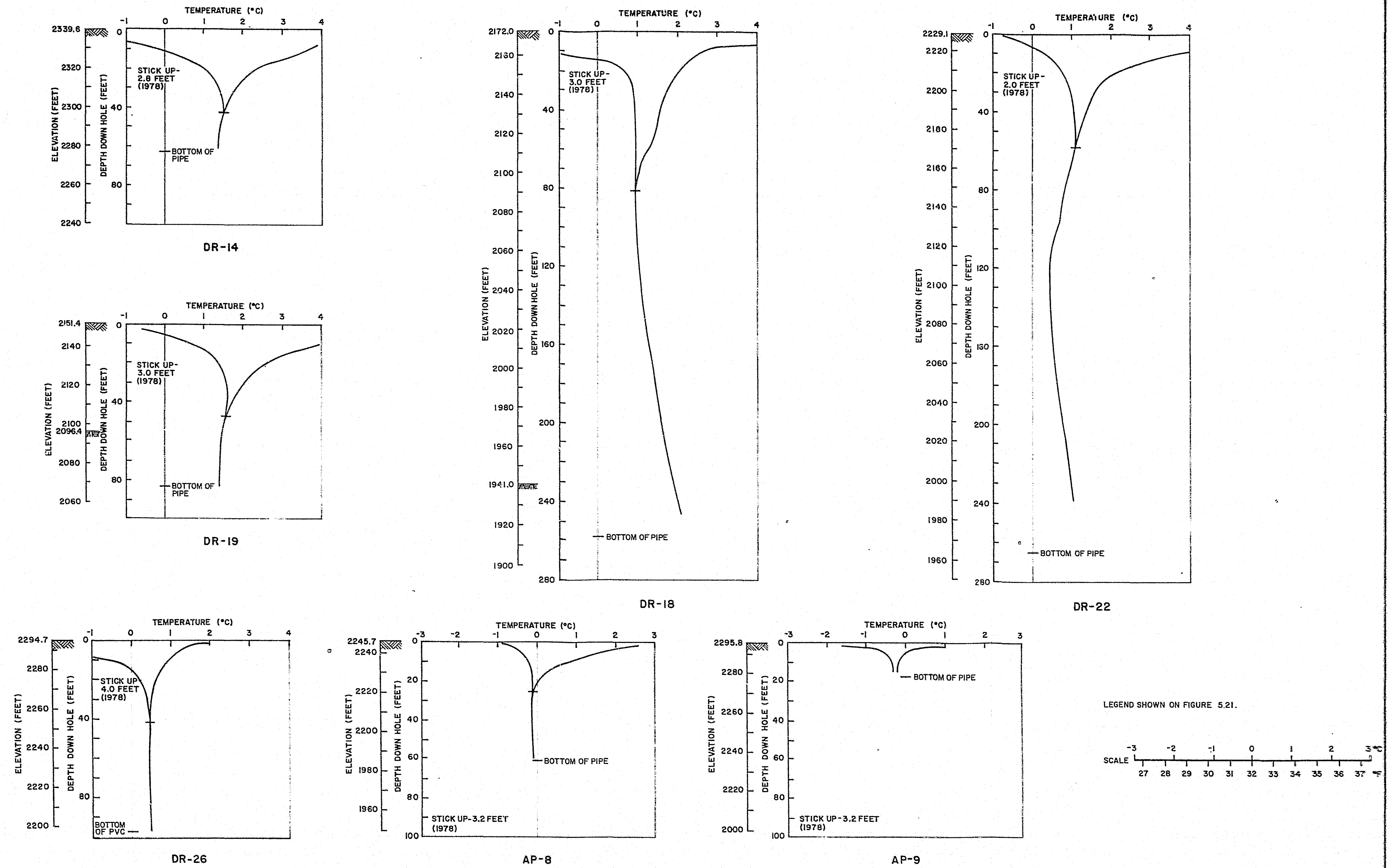
DRIVE SAMPLE BLOW COUNT DATA

UNIT J'/J

SHEET 10 OF 10

FIGURE 6.10

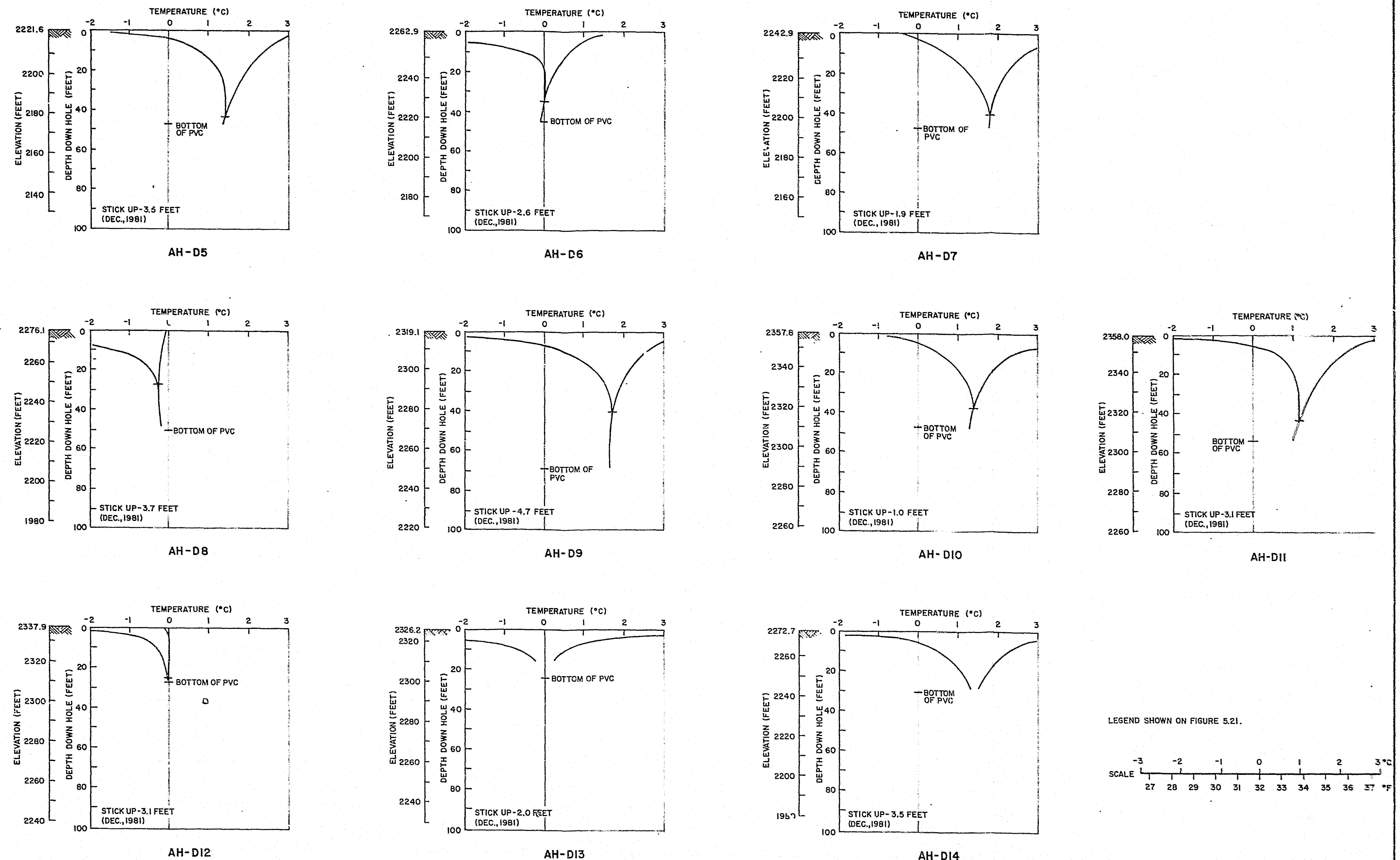
ACRES



WATANA RELICT CHANNEL / BORROW SITE D
THERMISTOR DATA
SHEET 1 OF 3

FIGURE 6.11

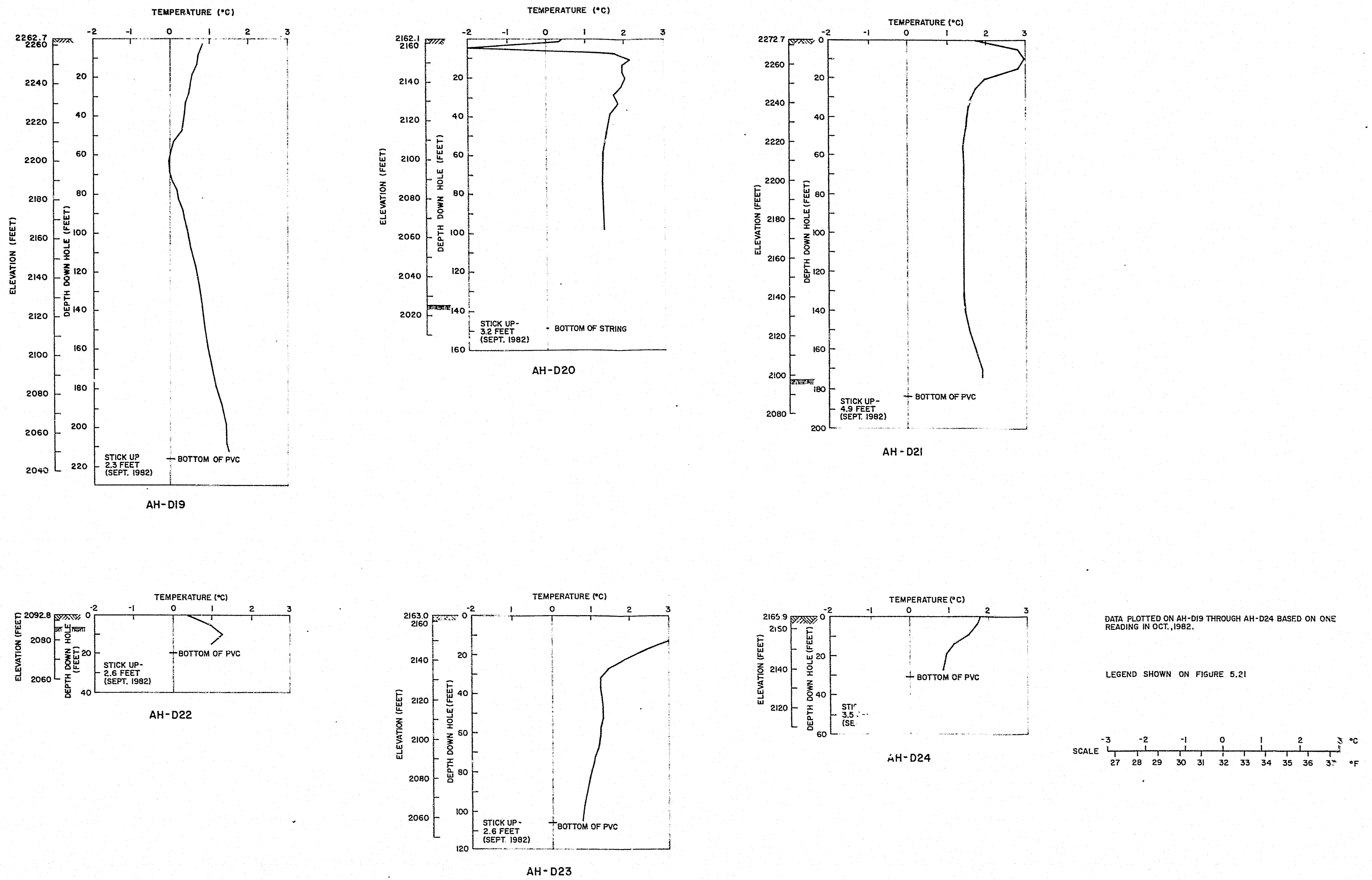
ACRES



WATANA RELICT CHANNEL / BORROW SITE D
THERMISTOR DATA
SHEET 2 OF 3

FIGURE 6.11

ACRES



WATANA RELICT CHANNEL / BORROW SITE D
THERMISTOR DATA
SHEET 3 OF 3

ACRES

FIGURE 6.11

7 - RESULTS OF GEOTECHNICAL INVESTIGATIONS - FOG LAKES RELICT CHANNEL

7.1 - Introduction

During the 1980-81 investigation a review of the site and regional geology was undertaken to determine if any other relict channels similar to the previously identified Watana Relict Channel, existed in the reservoir area. The purpose to find channels which would potentially affect reservoir impoundment. The results of the investigation indicated that a bedrock low may exist in the Fog Lakes area on the south side of the Susitna River. A seismic refraction survey performed in 1981 indicated that, in several areas bedrock dropped below the proposed reservoir level of Elevation 2,200 (1). For the purpose of this study this area was identified as the Fog Lakes Relict Channel. In 1982 additional seismic surveys and geologic mapping were done to define the geology, geometry, and gradients of this relict channel (Figure 3.3). Details of the seismic refraction survey are presented in Appendix C. The following sections summarize the results of these surveys and the potential impacts of this area to the project.

7.2 - Location and Configuration

The location of the Fog Lakes Relict Channel is shown on Figure 7.1 with the location of explorations and the interpreted top of bedrock surface. The width of the channel was defined as that area below maximum reservoir level (Elevation 2,200). During the 1981 investigation, the Fog Lakes Relict Channel divided into three areas: east, central and west sections. This terminology has been retained for discussion purposes.

The west section of the relict channel lies between the bedrock high of Quarry Site A and the bedrock high of the central section. Seismic refraction in this area indicate that the bedrock surface is a series of ridges and valleys. Three of these valley, (from 200 to 800 feet wide) fall below reservoir level (Figure 7.1 and Appendix C). The bedrock surface in these channels is every where and less than 200 feet below reservoir level, where crossed by the 1981 seismic line. The west section channels appear to be oriented in a north-northeast direction. Bedrock is exposed across most of the inlet area (4,500-feet-wide) to an approximate Elevation of 2,000.

The central section of the Fog Lakes Relict Channel extends from the edge of the west section channels, approximately 4.5 miles eastward to the east section channel. Bedrock in this area is relatively shallow and generally flat to slightly undulating. Except for one 300 foot wide channel the entire central section is above reservoir level. This channel is about 20 feet below maximum reservoir level. Bedrock is nearly continuously exposed along the Susitna River across the central section, generally between Elevation 1,950 and 2,000.

The east section of the Fog Lakes Relict Channel lies between the central section and the rock knob to the southeast. This section is the largest of the Fog Lakes channels with a channel width of from 6,000 to 7,000 feet wide. The channel consists of a broad area of bedrock above Elevation 2,100 flanking a steep sided bedrock gorge trending northeast-southwest (Figure 7.1). Seismic refraction lines indicate that a bedrock "saddle" exists in the channel where it is crossed by the 1982 seismic line. The elevation of the base of the gorge at this point is about 1940 feet. Within the gorge, the bedrock surface in the thalweg of the channel slopes off to the northeast and southwest, where the deepest observed portions of the gorge are at Elevation 1750 and 1730 on SL82-FL2 and SL82-F11, respectively.

The nearest bedrock exposed along the trend of the channel is 5 miles to the southwest in Fog Creek at an elevation of about 2,100 feet. The hydraulic head between the minimum gorge depth and Fog Creek is about 160 feet or about a 1/3 percent gradient.

7.3 - Geology

(i) Introduction

The geology of the Fog Lakes area is shown on Figure 4.1 and has been based on reconnaissance level surveys and seismic refraction surveys. The following sections discuss the sediments, bedrock, ground water and permafrost in the Fog Lakes Relict Channel.

(ii) Sediments

Three types of sediment were delineated in the Fog Lakes Relict Channel (Appendix C):

(a) Surficial deposits,
(b) Poorly consolidated glacial sediments, and
(c) Well consolidated glacial sediments.

Surficial deposits consist of a layer of 1,300 to 5,000 fps material. This layer is generally discontinuous, ranging from 0 to 40 feet thick, except in SL82-FL1 where it ranges from 10 to 85 feet but is usually less than 40 feet. The surficial deposits overlie bedrock in the central section and on the southeast end of SL82-FL1, and the glacial sediments in the channel areas.

The glacial sediments consist of material ranging in seismic velocity from 4,300 to 11,000 fps. The boundary between the poorly and well consolidated sediments is not distinct but appears to grade laterally. Velocities of the poorly consolidated saturated material is generally 4,600 to 7,000 fps. The velocities of the well consolidated materials are from 7,000 to 11,500 fps. This material may be partially to completely frozen. The glacial sediments occur primarily in the deeper channels. In the east section channel the material is up to 580 feet thick. High seismic velocities of this material indicate probably well consolidated material. In the west channel the glacial sediments vary from high to low velocity indicating varying degrees of consolidation. Thickness here reaches a maximum of 270 feet. Overall, the thickness of the glacial sediments is less than 200 feet in the channels.

Outcrops of the glacial sediments are rare. Only till was observed in the outcrops; however, it is likely that other types of glacial sediments such as outwash may be present.

(iii) Bedrock

The bedrock in the Fog Lakes Relict Channel consist of a variety of rock types, as inferred from bedrock exposed along the Susitna River and at Fog Creek. The west section of the channel is underlain by diorite bordered by andesite porphyry to the west and argillite and graywacke to the east. Bedrock beneath the central section appears to be argillite and graywacke. The east section is underlain by Triassic volcanic rocks. The contact between these volcanic rocks and the argillite and graywacke is interpreted to be the Talkeetna Thrust Fault (10, 11, 16, 24). The trend of this fault is nearly coincident with the east section channel.

The trend of the east and west Fog Lakes Relict Channels aligns with the present northeast-southwest drainage trends of the Watana and Deadman Creeks, respectively. This suggests that the drainage at one time was continuous across the present location of the Susitna River. The east section channel is broad with a deep gorge superimposed on it, similar to the present day Susitna River valley. It is possible that the original broad channel was the result of glaciation followed by fluvial erosion of the gorge. Later glacial processes filled in the channel.

(iv) Groundwater and Permafrost

No additional data on groundwater and permafrost were gathered during the 1982 field investigation. A discussion of these parameters is presented in the 1980-81 Geotechnical Report (1).

7.4 - Engineering Impacts

(a) Introduction

As with the Watana Relict Channel, the potential engineering impacts of the Fog Lakes Relict Channel are seepage and liquefaction potential. Surface flow are not considered a potential

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problem in that the topographic low in this area is at a minimum of Elevation 2,300, one hundred feet above maximum flood level.

(b) Leakage

Estimated maximum gradient from maximum pool level to Fog Creek is about a third percent over a maximum possible flow area of 8,000 feet wide by an average of less than 150 feet deep with a 5-mile flow path. To achieve a flow in excess of 60 cfs, the average permeability over this area would have to be approximately 5×10^{-1} cm/sec. This high an average permeability would require an extremely clean sorted gravel or sand over the entire area. Although no borings have been performed in this area, the geologic history and seismic velocitites measured in this area indicate significant presence of densely compacted glacial tills which are expected to exhibit permeabilities in the range of 10^{-3} to 10^{-5} cm/sec. Although drilling should be carried out in this area to confirm the seismic data, the Fog Lakes Relict Channel is not considered to have any significant economic impact on the project as a result of leakage.

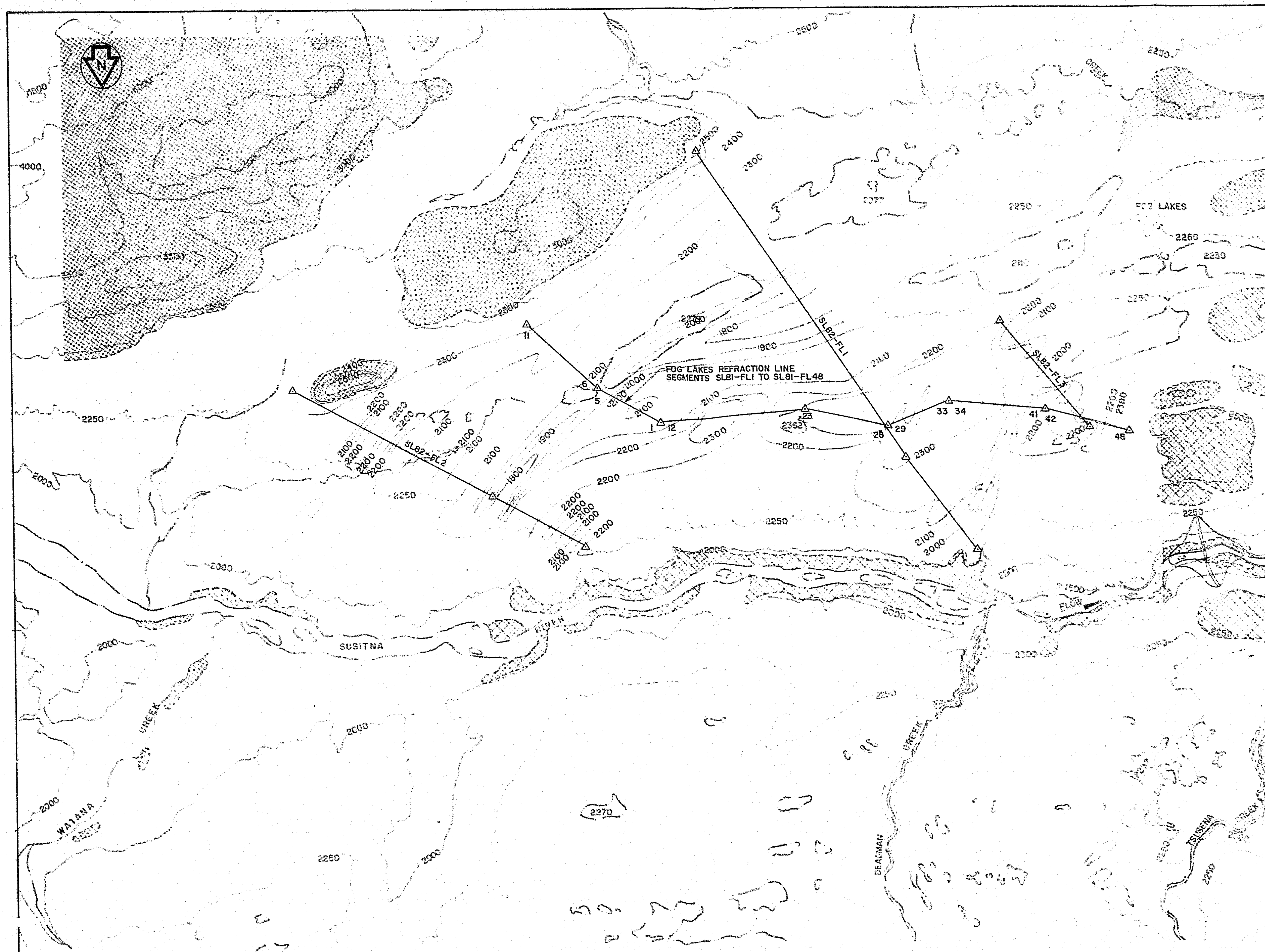
(c) Piping

The potential for piping failure is not considered possible due to the low gradient and long flow path (about 5 miles).

(d) Liquefaction

Liquefaction failure would require that three conditions be present: (a) material of low relative density which is saturated, and could thereby be shaken to a denser state or trend to "flow" under earthquake vibrations; (b) exposure of this unit to or near a free surface so that it can escape confinement; and (c) continuity of the unit from the free surface to the point where the topography is low enough to cause breaching.

For the Fog Lakes Relict Channel, it is highly unlikely that a liquefiable unit exists in adequate continuity, thickness, and susceptibility that a section of reservoir rim could fail to a depth of more than 100 feet. This magnitude of failure, on a ground surface with a slope of not more than 5 percent, would involve probable quantities in excess of 30 million cubic yards. Field verification by drilling will likely dispell any concerns regarding liquefaction.



LEGEND:

LITHOLOGY:

BEDROCK OUTCROP OR SHALLOW BEDROCK, UNDIFFERENTIATED.

CONTACT:

BEDROCK/SURFICIAL DEPOSITS, APPROXIMATE.

CONTOUR LINES:

TOP OF BEDROCK, CONTOUR INTERVAL 100 FEET.
TOPOGRAPHY, CONTOUR INTERVAL 500 FEET.
TOPOGRAPHY, EL. 2250 CONTOUR DASHED.

NOTES:

1. BASE MAP MODIFIED FROM U.S.G.S. TALKEETNA MOUTAINS D-5 AND D-4 QUADRANGLE MAPS, SCALE 1IN.=1ML
2. SEISMIC LINE SECTIONS SHOWN IN APPENDIX D AND AAI, 1982.

SCALE 0 2000 4000 FEET

WATANA
FOG LAKES RELICT CHANNEL
TOP OF BEDROCK

ACRES

FIGURE 7.1

8 - RESULTS OF GEOTECHNICAL INVESTIGATIONS - QUARRY AND BORROW SITES

8.1 - Introduction

During 1982 additional investigations were carried out in the quarry and borrow sites. The principal emphasis of the program was in Borrow Site D, whereas additional work in the other sites principally consisted of continuing instrumentation monitoring and long-term laboratory testing. The results of the work performed during 1982 are presented in the following sections. Locations of the quarry and borrow sites are shown in Figure 8.1.

8.2 - Quarry Sites

(a) Quarry Site A

The only work performed for Quarry Site A (Figure 8.1) during 1982 was the completion of the long-term freeze thaw durability testing begun late in 1981. As shown in Table 8.1, the rock samples collected from the andesite and diorite rock (Samples W80-303 and 80-304) showed a maximum loss after 150 cycles of just over 2 percent by weight, which would be considered excellent rock for construction material (Table 8.1). No indication of any softening or deterioration of the rock was noted confirms previous testing performed by the COE (2) which showed the rock to be very resistant to weathering. It is concluded that Quarry Site A rock represents a good source of thermal and water-deterioration resistant rock. If Quarry Site A is to be developed, further testing should be conducted during final design to determine which areas of the site would produce the highest quality material, depth of weathering and natural gradation resulting from blasting. Use of the andesite in the quarry area will be dependent on its degree of weathering. Use of the quarry rock for concrete aggregate would depend on the results of reactivity testing. Work performed by the COE (28, 30) indicate moderate to high presence of potentially reactive constituents in the andesite and andesite porphyry.

(b) Quarry Site B

No further direct exploration or testing was conducted in Quarry Site B. However, the Watana Relict Channel area mapping and seismic lines did extend into this area. This mapping confirmed that any quarry operation in this area would involve difficult overburden slope stability, access, and adverse haul gradient problems.

8.3 - Borrow Site D

(a) Introduction

Borrow Site D is the identified source for impervious/semipervious construction material (Figure 1.2). The borrow site was

ACRES

further explored in 1982 in the course of the investigations for the Watana Relict Channel. The objective of the 1982 program was to further delineate the Borrow Site's stratigraphy and material properties. Results of that study are presented below.

(b) Location and Geology

The borrow site lies on the southern corner of the Watana Relict Channel area, abutting Deadman Creek on the east, the Susitna River Valley on the south, and extending to near the exposed bedrock at "The Fins" on the west, near the damsite (Figure 8.1). The general slope of the area is gentle towards the south. The surface topography forms swales, benches, and terraces up to 50 feet in height. Photos of the topography and vegetation are presented in the 1980-81 Geotechnical Report (1). The geology of the borrow material is described in detail in Sections 6.3 and 6.4 (Units C through F) and the stratigraphic sections of the combined Watana Relict Channel/Borrow Site D areas are presented in Figures 6.1 - 6.6, along with typical photos of the materials in Figure 6.5. Generally, the borrow material is composed of ice disintegration, alluvial and outwash types of materials, generally not exceeding gravel size with some zones of cobbles and boulders (Units C, D, E, and F). Local zones of till (Unit M) and lacustrine sediments (Unit D') exist in the area as described in detail in Section 6. This material overlies a lacustrine deposit of sandy silts with some clay (Unit G).

(c) Material Quantities

The overall quanity of materials, which includes all of Units C, D, D', M, E, and F, has been estimated at about 180 million cubic yards, over an area of approximately 1130 acres. This area represents all the desirable material above Unit G between Deadman Creek, the Susitna River Valley, and a northeastern and northern boundary line drawn for topographic considerations. The material extends to considerable depth, as indicated on the borrow material isopach map (Figure 8.2).

The northwest limit of the borrow area was established by the presence of Unit G very near the surface, and by the requirement that borrow site development not remove the topographic crest forming the reservoir rim in the buried channel area.

The total volume of potential borrow material equals an average of about 100 feet of excavation over the identified limits of the borrow site. Based on the borrow material isopach (Figure 8.2, Sheet 1), the thickest deposits are along the Susitna River and Deadman Creek. The selection of the final borrow pit location will depend on material requirements, permafrost locations, environmental factors, and haul distance.

The major portion of the borrow material, that which exhibits the most consistent suitable properties, is Unit E/F. This unit, which lies directly on top of Unit G, is an outwash (see Section 6). The estimated quantity of Units E and F in the borrow limits is 133 million cubic yards, or about 75 percent of the total volume above Unit G (Figure 8.2, Sheet 2). These materials can be found near the surface in the central and northwest portions of the area, whereas the overlying units are thickest to the northeast and south sides. Based on 28 borings, the overlying weathered and organic zone range from 0 - 6 feet, averaging approximately 3 feet. As may be seen from Figure 6.7, bedrock is deep throughout the area, generally more than 100 feet deep, below grade throughout the area.

(d) Material Properties

The material properties defined in the 1980-81 Geotechnical Report (1) remain generally unchanged. The work conducted in 1982 resulted in only minor modifications to average properties or ranges.

- Gradation

The grain size distribution, which are presented as typical gradations in Figure 6.8, are shown in Figure 8.3 as bands of all observed data with the mean and plus and minus one standard deviation band shaded. These curves include all usable data from the COE and the 1980-82 Acres programs. A plot of auger/rotary core samples versus test pit samples reduced to 1 inch maximum particle size show identical mean gradations. This confirms that samples from soil drilling in the area are representative of the in-place material provided allowance is made for over 2 inch size material as indicated by the gradations of the complete material as taken in test pits (Figure 6.8, Sheets 1 and 5).

The range and numerical average gradation curves show that Units C, D, and E/F are similar in grain size and distribution. Units D' and M have some significantly finer gradation and wider deviation (Figure 8.3), and they are not considered suitable as borrow material. Selective mining may be required in borrow pit development to avoid some of the finer materials that may occur in thin layers of lenses. The range and means of Unit G gradation is presented in Figure 8.3 for comparison purposes since Unit G is considered unsuitable for compacted fill construction.

The general gradation ranges presented in Figure 6.42, Sheet 2 of 2 of the 1980-81 Geotechnical Report match the typical samples (Figure 6.8) for Unit C, D, and E/F and includes most of D' and M.

- Moisture

The composite moisture data show a fairly consistent mean moisture of around 11-12 percent for the borrow materials (Figure 8.4). It is evident that Unit G's high moisture (23%) makes it unacceptable for construction use.

The moisture contents for the various units show a definite trend toward higher moisture in the samples with more fines, with Units D and D' having the highest fines content in the borrow materials (Figure 8.9). The average moisture in the borrow materials of 11.6 percent could be reduced (if desirable) by wasting the finer material by select mining. Approximately 25 percent of the samples are above the mean (Figure 8.6) while about 75 percent lie below the mean. This fact, combined with the bias of sampling where the finer, more plastic materials have higher sampling recovery, suggest that the 11.6 percent average natural moisture as calculated is higher than the true average for materials likely to be utilized in the dam.

- Atterberg Limits

The Atterberg limits for the various stratigraphic units are summarized in composite form Figure 8.7 with all data presented by stratigraphic unit on Figures 8.8 through 8.11. It is evident that the borrow material contains relatively low plasticity materials while Unit G and the tills have the high plasticity and cohesive materials. The data presented represents the means and ranges of only those samples which were apparently plastic and hence were tested based on field observation and do not represent a statistical percent of plastic versus non-plastic material. Therefore, the mean plasticity and plastic index of the borrow materials will be near to zero and to obtain a plastic material one would need to produce from Units D', G or G' and possibly Unit I.

- Proctor Density Tests

Due to the limitations on sample sizes, only face exposure samples were tested in a Proctor mold in 1982. Because the material moisture content in the borrow materials is relatively high, the Standard Proctor rather than Modified Proctor tests were performed so as to enable more accurate determination of the optimum density data point. Figure 8.12 shows the range of all Standard Proctor tests to date with the maximum densities between 128-134 pcf at about 8-9 percent optimum moisture content for Unit E/F. As seen in Figure 8.12 through 8.15, 90 percent Standard Proctor density should be obtainable at natural moisture.

Figures 8.16 and 8.17 show the Modified Proctor test results to date on Unit E/F and Unit G, respectively. They illustrate that

ACRES

the change from Standard to Modified Proctor specification would add only about 5 percent greater density. Figure 8.17 illustrates the low maximum density and very dry (relative to the 23 percent natural moisture content) optimum moisture content of Unit G material.

(e) Ground Water Regime

As discussed in Section 6, the ground water regime in the Borrow Site is highly complex due to perched water tables, aquicludes, and sporadic permafrost. Basically, the ground water table seems to perch on frozen and impervious Units D', M, and G. Surface water is perched on frozen or on silt pockets in Unit A, B, and C. Because of the impervious characteristics of Unit G, and possibly portions of locally D' and M, locally trapped and perched aquifers likely exist throughout the coarse cobbly and bouldery material in the bottom of Unit F which probably acts as a principal aquifer. Natural surface and subsurface drainage on the borrow site is believed to be predominately to the south.

(f) Permafrost Regime

Thermometers readings indicate that a significant portion of the borrow materials are below freezing in the natural state, however, no temperature below -0.2°C have been detected during drilling or by the various thermistor installations below the active zone (Figure 6.11). Very few borehole samples recovered show visible ice or ice lenses from the borrow material and the only unit with significant frequency of temperatures below zero with visible ice crystals and lenses is Unit G below the borrow materials.

The instrumentation ground temperature summary sheets (Figure 6.11) shows envelopes with depths of zero annual amplitude and active zone around 25-40 and 10-15 feet, respectively in most areas. The most extreme depth of annual amplitude is about 80 feet. Only four borings show possible stabilization below freezing. There is no apparent correlation with locale or stratigraphic unit for these cases. These holes may have been drilled in remnant frost bulbs in the old ice disintegration deposits, i.e., relict pingos, ice wedges, or palsas. While there is considerable surficial evidence of permafrost structures, only a very few areas in Borrow Site D has any evidence of current permafrost activity.

From the evidence to date, it is considered that permafrost in Units C, and E/F does not affect material suitability and that frozen areas (where encountered) could be bypassed in mining.

8.4 - Borrow Sites E and I

The 1982 investigations in the granular borrow sites were limited to surficial geologic mapping in Borrow Sites E and I and completion of the concrete aggregate suitability testing begun in late 1981.

(a) Geology

The geologic mapping of Borrow Site E and I were performed by aerial photo interpretation and reconnaissance mapping. The results of the mapping are presented on Figures 8.18 and 8.19. The mapping did not reveal any conditions which would change the data assumptions or reserve calculations presented in the 1980-81 Geotechnical Report (1).

(b) Material Properties

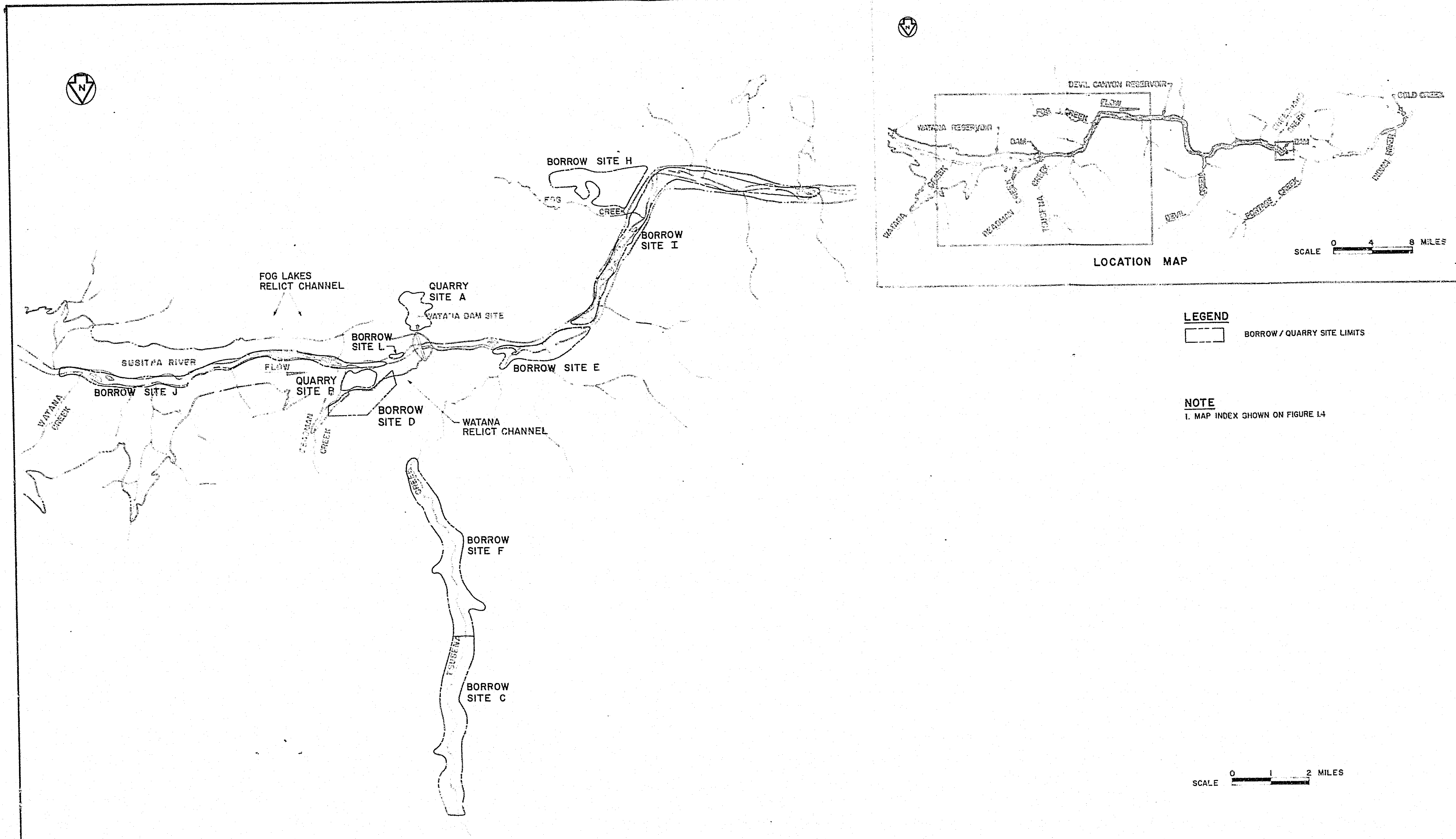
Freeze-thaw tests performed on aggregate from the Borrow Sites showed losses of 2.3 to 7.8 percent after 140 cycles (Table 8.1).

The results of the absorption, soundness and abrasion test shows that the aggregate meets the applicable standards for general structural and dam construction established by the American Association of State Highway and Transportation Officials (5) and American Society for the Testing of Materials (4), U.S. Army Corps of Engineers (31, and the U.S. Bureau of Reclamation (33) (Table 8.2).

Results of reactivity testing of the aggregate with cement is shown in Table 8.3. The results indicate that adverse reactivity is negligible as all data falls well into the zone considered as innocuous (Figure 8.20).

8.5 - Borrow Site H

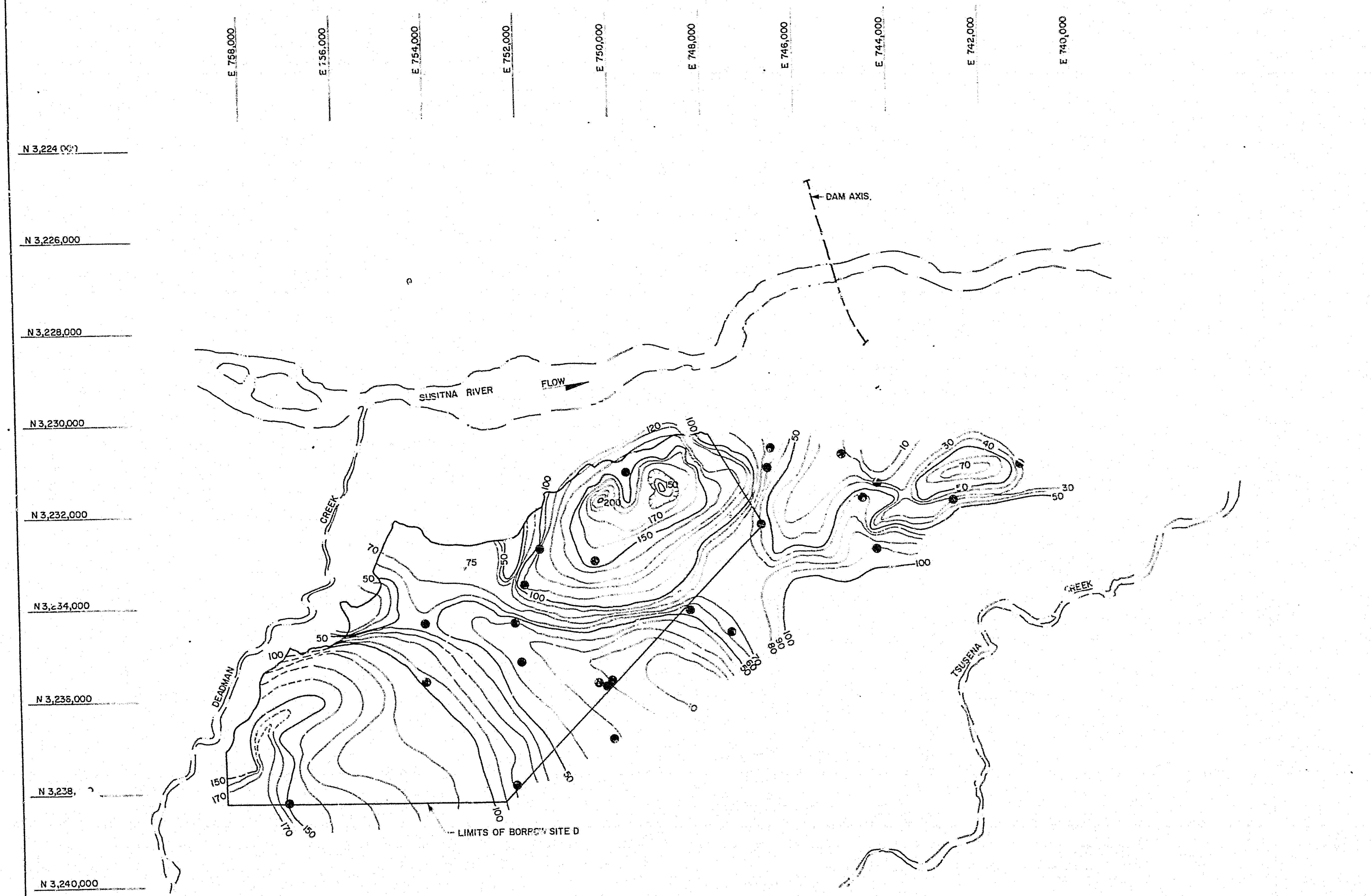
No work was performed in Borrow Site H except for the continued readings of the thermistor strings installed in 1981. Although preliminary readings in 1981 indicated potential permafrost in several of the holes, readings performed in 1982 showed no temperatures at depth below freezing (Figure 8.21). Readings over the past year show one boring (AH-H-5) may be below freezing near the bottom of the hole, but the other probe installations are showing temperatures below the active zone (approximately 8 feet average) of about +1°C indicating that what permafrost existed at the time of drilling was so close to thawing and contained so little frozen water that refreezing is highly unlikely. The depth of annual frost penetration appears to be related more to vegetation cover and sunlight exposure than to watertable or presence of frost. The depth of zero annual amplitude ranges from 25 feet to greater than 45 feet (Figure 8.21).



WATANA
BORROW SITE MAP

ACRES

FIGURE 8.1



LEGEND:

—100— ISOPACH CONTOUR (LINES OF EQUAL BORROW MATERIAL THICKNESS)

● BOREHOLES PROVIDING CONTROL FOR BORROW MATERIAL THICKNESS.

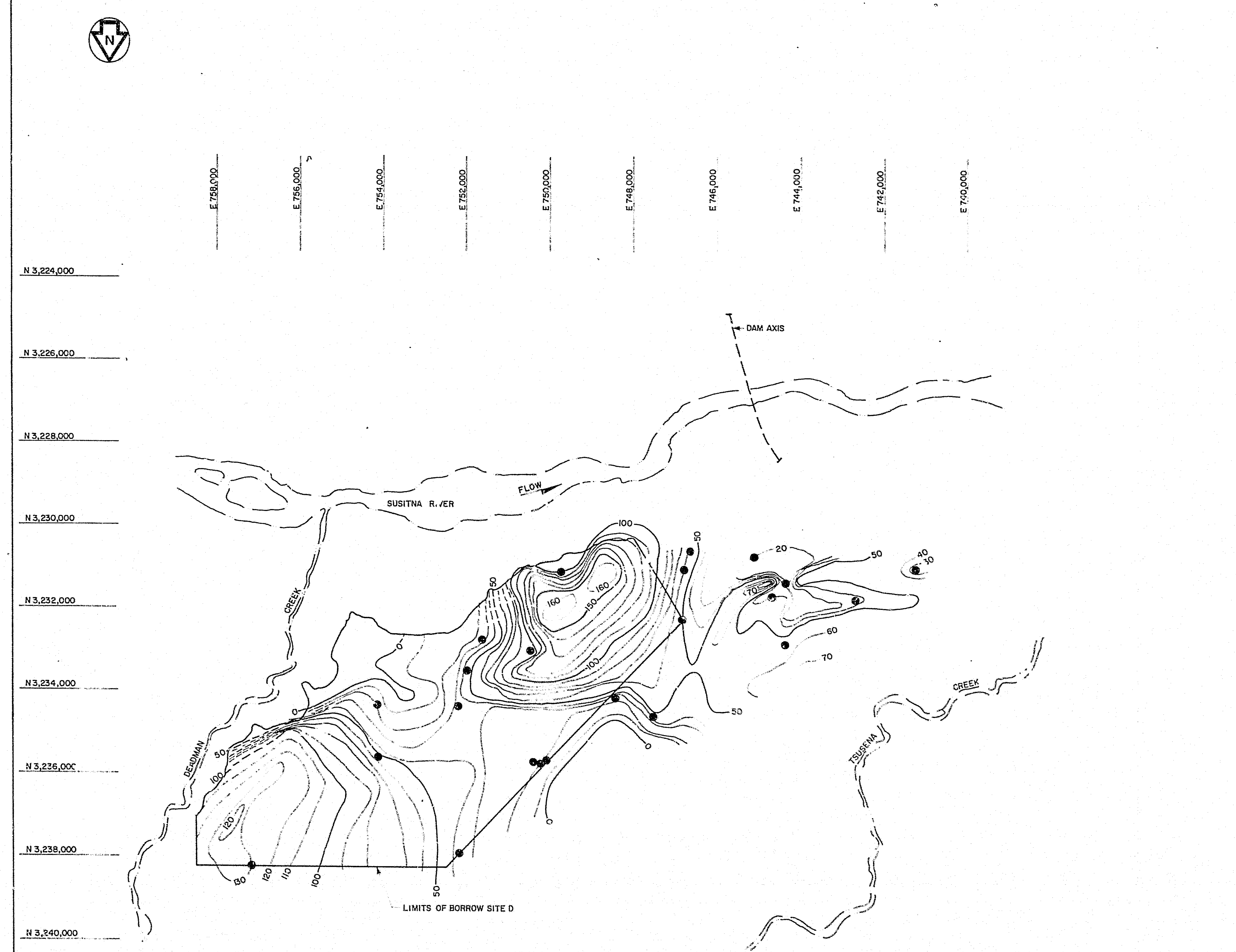
NOTE:

1. ISOPACH OF BORROW MATERIAL EXTRAPOLATED FROM TOP OF UNIT G CONTOURS FIGURE 6.6 SHEET 2 OF 3 AND TOP OF GROUND CONTOUR MAP.

WATANA BORROW SITE D
ISOPACH MAP OF ANTICIPATED BORROW MATERIAL
STRATIGRAPHIC UNITS C THROUGH F
SHEET 1 OF 2

FIGURE 8.2

ACRES



LEGEND:

—100— ISOPACH CONTOUR (LINES OF EQUAL BORROW MATERIAL THICKNESS)

● BOREHOLES PROVIDING CONTROL FOR BORROW MATERIAL THICKNESS.

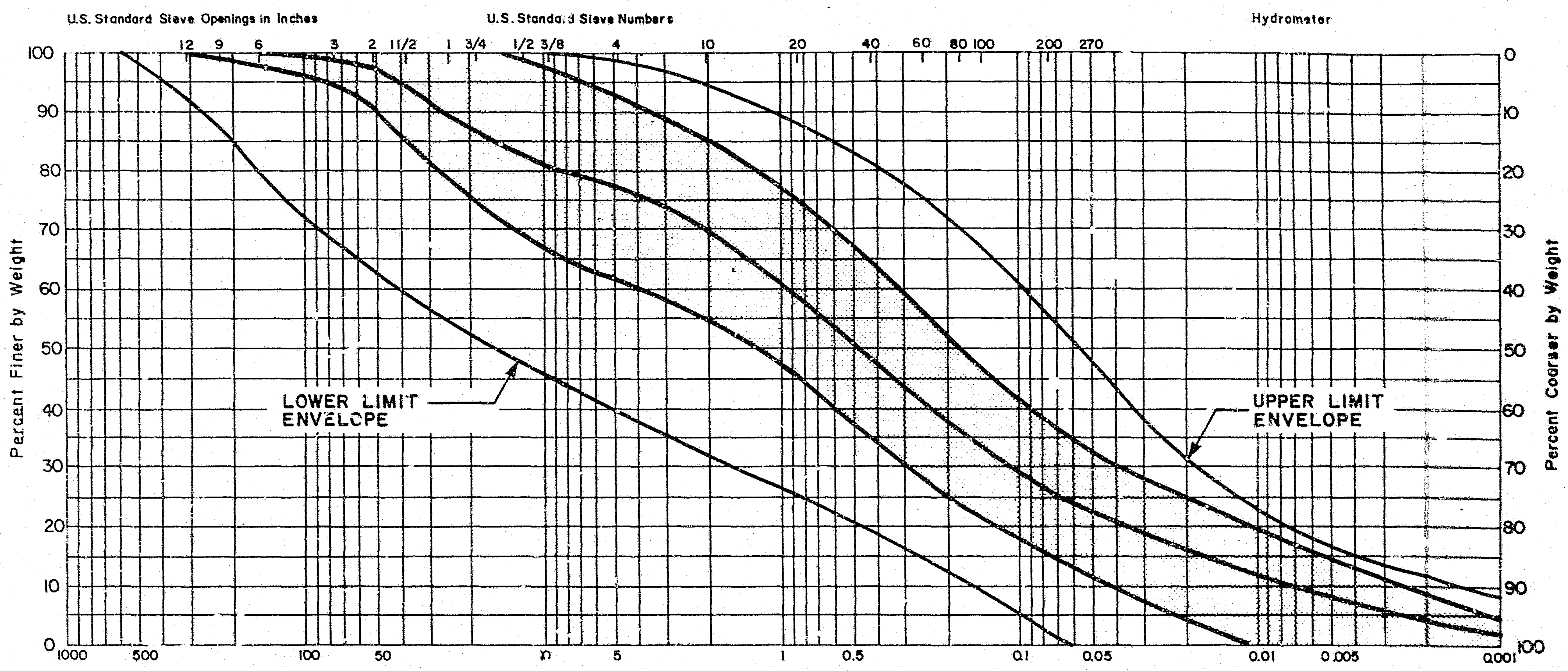
NOTE:

1. ISOPACH OF BORROW MATERIAL EXTRAPOLATED FROM TOP OF UNIT G CONTOURS FIGURE 6.6 SHEET 2 OF 3 AND TOP OF UNIT E/F CONTOURS FIGURE 6.6 SHEET 1 OF 3.

WATANA BORROW SITE D
ISOPACH MAP OF ANTICIPATED BORROW MATERIAL
STRATIGRAPHIC UNITS E AND F
SHEET 2 OF 2

FIGURE 8.2

ACRES



BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

NOTES

1. STATISTICAL DATA BASED ON SAMPLES RECOVERED IN 3" O.D. SAMPLER.
2. FOR TYPICAL GRADATION CURVES OF EACH STRATIGRAPHIC UNIT SEE FIGURE 6.8.

NUMBER OF POINTS = 78

LEGEND

$+\sigma$

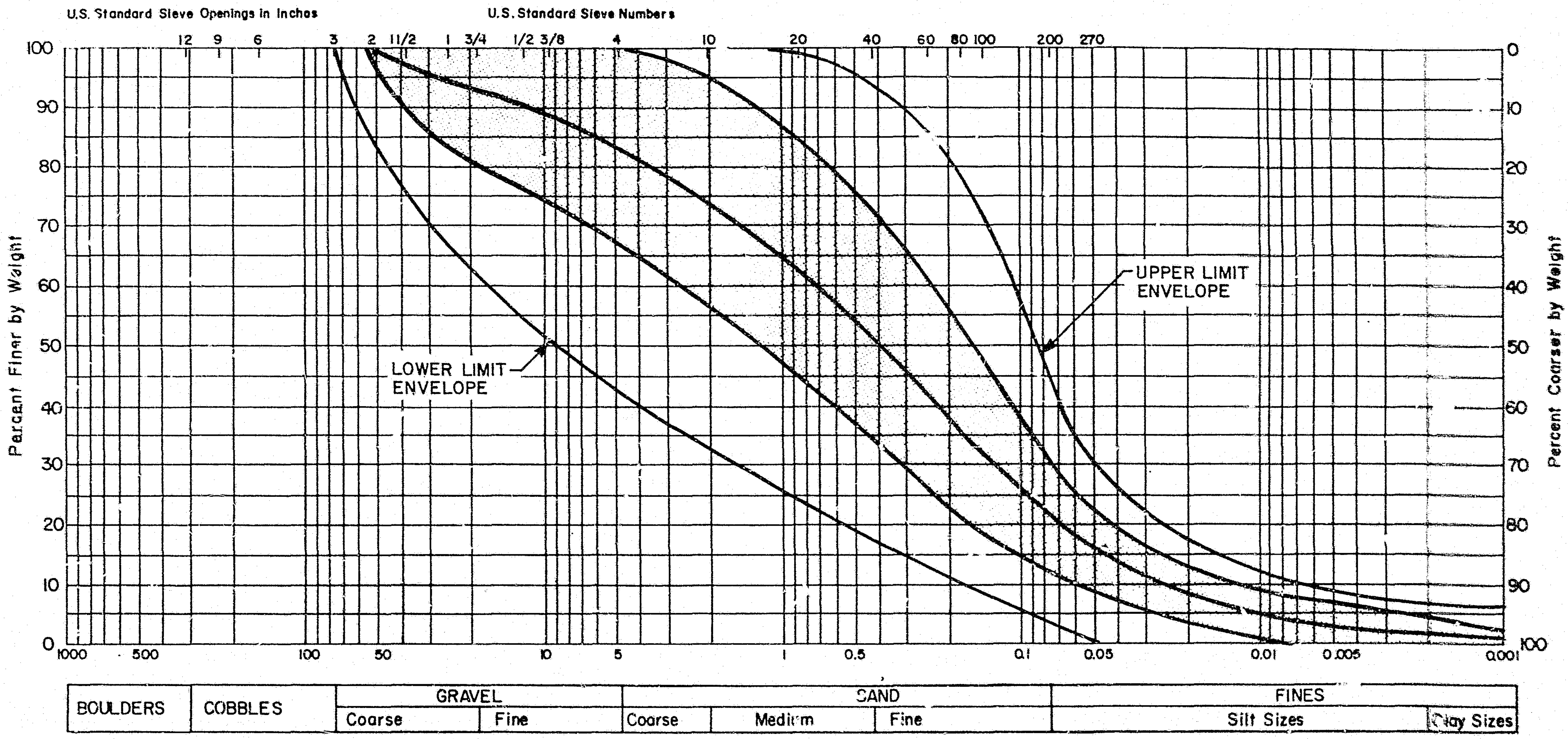
$\bar{x}$

$-\sigma$

WATANA RELICT CHANNEL / BORROW SITE D
COMPOSITE STRATIGRAPHIC UNIT C GRADATIONS
SHEET 1 OF 6

FIGURE 8.3

ACRES



NOTES

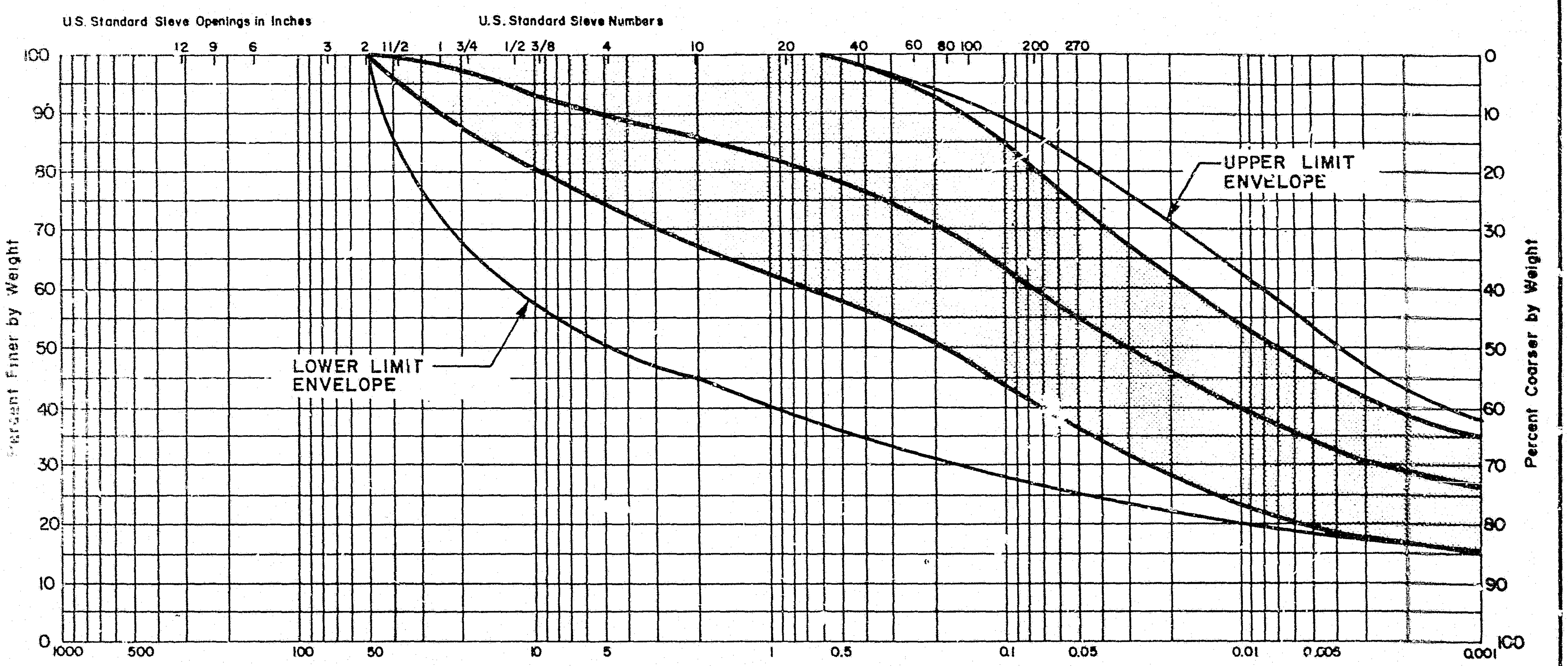
NUMBER OF POINTS = 33

1. STATISTICAL DATA BASED ON SAMPLES RECOVERED IN 3" O.D. SAMPLER.
2. FOR TYPICAL GRADATION CURVES OF EACH STRATIGRAPHIC UNIT SEE FIGURE 6.8.

WATANA RELICT CHANNEL/BORROW SITE D
COMPOSITE STRATIGRAPHIC UNIT D GRADATIONS
SHEET 2 OF 6

ACRES

FIGURE 8.3



BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

NOTES

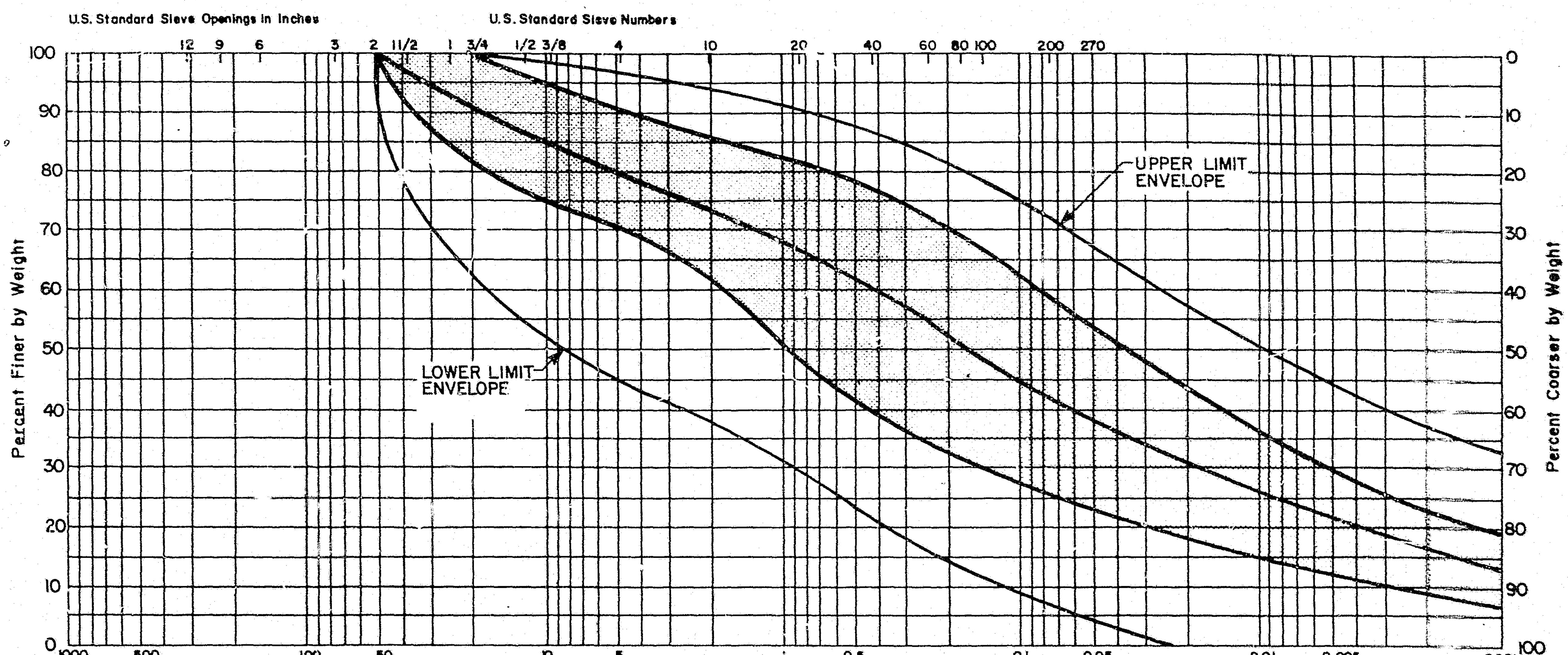
1. STATISTICAL DATA BASED ON SAMPLES RECOVERED IN 3" O.D. SAMPLER.
2. FOR TYPICAL GRADATION CURVES OF EACH STRATIGRAPHIC UNIT SEE FIGURE 6.8.

NUMBER OF POINTS = 12

WATANA RELICT CHANNEL/BORROW SITE D
COMPOSITE STRATIGRAPHIC UNIT D' GRADATIONS
SHEET 3 OF 6

FIGURE 8.3

ACRES



BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

NOTES

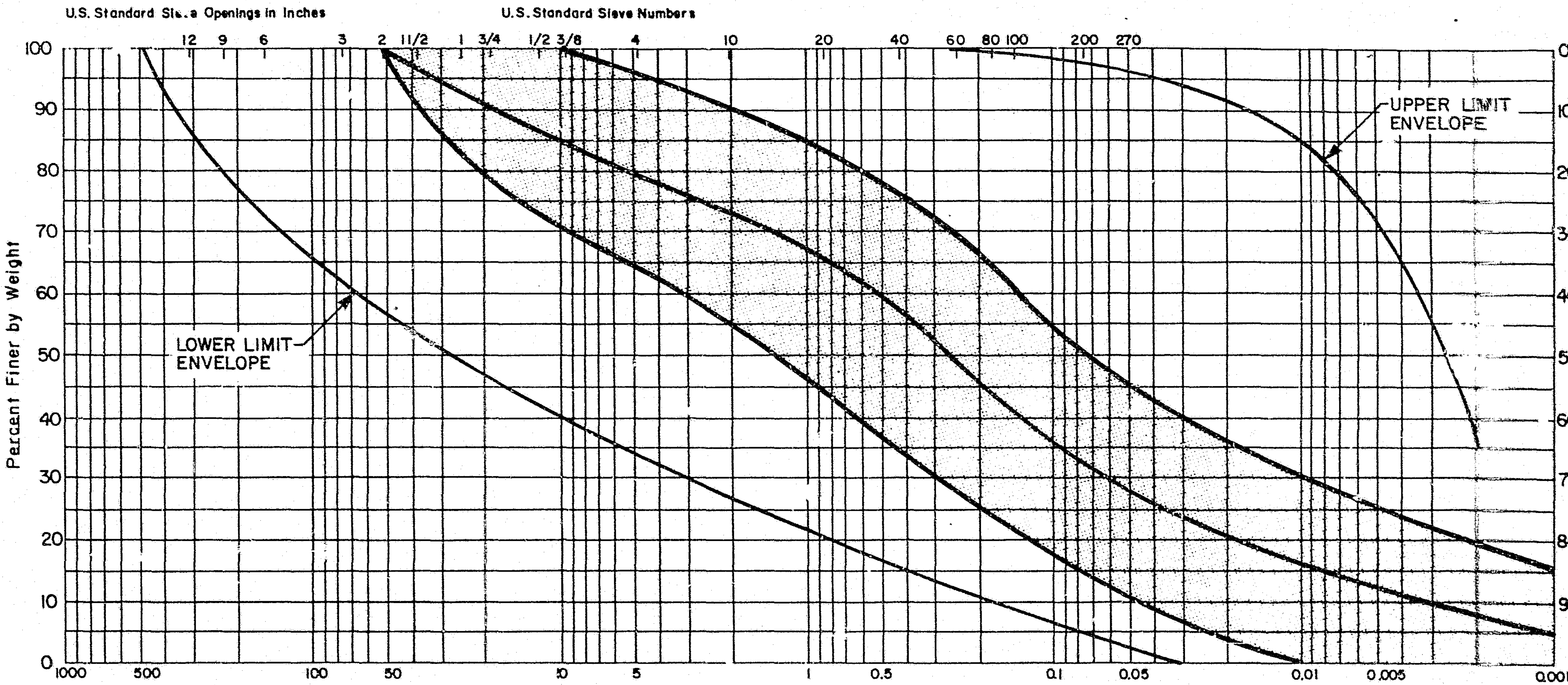
NUMBER OF POINTS = 32

1. STATISTICAL DATA BASED ON SAMPLES RECOVERED IN 3" O.D. SAMPLER.
2. FOR TYPICAL GRADATION CURVES OF EACH STRATIGRAPHIC UNIT SEE FIGURE 6.8

WATANA RELICT CHANNEL / BORROW SITE D
COMPOSITE STRATIGRAPHIC UNIT M GRADATIONS
SHEET 4 OF 6

FIGURE 8.3

ACRES



BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

NOTES

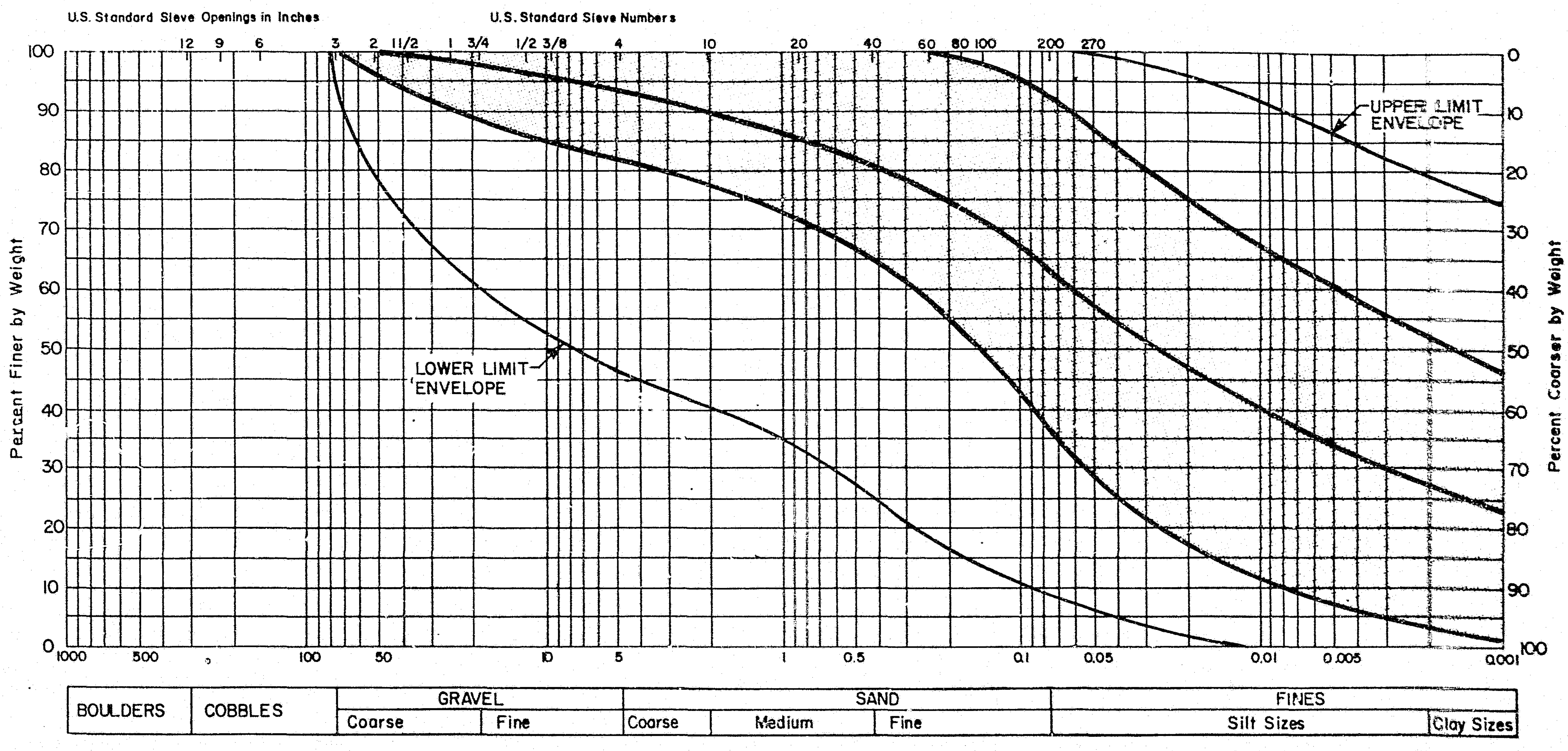
NUMBER OF POINTS = 137

1. STATISTICAL DATA BASED ON SAMPLES RECOVERED IN 3" O.D. SAMPLER.
2. FOR TYPICAL GRADATION CURVES OF EACH STRATIGRAPHIC UNIT SEE FIGURE 6.8

WATANA RELICT CHANNEL/BORROW SITE D
COMPOSITE STRATIGRAPHIC UNIT E/F GRADATIONS
SHEET 5 OF 6

FIGURE 8.3

ACRES



NUMBER OF POINTS = 87

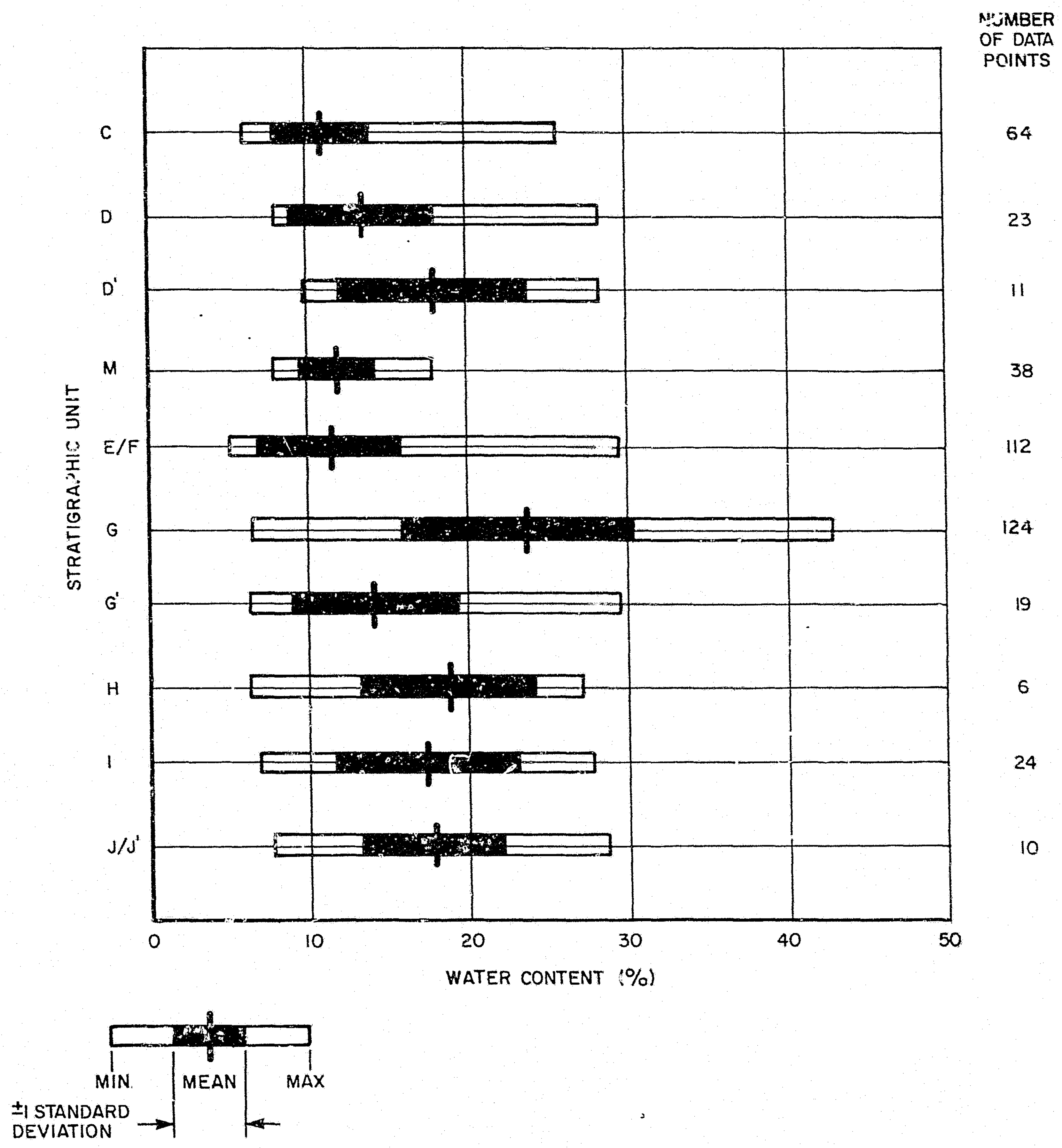
NOTES

1. STATISTICAL DATA BASED ON SAMPLES RECOVERED IN 3" O.D. SAMPLER.
2. FOR TYPICAL GRADATION CURVES OF EACH STRATIGRAPHIC UNIT SEE FIGURE 6.8

WATANA RELICT CHANNEL/BORROW SITE D
COMPOSITE STRATIGRAPHIC UNIT G GRADATIONS
SHEET 6 OF 6

ACRES

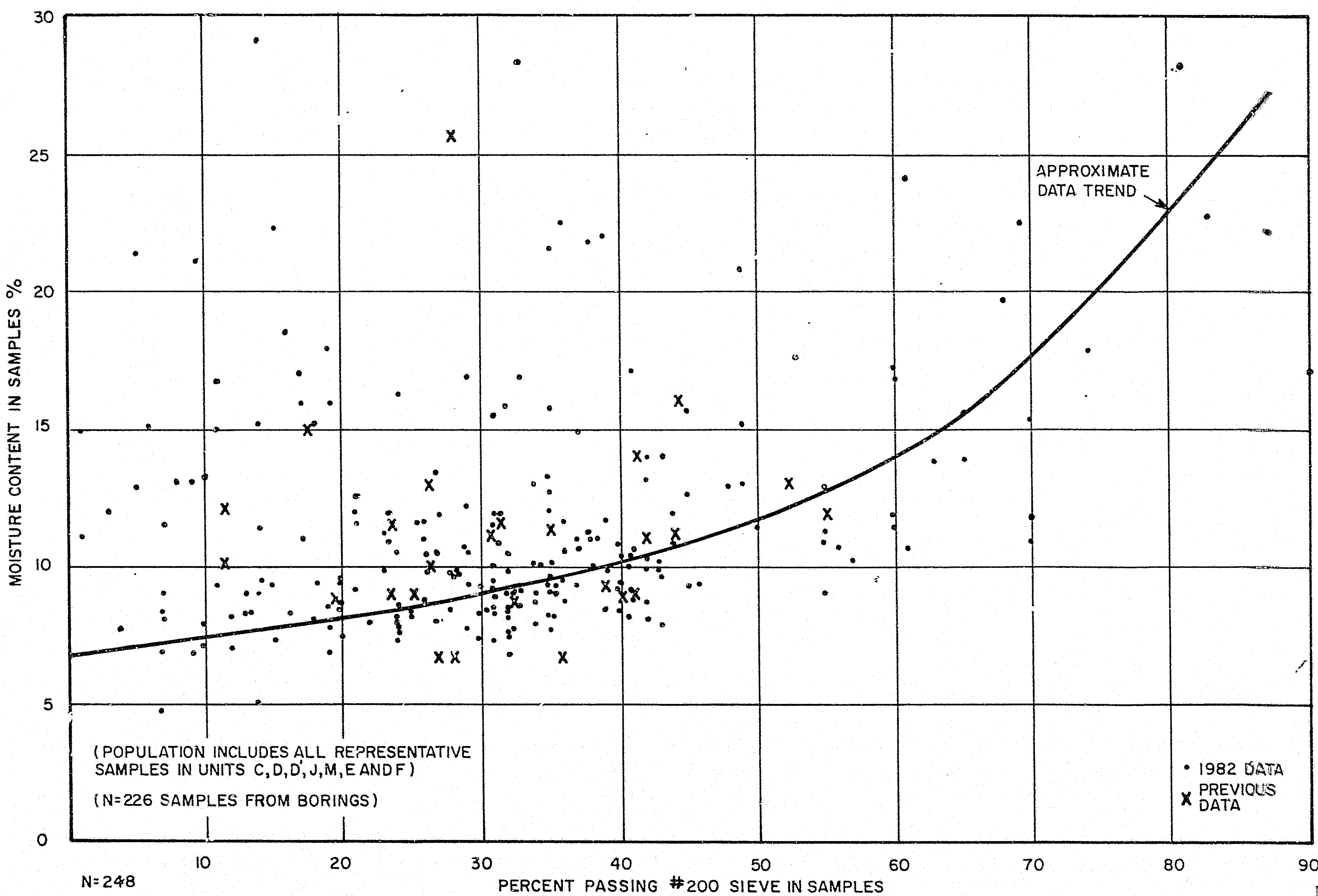
FIGURE 8.3



WATANA RELICT CHANNEL/BORROW SITE D
COMPOSITE NATURAL MOISTURE DATA

ACRES

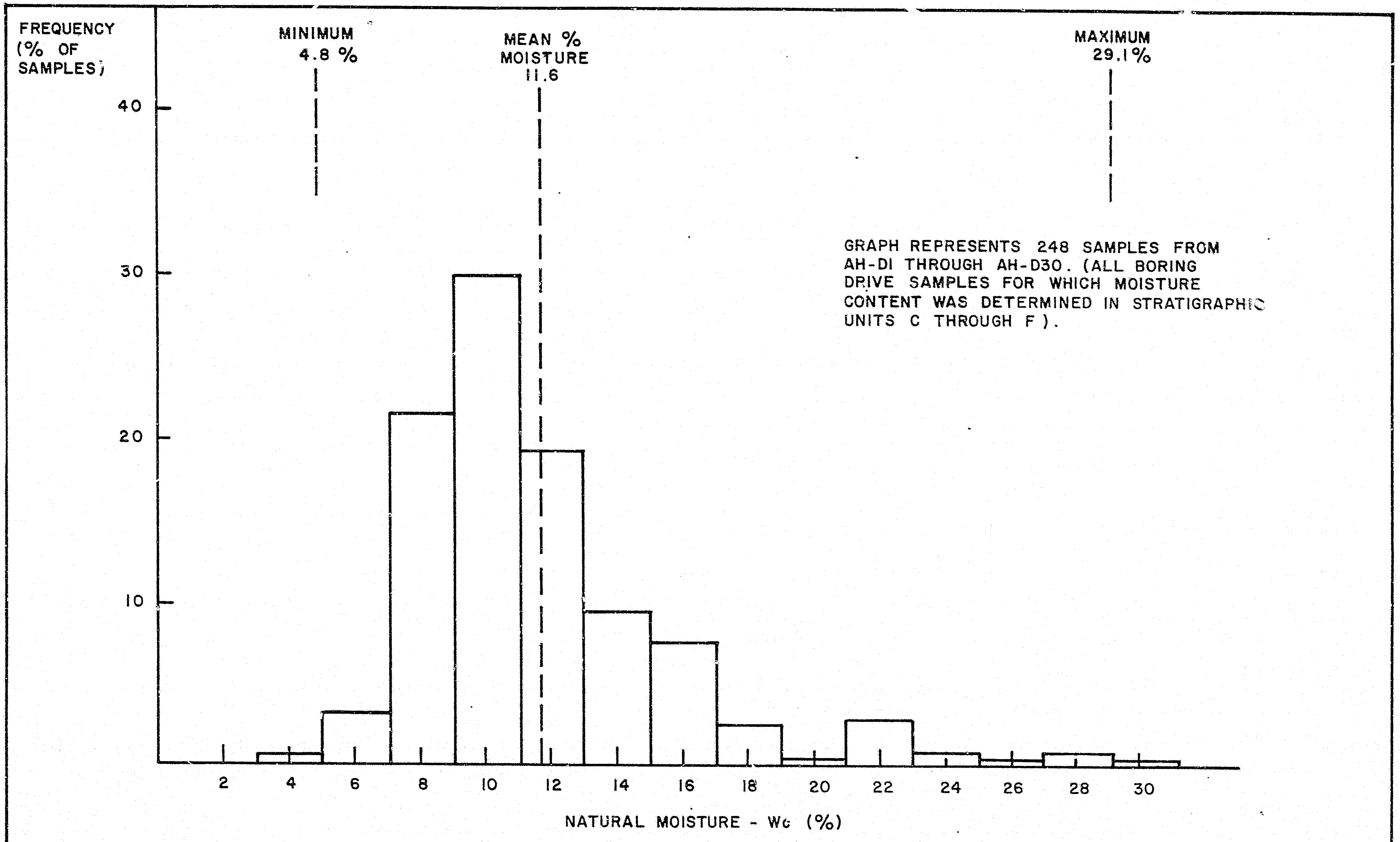
FIGURE 8.4



WATANA BORROW SITE D
BORROW MATERIAL MOISTURE / GRADATION RELATIONSHIP

FIGURE 8.5

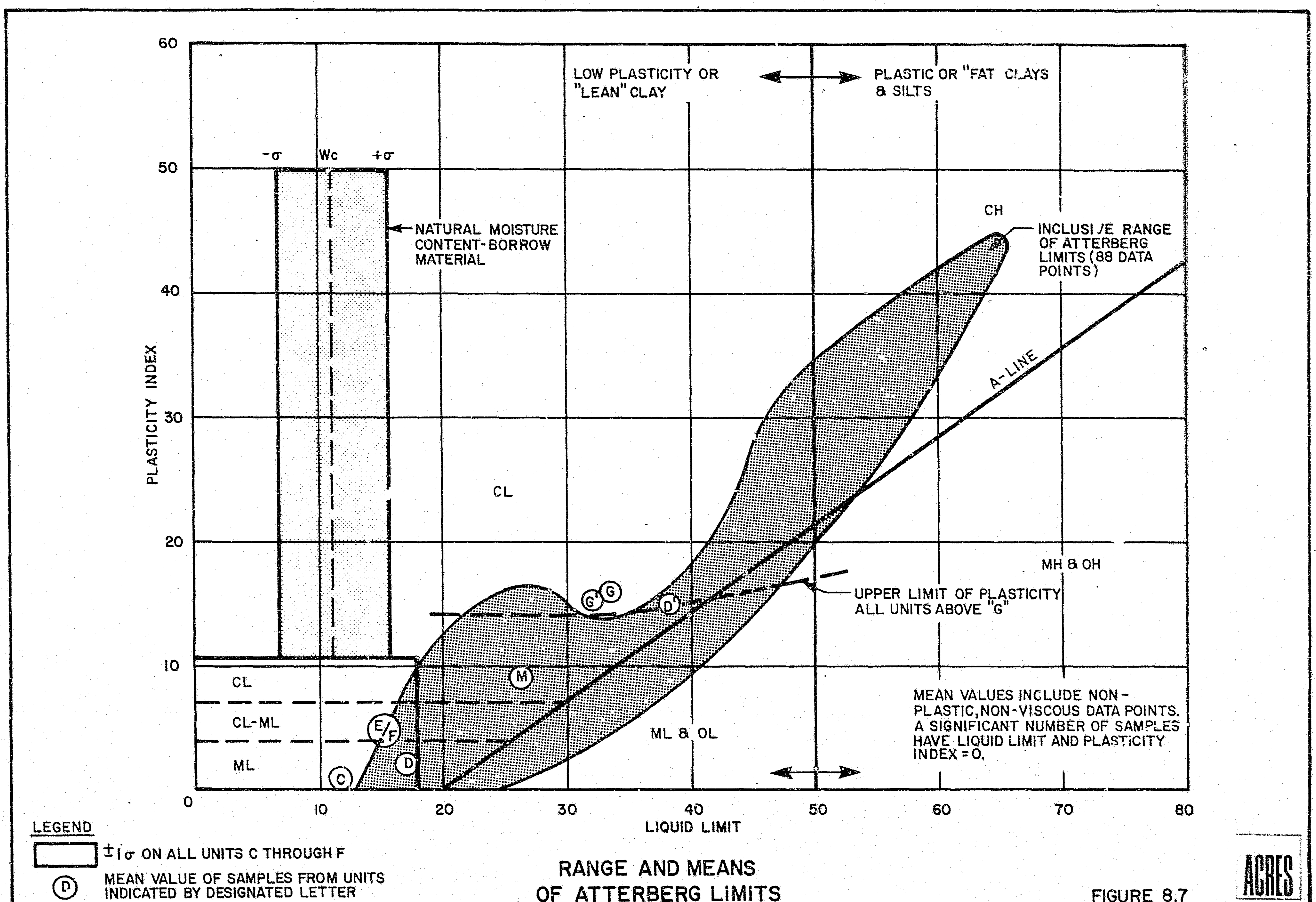
ACRES



WATANA BORROW SITE D
BORROW MATERIAL MOISTURE FREQUENCY DISTRIBUTION

FIGURE 8.6

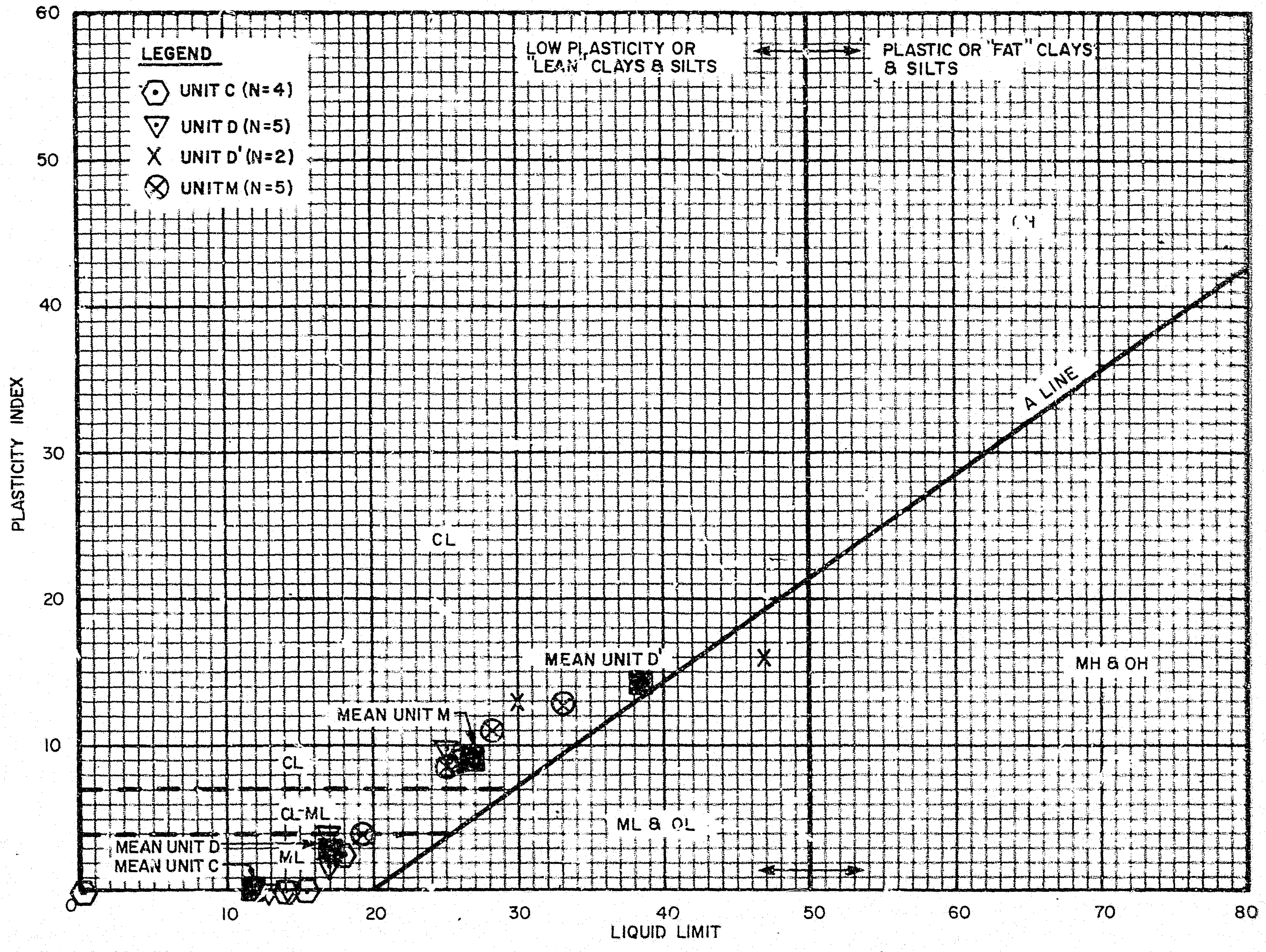
ACRES



RANGE AND MEANS
OF ATTERBERG LIMITS

FIGURE 8.7

ACRES



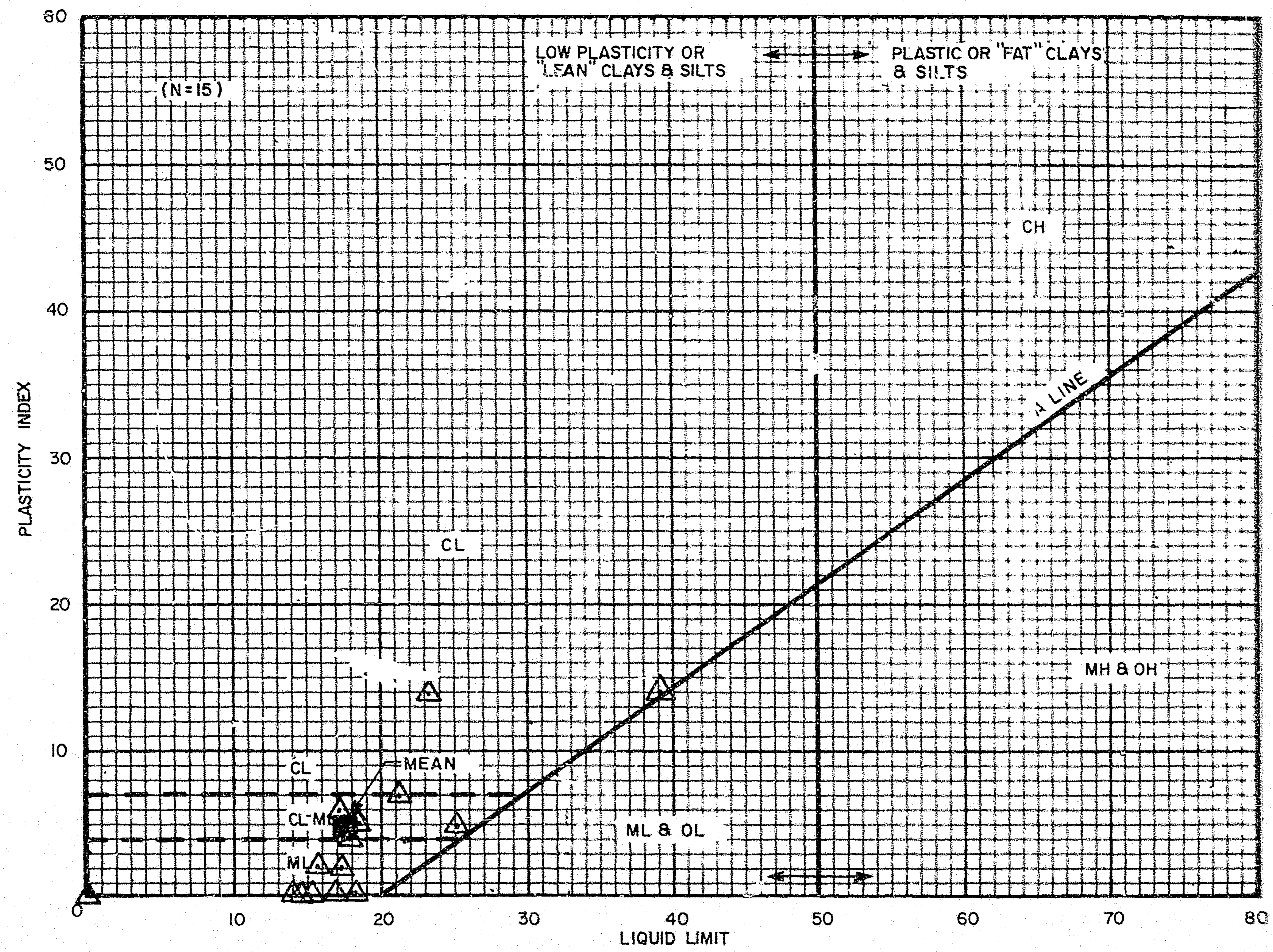
TEST PERFORMED ON MATERIAL PASSING NO. 40 SIEVE IN ACCORDANCE WITH ASTM D423-66 (1972) AND D424-59 (1971)

(INCLUDES ALL TESTS 1978-1982)

ATTERBERG LIMITS TESTS
STRATIGRAPHIC UNITS ABOVE UNIT E

FIGURE 8.8

ACRES



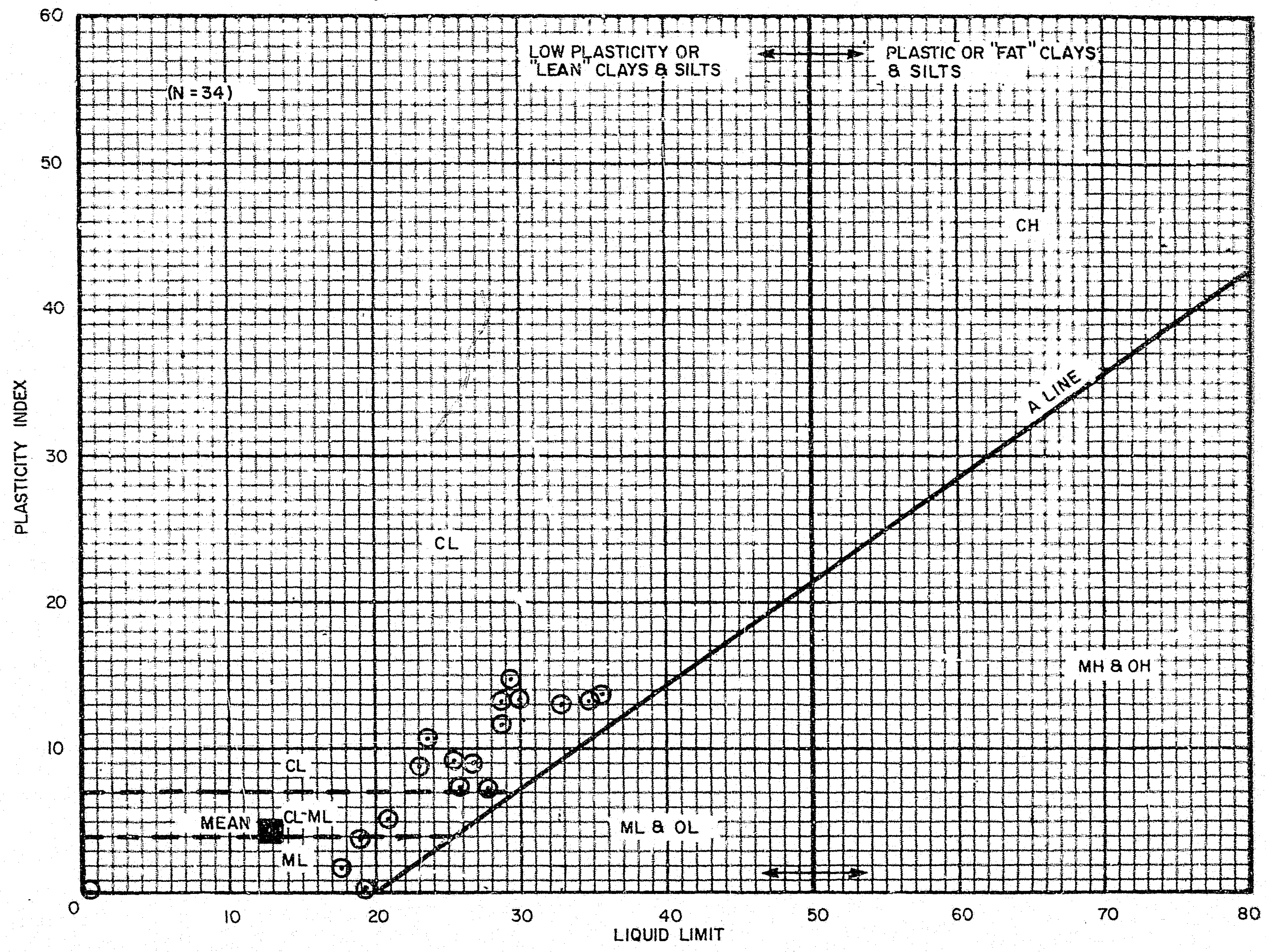
TEST PERFORMED ON MATERIAL PASSING NO. 40 SIEVE IN ACCORDANCE WITH ASTM D423-66 (1972) AND D424-59 (1971)

(INCLUDES ALL TESTS 1978-1982)

ATTERBERG LIMITS TESTS
STRATIGRAPHIC UNITS E AND F

FIGURE 8.9

ACRES

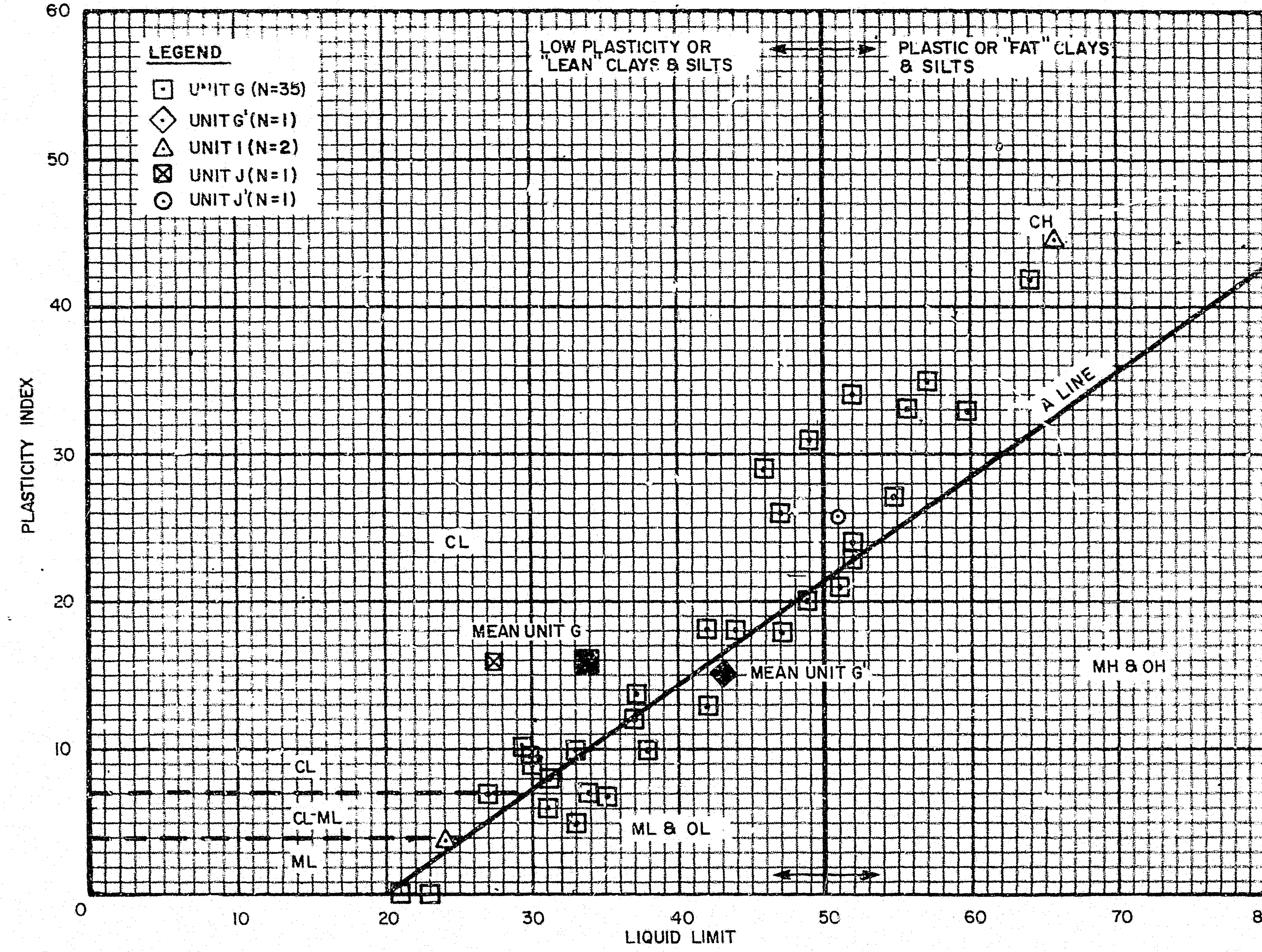


TEST PERFORMED ON MATERIAL PASSING NO. 40 SIEVE IN ACCORDANCE WITH ASTM D423-66 (1972) AND D424-59 (1971)
(HOLES TOO SHALLOW TO IDENTIFY STRATIGRAPHIC UNITS, BELIEVED TO CONTAIN UNITS A THROUGH G)

ATTERBERG LIMITS TESTS
COE "AP" SERIES AUGER PROBES (1978)

FIGURE 8.10

ACRES



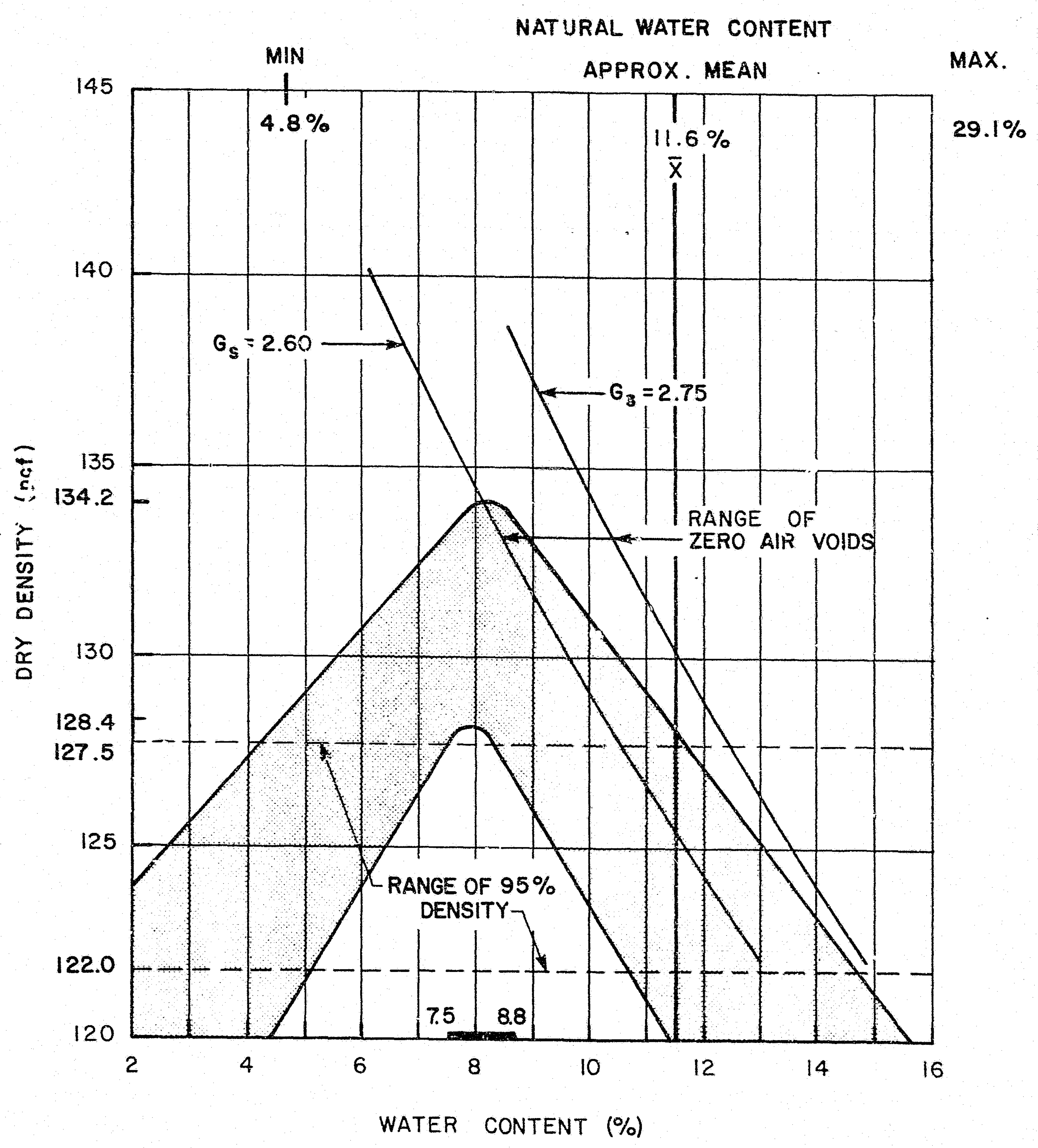
TEST PERFORMED ON MATERIAL PASSING NO. 40 SIEVE IN ACCORDANCE WITH ASTM D423-66 (1972) AND D424-59 (1971)

(INCLUDES ALL TESTS 1978-1982)

ATTERBERG LIMITS TESTS
STRATIGRAPHIC UNITS BELOW BORROW MATERIALS

FIGURE 8.11

ACRES



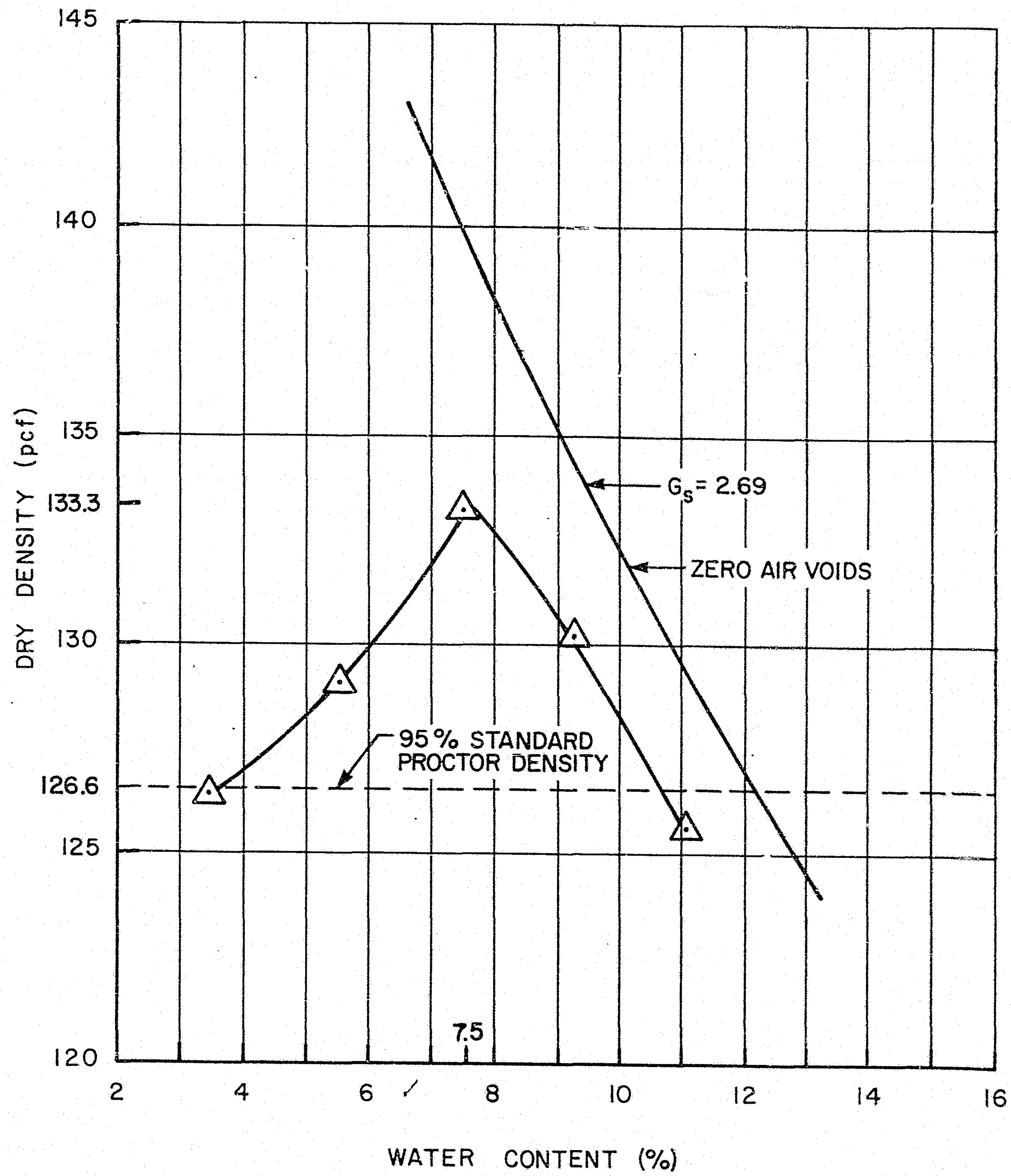
NOTE:
MATERIAL PASSING 3/4" SIEVE
(7 TESTS- FIGURES 8.13-8.15)
ASTM D698-78 METHOD C

INCLUDES ALL STANDARD PROCTOR DENSITY TESTS PERFORMED TO DATE ON PROSPECTIVE BORROW MATERIAL

WATANA BORROW SITE D
RANGE OF STANDARD PROCTOR DENSITY TESTS
STRATIGRAPHIC UNITS C THROUGH F

ACRES

FIGURE 8.12



NOTE:
MATERIAL PASSING 3/4" SIEVE
(12 TEST PITS, IDENTIFIED AS UNITS "C" THROUGH "F", UNDIFFERENTIATED)

AASHTO T-99 METHOD D
(COE, 1978)

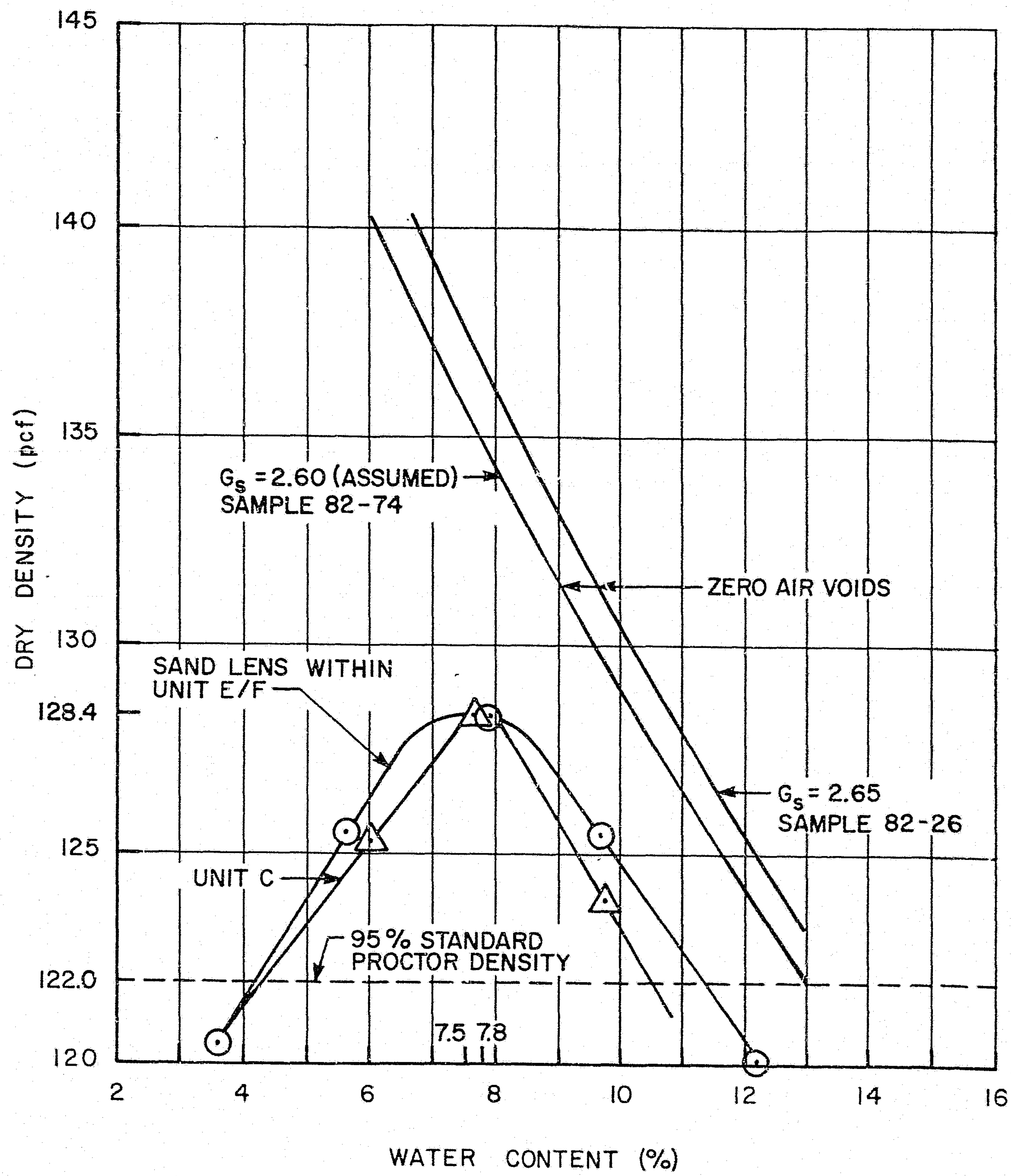
LEGEND:
△ COMPOSITE SAMPLE OF COE TEST PITS:

TP8-1	TP14-2
TP9-1,2 & 3	TP15-2
TP10-1 & 2	TP16-1 & 2
TP11-1	TP17-2
TP12-1 & 2	TP18-1
TP13-1	TP19-1 & 2

WATANA BORROW SITE D
STANDARD PROCTOR DENSITY TEST
COE COMPOSITE SAMPLE (1978)

FIGURE 8.13

ACRES



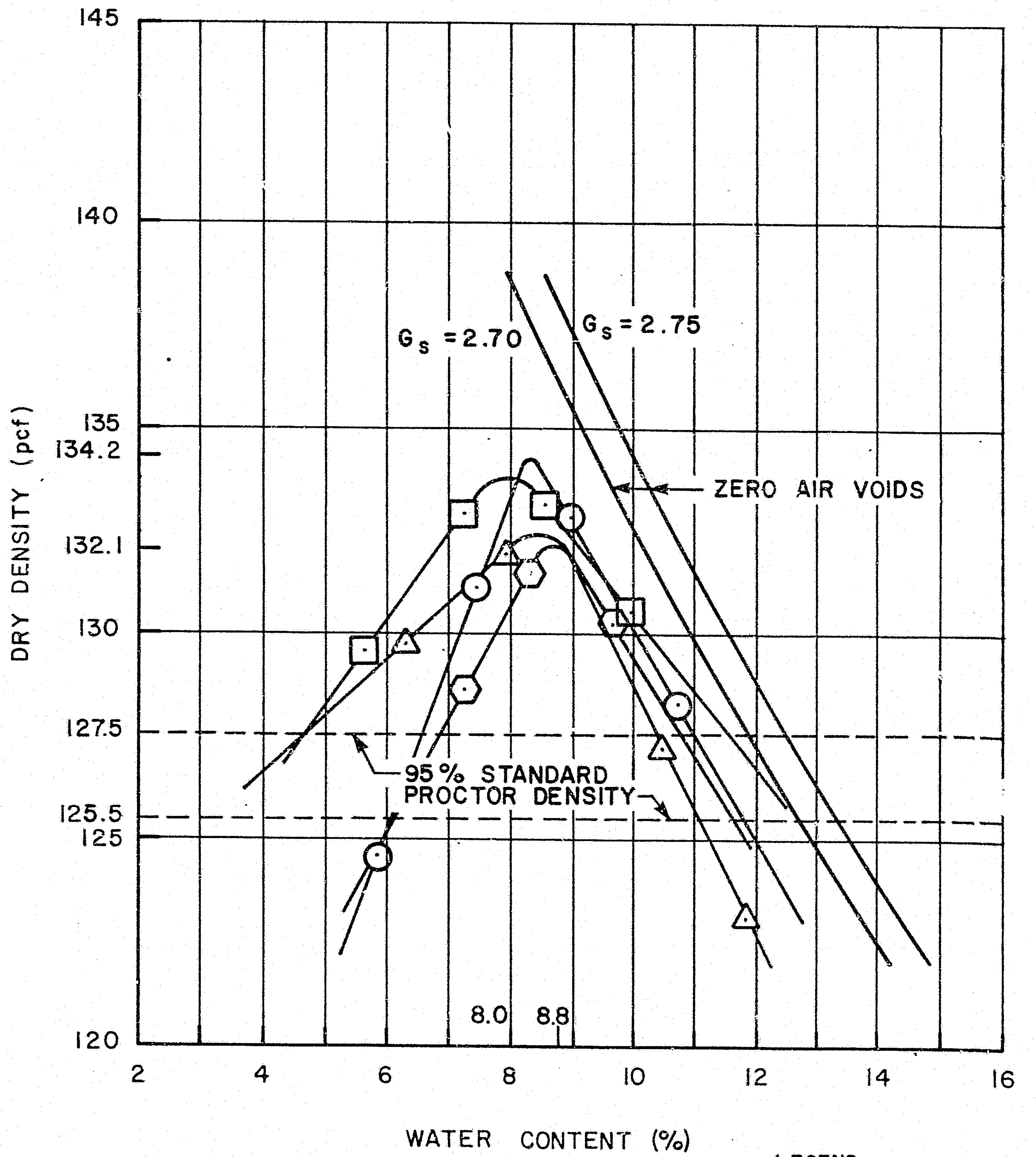
NOTE:
MATERIAL PASSING 3/4" SIEVE
ASTM D698 METHOD C

LEGEND:
⊙ W82-26 PIT 4
△ W82-74
(1982 ACRES)

WATANA BORROW SITE D
STANDARD PROCTOR DENSITY TESTS
SELECTED SANDY SAMPLES

FIGURE 8.14

ACRES

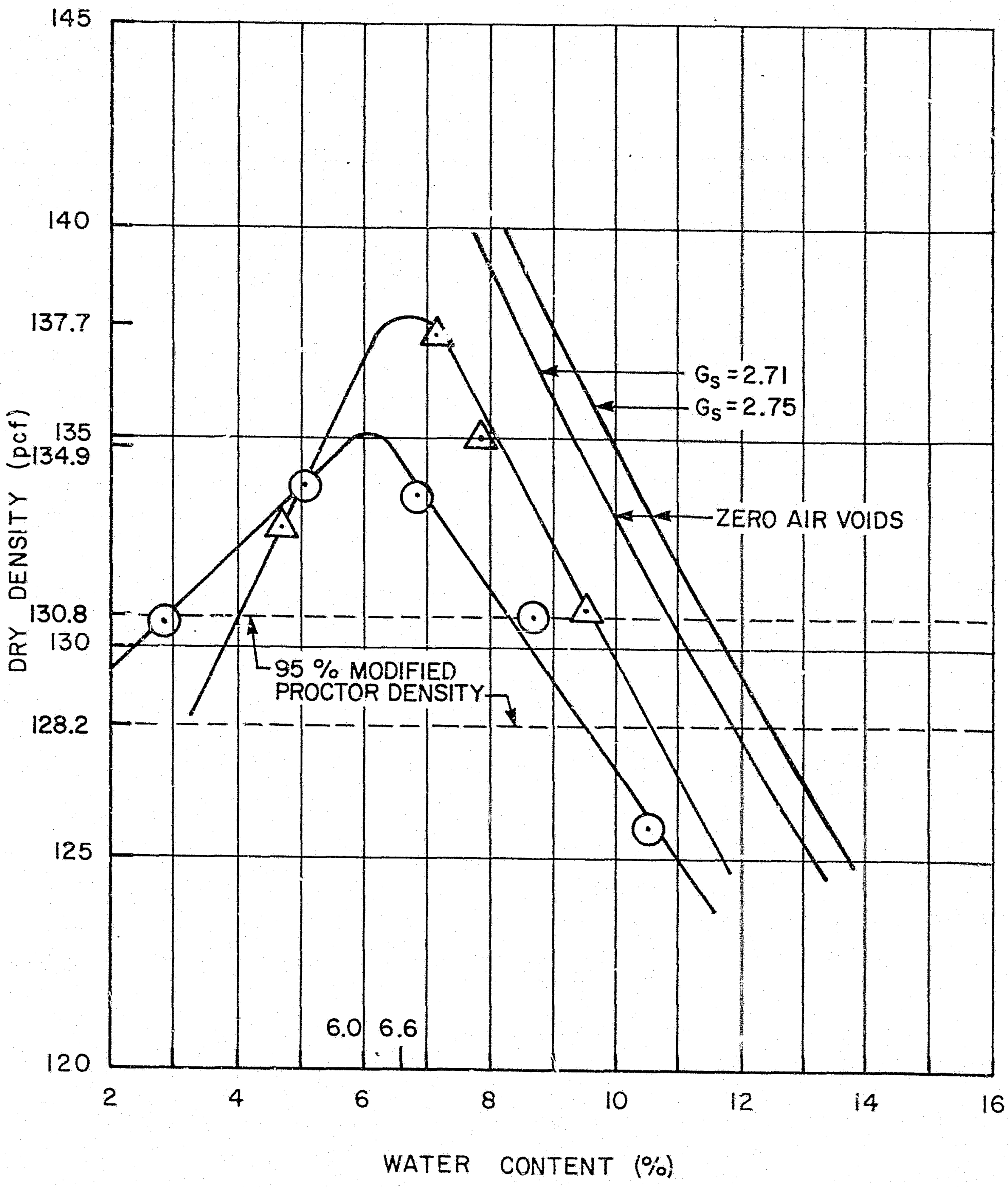


NOTE:
MATERIAL PASSING 3/4" SIEVE
ASTM D698 METHOD C

LEGEND
- W82-2 PIT 3, 3a, 3b
- W82-30
- W82-44 PIT 2
- W82-91

WATANA BORROW SITE D
STANDARD PROCTOR DENSITY TESTS
STRATIGRAPHIC UNITS E & F

FIGURE 8.15



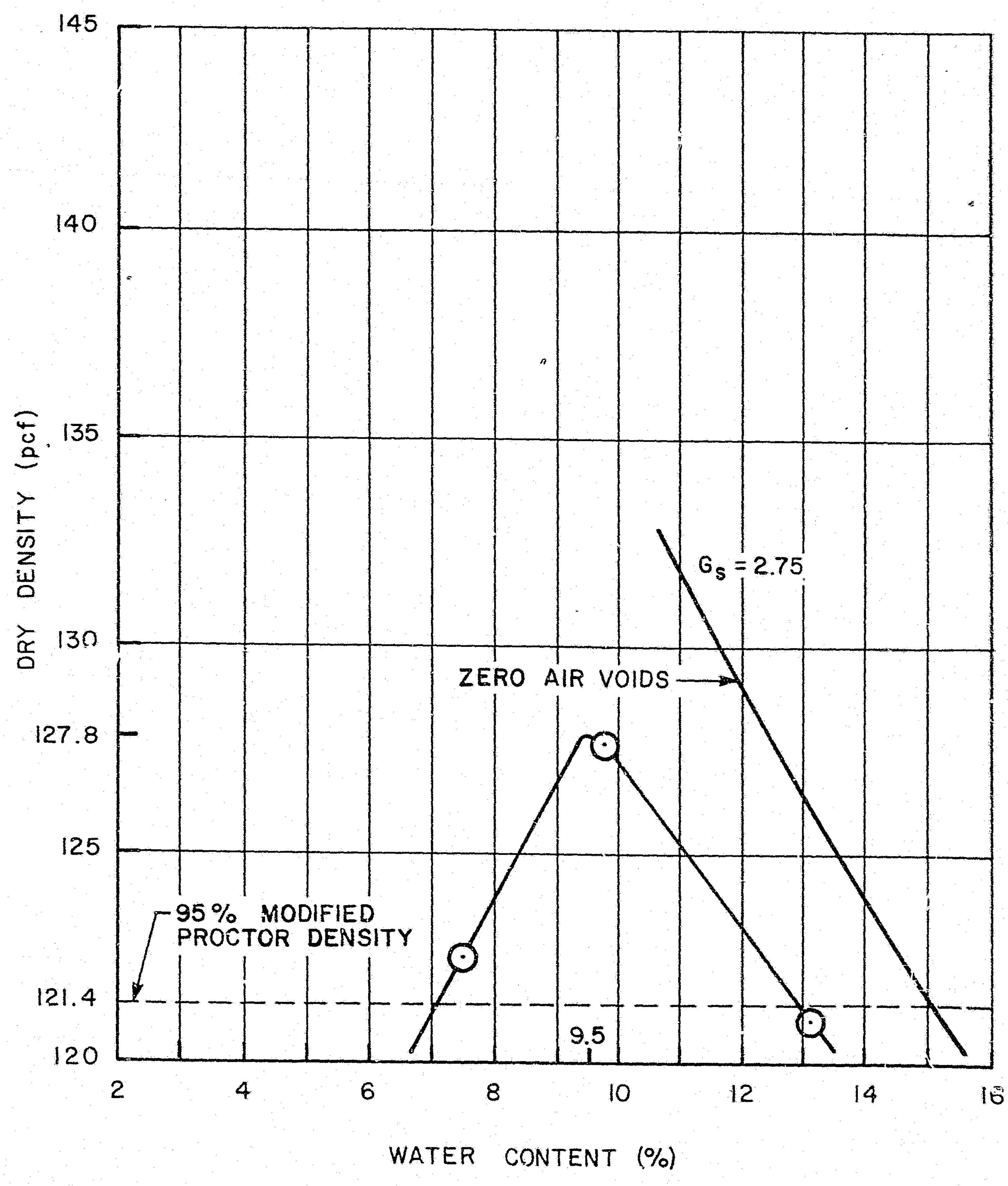
NOTE:
MATERIAL PASSING 3/4" SIEVE
ASTM D1557 METHOD C (1982 TEST)
AASHTO T-180 METHOD D (1980 TEST)

LEGEND:
△ W82-2 PIT 3,3A & 3B (1982)
⊙ W80-300 (1980)

WATANA BORROW SITE D
MODIFIED PROCTOR DENSITY TESTS
STRATIGRAPHIC UNITS E & F

FIGURE 8.16

ACRES



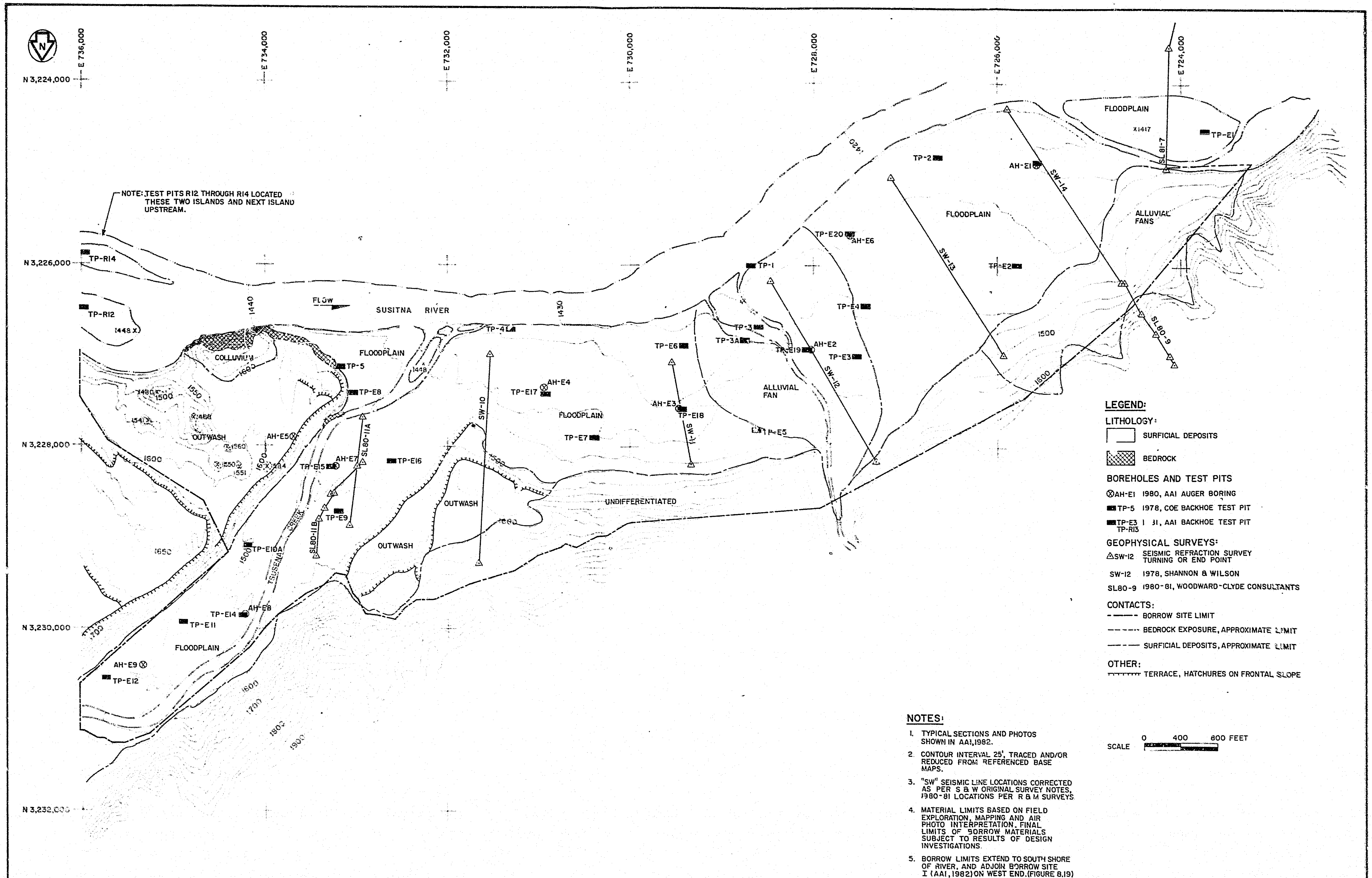
NOTE:
MATERIAL PASSING 3/4" SIEVE
ASTM D1557-78 METHOD C

LEGEND
⊙ W82-2 PIT 5, 6 & 7

WATANA BORROW SITE D
MODIFIED PROCTOR DENSITY TEST
STRATIGRAPHIC UNIT G

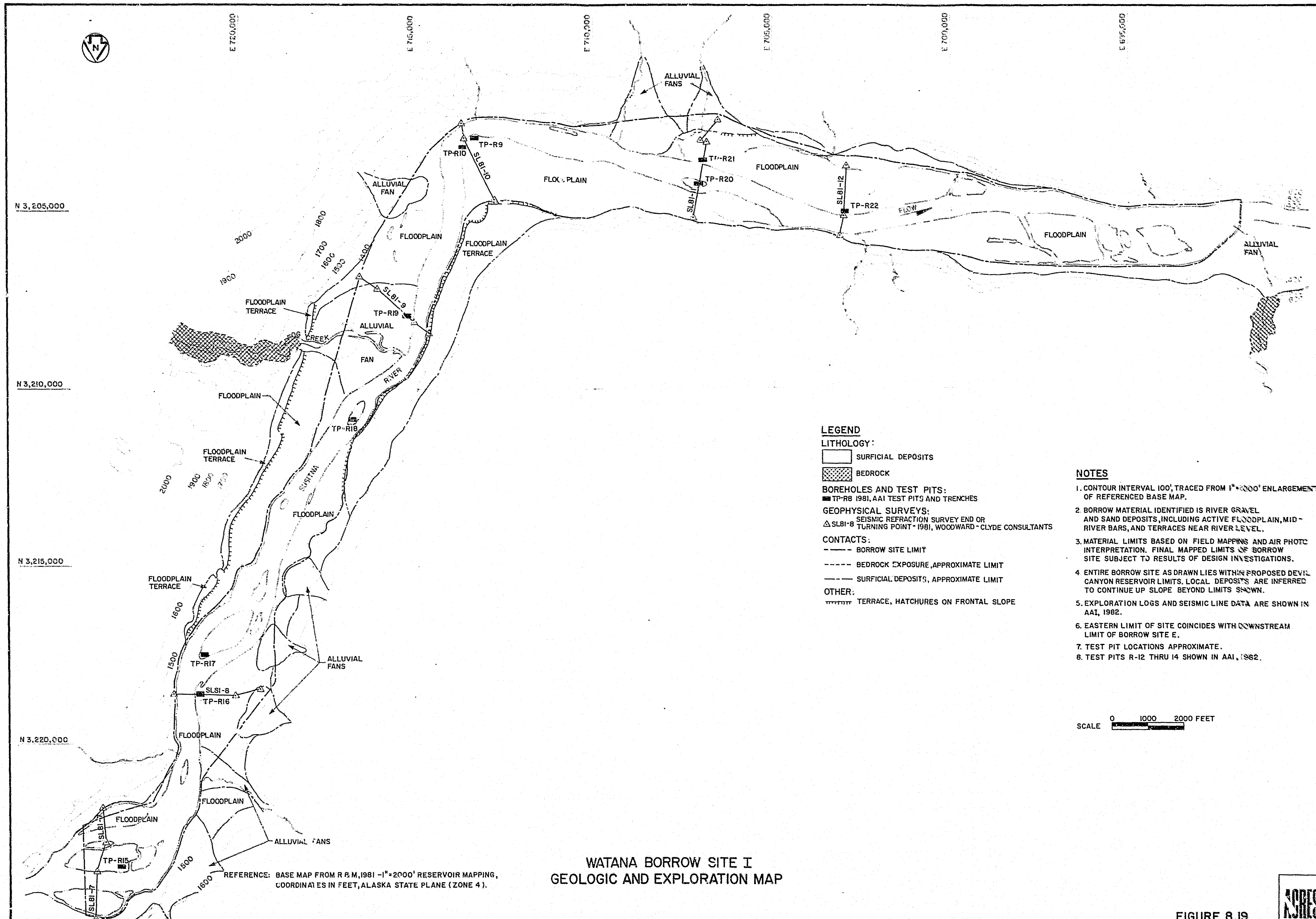
ACRES

FIGURE 8.17



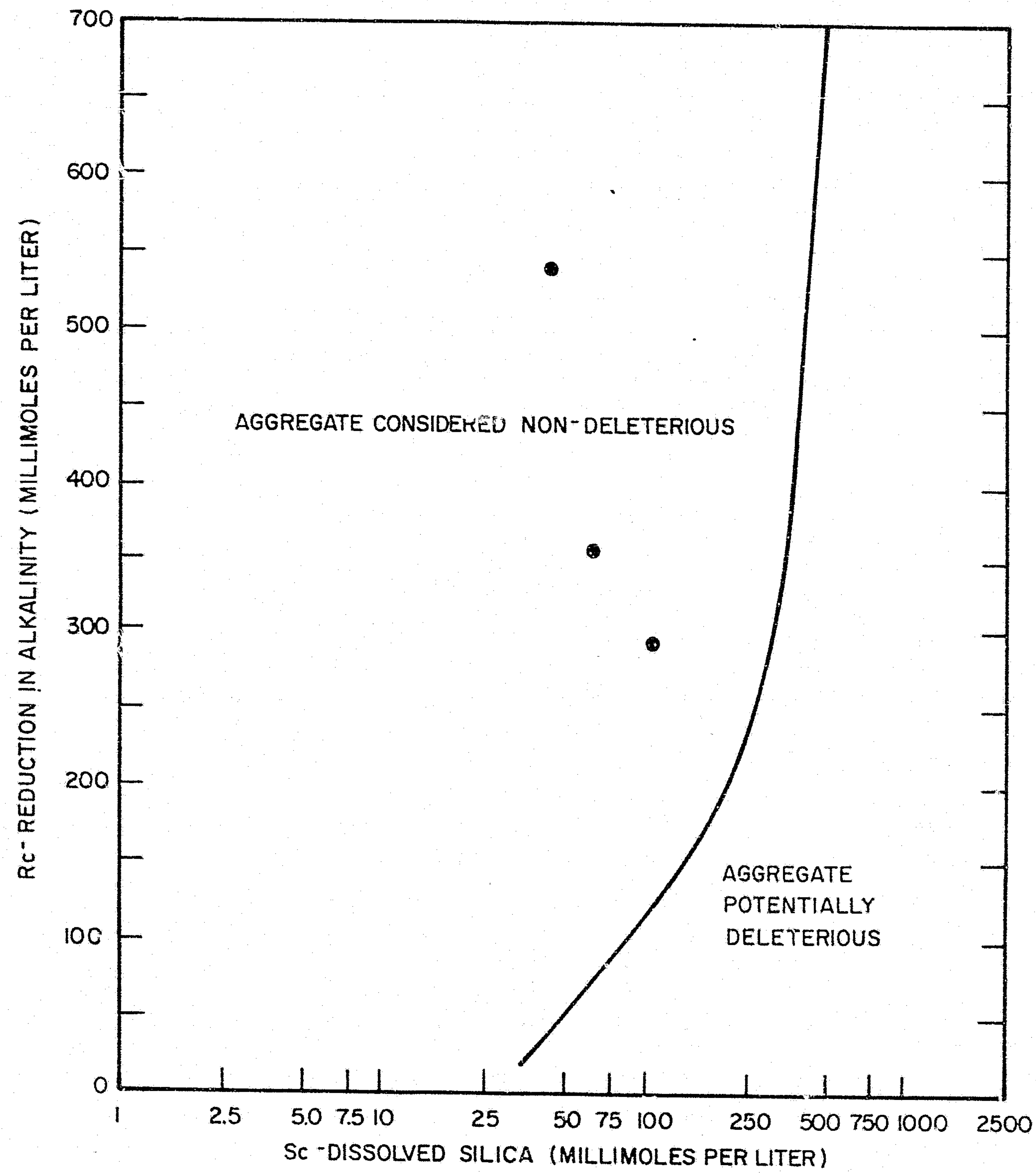
WATANA BORROW SITE E
GEOLOGIC AND EXPLORATION MAP

FIGURE 8.18



WATANA BORROW SITE I
GEOLOGIC AND EXPLORATION MAP

FIGURE 8.19



NOTES: REFERENCE; ASTM C 289-81
FOR TEST SAMPLE DESCRIPTIONS
SEE TABLE 8.2.

WATANA BORROW SITE E
AGGREGATE REACTIVITY TEST DATA

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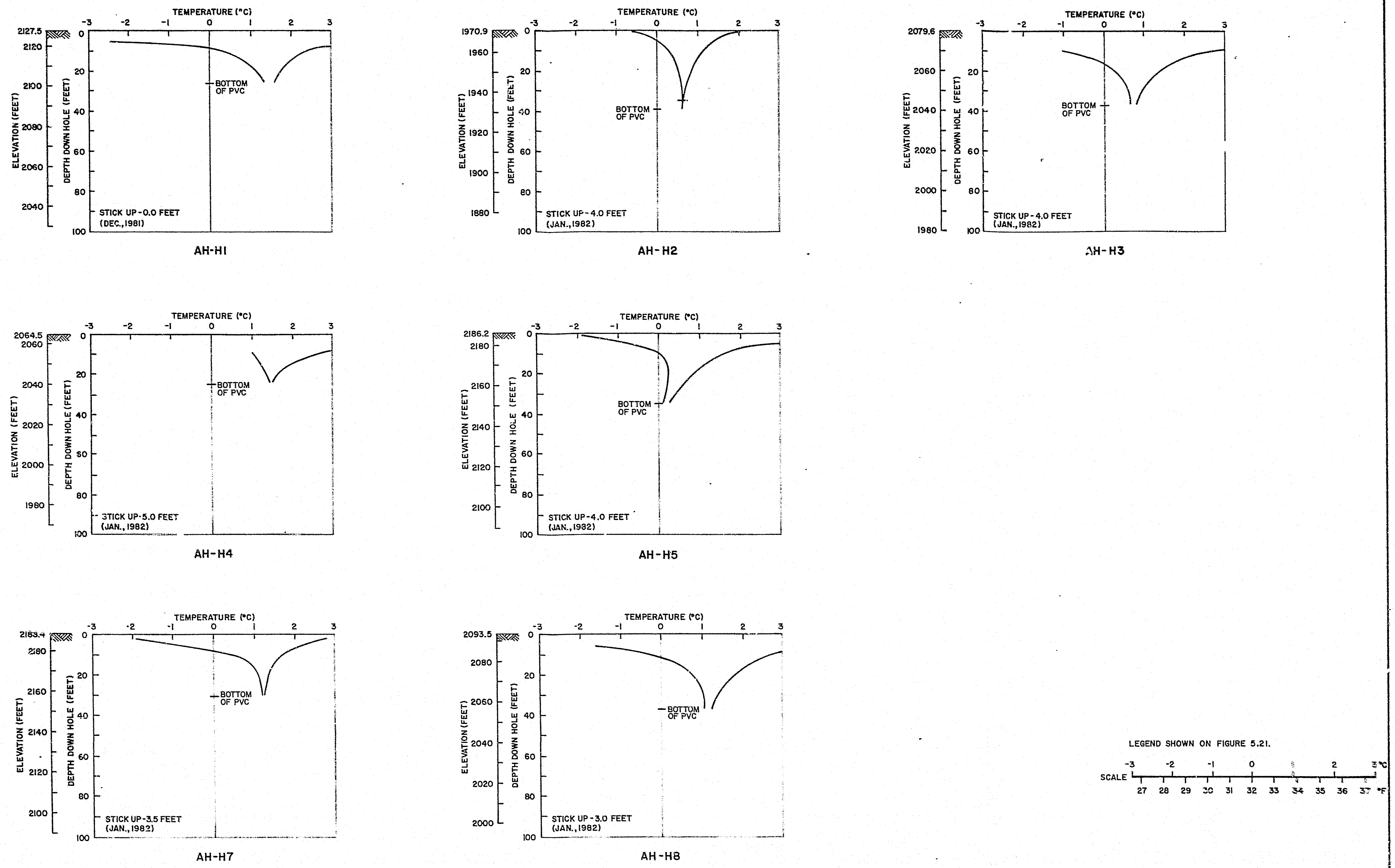
FIGURE 8.20



WATANA BORROW SITE H
THERMISTOR DATA

FIGURE 8.21

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9 - RESULTS OF GEOTECHNICAL INVESTIGATIONS - DEVIL CANYON DAMSITE

9.1 - Introduction

The results of the on-going studies at the Devil Canyon Damsite during the summer of 1982 are presented in this section. The three principal subsections are:

Subsection 9.1: Materials Properties
Subsection 9.2: Groundwater Regime
Subsection 9.3: Permafrost Regime

The work related to the Devil Canyon damsite in the 1982 summer program involved completion of the laboratory testing of quarry and concrete aggregate materials begun in 1981, and reading of borehole instrumentation installed in 1980-81 for groundwater and permafrost regimes at the damsite.

9.2 - Material Properties

(a) Borrow Site G

The 1980-81 exploration program had obtained test trench samples in Borrow Site G, which were classified and then submitted for testing (1). Because this area was designated as the source for all concrete aggregate, grout sand and filter gravels and sands, the suitability of the materials for use in concrete and as granular fill was tested. Additional complete concrete mix design and mortar bar tests were not deemed necessary until final design, since previous tests (36, 37) had shown that this source could produce a suitable mix design.

The results of the general aggregate suitability tests show that the aggregate readily meets the ASTM, COE and USBR generic standards (Table 9.1). All factors were well within the limits for general construction (non-architectural) use in concrete, and the low absorption and high abrasion resistance indicate probable suitability for general aggregate use in roads, filters, and related uses.

The aggregate testing for freeze-thaw durability shows only moderate losses up to 150 cycles (Table 9.2). While there is no generally accepted standards, losses of not more than 5 percent for 200 cycles is frequently considered a reasonable limit for cold regions use.

Preliminary laboratory analysis of various material types within Borrow Site G show the alluvial material near river level to have a more favorable petrographic composition and quality than the material in the upper terrace. This could be because the lower bar represents more worn, abrased materials, and hence has had much of the poor quality material removed naturally.

The materials from the upper terrace Zone I (1) exhibit generally poorer quality particles, but fewer potentially reactive silicates such as chert and glossy volcanics such as dacites and andesites than the lower terrace. This material also showed poorer performance in sodium sulfate soundness and absorption testing, although the differences were not critical (Table 9.1).

Because the lower, near-river level terrace (Zone I, Figure 7.22) Reference (1) comprises the majority of the proven and inferred reserves, and apparently has higher quality freeze-thaw performance, chemical reactivity tests (Table 9.3) were run on this material to determine if the free silicates identified by the USBR testing would pose a problem in mix design. While the USBR tests showed very suitable performance on a 6 month test mix series, additional samples were tested during 1981-82 using the chemical test method of reduction of alkalinity in silica solution. The test data indicates that the aggregate is well within the normally accepted range of values for aggregate and is unlikely to have an adverse silicate reaction (Figure 9.1).

On the basis of these tests, physical examination of the aggregate, and working within the estimating assumption that significant aggregate processing will be performed on the material to reduce the poor quality fraction, it is felt that this borrow source is fully suitable for all uses at the damsite.

However design level investigation will require a systematic development of a mix design with high freeze-thaw durability using special screening, washing, and drum rolling processing as may be necessary for construction. In addition, testing should include using a variety of material types found throughout Borrow Site G.

It is also recommended that detailed drilling be conducted to depth over the entire borrow site.

(b) Quarry Site K

Quarry Site K has been identified at Devil Canyon as a potential source of quarry rock (1). To confirm the suitability of the rock as construction material, a 150 cycle freeze-thaw test was performed. The results of the test showed an 8 percent loss at 150 cycles. This unusually high loss, which is in contrast to the test results obtained from the same rock type in Quarry Site A (see Section 8.1), may be due to the fact that the samples were hand-samples from the surface that may have been weathered and severely microfractured. To confirm these results additional detailed testing will be required on "fresh" samples during the design level investigation.

9.3 - Ground Water Regime

The groundwater readings during 1982 continued to show a seasonal fluctuation in the two north abutment holes (BH-1 and BH-2), with the level in BH-1 fluctuating from about 50 to 150 vertical feet below the surface, and BH-2 showing water levels equal to or slightly exceeding the collar elevation of the hole. Artesian flow has been observed occassionally at the hole. Previous readings of BH-4 (1) had, as would be expected from its proximity to the lake, reflected only a few feet of annual variation from mean lake level. The most recent readings of BH-4 indicate the pneumatic piezometer is defective and will have to be replaced.

9.4 - Permafrost Regime

The 1982 thermistor readings in BH-1, BH-2 and BH-3 (Figure 9.2) confirm the previous data presented in the 1980-81 Geotechnical Report (1). Complete annual amplitude envelopes are shown in Figure 9.3. The depth of annual frost penetration in bedrock appears to be about 10 to 18 feet, with the deepest frost penetration being in May to June. Depth to annual amplitude is deep, ranging from 40 to 100 feet.

As noted in the 1980-81 Geotechnical Report (1), it appears that the instrumentation installed in BH-4 is defective with failure slowly progressing up the string in a constant, uniform progression. Additional instrumentation will be required in this area to determine the subsurface thermal conditions.

TABLE 9.1

DEVIL CANYON BORROW SITE G
AGGREGATE SUITABILITY TEST DATA

Sample Number	Depth	Sodium Sulfate Soundness ASTM C-88 (1976) % Loss		% Absorption		% Lightweight Particles ASTM C-123 (1975)		Specific Gravity		L.A. Abrasion ASTM C-131 (1981) (500 revolutions)	
		C.A.	F.A.	ASTM C127 (1980) C.A.	ASTM C128 (1979) F.A.	C.A	F.A.	ASTM C127 (1980) C.A.	ASTM C128 (1979) F.A.	% Loss	Grading
TT K-6 & TT K-19	0-58.1'	2.3	3.7	0.3-0.7	0.8	not run	0.0	2.74	2.71	17.6	A
TT K-21 & TT K-93	0-30.0' (USBR) (AAI)	2.5	5.1	0.5-0.9	0.9	not run	0.0	2.75-2.82	2.71	16.7	A
TT G-1-2 TT G-1-3	5.0 16.0	1.0		0.62	3.2	0.0	not run	2.76	2.71	18	A
TT G-1-4 TT G-1-5	25.5 37.0										
TT G-2-3 TT G-2-4 TT G-2-5	6.5 8.0 15.0	0.6		0.6	3.7	0.0	not run	2.81	2.71	16	A
TT G-2-8 TT G-2-9	18.0 24.5										
ASTM (1) & COE (2) Recommended Limits		12	12	5%		3	3	2.40	2.40	50	A
USBR (3) Recommended Limits		10	8	10%		2	2	2.60	2.60	40	A

TABLE 9.2

DEVIL CANYON BORROW MATERIALS
FREEZE-THAW DURABILITY TEST DATA

SAMPLE NUMBER	SAMPLE DEPTH	Aggregate Cumulative Loss (% of Weight) (1) (2)				
		35 Cycles	40 Cycles	80 Cycles	115 Cycles	150 Cycles
W80-82 (Quarry K)	Outcrop, Surface		1.1		7.2	8.0
TT-G1 (Borrow G)	0-37'	1.3		2.0	2.3	2.5
TT-G2	0-24.5'	1.5		2.0	2.1	2.3

		w/c Ratio	% Air	28 Day Strength	# Cycles to 25% Loss (3)
TT-K-6 & TT-K-19 (SUBR)	0-58.1'	0.51	6.2	4280 psi	515
TT-K-21 & TT-K-93	0-30.0'	0.51	6.2	3860 psi	390

Notes: (1) (AASHTO, 1978) T103-78 Method A, Course Aggregate & Ledgework Samples

(2) Tests performed by R&M Consultants

(3) USBR Method, similar to ASTM C-227

TABLE 9.3

DEVIL CANYON BORROW MATERIALS
POTENTIAL REACTIVI˜ OF AGGREGATES-TEST DATA (1)

COMBINED SAMPLE SITE	SIEVE SIZE				
	PASSING	RETAINED	Rc	Sc	RESULTS
TT-G1	3/8"	#4	180	28.2	Innocuous
TT-G2	3/8"	#4	211	72.9	Innocuous
TT-G2	3/8"	#4	162	67.3	Innocuous
TT-G2	1/2"	3/8"	220	39.9	Innocuous
TT-G2	3/4"	1/2"	158	61.3	Innocuous
TT-G2	1"	3/4"	242	31.0	Innocuous
TT-G2	1-1/2"	1"	145	30.5	Innocuous
TT-G2	2"	1-1/2"	89	41.5	Innocuous

Notes: Rc = Reduction in Alkilinity (millimoles/liter)

Sc = Concentration of SiO_2 (millimoles/liter) in the original filtrate

(1) ASTM C-209 (1981)

(2) Tests performed by Chemical & Geological Laboratories of Alaska, Inc., under direction of .&M Consultants.

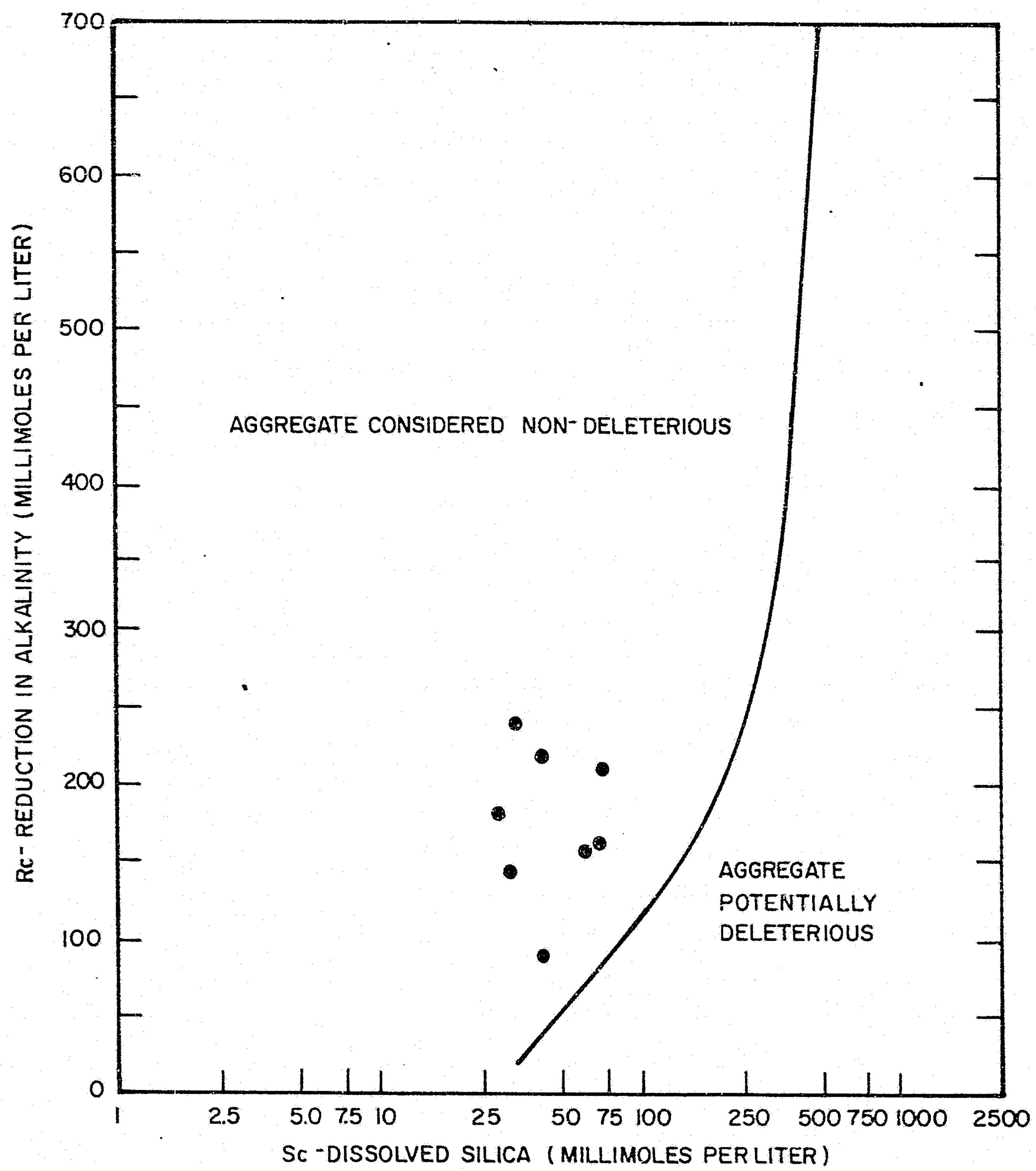
TABLE 9.4

DEVIL CANYON BORROW SITE G
ESTIMATED BORROW MATERIAL AVAILABILITY

MATERIAL TYPE	MATERIAL ZONES (1)	"KNOWN" RESERVES	TOTAL "KNOWN" + "INFERRED" RESERVES
High quality gravels and sandy gravels	Ia/Ia & Ib	1.1 mcy	3.1 mcy
Cobbly & bouldery gravels, (believed to be high quality)	III	0.3	1.1
Upper terrace gravelly sands, marginal to submarginal quality	II	0.5	2.0
Talus deposits, minor Cheechako Creek reworking	IV	0.0	0.05
Miscellaneous Upper Level Terraces (thin overburden zones unexplored)	Saddle Dam Area	0.0	(0.9)
TOTALS		1.9 mcy	7.2 mcy

ANTICIPATED PROJECT DEMAND - 2.0 - 2.1 mcy

Reference (1)



NOTES: REFERENCE; ASTM C 289-81
FOR TEST SAMPLE DESCRIPTIONS
SEE TABLE 9.2.

DEVIL CANYON BORROW SITE G
AGGREGATE REACTIVITY TEST DATA

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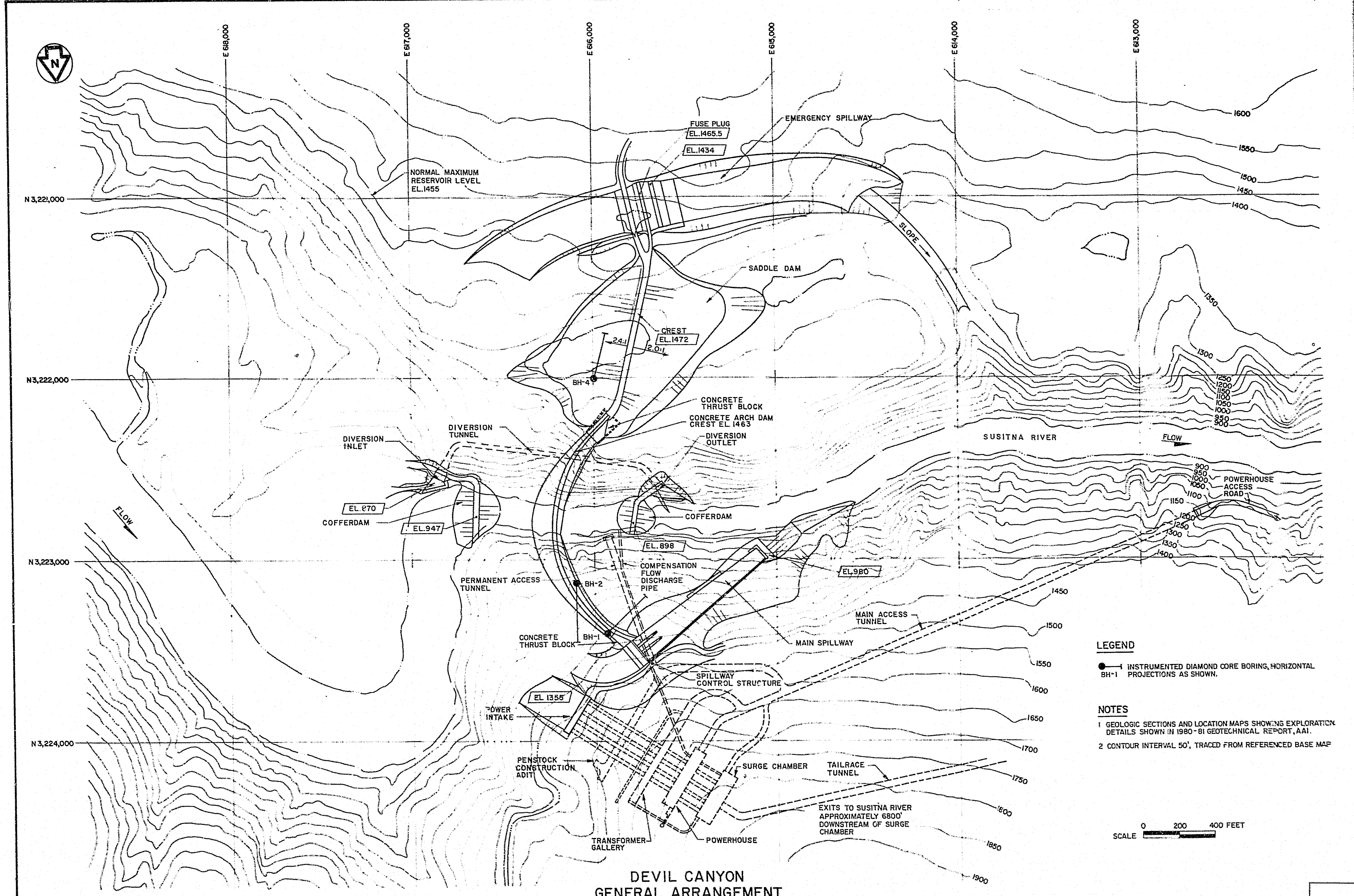
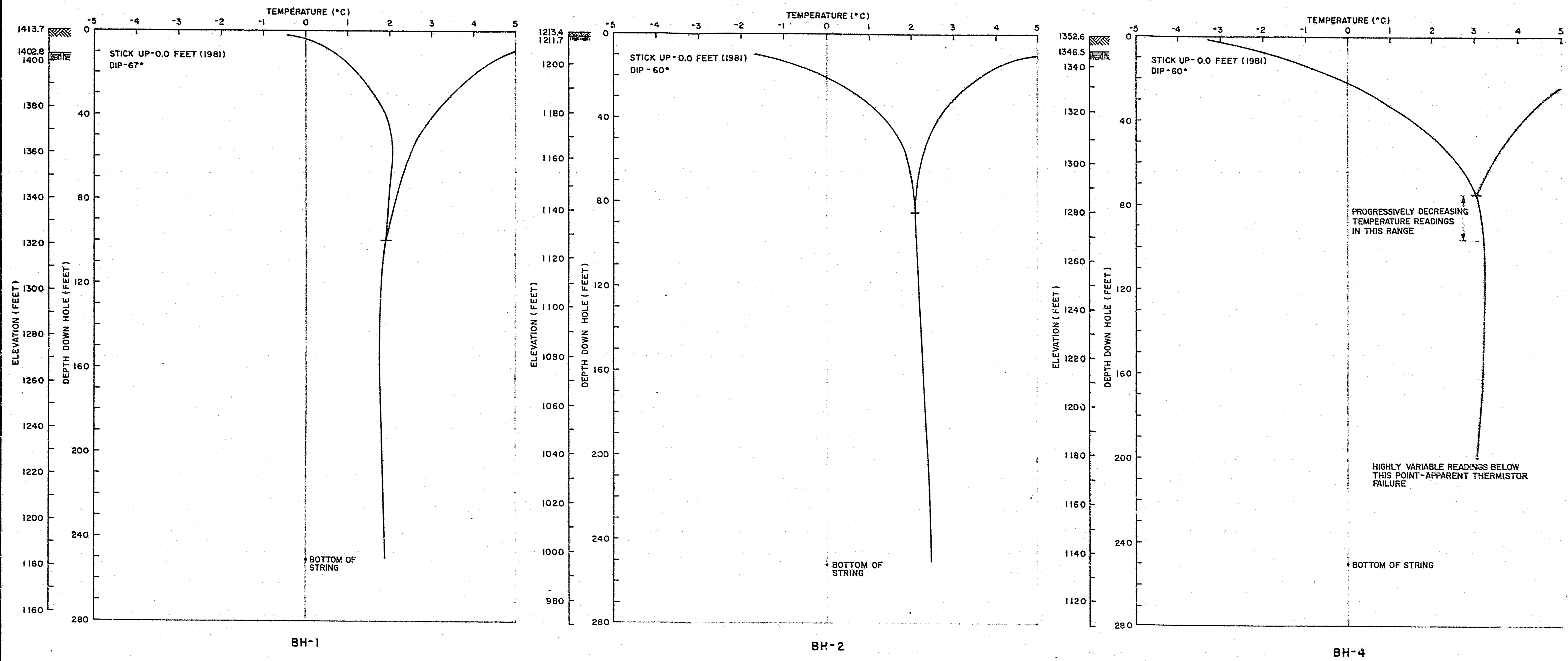
FIGURE 9.1



DEVIL CANYON
GENERAL ARRANGEMENT
AND INSTRUMENTATION LOCATION MAP

REFERENCE: BASE MAP FROM R & M, 1981 - 1" = 200' DEVIL CANYON TOPOGRAPHY
COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4)

FIGURE 9.2



LEGEND

LITHOLOGY:

GROUND SURFACE

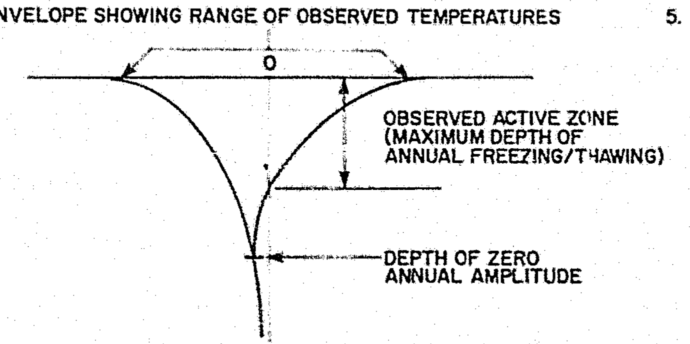
TOP OF ROCK

BOREHOLES:

AH AUGER HOLE } ACRES AMERICAN INCORPORATED
BH BORE HOLE

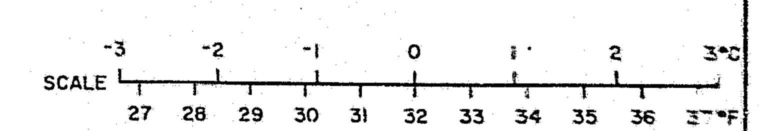
DATA SYMBOLS:

ENVELOPE SHOWING RANGE OF OBSERVED TEMPERATURES



NOTES

1. LOCATION OF HOLES SHOWN ON FIGURE 9.2.
2. THERMISTOR STRINGS MANUFACTURED BY INSTRUMENTATION SERVICES IN FAIRBANKS, ALASKA.
3. BORINGS ARE INSTRUMENTED WITH PERMANENT MULTI-POINT THERMISTOR STRINGS, WITH TWO THERMISTORS AT EACH READING POINT. DATA FOR TWO POINTS IS AVERAGED.
4. THERMISTOR READOUT BOXES MANUFACTURED BY KEITHLEY (172 A) AND FLUKE, USED FOR 1980 THROUGH 1982 READINGS.
5. AUGER HOLES AH-G11 THRU AH-G14 CONTAIN THERMISTOR PROBES, BUT NO DATA WAS OBTAINED.



DEVIL CANYON DAMSITE
THERMISTOR DATA

FIGURE 9.3

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