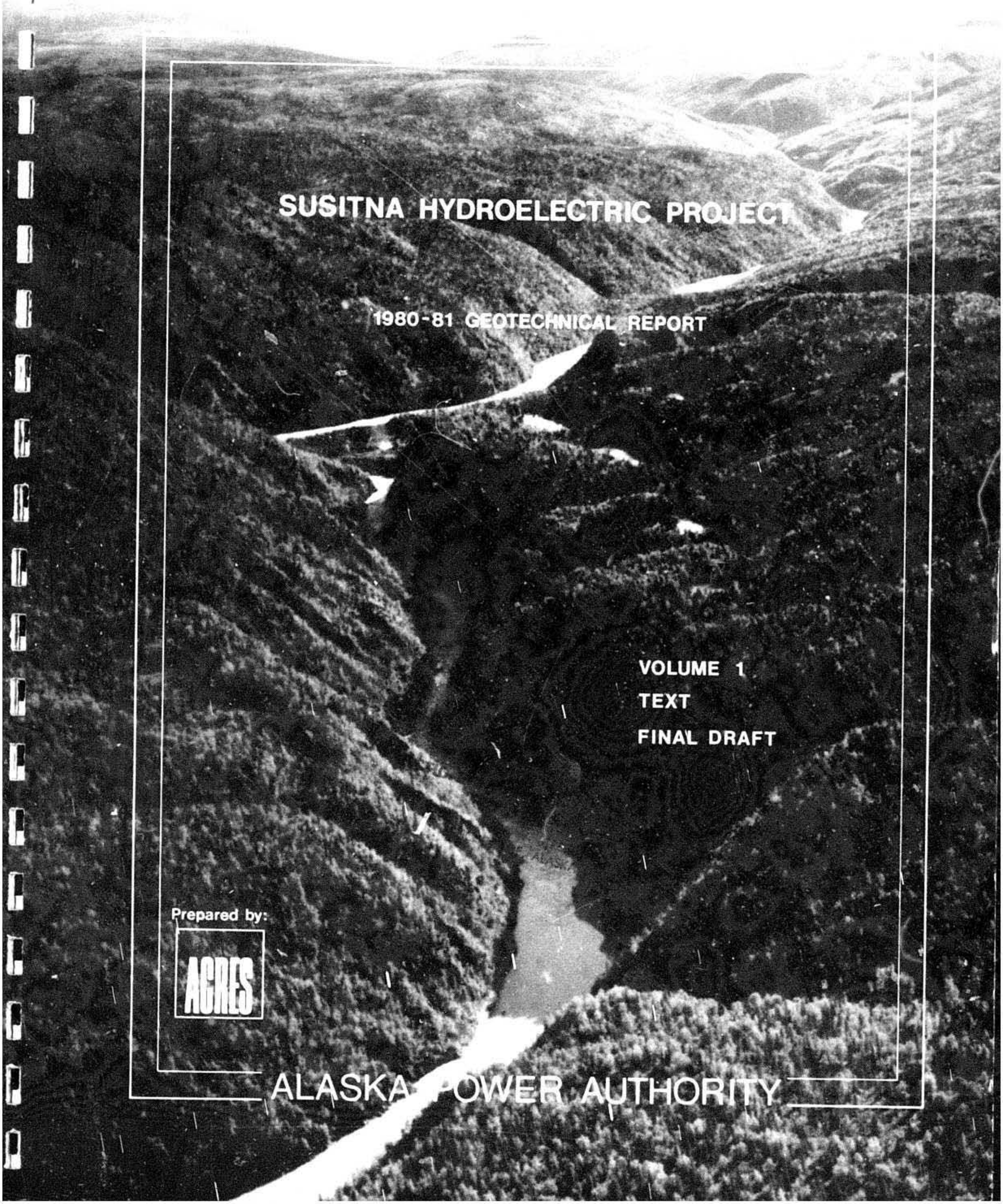

SUSITNA HYDROELECTRIC PROJECT

1980-81 GEOTECHNICAL REPORT

VOLUME 1

TEXT

FINAL DRAFT

Prepared by:

ACRES

ALASKA POWER AUTHORITY

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TABLE OF CONTENTS - VOLUME 1

LIST OF TABLES
LIST OF FIGURES

		Page
1 -	INTRODUCTION	1-1
	1.1 - General	1-1
	1.2 - Project Description and Location	1-1
	1.3 - Plan of Study	1-2
	1.4 - Report Contents	1-4
	1.5 - Acknowledgements	1-5
2 -	SUMMARY AND CONCLUSIONS	2-1
	2.1 - Introduction	2-1
	2.2 - Watana Site	2-1
	2.3 - Devil Canyon Site	2-4
3 -	REVIEW OF PREVIOUS INVESTIGATIONS	3-1
	3.1 - Introduction	3-1
	3.2 - Watana	3-1
	3.3 - Devil Canyon	3-2
	3.4 - Conclusions	3-3
4 -	REGIONAL GEOLOGY	4-1
	4.1 - Introduction	4-1
	4.2 - Stratigraphy	4-1
	4.3 - Tectonic History	4-2
	4.4 - Glacial History	4-2
5 -	SCOPE OF GEOTECHNICAL INVESTIGATION	5-1
	5.1 - Introduction	5-1
	5.2 - Geologic Mapping	5-1
	5.3 - Subsurface Investigation	5-4
	5.4 - Seismic Refraction Surveys	5-6
	5.5 - Borrow Investigation	5-7
	5.6 - Laboratory Testing	5-8
6 -	RESULTS OF GEOTECHNICAL INVESTIGATIONS - WATANA	6-1
	6.1 - Watana Damsite	6-1
	6.2 - Relict Channel	6-1
	6.3 - Borrow and Quarry Material	6-32
7 -	RESULTS OF GEOTECHNCIAL INVESTIGATIONS - DEVIL CANYON	7-1
	7.1 - Devil Canyon Damsite	7-1
	7.2 - Borrow and Quarry Material	7-27

REFERENCES
GLOSSARY

ACRES

ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
1980-81 GEOTECHNICAL REPORT

TABLE OF CONTENTS - VOLUME 2

APPENDIX A - Selected Bibliography of Previous Investigations

APPENDIX B - Watana Diamond Core Drilling Logs

APPENDIX C - Devil Canyon Diamond Core Drilling Logs

APPENDIX D - Watana Water Pressure Testing Details

APPENDIX E - Devil Canyon Water Pressure Testing Details

APPENDIX F - Watana Borrow Site Investigation
- F.1 - Borrow Site D
- F.2 - Borrow Site E
- F.3 - Borrow Site H
- F.4 - Borrow Sites I & J

APPENDIX G - Devil Canyon Borrow Site Investigation
- G.1 - Borrow Site G

APPENDIX H - Seismic Refraction Survey - 1980

APPENDIX I - Seismic Refraction Survey - 1981

APPENDIX J - Airphoto Interpretation

APPENDIX K - Reservoir Slope Stability

LIST OF TABLES

Table No.	Title
3.1	Summary of Previous Investigations - Watana Damsite
3.2	Summary of Previous Investigations - Borrow Site D - Watana
3.3	Summary of Previous Investigations - Borrow Sites E, F, and C - Watana
3.4	Summary of Previous Investigations - Devil Canyon Damsite
3.5	Summary of Previous Investigations - Borrow Site G - Devil Canyon
4.1	Geologic Time Scale
5.1	Summary of the 1980-81 Investigation - Watana Damsite
5.2	Summary of the 1980-81 Investigation - Devil Canyon Damsite
5.3	Summary of the 1980-81 Seismic Refraction Line Data
5.4	Summary of 1980-81 Investigation - Borrow Site D - Watana
5.5	Summary of 1980-81 Investigation - Borrow Site E - Watana
5.6	Summary of 1980-81 Investigation - Borrow Site G - Devil Canyon
5.7	Summary of 1980-81 Investigation - Borrow Site H - Watana
5.8	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	Watana Seismic Velocity Correlations
6.2	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	Quaternary Stratigraphy of Buried Channel Area
6.8	Material Properties - Borrow Site D
6.9	Gradation Results - Borrow Site D
6.10	Material Properties - Borrow Site E
6.11	Material Properties - Borrow Site H
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	Material Properties - Borrow Site G

ACRES

LIST OF FIGURES

Figure No.	Title
1.1	General Location Map
1.2	Watana General Arrangement
1.3	Devil Canyon General Arrangement
4.1	Regional Geology Map
5.1a	Watana: Damsite Vicinity Exploration Map
5.1b	Watana: Exploration Map
5.2	Devil Canyon Exploration Map
5.3	Borehole Typical Instrumentation
5.4	Borehole Typical Instrumentation
6.1	Watana Index Map
6.2	Watana Top of Bedrock and Surficial Geologic Map
6.3	Watana Geologic Map
6.4	Watana Geologic Section W-1
6.5	Watana Geologic Section W-2
6.6	Watana Geologic Section W-3
6.7	Watana Geologic Section W-4
6.8	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	Watana Composite Joint Plots
6.14	Watana Typical Shear
6.15	Watana Shear/Alteration Zone
6.16	Watana "The Fins"
6.17	Watana Geologic Features GF4A, GF4B, and GF5
6.18	Watana Geologic Features Downstream of Centerline
6.19	Watana "Fingerbuster" Area North Bank
6.20	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	Watana Thermistor Data
6.28	Watana Thermistor Data - Relict Channel
6.29	Watana Thermistor Data - Borrow Site H and Borrow Site D
6.30	Watana Relict Channel Photos
6.31	Watana Relict Channel Section
6.32	Watana Relict Channel and Borrow Site D/Stratigraphic Fence Diagram Sheets
6.33	Watana Relict Channel - Expanded Thalweg Section
6.34	Watana Relict channel Profiles

LIST OF FIGURES (Cont'd)

Figure No.	Title
6.35	Relict Channel - Top of Bedrock
6.36	Watana Quarry and 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	Borrow Site D - Plan
6.41	Watana Borrow Site D - Range of Gradations
6.42	Watana Borrow Site D - Material Gradation Types
6.43	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	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
7.11	Devil Canyon Typical Argillite/Graywacke
7.12	Devil Canyon Aerial View of Site
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	Thermistor Plots - Damsite
7.22	Borrow Site G - Plan
7.23	Borrow Site G - Sections

LIST OF FIGURES (Cont'd)

Figure No.	Title
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 - 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 feasibility studies for hydroelectric development 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;
- 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 project locations at Watana and Devil Canyon. The purpose of this report is to present a detailed description of the geologic and geotechnical conditions at these sites.

1.2 - Project Description and Location

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

The scheme calls for a large embankment dam with an underground powerhouse at Watana and a high concrete dam with underground powerhouse at the Devil Canyon site. General site arrangements are shown in Figures 1.2 and 1.3.

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 U-shaped valleys which include the proposed damsites, winding through the Talkeetna Mountains until it emerges into a broad glacial 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 a 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 is located on the Susitna River 14 miles upstream from the Alaskan Railroad, 140 miles north of Anchorage, and 160 miles south of Fairbanks. The site is located at approximate river mile 152 (32 river miles downstream from the Watana site). At the Devil Canyon site, the river enters a very narrow "V"-shaped gorge about two miles in length with steep walls up to 600 feet high. The damsite is several hundred feet downstream from the entrance of Devil Canyon. The valley is generally asymmetrical in shape, with the north abutment sloping at about 45° and the south abutment steeper, about 70°. The south abutment displays overhanging cliffs and detached blocks of rock. The north abutment is somewhat less rugged in the upper half, the lower portion is very steep. Access at river level is very limited, but narrow benches are accessible at low water levels. The Susitna River in Devil Canyon is approximately 150 feet wide and very turbulent. The canyon itself is approximately 1,000 feet wide at the proposed dam crest elevation.

1.3 - Plan of Study

(a) Objectives

The objectives of the Task 5 studies 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

The task was subdivided into a series of subtasks to meet the overall objectives. The subtasks and their corresponding objectives were:

Subtask	Objectives
5.01 - Data Collection and Review	To collect and review all existing geological and geotechnical data pertaining to the project including the access road and transmission line corridors and the upper Susitna River basin.
5.02 - Airphoto Interpretation	Perform airphoto interpretation and terrain analysis of the Watana and Devil Canyon damsite area, reservoir areas, borrow sites and access road, and transmission line corridors, and identify adverse geological features and geotechnical conditions that could significantly affect the design and construction of project structures.
5.03 - Exploratory Program Design (1980)	Design the geotechnical exploratory investigation programs for 1980 for Watana and Devil Canyon damsites, dam construction materials, and reservoir areas, and along the access road route.
5.04 - Exploratory Program (1980)	Perform initial surface and subsurface program investigations at Watana and Devil Canyon sites and reservoir areas and access road routes to establish general and specific geological and foundation conditions.
5.05 - Exploratory Program Design (1981)	Design the geotechnical exploratory investigation program for 1981 for Watana and Devil Canyon damsites, dam construction materials and reservoir areas, and for the selected access road and transmission line routes.
5.06 - Exploratory Program (1981)	Complete surface and subsurface investigations at Watana and Devil Canyon damsites, reservoir areas, access roads, and transmission line routes to the extent necessary to provide adequate data to confirm project feasibility and for submission of FERC license application, currently scheduled for September 1982.

5.07 - Exploratory Program Design (1982-1984)	Design of the geotechnical exploratory investigation program for 1982 to 1984 to obtain basic design data for Watana damsite, dam construction materials, and reservoir areas, and for the selected access road and transmission line routes.
5.08 - Data Compilation	Assemble all geotechnical exploratory data into documents suitable for inclusion in relevant project reports and licensing documentation.

(c) Approach

To meet the objectives of the task in an orderly and timely manner, the geotechnical exploratory programs were divided into three stages: the 1980 activities, the 1981 activities, and the activities during and after 1982 (after the FERC license application is submitted). The 1980 geotechnical activities were planned to identify and investigate in limited detail, those geological and geotechnical conditions which had been identified by previous studies that may have an effect on the feasibility of the project. These activities included Subtasks 5.01 through 5.04.

Subtasks 5.05 through 5.08 were undertaken during 1981 and early 1982, respectively. Under these activities, a more detailed study was made of those geological and geotechnical conditions identified during the 1980 studies as warranting further investigation. The 1981 program also included the investigation for the access roads and the transmission lines. These data were subsequently inputs into other task activities for final presentation.

It should be noted that the findings and conclusions presented in this report are based on a limited scope of geotechnical investigation and that more detailed investigations will be undertaken in the subsequent phases of the project.

1.4 - Report Contents

This Geotechnical Report is presented in seven sections. A summary and preliminary conclusions of the studies are presented in Section 2, a review of previous work undertaken by the COE, USBR, and others is presented in Section 3; a preliminary assessment of regional geology is in Section 4; the scope of the 1980-81 geotechnical exploration program is presented in Section 5, and the results of the study in Sections 6 and 7. A comprehensive bibliography of geotechnical information for the site area was compiled during Subtask 5.01 and is presented in Appendix A. Detailed results of drilling, testing, seismic refraction surveys, airphoto interpretation and reservoir mapping performed during the project are included in Appendices B through K. Engineering significance and application of the data developed in Task 5 and presented in this report have been addressed in the Susitna Feasibility Report (1). This study, therefore, stands as a referenced document to that report.

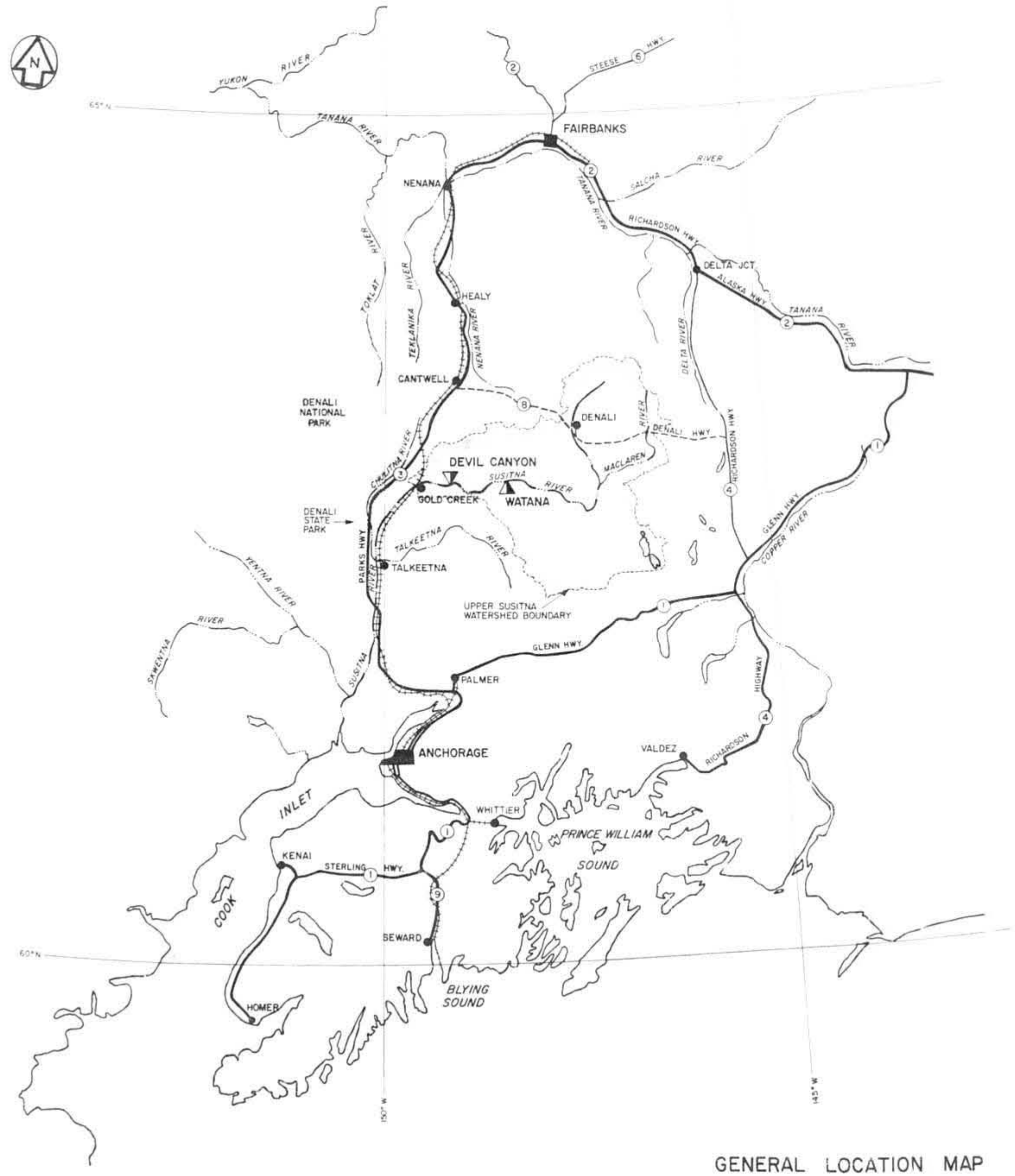
1.5 - Acknowledgements

Some material presented in this report has been obtained from reports previously published by the USBR and others. The cooperation of the COE in providing access to records and data and opinions on interpretation is gratefully acknowledged.

Drilling at the sites was performed by The Drilling Company (TDC) and Interstate Exploration, Inc., under the direct supervision and direction of Acres staff and R&M Consultants, Anchorage, Alaska. Seismic refraction surveys were performed by Woodward-Clyde Consultants. Inhole geophysical logging work was by EDCON (Exploration Data Consultants, Inc., of Denver, Colorado). Airphoto interpretation was done by R&M Consultants, and laboratory testing by R&M and Acres.

Logistical support during field activities was provided by KNIK/ADC - Joint Venture under its subcontract with Cook Inlet Region, Inc./Holmes & Narver, Inc., and Acres for camp accommodations, and by Akland Helicopters, ERA Helicopters, Air Logistics, Inc., also under subcontract with Acres, for personnel and equipment transportation requirements.

The results of these activities were presented to the Acres External Review Panel (Dr. R. Peck, Dr. S. Hendron, Mr. M. Copen), to the Power Authority, and to the Power Authority Review Board Members (Dr. H. Seed and Dr. A. Merritt) during technical meetings and discussions. Acres is very grateful for their critical and very objective review of the information. Thanks are due to Mr. L. A. Rivard for his contributions to Subtask 5.02 - Airphoto Interpretation.



KEY MAP

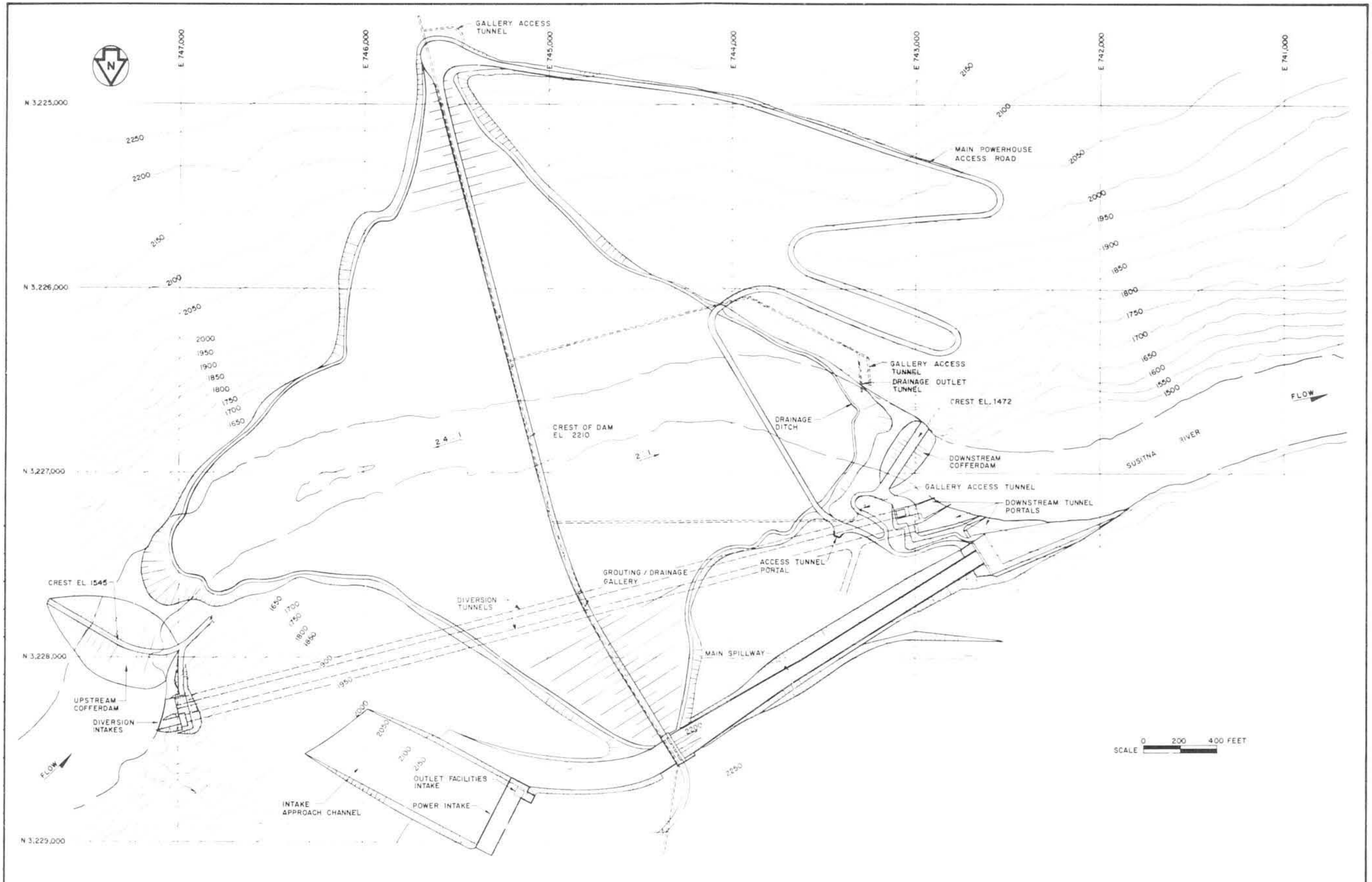
LEGEND

- PRIMARY PAVED UNDIVIDED HIGHWAY
- SECONDARY PAVED UNDIVIDED HIGHWAY
- SECONDARY GRAVEL HIGHWAY
- RAILROAD
- RIVER

SCALE 0 20 40 MILES

GENERAL LOCATION MAP

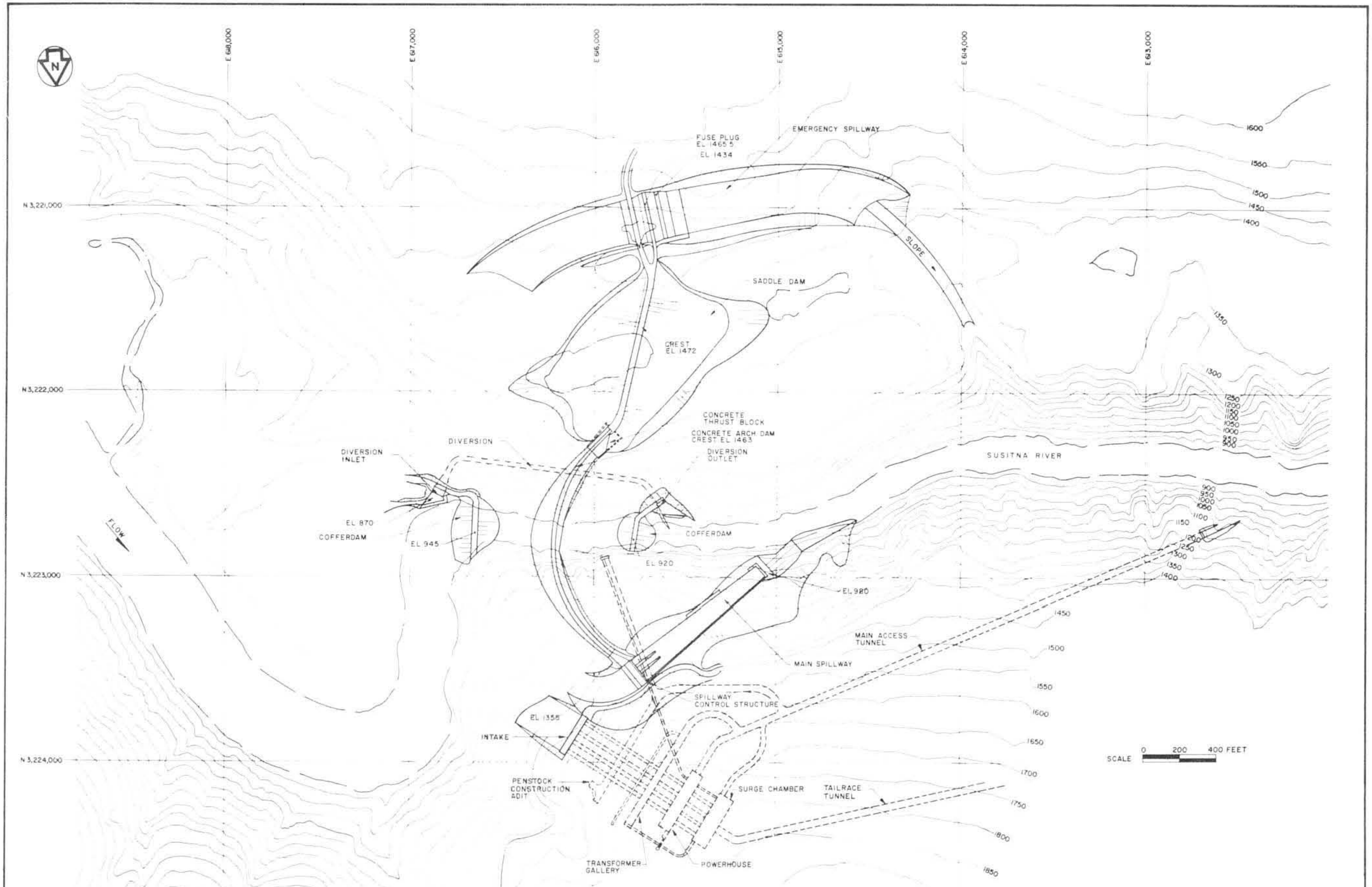
FIGURE 1.1



WATANA
GENERAL ARRANGEMENT

ACRES

FIGURE 1.2



DEVIL CANYON
GENERAL ARRANGEMENT

ACRES

FIGURE 1.3

2 - SUMMARY AND CONCLUSIONS

2.1 - Introduction

The following subsections present the main findings and conclusions of the 1980-81 geotechnical study for the Watana and Devil Canyon sites.

2.2 - Watana Site

(a) Results of Study

- Bedrock at the damsite is a large granitic pluton consisting of a quartz diorite, diorite and granodiorite. An andesite porphyry, an extrusive volcanic rock, is exposed immediately downstream from the damsite.

- Where mapped and drilled, the contact between the diorite and andesite is generally a highly fractured, weathered, poor quality rock. The contact zone ranges from 2 to 15 feet, but is generally less than 10 feet.

- Two major and two minor joint sets were mapped at the damsite. These are in the order of most to least pronounced: (a) strike 320°, dip near vertical; (b) strike 045°-080°, dip near vertical; (c) strike 340°-030°, with dips between 40° east to 65° west; and (d) strike 080° with low angles of dip.

- Two pronounced sheared and highly fractured zones named "The Fins" and "Fingerbuster" have been mapped immediately upstream and downstream from the damsite.

- Small localized fractured, sheared, and altered zones have been mapped within the damsite. These zones average up to 10 feet wide. No evidence of recent faulting was found.

- A large altered and sheared zone up to 300 feet wide was mapped on the upper left abutment of the main dam.

- The riverbed is filled with alluvium consisting of gravels, cobbles, and boulders in a matrix of sand and silty sand ranging from 40 to 80 feet, and may exceed 100 feet in depth in places.

- Overburden thickness at the damsite is generally shallow ranging from 50 to 60 feet on the upper abutment to 0 on the steeper rock slopes. Overburden generally consists of glacially derived silts, sands, and boulders and talus.

- Rock quality at the damsite is good to excellent with average rock quality designations (RQDs) ranging from 75 to 90 percent. Below the upper 20 to 40 feet of weathered rock, rock quality tends to improve.

- Rock strengths are high with an average unconfined compressive strength greater than 20,000 psi.

- The rock mass has, in general, a low permeability with an average of 10^{-6} cm/sec below the weathered zones. Higher permeabilities are found in the more highly fractured and sheared zones.

- Groundwater at the damsite is a subdued replica of the topography. Groundwater table on the right abutment is deep, on the average of 110 to 280 feet. Groundwater conditions on the left abutment are complicated by the apparent deep and continuous permafrost. A perched groundwater table exists on top of the permafrost. Artesian conditions were encountered at depth on this abutment within the thick alteration zone beneath the permafrost.

- Permafrost appears to be continuous in the bedrock throughout the left abutment, reaching a depth of 200 to 300 feet. Although no permafrost was encountered on the right abutment, localized sporadic permafrost may be present.

- A relict channel exists on the right abutment extending from Deadman Creek to Tsusena Creek. The thalweg reaches Elevation 1,800 (400 feet below maximum pool elevation). The width of the relict channel at the upstream face is about 15,000 feet. Investigations in and adjacent to the channel show that it is filled with a sequence of alluvial materials overlain by a sequence of glaciofluvial silts, sands and clays. The average hydraulic gradient through the channel at maximum reservoir level is estimated to be approximately 10 percent. The permeabilities within the channel are variable with high permeabilities in the coarser bouldery strata and lower permeabilities in the river silts, clays, and lacustrine deposits. Perched water tables, aquicludes and localized permafrost exist throughout the channel.

- Bedrock surface drops below the maximum pool elevation on the left bank approximately 2 miles upstream from the damsite in the area of Fog Lakes. Based on seismic velocity measurements, bedrock was estimaed to be below reservoir level over a distance of approximately 9,500 feet. The nearest drainage from this area is Fog Creek, a distance of 5 miles southwest from the reservoir.

- The riverbed is filled with alluvium consisting of gravels, cobbles, and boulders in a matrix of sand and silty sand ranging from 40 to 80 feet, and may exceed 100 feet in depth in places.

- Ten potential borrow and quarry sites were identified for potential construction material. Several of these sites, which had been delineated in previous studies, were eliminated from further consideration because of lengthy haul distances, more locally available material, or insufficient volume. Those sites considered as primary borrow and quarry sources are:

  . Rock fill - Quarry Site A;
  . Impervious and semi-pervious material - Borrow Sites D and H;
  . Pervious material - Borrow Sites E and I; and
  . Construction gravel and fill - Borrow Site F.

- Areas of existing and potential slope instability and erosion, as well as areas of permafrost were delineated within the Watana reservoir.

(b) Conclusions

Based on these findings, 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.

- The significant geologic features "The Fins" and "Fingerbuster" are considered unsuitable rock for construction of surface and underground facilities and should be avoided if at all possible.

- Subsurface exploration at the damsite shows that rock quality on the right abutment is suitable for the construction of large underground facilities. Localized sheared, fractured, and altered zones are likely to be encountered during underground excavation; however, it is considered that these features are of limited extent and could be handled by conventional construction procedures.

- There is an altered and fractured zone on the left abutment downstream from the main dam. Any structure sited on this zone would incur high costs for excavation and treatment.

- Although localized zones of sheared and fractured rock were encountered in all borings, no evidence of major faulting was found in either the riverbed or within the damsite area.

- Further investigations of the material within the relict channel will be required to accurately define its properties, stratigraphy, permeability, and extent of permafrost for the purpose of assessing potential reservoir seepage and behavior under earthquake conditions.

- Suitable types and adequate amounts of borrow and quarry material were found near the damsite.

- Although local slumps and landslides will probably occur in many areas of the reservoir, there appear to be no potentially large landslides which might pose a threat to the dam.

2.3 - Devil Canyon

(a) Results of Study

The following geologic and geotechnical conditions have been identified at the Devil Canyon site:

- The proposed damsite is underlain by a metamorphic argillite and graywacke rock.

- The bedrock has been intruded by a series of mafic and felsic dikes which crosscut the damsite. The contacts of the dikes with the host rock are welded with some secondary localized shearing or fracturing occurring at or near the contact.

- Two major and two minor joint sets have been mapped in the damsite area. These are, in the order of most to least pronounced: (a) strike 340°, dip near vertical; (b) strike 020° to 100°, dip from 55° southeast to 75° north; (c) strike 060° to 080°, dip to northwest; and (d) strike northeast to east with low angle dips. Average joint spacing for the most prominent set is 1.5 to 2 feet.

- Localized sheared and fractured zones ranging from 1 to 3 feet wide have been mapped at the damsite.

- A highly sheared and fractured zone was found to parallel the river beneath the proposed saddle dam on the left abutment. A boring through this feature encountered breccia and gouge up to 3 feet wide. The east-west extent of this feature could not be accurately determined; however, based on surface topography, it is estimated to be no greater than 1,500 feet long.

- Stress relief joints were mapped up to 100 feet back from the damsite gorge walls on the left abutment.

- A marked drop off in bedrock elevation was noted in previous investigations along the eastern portion of Borrow Site G approximately 1,000 feet upstream from the damsite. Land access restrictions imposed during this study prohibited any further investigation at this feature. Work, however, performed in proximity to this area showed no compelling evidence for this feature to be a fault.

- Minor fractures and shear zones were encountered in several of the boreholes in the river; however, these were limited in extent and could not be correlated between borings. No indication was found of faulting beneath the river or of recent faulting anywhere at the damsite.

- Rock quality at the damsite was good to excellent with an overall RQD greater than 80 percent.

- Rock strengths are high, averaging approximately 20,000 psi.

- Rock permeabilities are low, ranging from 1×10^{-4} to 1×10^{-6} cm/sec with the lower permeabilities occurring in the more highly fractured and sheared zones.

- Based on preliminary data, groundwater levels appear to be variable across the site, principally controlled by the degree of fracturing within the rock mass. Readings in boreholes and piezometers show water levels range from near surface above the break in slope to as deep as 120 feet on the north abutment.

- No permafrost was found in the main damsite area.

- Borrow Site G, located approximately 1,000 feet upstream from the damsite, has been identified as the principal source for concrete aggregate and fill material. Quarry Site K, located on the left bank downstream from the damsite, has been identified as the principal source for rockfill; and Borrow Site D, adjacent to the Watana site, has been identified as the principal source for impervious and semi-pervious material.

(b) Conclusions

Based on these findings, the following conclusions have been made regarding the Devil Canyon site:

- No geologic or geotechnical conditions were found at the Devil Canyon damsite that would adversely affect feasibility for the construction of a concrete arch dam.

- Rock quality was considered suitable for the construction of underground power facilities, including a powerhouse and related structures.

- Localized sheared and fractured rock is likely to be encountered during underground excavation; it is considered that these features are of limited extent and could be handled by conventional construction procedures.

- Suitable types and quantities of borrow material have been identified for this study for dam construction.

- The abrupt drop-off in bedrock east of the damsite beneath Borrow Site G, as well as the shear and fracture zones beneath the saddle dams, will require additional investigation in subsequent phases of study. However, these features are not expected to have an impact on site feasibility.

- Although no permafrost was found during explorations, sporadic permafrost may exist at the site.

- There are no known areas that could result in significant leakage or slope instability in the reservoir.

3 - REVIEW OF PREVIOUS INVESTIGATIONS

3.1 - Introduction

The development of the Susitna Hydroelectric Project has been studied by several federal and private agencies in the last 30 years. However, it was not until the late 1950s that any geotechnical investigations were conducted.

Between June 1957 and August 1958, the USBR performed geologic mapping and drilling investigations at the Devil Canyon site and limited geologic mapping at the Watana site (51).

Subsequently, during the 1970s, the COE performed additional investigations at both sites. These included seismic refraction surveys at Devil Canyon, and detailed geologic mapping, seismic refraction survey, diamond and auger drilling, and material testing at the damsite and potential borrow sites at Watana.

This report briefly discusses the findings of these investigations as documented by the USBR and COE. These reports, which are identified in the bibliography (Appendix A), are available from the Power Authority and Acres for reference.

3.2 - Watana

The preliminary reconnaissance work by the USBR in the 1950s was expanded during the 1970s by the COE investigations of the damsite, reservoir, and potential borrow sites. The location and extent of the investigations in the main dam area are shown in Figure 5.1. Detailed investigations in the borrow sites are presented in Section 6.3.

In 1975, a total of 22,500 linear feet of seismic refraction surveys was performed by Dames & Moore (12) for the COE in their initial feasibility report. This was expanded by Shannon & Wilson (39) in 1978 with an additional 47,665 feet of survey. This work served to support the results of the drilling and mapping programs (Figure 5.1).

During the 1978 season, the site was explored with 28 diamond and rotary drill holes (both vertical and inclined) ranging from 30 to 600 feet in length (Table 3.1). Six of the diamond drill holes were located in the river bottom and reached a maximum of 520 feet into rock. Five borings were drilled on the left abutment and six on the right, reaching a maximum depth of 300 feet or an elevation of 1560. On the right bank, eleven boreholes were located in what was identified as a deep, relict channel to determine the thickness and characteristics of the overburden, the depth of the water table, and the permafrost conditions. These boreholes were also designed to obtain samples of potential borrow materials and to evaluate bedrock depth to control spillway location.

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A total of six potential quarry and borrow sites were identified for construction material. Of these, four borrow sites were explored with 27 backhoed test pits and 24 auger borings (Tables 3.2 to 3.3). These areas included Borrow Site D on the right abutment, Borrow Site E located approximately 15,000 feet downstream from the dam, and Borrow Site F located on Tsusena Creek three miles upstream from its confluence with the Susitna River (Section 6.3).

Geologic mapping was conducted in the damsite area to delineate major structural features.

A limited laboratory testing program was conducted on potential borrow material from the various borrow sites to establish the indexes and engineering characteristics of the borrow materials. These tests included determination of grain size distribution, permeability, triaxial shear tests, Modified Proctor compaction tests, concrete aggregate tests, and petrographic analyses (46,48).

The COE also installed a series of ten open-well piezometers and thirteen temperature-logging casings in boreholes.

3.3 - Devil Canyon

The bulk of the previous geotechnical investigation for Devil Canyon was performed by the USBR between June 1957 and August 1958 (51) as shown in Figures 5.2 and 7.22. A total of 21 diamond drill borings were drilled in the damsite area. Six holes, drilled to depth of 50 to 110 feet were located on the left abutment. Four holes were drilled near the dam axis on the upper abutment to a maximum depth of 150 feet. The remaining 12 boreholes were drilled along the riverbed (Table 3.4).

Fourteen test pits were dug in the alluvial fan and terrace deposits immediately upstream from the dam axis (Table 3.5).

Four rock benches were excavated on the dam abutments to define rock conditions.

Laboratory tests, including gradation determinations and petrographic analysis, were conducted on samples of the borrow site materials to determine their suitability for use as concrete aggregate. Representative rock samples from the abutments were examined petrographically to determine mineralogy and tested to determine compressive strength, elasticity, absorption, and porosity of the foundation material.

During 1978, Shannon & Wilson (39), under COE contract, ran three seismic refraction lines totalling 3,300 feet in the borrow site and along the proposed saddle dam to expand the drilling information (Figures 5.2 and 7.22). This survey, along with sampling of the alluvial fan material, was the only work COE performed at the site during their 1978-1979 investigation.

3.4 - Conclusions

The investigations conducted by the COE and USBR were the first detailed efforts to establish the feasibility of the project. A brief summary of their investigation is stated below:

(a) Watana

Based on the COE work, the Watana site was found suitable for an earthfilled dam. The following is a brief summary of the COE's findings and conclusions relative to the site geotechnical conditions:

(1) The river valley is filled with alluvium consisting of gravels, cobbles, and boulders in a matrix of sand or silty sand ranging in depth from 40 to 80 feet thick, and may be exceeding 100 feet in places. Overburden on the valley slopes ranges from 0 to 60 feet thick with an average of 10 to 20 feet.

(2) Underlying bedrock is fresh, hard-to-very hard diorite, granodiorite, and quartz diorite with local andesite porphyry dikes and more widely scattered minor felsite dikes.

(3) Fractures are closely spaced on the surface becoming more widely spaced with depth. Deep fractures are generally healed.

(4) The prominent jointing and shearing direction is northwest trending with steep dips. Many fractures have thin clay gouge seams and slickensides.

(5) No major fault or significant change in material was found beneath the river.

(6) Andesite porphyry, an extrusive rock, was mapped slightly downstream from the damsite on the left abutment. The contact between this rock and the diorite was not defined.

(7) Two prominent shear zones named "The Fins" and "Fingerbuster" were mapped as exposures in the damsite area. Both of these zones trend northwest with strikes from 300° to 320° and dip between 70° to 90° southwest and northeast.

(8) A relict channel was found on the right abutment upstream from the damsite. Material in the channel consists of a mixture of glacial tills, glaciofluvial and lacustrine deposits, reaching a depth greater than 450 feet deep at its deepest known point.

(9) Deep permafrost was found on the left abutment.

(10) Permafrost in the relict channel, although found within one foot of the surface, is expected to be confined to a relatively shallow layer.

(11) Geology within the reservoir is complex and consists of variable thicknesses of surficial tills; glaciofluvial outwash; lacustrine material; and alluvium overlying igneous and metamorphic rocks, schists, volcanics, and granites.

(12) Potentially suitable borrow material was found near the dam site. Material from Borrow Site D on the right abutment was classified as semi-pervious to impervious core material. Material from Borrow Site E from the alluvial deposit downstream from the dam axis was identified as a potential source for clean aggregate and filter material.

(13) Two potential quarry sites were identified as sources of rockfill, riprap, and coarse filter materials. The rock in both sites was classified as diorite and of good quality.

(b) Devil Canyon

The previous investigations suggested that the Devil Canyon site would be feasible for the construction of a high concrete gravity or thin arch dam with an underground powerhouse. A brief summary of the geotechnical conditions found by the USBR and COE are highlighted below.

(1) Bedrock at the site is an argillite with occasional beds of graywacke. The rock is hard and brittle and contains numerous quartz stringers.

(2) Stratigraphy strikes approximately east-west with a dip of 45° to 75° south. Three joint sets were defined with the master set striking approximately 335° and dipping from 75° east to vertical. Joint spacing ranges about 4 to 5 feet apart.

(3) Several well-developed shears or fault zones occur on both sides of the river and strike generally 335° and dip 80° northeast to vertical.

(4) No permafrost was found at the damsite.

(5) Shearing was found both normal and parallel to the canyon rim on the south abutment.

(6) Large detached blocks of rock up to 25 feet by 50 feet were observed on the left abutment.

(7) A deep, buried channel was found striking approximately east-west beneath the lake-filled depression on the south abutment. This depression may be underlain by a fault or shear zone.

(8) River alluvium and water depth appears to be approximately 85 feet deep at the site.

(9) No faulting was found beneath the river.

(10) Rock conditions were considered suitable for underground excavations.

(11) The alluvial fan upstream from the site was found to contain acceptable borrow material for concrete aggregate.

(12) Seismic refraction shows an unexplained steep slope of the bedrock surface beneath the alluvial fan. This drop-off occurs over a horizontal distance of approximately 500 feet. This depth to bedrock increases (from west to east) from 100 feet to 350 feet.

TABLE 3.1: SUMMARY OF PREVIOUS INVESTIGATIONS - WATANA DAMSITE

Hole Number	Surface Elevation	Dip (°)	Azimuth (°)	Total Depth (ft) (Downhole)	Depth to Bedrock (ft) (Downhole)	Date Drilled	Thermistor		Piezometer		
							Type	Reading Dates	Type	Reading Dates	Water Level (Vertical)(ft)
DH-1	1458.6	0	--	122.8	43.8	3/28/78					
DH-2	1461.4	0	--	29.0	--	3/23/78					
DH-3	1458.5	0	--	174.5	77.6	4/3/78					
DH-4	1462.4	0	--	122.9	77.7	4/17/78					
DH-5	1462.3	0	--	176.9	59.6	4/18/78					
DH-6	1715.5	0	--	149.5	3.5	4/28/78					
DH-7	1716.0	59	210	122.2	8.5	5/6/78					
DH-8	1910.3	0	--	150.0	16.2	5/21/78					
DH-9	1913.0	45	043	283.8	5.6	5/30/78					
DH-10	2033.2	0	--	203.5	19.6	5/8/78					
DH-11	2033.6	45	032	300.0	22.7	5/22/78					
DH-12	1950.9	0	--	301.1	9.5	6/11/78	T	7/11/78 8/10/78 7/30/80			
DH-21	1478.3	57.6	003.9	603.7	84.5	7/3/78	T	11/29/78			
DH-23	1951.5	45	220.3	119.2	7.0	7/7/78	T	7/30/78 8/10/78 8/23/78 10/26/78 11/29/78			
DH-24	2061.4	0	--	139.9	6.9	7/25/78	T	8/10/78 8/23/78 8/26/78 11/30/78 7/30/80 12/16/81			
DH-25	2044.9	44	047	79.9	--	8/8/78	T	7/30/80			
DH-28	1971.0	0	--	125.2	9.2	8/17/78	T	10/26/78 11/29/78			

DH = Drill hole
T = Thermistor probe - fluid-filled standpipe

References (45) and (47)

TABLE 3.2: SUMMARY OF PREVIOUS INVESTIGATIONS - BORROW SITE D - WATANA

Hole Number	Surface Elevation	Total Depth (ft) (Downhole)	Depth to Bedrock (ft) (Downhole)	Date Drilled	Thermistor		Piezometer		
					Type	Reading Dates	Type	Reading Dates	Water Level (ft) (Vertical Depth)
AP1	2201.6	15.0	--	6/15/78			SP	1978 2/4/78	0.0 - 2.0 4.2 0.0
AP2	2199.0	11.0	--	6/20/78			SP	1978 2/4/82	Frozen at 1.2
AP3	2280.2	18.0	--	6/20/78					
AP4	2140.0	3.5	--	6/21/78					
AP5	2201.4	27.5	--	6/21/78					
AP6	2213.6	27.0	--	6/21/78					
AP7	2279.1	7.0	--	6/21/78					
AP8	2245.7	58.3	--	6/23/78	T	1978 12/16/81			
AP9	2295.8	18.0	--	6/23/78	T	1978 12/16/81			
AP10	2332.0	15.0	--	6/23/78					
AP11	2308.9	25.0	--	6/28/78					
AP12	2302.9	14.1	--	6/28/78					
AP13	2305.8	22.0	--	6/28/78					
AP14	2306.7	11.0	--	6/28/78					
AP15	2307.7	9.5	--	6/28/78					
AP16	2313.5	3.5	--	6/13/78					
AP17	2408.1	12.5	--	6/13/78					
AP18	2372.4	16.0	--	6/13/78					
AP19	2375.1	19.3	--	6/13/78					
AP20	2353.5	17.0	--	6/15/78					
AP21	2339.8	19.3	--	6/15/78					
AP22	2307.1	13.4	--	6/13/78					
AP23	2267.5	9.5	--	6/15/78					
AP24	2265.9	15.0	--	6/15/78					
TP8	2292.0	7.0	--	8/16/78					
TP9	2343.0	10.0	--	8/15/78					
TP10	2326.0	10.6	--	8/21/78					
TP11	2270.0	8.2	--	8/18/78					
TP12	2334.0	13.5	--	8/21/78					
TP13	2330.0	10.0	--	8/22/78					
TP14	2286.0	3.0	--	8/17/78					
TP15	2233.0	7.0	--	8/19/78					
TP16	2255.0	10.5	--	8/16/78					
TP17	2247.0	7.0	--	8/18/78					
TP18	2211.0	13.7	--	8/19/78					
TP19	2302.0	13.7	--	8/21/78					
TP20	2265.0	13.2	--	8/21/78					
TP21	2229.0	12.0	--	8/23/78					

TABLE 3.3: SUMMARY OF PREVIOUS INVESTIGATIONS - BORROW SITES E, F & C - WATANA

Hole Number	Surface Elevation	Total Depth (ft) (Downhole)	Depth to Bedrock (ft) (Downhole)	Date Excavated
Borrow Site E:				
TP1	1420.0	8.0	--	6/21/78
TP2	1415.0	9.2	--	6/24/78
TP3	1435.0	5.0	--	9/25/78
TP3A	1436.0	5.2	--	7/25/78
TP4	1442.0	9.2	--	7/26/78
TP5	1455.0	8.2	--	7/28/78
Borrow Site F:				
TP6	2110.0	5.7	--	6/29/78
TP22	2174.0	13.0	--	8/24/78
TP23	2160.0	14.0	--	8/25/78
TP24	2245.0	6.6	--	8/25/78
TP25	2190.0	7.4	--	8/25/78
TP26	2232.0	13.5	--	8/25/78
Borrow Site C:				
TP7	2390.0	4.0	--	6/23/78

TP = Test Pit

References (45) and (47)

TABLE 3.2 (Cont'd)

Hole Number	Surface Elevation	Total Depth (ft) (Downhole)	Depth to Bedrock (ft) (Downhole)	Date Drilled	Thermistor Type	Thermistor Reading Dates	Piezometer Type	Piezometer Reading Dates	Piezometer Water Level (ft) (Vertical Depth)
DR13	2321.4	84.0	--	4/17/78					
DR14	2339.6	75.0	--	4/25/78	T	12/16/71 1/4/82		1978	18.0 - 30.0
DR15	2294.0	316.5	286.0	4/27/78					
DR16	2099.4	91.5	67.0	5/31/78				1978	0.0 - 10.0
DR17	2167.0	35.7	9.0	6/6/78				1978 2/4/82	0.0 - 5.0 14.2
DR18	2172.0	248.3	231.0	6/9/78	T	7/30/80 12/16/81 2/4/82	SP	1978 2/4/82	4.0 - 20.0 38.4
DR19	2151.4	78.3	55.0	6/29/78	T	7/30/80 12/16/81 2/4/82	SP	1978 2/4/82	2.0 - 6.0 13.6
DR20	2207.3	252.6	210.0	5/17/78			SP	1978 2/4/82	27.0 - 40.0 72.7
DR22	2229.1	493.6	454.0	7/5/78	T	1978 7/30/80 12/16/81 2/4/82	SP	1978 2/4/82	195.0 - 200.0 213.0
DR26	2294.7	94.8	--	8/9/78	T	1978 12/15/81 2/4/82	SP	1978 2/4/82	0.0 - 13.0 23.7
DR27	2321.6	44.0	--	8/13/78					

AP = Auger probe
TP = Test pit
DR = Rotary drilled hole
SP - Standpipe

References (45) and (47)

TABLE 3.3: SUMMARY OF PREVIOUS INVESTIGATIONS - BORROW SITES E, F & C - WATANA

Hole Number	Surface Elevation	Total Depth (ft) (Downhole)	Depth to Bedrock (ft) (Downhole)	Date Excavated
Borrow Site E:				
TP1	1420.0	8.0	--	6/21/78
TP2	1415.0	9.2	--	6/24/78
TP3	1435.0	5.0	--	9/25/78
TP3A	1436.0	5.2	--	7/25/78
TP4	1442.0	9.2	--	7/26/78
TP5	1455.0	8.2	--	7/28/78
Borrow Site F:				
TP6	2110.0	5.7	--	6/29/78
TP22	2174.0	13.0	--	8/24/78
TP23	2160.0	14.0	--	8/25/78
TP24	2245.0	6.6	--	8/25/78
TP25	2190.0	7.4	--	8/25/78
TP26	2232.0	13.5	--	8/25/78
Borrow Site C:				
TP7	2390.0	4.0	--	6/23/78

TP = Test Pit

References (45) and (47)

TABLE 3.4: SUMMARY OF PREVIOUS INVESTIGATIONS - DEVIL CANYON DAMSITE

Hole Number	Surface Elevation	Dip (°)	Asimuth (°)	Total Depth (ft) (downhole)	Depth to Bedrock (ft) (Downhole)	Date Drilled
DAMSITE:						
DH-1	1419.7	45	157.5	117.3	0.0	6/4/57
DH-3	1381.1	0	--	Trenched	--	--
DH-4	1375.7	0	--	52.5	24.7	9/10/57
DH-5	1373.9	0	--	86.2	55.5	7/25/57
DH-6	1370.1	0	--	107.3	86.9	8/10/57
DH-7	1376.6	0	--	59.5	33.9	8/27/57
DH-8	1446.7	30	351	150.4	0.0	6/20/57
DH-9	1424.1	45	360	87.0	0.0	7/8/57
DH-10	1425.1	52	065	121.7	0.0	7/13/57
DH-11	893.5	42	355	30.5	0.0	7/30/57
DH-11A	893.5	45	355	29.1	0.0	8/4/57
DH-11B	893.5	51	355	33.9	0.0	8/8/57
DH-11C	892.7	57	355	150.1	0.0	8/13/57
DH-12	--	60	045	127.5	0.0	9/16/57
DH-12A	896.0	45	045	149.3	0.0	10/1/57
DH-13	912.3	45	162	137.0	0.0	7/22/57
DH-13A	912.0	37	162	80.7	0.0	8/2/58
DH-14	903.1	45	225	50.0	0.0	6/5/58
DH-14A	903.0	53	225	130.4	0.0	6/10/58
DH-14B	901.5	60	225	146.2	0.0	6/12/58
DH-14C	902.8	55	171	82.0	0.0	6/25/58
DH-15	1329.1	0	--	68.3	47.6	9/24/57
S1	1340.0	--	--	--	--	1958
S2	1230.0	--	--	--	--	1958
S3	1315.0	--	--	--	0.0	1958
S4	1060.0	--	--	--	0.0	1958

References (28, 29 and 51)

TABLE 3.5: SUMMARY OF PREVIOUS INVESTIGATIONS - BORROW SITE G - DEVIL CANYON

Test Pit Number	Surface Elevation	Total Depth (Downhole) (ft)	Depth to Bedrock (Downhole) (ft)	Date Excavated
TP6	--	22.5	--	1958
TP7	--	--	--	--
TP:7	--	--	--	--
TP18	--	--	--	--
TP19	--	58.1	--	1958
TP20	--	--	--	--
TP21	--	30.0	--	1958
TP22	--	--	--	--
TP23	--	--	--	--
TP24	--	--	--	--
TP25	--	--	--	--
TP26	--	--	--	--
TP27	--	--	--	--
TP93	--	--	--	--
TP94	--	15.0	--	1958

NOTES:

No data were available for TP7, TP17, TP18, TP20, TP22-TP27, and the two unnumbered test pits.

References (28, 29, and 51)

4 - REGIONAL GEOLOGY

4.1 - Introduction

The Devil Canyon and Watana damsites lie in the Susitna River basin within the Talkeetna Mountains of south-central Alaska. The regional stratigraphy, structure, and glacial history are briefly discussed in this section. A more detailed discussion of specific regional tectonics is presented in the Woodward-Clyde Consultants' report (58).

The geologic setting of the Talkeetna Mountains and the adjacent Susitna River basin has been interpreted as an enormous tectonic mosaic composed of separate continental structural blocks and fragments that accreted to the North American plate during Mesozoic time (7,11,25,27, 38). The exact number of these blocks is unknown; however, geologic and geophysical evidence suggest that the blocks moved northward a considerable distance prior to collision with the North American plate (22,33,42). This geologic history is reflected by the highly complex structure and stratigraphy found throughout the region.

4.2 - Stratigraphy

The oldest rocks which outcrop in the region are a metamorphosed upper Paleozoic (Table 4.1) rock sequence which trends northeastward along the eastern portion of the Susitna River basin (Figure 4.1). These rocks consist chiefly of coarse to fine grained clastic flows and tuffs of basaltic to andesitic composition, locally containing marble interbeds (8). This system of rocks is unconformably overlain by Triassic and Jurassic metavolcanic and sedimentary rocks. These rocks consist of a shallow marine sequence of metabasalt flows, interbedded with chert, argillite, marble, and volcaniclastic rocks. These are best expressed in the project area around Watana and Portage Creeks. The Paleozoic and lower Mesozoic rocks are intruded by Jurassic plutonic rocks composed chiefly of granodiorite and quartz diorite. The Jurassic age intrusive rocks form a batholithic complex of the Talkeetna Mountains (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 graywackes during the Cretaceous. These rocks underlie a large part of the project area and form the bedrock at the Devil Canyon site (10). These rocks were subsequently deformed and intruded by a series of Tertiary age plutonic rocks ranging in composition from granite to diorite in composition and includes related felsic and mafic volcanic extrusive rocks. The Watana site is underlain by one of these large plutonic bodies, which appears to comprise the southern limit of the diorite pluton which predominates along upper Tsusena Creek (6). These plutons were subsequently intruded and overlain by felsic and mafic volcanics. Mafic volcanics, composed of andesite porphyry lie downstream from the Watana site.

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4.3 - Tectonic History

At least three major episodes of deformation are recognized (10) for the project 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 in the Devil Canyon area 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 Thurst is postulated as representing an old suture zone, involving the thrusting of Paleozoic, Triassic and Jurassic rocks over the Cretaceous sedimentary rocks (10,11, 20,26,38). 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 fault displacement during the Holocene (18).

4.4 - Glacial History

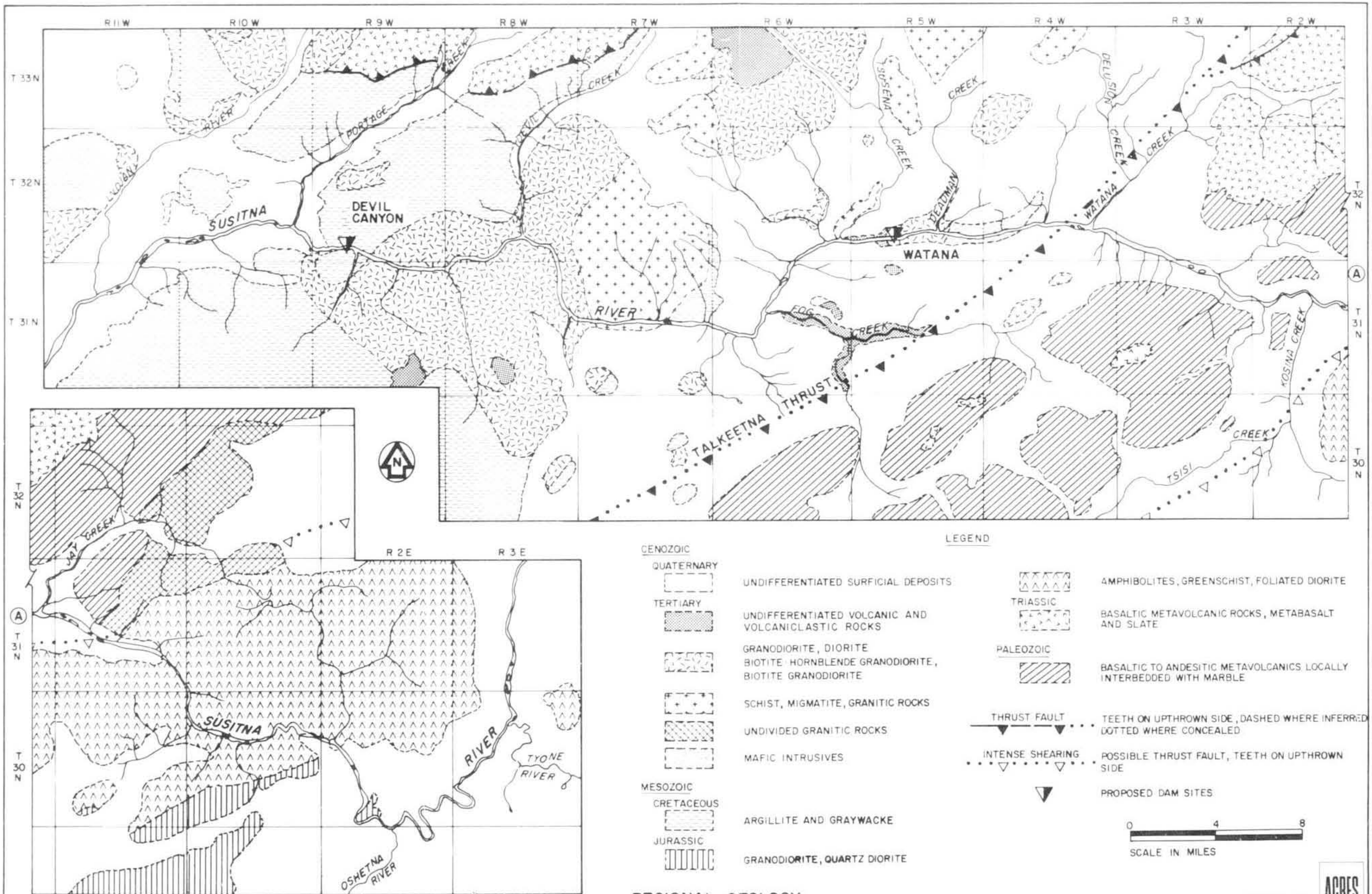
A period of cyclic climatic cooling during the Quaternary resulted in repeated glaciation of southern Alaska. Little information is available regarding the glacial history in the upper Susitna River basin. Unlike the north side of the Alaska Range, which is characterized by alpine type glaciation, the 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 region based on the glacial stratigraphy (30,34). During the most recent period (late Wisconsinian), glaciers filled the adjoining lowland basins and spread onto the continental shelf (30). 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 this repeated glaciation, the Susitna and Copper River basins are covered by varying thicknesses of tills and lacustrine deposits.

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 (54)



REGIONAL GEOLOGY

FIGURE 4.1

5 - SCOPE OF GEOTECHNICAL INVESTIGATION

5.1 - Introduction

The overall geotechnical investigation program for the Watana and Devil Canyon sites was designed to determine technical feasibility of the sites for development of hydroelectric facilities.

The principal objectives of the 1980-81 investigation were to:

- Determine the suitability of the bedrock for excavating underground structures which include penstocks, powerhouse, tailrace, and diversion tunnels;
- Determine foundation conditions in the damsite areas. Specifically, to determine soil type and depth, thickness of weathered rock, rock permeability, groundwater regime and extent of permafrost;
- Define and investigate specific geologic structural features to include faults, shear and fractured zones, alteration zones, and joints;
- Determine the availability of the required quantities of suitable construction materials for the dams and related facilities; and
- Examine the stability of the reservoir slopes during filling and operating the reservoir.

The scope developed to meet these objectives was based on:

- Discussions with individuals involved in previous studies;
- Detailed review of all previous data; and
- Information developed during the course of this study.

The engineering application of the data collected during this investigation was applied to the design phase of the project in Task 6 and is presented in the Feasibility Report (1).

The details of the program for each site are discussed in Sections 6 and 7.

5.2 - Geologic Mapping

(a) Damsites

A geologic mapping program was undertaken to define the lithology and structure of the damsites and reservoirs. All the geologic data obtained in previous studies were used to supplement the data collected during the 1980-81 program.

The Acres geologic mapping program was performed in three phases: 1980 summer, 1980/81 winter, and 1981 summer. The geologic mapping program for each phase was initiated by aerial reconnaissance followed by a walking ground traverse.

The principal objective of the 1980 program was to perform general reconnaissance mapping of the damsites and reservoirs to:

- Verify existing data;
- Locate potential borrow and quarry sources and refine limits and and quantity estimates; and
- Identify areas that would require detailed mapping during the next two phases of the program.

Data from the 1980 program were plotted on 1:6000 scale aerial photographs. The mapping was performed by a team of two geologists during the period of June through August.

The 1981 winter program was performed during the month of March and consisted of mapping those areas along the Susitna River and Tsusena and Cheechako Creeks that were not accessible during the warmer months. However, poor ice conditions at Devil Canyon precluded mapping of several areas along the Susitna River. Particular attention was directed to mapping the extent and configuration of "The Fins" and "Fingerbuster" at the Watana site. Similarly, other sheared, fractured, and altered zones were mapped along the river where access could not be gained during the summer months.

Mapping consisted of identifying each outcrop and noting its size, orientation, weathering characteristics, lithology, and jointing, as well as any other significant geologic feature. All significant features were photographed.

The 1981 summer program entailed detailed mapping of both dam abutments at Watana and Devil Canyon with particular attention directed at defining the extent of any unusual geologic feature denoted in the previous phases of the investigation. The extent of the detailed mapping program is shown in Figures 6.3 and 7.3. Mapping at Watana extended for approximately 3,000 feet upstream and 3,000 feet downstream from the proposed dam axis. Mapping was performed in those areas having bedrock exposure. For the most part, this was limited to the valley walls. Mapping at Devil Canyon extended for approximately 2,000 feet upstream and 2,500 feet downstream from the proposed dam. Most of the mapping was confined to the gorge walls, since very little outcrop exposure exists beyond the break in slope. Mapping was performed by the "tape and Brunton" method with key areas being marked for future survey control. Mapping of the gorge walls was performed by geologists trained as technical climbers.

All geologic data were plotted on a 1-inch to 200-foot base map. A detailed discussion of the results of the geologic mapping program is presented in Sections 6 and 7.

(b) Reservoir Mapping

(i) General

The Watana and Devil Canyon reservoirs were geologically and geomorphically mapped to identify any geologic features and geotechnical conditions which might seriously affect the reservoir performance. Such features included buried channels and faults in the reservoir rim which may jeopardize the reservoir water tightness; faults which could be activated by reservoir loading; and natural slopes which may become unstable or erodible with reservoir filling or drawdown.

Reservoir mapping consisted of airphoto interpretation performed by R&M Consultants (Appendix J) and mapping of current slope stability and permafrost (Appendix K). The scope of these programs is discussed in the following sections.

(ii) Airphoto Interpretation

A terrain unit map was developed using a 1:24,000 airphoto base map. Field checks of specific features were performed as required. The interpretation identified 14 types of land forms or individual terrain units. These are:

- bedrock
- colluvium deposits
- landslide
- solifluction deposits
- granular alluvial fan
- floodplain
- old terraces
- ablation till
- basal till
- outwash
- esker deposits
- kame deposits
- lacustrine deposits
- organic deposits

Results of the airphoto interpretation are contained in Appendix J.

(iii) Slope Stability

The potential for instability of the slopes within the Watana and Devil Canyon reservoirs after impoundment was evaluated using color aerial photographs at a scale of 1:24,000, color infrared photographs at a scale of 1:120,000, and a brief field reconnaissance. Areas of current slope instability, and the distribution of permafrost were delineated. This information, in addition to the soil and rock conditions throughout the reservoirs, was used in identifying the potential types and zones of instability and erosion that could occur as a direct effect of the impounding of the reservoirs. Details of this study are presented in Appendix K.

5.3 - Subsurface Investigation

(a) Diamond Core Drilling

Diamond core drilling was performed on the abutments of both damsites using a skid-mounted Longyear-34 diamond drill equipped with triple tube wireline N-size core barrel. A total of approximately 8,000 linear feet of drilling was performed at Watana and 3,600 linear feet at Devil Canyon. Seven diamond core borings were drilled at each site. All logging and supervision were by geologists. All rock core was logged for lithology, core recovery, RQD, joints and fractures, shears, fracture zones and alteration zones, and other significant geologic features. A discussion of the results of the drilling program is presented in Sections 6 and 7 with Drilling Report and Summary Logs and permeability test results contained in Appendices B through E.

A summary of the drilling activity for the 1980-81 field season is shown in Tables 5.1 and 5.2 with drill hole locations shown in Figures 5.1 and 5.2.

(b) In-Hole Testing

(i) Permeability Testing

Permeability testing was conducted in all the diamond drill holes upon completion of the core drilling. Prior to testing, each hole was thoroughly flushed with clear water and the drill string withdrawn. Following flushing of the hole, a packer assembly was lowered into the borehole to the desired depth. The test procedure involved inflating the packers with nitrogen to isolate a section of the borehole, pumping water under pressure into the test zone, and recording pressure and flow rates. Based on the flow rates, hydraulic head, hole diameter, and length of test section, the permeability of the rock in the test section was calculated. In general, the packer assembly was installed to the bottom of the hole with tests being run over 16.1 foot intervals as the assembly was withdrawn.

The permeability for each test section was calculated using the following formula:

$$k = 0.0679 \quad \frac{q}{2\pi LH} \quad \ln \frac{L}{r}$$

Where k = permeability, cm/sec
q = constant rate of flow, gpm
L = length of test section, feet
H = differential head of water, feet
r = radius of hole, feet
$\ln$ = natural logarithm

A maximum test pressure equal to 1 psi per foot of vertical depth below the ground surface to the water table, plus 0.5 psi per foot of vertical depth below the water table down to the test section was used. However, in no case was the pressure allowed to exceed 200 psi. The actual gage pressure was adjusted to take into consideration the depth of water table.

In order to obtain accurate permeability values, it was necessary that the applied pressure and flow rates be measured accurately. A panel of four Fisher-Porter glass tube variable flow meters was set up as shown in Appendix D. These meters have an accuracy of 1 percent over full scale and individual ranges of 0.021-0.267 gpm, 0.095-1.19 gpm, 0.34-4.25 gpm and 0.88-11.0 gpm. The panel was set up to use any of the four meters or to bypass them altogether.

Water pressure was supplied by a Royal Bean fixed-displacement, piston pump. Test pressure was monitored using a liquid-filled Ashcroft model 1279 pressure gage with a 0-to-300-psi range and 2 psi divisions. The accuracy of this gage is $\pm$0.5 percent of full scale.

To eliminate pressure surging in the line to the gages, a surge tank was installed and pressure snubbers were used between the pressure gage and the main line.

Discussions of the results of the permeability tests are presented in Section 6.1(f) and 7.1(f).

(ii) <u>In-Hole Geophysical Logging</u>

In-hole geophysical logging was carried out in three diamond drill holes at the Devil Canyon site and two holes at the Watana site. BH-2 at the Watana site caved badly and was not tested. A total of 3,225 linear feet of logging was completed. The logging procedure involved lowering a geophysical probe in the hole on a wireline with the data being returned to the surface and recorded on a self-contained logging unit. The logs run in each hole included: temperature, caliper, resistivity, and sonic velocity.

The purpose for the geophysical logging was to aid in interpreting the subsurface conditions found at depth. Because of poor data resolution, the results of the survey have not been included in this report.

(iii) Instrumentation

To monitor the groundwater and permafrost conditions in the bedrock, piezometers and thermistor strings were installed in boreholes BH-3 and BH-6 at Watana (Figure 5.1); and BH-1, BH-2, and BH-4 at Devil Canyon (Figure 5.2).

The piezometers used were a pneumatic type assembly manufactured by Petur Instrument Company of Seattle, Washington. The pneumatic type piezometers were selected because subfreezing temperatures were likely to be encountered in the upper portions of the holes which would cause blockage in conventional standpipe piezometers. Pneumatic type piezometers are also quick to install and easy to read.

The thermistor strings were manufactured by Instrumentation Services in Fairbanks, Alaska. The thermistor strings were each 250 feet long with thermistor points attached at 3, 6, 9, 12, 15, 18, 21, 25, 50, 75, 100, 125, 150, 175, 200, and 250 feet. A 40-strand cable was used to connect the thermistors to the surface, where a quick connect plug on the cable was plugged into a switch box which in turn was connected to a portable readout box. The system is designed to obtain two readings at each depth so readings can be cross checked. Each thermistor point was initially calibrated in the laboratory before installation and a computer program set up to convert readings to temperature, taking into account the correction factors for each thermistor. An accuracy of 0.05°C was obtained with this equipment.

The installation details of piezometers and thermistors are shown in Figures 5.3 and 5.4.

5.4 - Seismic Refraction Surveys

Seismic refraction surveys were performed at both damsites during the 1980 and 1981 field seasons. This survey data was used in conjunction with borehole data, geologic mapping, and previous geophysical surveys to define:

- Depth to bedrock;
- Bedrock seismic velocities;
- Extent of possible shear and fracture zones;
- Location and configuration of relict channels, and;
- Location and extent of potential borrow material.

A total of approximately 100,000 linear feet of seismic lines were performed for this program with the results presented in Appendices H and I. The location of the seismic lines in the damsite areas are shown in Figure 5.1 for Watana and Figure 5.2 for Devil Canyon. Discussion of the seismic lines in the borrow sites are presented in Section 6.3 and 7.2 with locations being shown on individual borrow site figures.

Most of the surveys were performed using a 1,100-foot seismic line increment with 100 foot spacing between geophones. Shorter geophone spacing was used where terrain was rugged or overburden was shallow. Explosive charges of 1 to 2 pounds were used as the energy source and were placed at a distance of half the geophone spacing beyond the end geophones and at the middle of the lines. For shorter lines, a hammer and plate provided adequate energy. The seismic velocities were recorded on a Geometrics/Nimbus model ES-1210F 12-channel stacking seismograph. A digital/analog converter was used to display the results for data reduction.

At Watana damsite, 5 traverses were run in the immediate damsite area, 10 traverses in the relict channel area, and 15 traverses in the borrow sites.

At Devil Canyon, a total of four traverses were run in the immediate vicinity of the small ponds on the left abutment. Land access restrictions prohibited any seismic work in Borrow Site G.

Details of the seismic survey are given in Table 5.2. The results have been applied to the geologic and geotechnical interpretation of the site presented in Sections 6 and 7.

5.5 - Borrow Investigation

Test pits and auger holes were excavated and drilled in the proposed borrow sites to determine their material properties, quantities and extent.

Tables 5.4 to 5.8 provide a summary of the work in the borrow sites performed during the 1980-81 field seasons.

The program initially used a platform-mounted CME-45 rig that was replaced by a CME-55 because of the difficult drilling conditions. Drilling was performed using a hollow-stem, continuous-flight auger string, having an 8-inch O.D. and a 3-1/4 inch I.D., to a maximum depth of 75 feet. Material samples were collected using a split-spoon sampler continuously in the upper 10 feet of the hole and then at 5-foot intervals to full depth. The sampling procedures consisted of drilling the augers down to the required sampling depth, removing the inner plug and stem, and advancing the split-spoon sampler 18 inches into the soil below the cutting head by driving it with a 140-lb hammer falling freely 30 inches (Standard Penetration Test). The samples were returned to the surface, logged by a geologist, and prepared for transport and storage. In most cases, 4- to 6-inch long, thin brass liners were used inside the split-spoon sampler, which allowed selected samples to be capped and sealed. Following completion of the hole, the auger string was withdrawn and the hole backfilled with the drill cuttings.

Test pits were excavated utilizing a JD-350 dozer equipped with a backhoe. Average depth of the test pits ranged from 4 to 13 feet. Three trenches were excavated along the edge of the alluvial fan in Borrow Site G using the JD-350 (Figure 5.2).

Bulk samples from the holes and pits were collected and sealed in air tight bags for subsequent laboratory testing.

The logs for the auger holes and test pits are presented in Appendices F and G. The properties of the borrow materials are discussed in Sections 6.3 and 7.2.

5.6 - Laboratory Testing

(a) Soil

Representative soil samples obtained from the potential borrow sites were tested to determine their physical properties and verify their field classification. Soil samples were tested to determine grain-size distribution, moisture content, Atterberg limits, moisture-density relationship, permeability values, consolidation rates, and shear strength. All testing was done using ASTM or AASHTO standard procedures where applicable. The results of the testing program are summarized in Sections 6.3 and 7.2 with the laboratory data included in Appendices F and G.

(b) Rock

Previous rock testing at the Watana and Devil Canyon sites was carried out by the USBR and COE. The results of this testing were incorporated into the analysis of the rock conditions where applicable.

The rock-testing program undertaken in 1980-81 was intended to provide sufficient data to develop preliminary criteria for design of underground structure excavations and foundations. Rock samples were selected for testing mainly to determine the range or rock properties to be encountered at the site. Samples selected included weathered rock, rock with discontinuities, and fresh relatively homogeneous rock. Samples of low-strength rock, which could not be recovered as solid core, were tested only for direct shear tests on discontinuities. All samples were tested using the appropriate ASTM standard procedures.

The scope of the 1980-81 rock testing program is shown in Tables 5.9 and 5.10, with the results presented in Sections 6.1 and 7.1.

TABLE 5.1: SUMMARY OF 1980-81 INVESTIGATION - WATANA DAMSITE

Hole Number	Surface Elevation	Dip (°)	Azimuth (°)	Total Depth (ft) (Downhole)	Depth to Bedrock (ft) (Downhole)	Date Drilled	Thermistor Type	Thermistor Reading Dates	Piezometer Type	Piezometer Reading Dates	Piezometer Water Level (ft) Vertical
BH-1	2049.7	70	030	299.9	18.7	8/10/81					
BH-2	1838.8	55	043	401.1	10.0	7/14/80					
BH-3	2150.7	55	338	955.7	31.7	8/15/81	MPT	11/11/81 12/9/81 1/5/82	PN	9/1/81 11/11/81 1/5/82	0.0 0.0 0.0
BH-4	2187.8	58	060	949.6	12.4	9/11/81			SP	9/22/81	50.0
BH-6	1608.8	60	225	740.4	8.0	6/26/80	MPT	11/21/80 4/26/81 5/24/81 6/25/81 8/3/81 12/9/81	PN	11/21/80 5/24/81 6/25/81 12/9/81	147.0 126.2 103.2 115.0
BH-8	1979.7	60	060	752.4	8.0	7/29/80			SP	8/9/80	15.0
BH-12	1975.7	36	220	798.9	27.0	7/18/81			SP	7/28/81	0.0

BH = Diamond core hole
PN = Pneumatic piezometer
MPT = Multi-point thermistor string
SP = Standpipe

Reference - Figure 5.1

TABLE 5.2: SUMMARY OF 1980-81 INVESTIGATION - DEVIL CANYON DAMSITE

Hole Number	Surface Elevation	Dip (°)	Azimuth (°)	Total Depth (ft) (Downhole)	Depth to Bedrock (ft) (Downhole)	Date Drilled	Thermistor		Piezometer		
							Type	Reading Dates	Type	Reading Dates	Water Level (ft) Vertical
BH-1	1413.7	67	225	750.2	11.8	8/23/80	MPT	4/21/80 4/19/81 5/24/81 6/24/81 8/3/81 11/13/81 12/9/81 1/7/82	PN	10/6/80 5/24/81 6/24/81 12/9/81 1/7/82	144.5 153.1 138.2 152.0 145.3
BH-2	1213.4	60	0	655.5	2.0	9/10/80	MPT	12/9/81 1/7/82	PN	High	
BH-3	1398.0	32	058	391.1	7.5	6/28/81					
BH-4	1352.6	60	195	500.7	7.0	8/14/80	MPT	4/19/81 5/24/81 6/24/81 8/3/81 12/9/81 1/7/82	PN	4/19/81 5/24/81 6/24/81	13.2 9.2 9.2
BH-5A	974.5	45	189	597.9	0.0	6/4/81					
BH-5B	976.6	45	277	200.3	0.0	6/19/81					
BH-7	1351.0	45	009	498.3	11.0	5/18/81					

BH = Diamond cored hole
MPT = Multi-point thermistor string
PN = Pneumatic piezometer

Reference - Figure 5.2

TABLE 5.3: SUMMARY OF 1980-81 SEISMIC REFRACTION LINE DATA

WCC* Line No.	R&M Survey No.	Line Length (feet)	Number of Segments/Shots	Comments
80-1	80-1	6,600	8/31	Watana Rt Abutment-Relict Channel - Extended NE by 81-13
80-2	80-2	5,500	5/19	Watana Rt Abutment-Relict Channel - Extended NE by 81-13
80-3	80-3	2,000	4/11	Watana Abutments Upstream - 81-6 Crosses River in Middle
80-4	--	--	--	Not Used
80-5	--	--	--	Not Used
80-6	80-6	1,100	2/5	Watana Rt Abutment - "The Fins" Area
80-7	80-7	2,200	2/10	Watana Rt Abutment - Upper Relict Channel Area
80-8	80-8	2,200	2/110	Quarry Source B Area - Extends SW-5 to South
80-9	80-9	1,100	1/3	Borrow Site E - Extends SW-14 to Northwest
80-10	--	--	--	Not Used
80-11	80-11	2,200	4/13	Borrow Site E - Adjacent to Tsusena Creek
80-12	80-12	1,120	3/8	Devil Canyon Saddle Dam Area
80-13	80-13	1,120	3/8	Devil Canyon Saddle Dam Area
80-14	--	--	--	Not Used
80-15	80-15	440	1/2	Devil Canyon Saddle Dam Area
81-1	81-1	1,000	1/3	Run Over River Ice, 2.1 Miles Upstream from Watana Centerline
81-2	81-2	2,000	2/6	Run Over River Ice, 1.6 Miles Upstream from Watana Crest
81-3	81-3	500	1/2	Run Over River Ice, 1.1 Miles Upstream from Watana Crest
81-4	81-4	900	1/3	Run Over River Ice, 0.6 Mile Upstream from Watana Crest
81-5	81-5	450	1/3	Run Over River Ice, 0.5 Mile Upstream from Watana Crest
81-6	81-6	450	1/2	Run Over River Ice, 0.1 Mile Upstream from Watana Crest
81-7	81-7	3,200	3/9	Run Over River Ice, 4.0 Miles Downstream from Watana Crest
81-8	81-8	2,500	3/6	Run Over River Ice, 5.2 Miles Downstream from Watana Crest
81-9	81-9	2,000	2/6	Run Over River Ice, 7.3 Miles Downstream from Watana Crest
81-10	81-10	2,100	2/6	Run Over River Ice, 8.2 Miles Downstream from Watana Crest
81-11	81-11	2,800	3/9	Run Over River Ice, 9.3 Miles Downstream from Watana Crest
81-12	81-12	2,000	2/7	Run Over River Ice, 10.1 Miles Downstream from Watana Crest
81-13	81-1X	3,200	3/10	Relict Channel Area - Extends 80-1 to Northwest
81-14	8C-2X	3,300	3/5	Relict Channel Area - Extends 80-2 to NE - Northwest - North End Not Surveyed
81-15	BH-11	2,100	4/11	Offset to Accommodate Topography
81-16	16-81	2,200	2/8	Watana Upper Relict Channel Area
81-17	--	1,100	1/5	Watana Upper Relict Channel Area - Not Surveyed
81-18	QSB	2,200	2/10	Watana Upper Relict Channel Area - North of Quarry Source B
81-19	QSB	1,100	1/6	Watana Upper Relict Channel Area - North of Quarry Source B
81-20	SW-1X	1,600	5/11	Watana Left Abutment - Extends SW-1 East
81-21	B-12	1,850	5/19	Watana Left Abutment - Crosses 81-20
81-22	17	1,500	3/6	Devil Canyon Left Abutment - Crosses 80-12 and 80-13
81-FL-1 to 81-FL-48	Fog Lakes	28,800	48/138	Continuous Profile - Fog Lakes Area

*Profiles and time-distance plots included in (57)
Location reference - Figures 5.1, 5.2, 6.38, 6.40, 6.43, and Appendices H and I

TABLE 5.4: SUMMARY OF 1980-81 INVESTIGATION - BORROW SITE D - WATANA

Hole Number	Surface Elevation	Total Depth (ft) (Downhole)	Depth to Bedrock (ft) (Downhole)	Date Drilled	Thermistor Type	Thermistor Reading Dates	Piezometer Type	Piezometer Reading Dates	Piezometer Water Level (ft) (Vertical Depth)
AH-D1	2261.7	20.0	--	7/14/80					
AH-D2	2335.3	29.0	--	7/15/80					
AH-D3	2339.9	20.5	--	7/15/80					
AH-D4	2255.0	15.0	--	7/17/80					
AH-D5	2221.6	48.3	--	8/14/81	T	1/5/82 2/4/82	SP	2/4/82	9.0
AH-D6	2262.9	50.0	--	8/22/81	T	1/5/82	SP		
AH-D7	2242.9	48.3	--	8/12/81	T	1/5/82 2/4/82	SP	2/4/82	Blocked at 29.0
AH-D8	2276.1	50.3	--	8/9/81	T	1/5/82			
AH-D9	2319.1	74.0	64.0	7/25/81	T	1/5/82	SP		
AH-D10	2357.8	50.0	--	8/1/81	T	1/5/82	SP		
AH-D11	2358.0	54.7	--	7/27/81	T	1/5/82	SP		
AH-D12	2337.9	60.0	--	7/30/81	T	1/5/82			
AH-D13	2326.2	50.0	--	8/3/81	T		SP		
AH-D14	2272.7	75.0	--	8/27/81	T	12/9/81 1/4/82 2/3/82	SP	2/3/82	10.0
W80-282		Grab		1980					
W80-300		Grab		1980					

AH = Auger hole
W = Grab sample
SP = Standpipe
T = Thermistor probe - fluid-filled standpipe

Reference - Figure 6.40

TABLE 5.5: SUMMARY OF 1980-81 INVESTIGATION - BORROW SITE E - WATANA

Number	Surface Elevation	Total Depth (ft) (Downhole)	Depth to Bedrock (ft) (Downhole)	Date Drilled
AH-E1	1424.5	25.0	--	7/1/80
AH-E2	1463.3	10.0	--	7/18/80
AH-E3	1456.1	20.0	--	7/3/80
AH-E4	1443.7	20.0	--	7/17/80
AH-E5	1580.5	10.0	--	6/23/80
AH-E6	1436.8	26.5	--	7/19/80
AH-E7	1469.3	5.5	--	7/20/80
AH-E8	1504.0	6.0	--	7/21/80
AH-E9	1524.8	8.0	--	7/20/80
TP-E1	--	10.0	--	4/19/81
TP-E2	1436.6	12.0	--	4/18/81
TP-E3	1464.2	13.0	--	4/17/81
TP-E4	1454.9	13.0	--	4/18/81
TP-E5	1470.1	10.0	--	4/16/81
TP-E6	1443.4	9.0	--	4/15/81
TP-E7	1450.7	4.0	--	4/15/81
TP-E8	1450.2	12.0	--	4/20/81
TP-E9	1476.7	11.5	--	4/21/81
TP-E10A	1500.7	13.0	--	4/22/81
TP-E10B	1493.7	9.5	--	4/22/81
TP-E11	1512.7	12.0	--	4/24/81
TP-E12	1534.9	11.0	--	4/25/81
TP-E13	Not Dug	--	--	--
TP-E14	1503.0	10.5	--	4/26/81
TP-E15	1468.3	11.5	--	4/28/81
TP-E16	1463.8	11.5	--	4/30/81
TP-E17	1441.7	11.0	--	5/1/81
TP-E18	1455.1	12.5	--	5/2/81
TP-E19	1464.7	12.0	--	5/2/81
TP-E20	1435.0	12.0	--	5/3/81
TP-E21	1425.4	12.0	--	5/3/81

AH = Auger hole
TP = Test pit

Reference - Figure 6.43

TABLE 5.6: SUMMARY OF 1980-81 INVESTIGATION - BORROW SITE G - DEVIL CANYON

Hole Number	Surface Elevation	Total Depth (ft) (Downhole)	Depth to Bedrock (ft) (Downhole)	Date Drilled	Thermistor	
					Type	Reading Dates
AH-G1	982.3	23.0	--	7/22/80	--	--
AH-G4	983.1	11.0	--	7/22/80	--	--
AH-G9	982.0	55.0	--	8/22/81	--	--
AH-G10	980.0	19.0	--	8/26/81	--	--
AH-G11	--	31.0	--	8/26/81	T	None
AH-G12	--	13.5	10.5	8/27/81	T	to
AH-G13	--	35.0	--	8/28/81	T	Date
AH-G14	--	29.0	--	8/29/81	T	--
TT-G1	--	Trench	--	7/21/81	--	--
TT-G2	--	Trench	--	7/21/81	--	--

AH = Auger hole
TT = Test trench
T = Thermistor probe - fluid-filled standpipe

Reference - Figure 7.22

TABLE 5.7: SUMMARY OF 1980-81 INVESTIGATION - BORROW SITE H - WATANA

Hole Number	Surface Elevation	Total Depth (ft) (Downhole)	Depth to Bedrock (ft) (Downhole)	Date Drilled	Thermistor	
					Type	Reading Dates
AH-H1	2127.5	26.5	23.0	7/16/81	T	1/7/82
AH-H2	1970.9	40.9	--	7/19/81	T	1/5/82
AH-H3	2079.6	29.0	--	7/18/81	T	1/5/82
AH-H4	2064.5	25.5	22.0	7/14/81	T	--
AH-H5	2186.2	35.5	--	7/13/81	T	--
AH-H6	2181.0	43.0	--	7/12/81	T	--
AH-H7	2188.4	30.7	25.7	7/15/81	T	1/7/82
AH-H8	2093.5	35.0	--	7/17/81	T	1/7/82
W80-256	--	Grab	--	--	-	--
W80-257	--	Grab	--	--	-	--

AH = Auger hole
T = Thermistor probe - fluid-filled standpipe
W = Grab sample

Reference - Figure 6.48

TABLE 5.8: SUMMARY OF 1980-81 INVESTIGATION -
BORROW SITES I & J - WATANA

Test Pit Number	Surface Elevation	Total Depth (ft) (Downhole)	Depth to Bedrock (ft) (Downhole)	Date Drilled
TP-R1	--	4.5	--	9/17/81
TP-R2	--	5.0	--	9/17/81
TP-R3	--	5.5	--	9/17/81
TP-R4	--	4.5	--	9/17/81
TP-R5	--	4.5	--	9/18/81
TP-R6	--	5.0	--	9/18/81
TP-R7	--	4.0	--	9/18/81
TP-R8	--	2.5	--	9/17/81
TP-R9	--	3.5	--	9/18/81
TP-R10	--	5.5	--	9/18/81
TP-R11	--	4.0	--	9/18/81
TP-R12	--	5.0	--	9/19/81
TP-R13	--	6.0	--	9/19/81
TP-R14	--	6.0	--	9/19/81
TP-R15	--	6.0	--	9/20/81
TP-R16	--	5.5	--	9/20/81
TP-R17	--	4.5	--	9/20/81
TP-R18	--	5.0	--	9/20/81
TP-R19	--	4.0	--	9/21/81
TP-R20	--	5.0	--	9/21/81
TP-R21	--	4.5	--	9/21/81
TP-R22	--	5.0	--	9/21/81
W80-302	--	Grab	--	1980

TP = Test pit
W = Grab sample

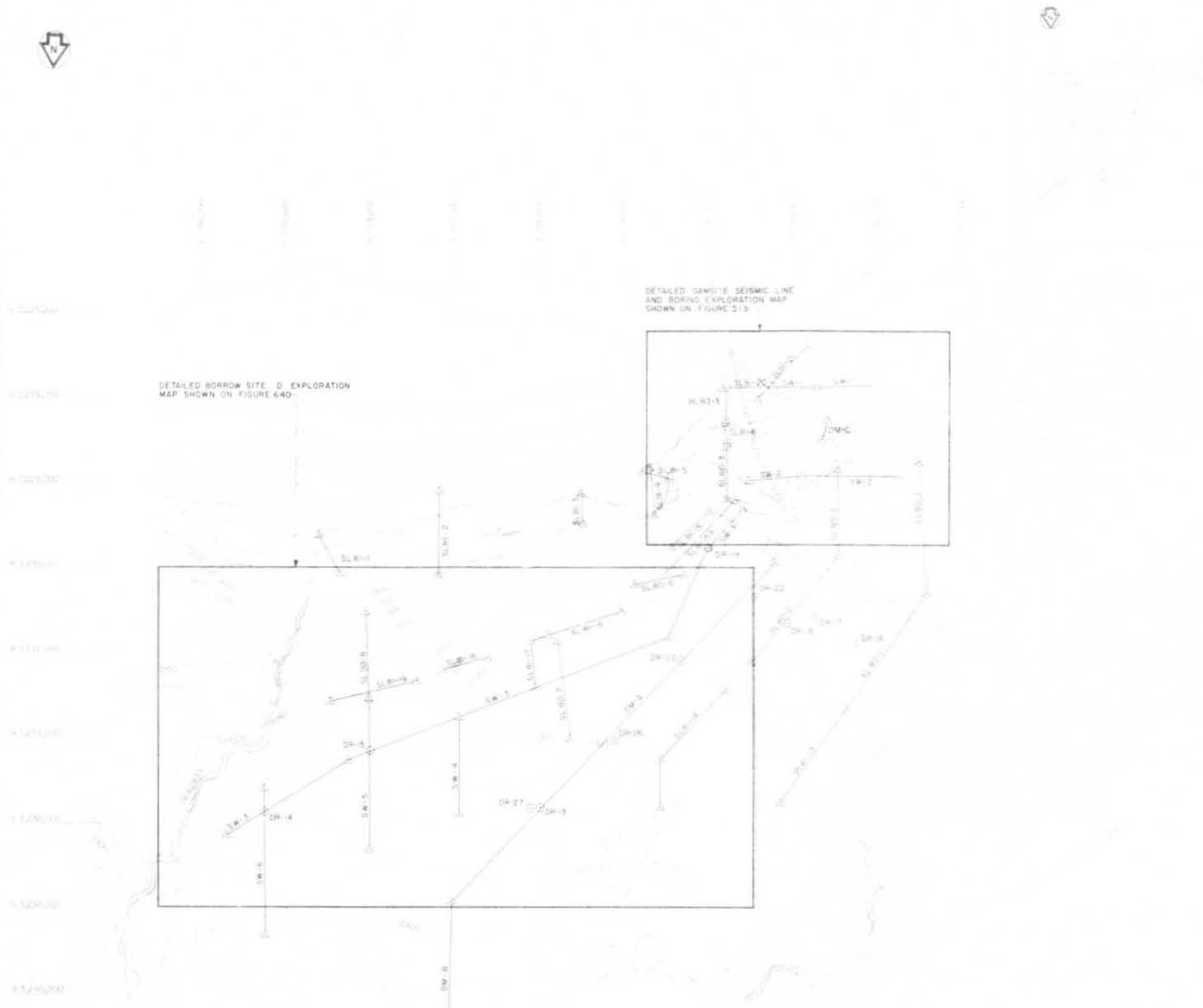
Reference - Figures 6.51 and 6.52

TABLE 5.9: SUMMARY OF ROCK TESTS - WATANA

Type of Test	No. of Tests By Acres	Standard	No. of Tests by Others
Unconfined Uniaxial Compression	29	ASTM D2938-71a	--
Unconfined Uniaxial Compression with Stress/Strain Plot	4	ASTM D3148	6
Direct Shear	3	--	--
Indirect Tension	11	ASTM C496	--
Point Load Test	303	--	--
Specific Gravity	44	ASTM C97-47 (1970)	5
Dynamic Modulus	2	ASTM D2845-69 (1976)	--

TABLE 5.10: SUMMARY OF ROCK TESTS - DEVIL CANYON

Type of Test	No. of Tests By Acres	Standard	No. of Tests by Others
Direct Shear	6	--	--
Indirect Tension	8	ASTM C496	--
Point Load Test	338	--	--
Specific Gravity	40	ASTM C97-47 (1970)	6
Dynamic Modulus	3	ASTM D2845-69 (1970)	8
Unconfined Unaxial Compression	26	ASTM D2938-71a	--
Unconfined Unaxial Compression with Stress/Strain Plot	6	ASTM D3148	7



LOCATION MAP

SCALE 0 4 8 MILES

LEGEND

BOREHOLES AND TEST PITS:

DR-H 1978, COE ROTARY DRILL BORING

GEOPHYSICAL SURVEYS:

SEISMIC REFRACTION SURVEY END OR TURNING POINT

DM-? 1975, DAMES & MOORE

SW-? 1978, SHANNON & WILSON

SLB1-5 1980-81, WOODWARD-CLYDE CONSULTANTS

NOTES

1. DETAILED EXPLORATION MAP OF DAMSITE ON FIGURE 5.1b
2. BORROW SITE D TEST PITS AND AUGER HOLES, AS WELL AS SEISMIC LINES, SHOWN ON FIGURE 6.40
3. DETAILED SECTION ON DM-A & B ON FIGURE 6.31
4. RIVER ALLUVIUM TEST PITS SHOWN ON FIGURES 6.51 AND 6.52
5. RELICT CHANNEL AREA MAP SHOWN ON FIGURE 6.35
6. CONTOUR INTERVAL 100', ENLARGED AND TRACED FROM REFERENCED BASE MAP
7. D&M SEISMIC LINE LOCATIONS CORRECTED PER COE SURVEY AND REFERENCED BASE MAPS
8. S&W SEISMIC LINE LOCATIONS CORRECTED FROM ORIGINAL FIELD BOOKS AND S&W, 1978
9. LINE DM-B CONTINUED 11,000 FEET NORTH OF TURNING POINT SHOWN
10. COE EXPLORATION LOGS AND S&W SEISMIC PROFILES AS REFERENCED
11. WCC SEISMIC REFRACTION DATA SHOWN IN APPENDICES H AND I
12. NORTHING GRID LINES ARE IN ERROR BY APPROXIMATELY 50 FEET, NORTH, FROM STATION N 3,232,000 TO N 3,234,000

SCALE 0 1000 2000 FEET

REFERENCE: 1"=200' COE, 1978 WATANA DAMSITE TOPOGRAPHY, SHEET 1 THROUGH 26

WATANA
DAMSITE VICINITY-EXPLORATION MAP

ACRES

FIGURE 5.1a

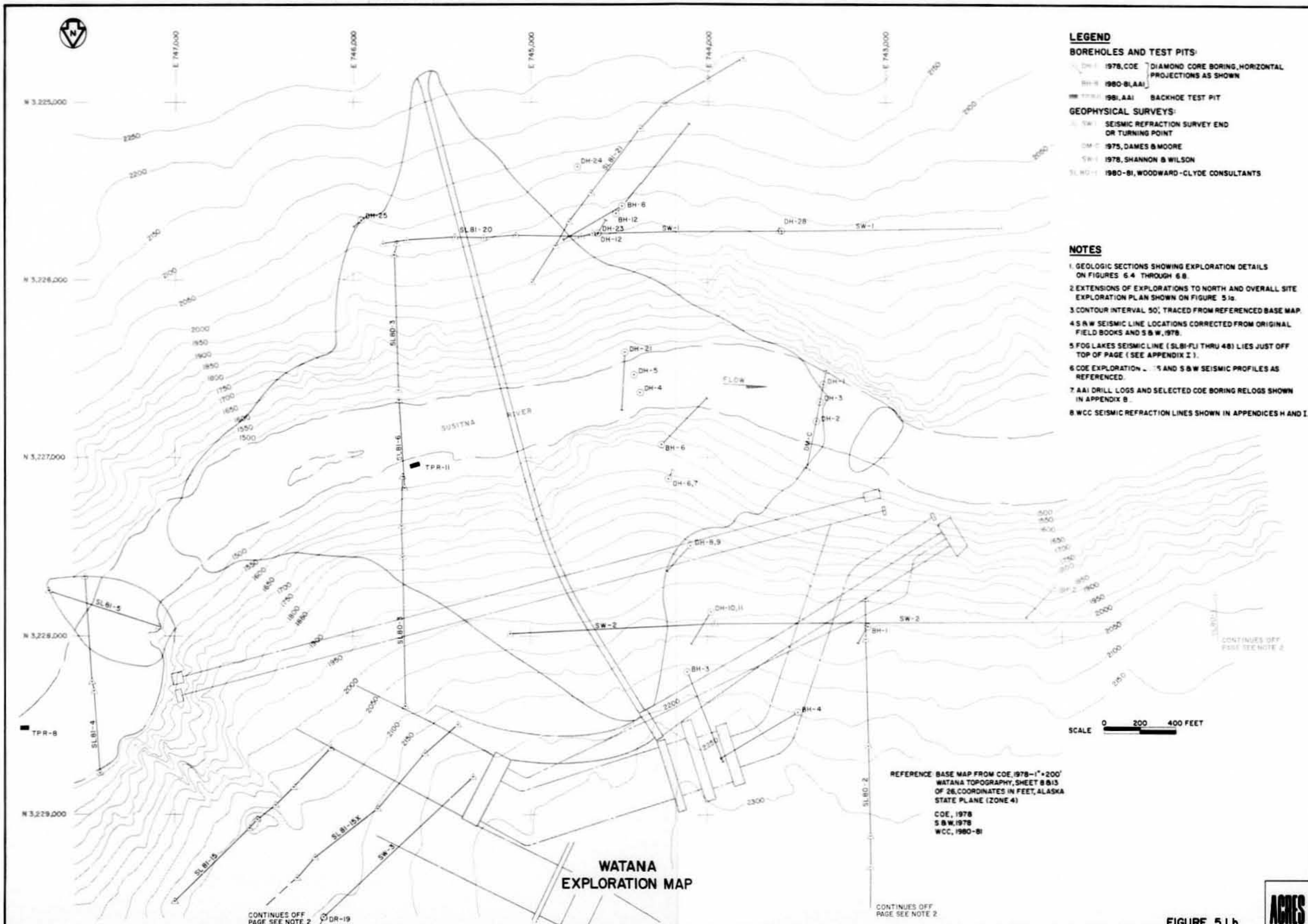
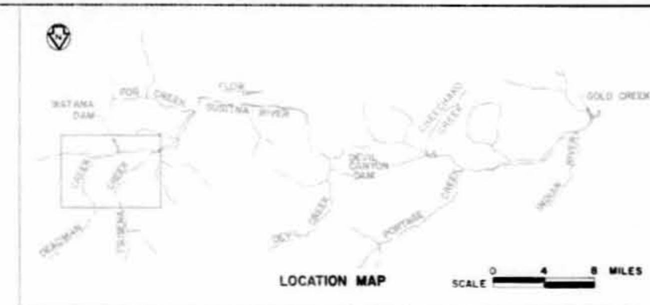
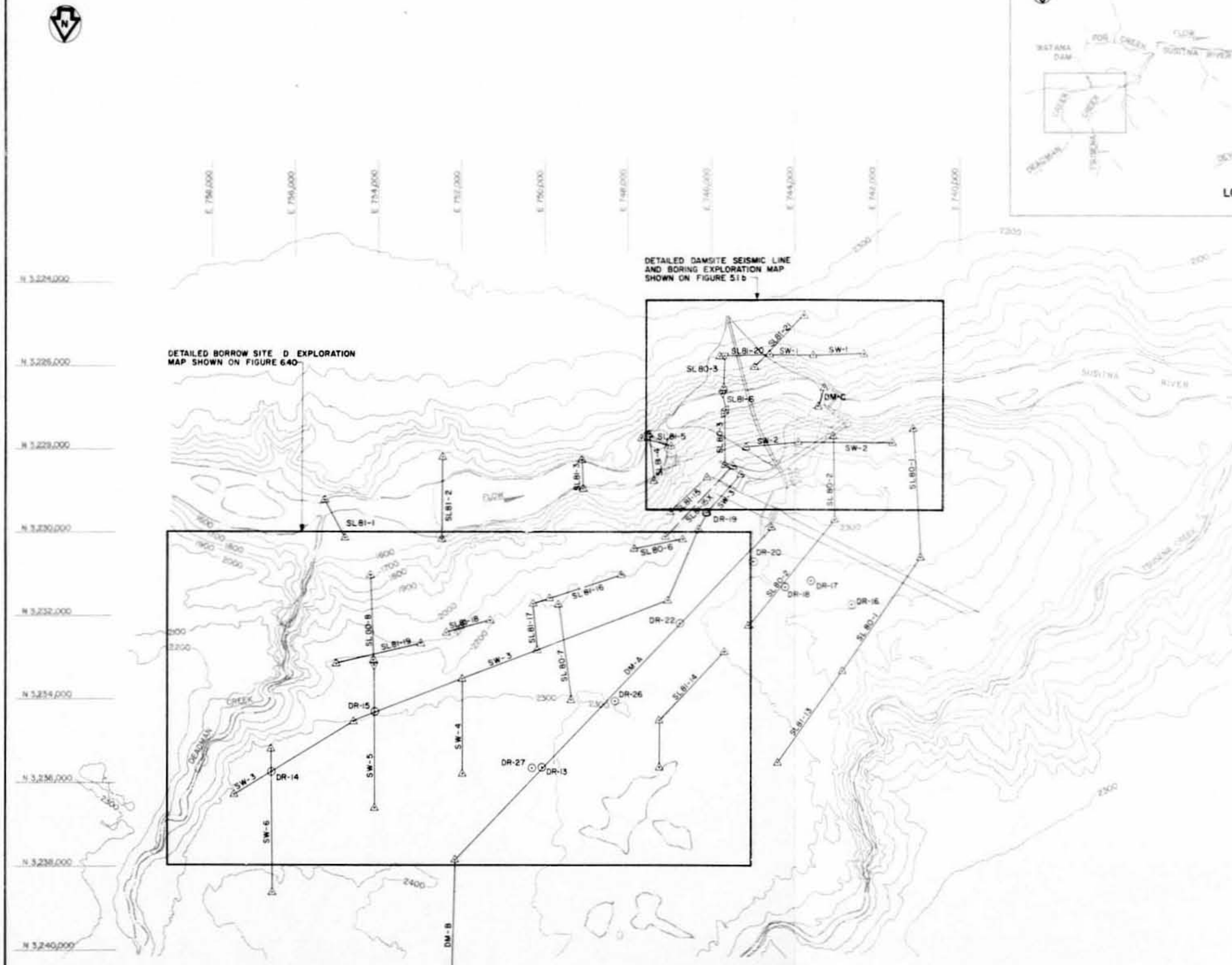

LEGEND
BOREHOLES AND TEST PITS:
1978, COE
1980-81, AAI
DIAMOND CORE BORING, HORIZONTAL PROJECTIONS AS SHOWN
1981, AAI BACKHOE TEST PIT
GEOPHYSICAL SURVEYS:
SEISMIC REFRACTION SURVEY END OR TURNING POINT
1975, DAMES & MOORE
1978, SHANNON & WILSON
1980-81, WOODWARD-CLYDE CONSULTANTS
NOTES
1. GEOLOGIC SECTIONS SHOWING EXPLORATION DETAILS ON FIGURES 6.4 THROUGH 6.8.
2. EXTENSIONS OF EXPLORATIONS TO NORTH AND OVERALL SITE EXPLORATION PLAN SHOWN ON FIGURE 5.1a.
3. CONTOUR INTERVAL 50', TRACED FROM REFERENCED BASE MAP.
4. S&W SEISMIC LINE LOCATIONS CORRECTED FROM ORIGINAL FIELD BOOKS AND S&W, 1978.
5. FOG LAKES SEISMIC LINE (SL81-FL1 THRU 48) LIES JUST OFF TOP OF PAGE (SEE APPENDIX I).
6. COE EXPLORATION ... S AND S&W SEISMIC PROFILES AS REFERENCED.
7. AAI DRILL LOGS AND SELECTED COE BORING RELOGS SHOWN IN APPENDIX B.
8. WCC SEISMIC REFRACTION LINES SHOWN IN APPENDICES H AND I.
SCALE 0 200 400 FEET
REFERENCE: BASE MAP FROM COE, 1978 – 1" = 200' WATANA TOPOGRAPHY, SHEET 8 & 13 OF 26, COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4)
COE, 1978
S&W, 1978
WCC, 1980-81
E 747,000
E 746,000
E 745,000
E 744,000
E 743,000
N 3,225,000
N 3,226,000
N 3,227,000
N 3,228,000
N 3,229,000
SUSITNA RIVER
FLOW
DH-24
SL81-21
BH-8
BH-12
DH-23
DH-12
SW-1
DH-28
DH-25
SL81-20
SL80-3
DH-21
DH-5
DH-4
DH-1
DH-3
DH-2
DM-C
BH-6
DH-6,7
SL81-6
TPR-11
DH-8,9
SL81-5
DH-10,11
SW-2
BH-1
BH-3
BH-4
TPR-8
SL81-4
SL80-2
SL81-15
SL81-15X
SW-3
DR-19
CONTINUES OFF PAGE SEE NOTE 2
WATANA EXPLORATION MAP
ACRES

FIGURE 5.1 b





LEGEND

BOREHOLES AND TEST PITS:

DR-16 1978, COE ROTARY DRILL BORING

GEOPHYSICAL SURVEYS:

SEISMIC REFRACTION SURVEY END OR TURNING POINT

DM-C 1975, DAMES & MOORE

SW-2 1978, SHANNON & WILSON

SL81-5 1980-81, WOODWARD-CLYDE CONSULTANTS

NOTES

1. DETAILED EXPLORATION MAP OF DAMSITE ON FIGURE 5.1b
2. BORROW SITE D TEST PITS AND AUGER HOLES, AS WELL AS SEISMIC LINES, SHOWN ON FIGURE 6.40.
3. DETAILED SECTION ON DM-A & B ON FIGURE 6.31.
4. RIVER ALLUVIUM TEST PITS SHOWN ON FIGURES 6.51 AND 6.52.
5. RELICT CHANNEL AREA MAP SHOWN ON FIGURE 6.35.
6. CONTOUR INTERVAL 100', ENLARGED AND TRACED FROM REFERENCED BASE MAP.
7. D & M SEISMIC LINE LOCATIONS CORRECTED PER COE SURVEY AND REFERENCED BASE MAPS.
8. S & W SEISMIC LINE LOCATIONS CORRECTED FROM ORIGINAL FIELD BOOKS AND S & W, 1978.
9. LINE DM-B CONTINUED 11,000 FEET NORTH OF TURNING POINT SHOWN.
10. COE EXPLORATION LOGS AND S & W SEISMIC PROFILES AS REFERENCED.
11. WCC SEISMIC REFRACTION DATA SHOWN IN APPENDICES H AND I.
12. NORTHING GRID LINES ARE IN ERROR BY APPROXIMATELY 50 FEET, NORTH, FROM STATION N 3,232,000 TO N 3,234,000

SCALE 0 1000 2000 FEET

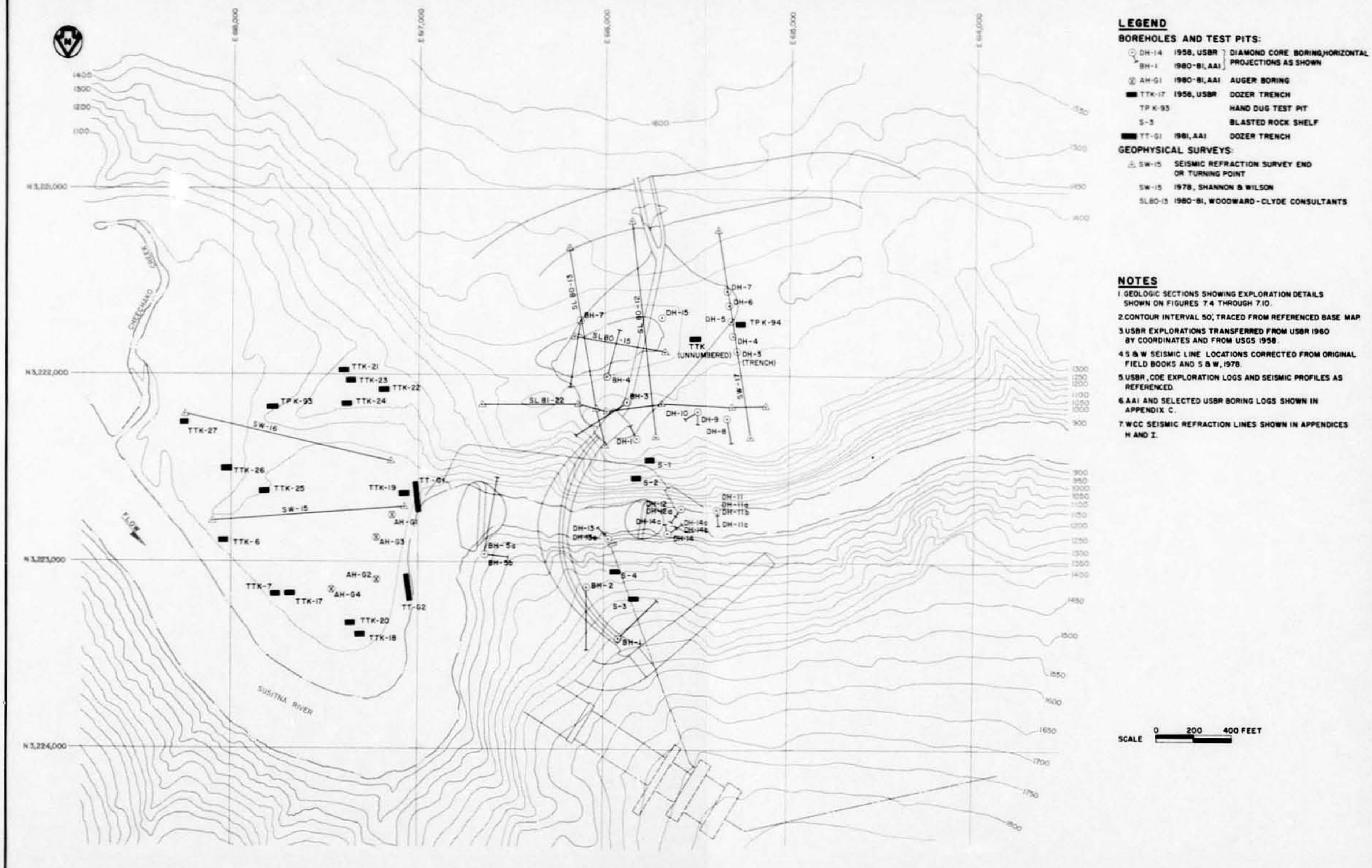
REFERENCE: 1" = 200' COE, 1978 WATANA DAMSITE TOPOGRAPHY, SHEET 1 THROUGH 26

CONTINUES OFF PAGE SEE NOTE 9

WATANA
DAMSITE VICINITY-EXPLORATION MAP

ACRES

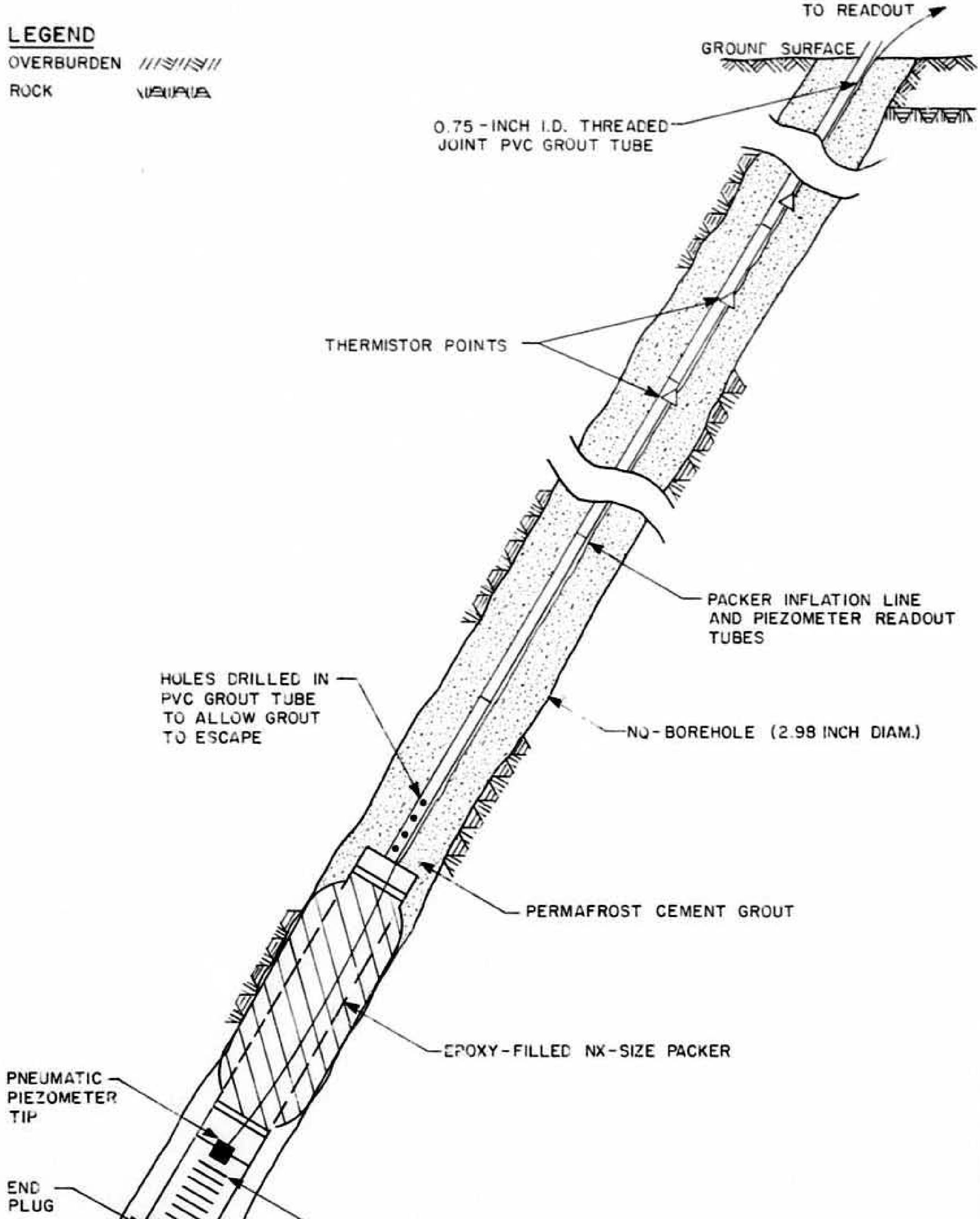
FIGURE 5.1a



REFERENCE: BASE MAP FROM R&M, 1981-1"=200' DEVIL CANYON TOPOGRAPHY
USBR, 1960
S & W, 1978
COE, 1978
COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4)

DEVIL CANYON
EXPLORATION MAP

FIGURE 5.2



TYPICAL BOREHOLE INSTRUMENTATION

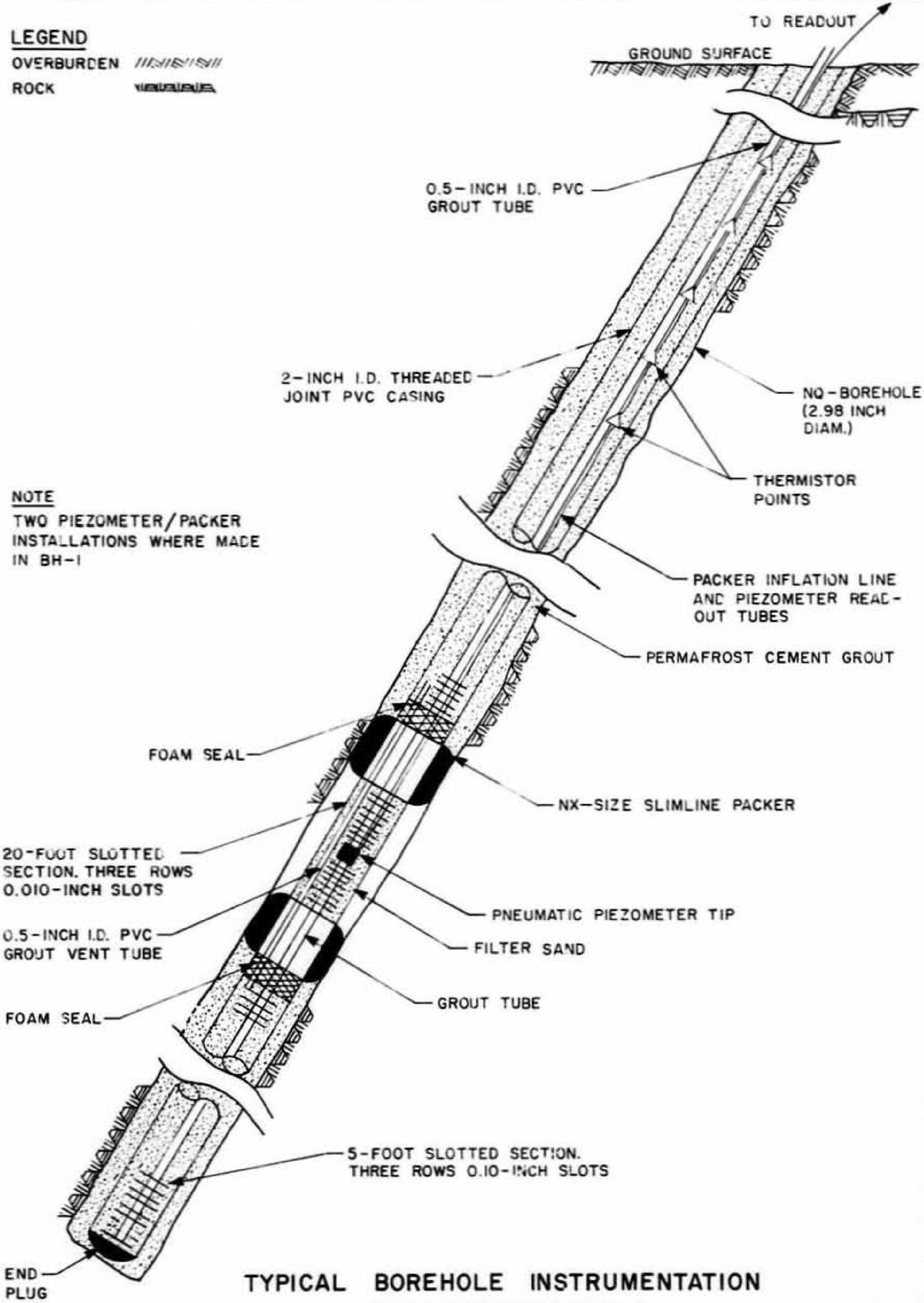
WATANA : BH-6 AND BH-3
DEVIL CANYON: BH-2

(NOT TO SCALE)

PREPARED BY R&M CONSULTANTS, INC.

ACRES

FIGURE 5.3



TYPICAL BOREHOLE INSTRUMENTATION

DEVIL CANYON: BH-I AND BH-4

(NOT TO SCALE)

PREPARED BY R & M CONSULTANTS, INC.

FIGURE 5.4

6 - RESULTS OF GEOTECHNICAL INVESTIGATIONS - WATANA

The results of the geotechnical studies performed at the Watana site are presented in this section. The three principal subsections are:

- Subsection 6.1: Watana Damsite;
- Subsection 6.2: Relict Channels; and
- Subsection 6.3: Borrow & Quarry Material.

Map locations presented in this section are shown on the Watana Index Map - Figure 6.1.

6.1 - Watana Damsite

(a) Overburden Conditions

(i) General

A top-of-bedrock and surficial geologic map for the damsite area is shown on Figure 6.2. Determination of these overburden thicknesses and material types at the site has been based on geological mapping, seismic refraction surveys, drilling, and test pits. Geologic profiles depicting subsurface stratigraphy in the main dam area and borrow sites are presented in later sections. Data used in developing these figures are provided in Appendices B, F, H, and I while Table 6.1 provides the correlation of seismic velocities with soil and rock types used for this study.

(ii) Damsite

Within the limits of the damsite, three distinct zones of overburden can be delineated at the site. These are: (a) top of slope (elevation approximately 2200) to approximate Elevation 1950 to 1900; (b) Elevation 1900 to river level, and (c) riverbed.

The upper areas of the abutments near the top of slope consist of deposits of till, alluvium, and talus. On the north abutment, the alluvium is significantly intermixed with talus material. The thickness of this cover may reach 50 to 60 feet. On the south abutment, the average overburden depth is estimated at 20 feet with isolated zones of apparent channel fill material reaching 70 feet or more, as shown by seismic line SL81-20 and DH-25 (Figure 6.2).

Below Elevation 1900 to 1950 where the valley changes from a "U" shape to a "V" shape, the overburden becomes thinner and more varied, ranging from probable maximums of 40 feet thick at the river edge (where there are talus and minor avalanche deposits) to zero along the numerous rock cliffs. Most of the material is rock derived from the cliffs with occasional remnants of silty sand and gravel river terrace deposits. Some larger, well-rounded boulders occur at the lower elevations. The average abutment overburden thickness in this zone is estimated to be 10 feet of alluvium and loose talus materials.

Cobbles and gravels occur from flood elevation (about 1470 feet) down to the river. Boreholes and seismic lines in the river show a relatively consistent deposit of river alluvium composed of gravel, cobbles, and boulders with a sand matrix interspersed. The maximum depth of river alluvium in the main dam area is estimated not to exceed 90 feet.

A recent seismic refraction survey suggests that there are bedrock shallows near the proposed upstream cofferdam site (Appendix I). This interpretation is questionable because of the poor resolution of the seismic data. A more reasonable interpretation would be either the existence of frozen material or the presence of very densely compacted talus material that has been eroded from the adjacent 'The Fins" structure (Section 6.1[c]). However, further work will be required in this area to confirm these velocities.

(iii) Emergency Spillway

The upper portion of the proposed emergency spillway is founded in an area of shallow overburden, whereas the west-northwest extension of the spillway that extends downslope off the flank of the pluton is in an area of deeper overburden. The estimated depth to rock in this area is shown in Figure 6.2.

(iv) Camp Areas

The proposed construction camp and permanent village site is northwest of the damsite in an area of deep overburden that consists primarily of sands and gravels with interspersed boulders. Bedrock depths are expected to exceed 100 feet throughout the area. A more complete discussion of the geology and overburden of this area is presented in Section 6.2.

(v) Access Roads

Construction of access roads to the site will encounter areas of very deep overburden. Access and haul roads outside the damsite area will, to some degree, be routed along gravel terraces, but in many areas will cross shallow, boggy, and swampy areas and zones of till, clays, and silts. Further detailed investigations will be required in subsequent phases of study to accurately determine soil and foundation conditions along proposed access routes.

(b) 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 site area by andesitic volcanic flows and volcaniclastic sedimentary rocks. These rocks have not been assigned formational names, but rather have been given lithologic names for mapping and correlation purposes.

The lithology and structure at the Watana site are shown on a geologic map, Figure 6.3, and five geologic sections, W-1 through W-5 (Figures 6.4 to 6.8).

The geology shown in these figures is based on field mapping, and borehole and seismic refraction data (Section 5). Where possible, mapped surface structures were 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 great distance. Therefore, future investigations will be necessary to confirm the location and continuance of those features shown in the figures.

For simplicity, borehole information shown on Figures 6.4 to 6.8 is limited to features five feet or greater in thickness. More detailed information is contained in Appendices B, D, H, and I.

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 6.2). 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 silica content from diorite to granodiorite. The rock types are observed in both outcrop and boreholes to grade 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. A similar gradational contact is found in boreholes BH-6 and BH-8 (Appendix B) over 0.3 foot at Elevation 1594 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.

The diorite here 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 planar structures. 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" area (Figure 6.3).

The diorite is generally fresh and hard to very hard. The rock is slightly weathered along the joint surfaces at a depths of about 50 to 80 feet (Section 6.1[c]). 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 altered to chlorite. Hydrothermal alteration is discussed in detail in Section 6.1(c).

(iii) Andesite Porphyry

The name andesite porphyry is used for a varied group of apparently related extrusive rock types (46). The andesite porphyry occurs along the western side of the diorite pluton and is exposed in outcrops on both sides of the Susitna River (Figure 6.3). 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 6.4), BH-8 (Figure 6.5), and BH-2 (Figure 6.7) to depths of 96.0, 43.0 and 103.0 feet, respectively. Borehole DH-28 bottomed at 125 feet in the porphyry (Figure 6.8). Andesite porphyry dikes are also found interspersed in the diorite. On 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). 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 and basalt. The latite occurs in the "Fingerbuster" area (47) and the dacite in Quarry A. The basalt occurs in the area of the volcaniclastic sediments downstream from the "Fingerbuster."

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. Figure 6.9 is a photograph of the andesite porphyry in the "Fingerbuster" area which shows numerous lithic inclusions, as well as flow structure lineation.

A sequence of volcaniclastic rocks (46) composed of tuffaceous sandstones and siltstones are exposed 2,500 feet downstream of the contact between the andesite porphyry and the diorite. The siltstones are medium gray, fine grained while the sandstone has a buff colored ground mass with grains of feldspar, quartz and argillite. Bedding of these units strike nearly north-south with dips generally less than 30° to the west. The rock is slightly weathered and iron oxide stained. The relationship between the volcaniclastic rocks and the andesite porphyry is not clearly defined because of outcrop exposure.

(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 left abutment and northerly across the right abutment (Figure 6.3). On the south bank it is intersected in BH-8 and BH-12 and 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. Figure 6.10 is a photograph showing the closely to very closely spaced joints in the andesite porphyry immediately above the diorite contact.

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 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 are 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 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 feet. 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 shear zone ("Fingerbuster") (Section 6.1[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 of the "Fingerbuster" and not necessarily representative of the contact. Above Elevation 2000, the contact is assumed to dip moderately to the 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 several inches by shears and healed shears in outcrop and in boreholes (BH-3 at 702.7 and 801.3 feet). Figure 6.11 shows a 7-inch wide felsic dike offset along a healed shear. The healed shear is tight and hard.

Mafic dikes are less common at the site than the felsic dikes. They are rarely seen in outcrop and only found 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 (BH-2,

Appendix B). 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 dike, 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 "The Fins" on the north bank and in Quarry L on the south bank (Figures 6.3). The dike is porphyritic with an aphanitic to fine grained ground mass. 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 20-foot-wide shear/alteration zone (see Section 6.1[c]). The eastern contact is not exposed.

(c) Structural Geology

(i) Introduction

This section discusses the structural geology at the Watana site 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 (Figure 6.12). Joint stations were chosen at representative areas having good

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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.

At stations WJ-1 through WJ-3, only 60 to 86 joint readings were taken because of limited exposure, while one hundred joints each were recorded at each of the other six stations. For each station, 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 (5) is presented on Figure 6.12.

In addition to the joint station plots, composite joint plots were constructed from both joint station and outcrop data. The site was divided into four quadrants. A composite plot for each quadrant is shown in Figure 6.13.

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, while Table 6.2 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 separately.

Joint Set I is the most prominent set at Watana. The average orientation is 320° in the four quadrants (Figure 6.13). Dips average 80° northeast in the northeast and southeast quadrants and vertical in the northwest and southwest quadrants. Joint surfaces are planar and smooth to 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 6.12). The joints are continuous and generally tight. Open joints are found at the surface in fracture zones and shears. Set I parallels most major shears, fracture zones, and alteration zones found at the site.

A subsidiary Joint Set (Ib) to Set I was found in the area downstream of the dam centerline at joint station WJ-7. This subset trends from 290° to 300° with an average dip of 75° northeast. This subset is also strongly developed at joint stations WJ-1, WJ-2, and WJ-9 (WJ-2 is in the area of the diversion tunnel outlet). The subset in the northwest and southwest quadrants (downstream from WJ-4) is parallel to the trend of the shears in geologic features GF 7A, GF 7B, and GF 7C (see Significant Geologic Features) (Figure 6.3). This trend is also parallel to the Susitna river between the dam centerline and diversion tunnel outlet.

Joint Set II is northeast-trending, ranging in strike from 045° to 080° with an average trend of 060° across the site. Most dips are steep from 80° southeast to 80° northwest. Set II is best developed in the northeast and southeast quadrants where the trend averages 050° with a preferred dip to the northwest. At stations WJ-3 and WJ-5, near the diversion tunnel entrance, 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 dips vertically. Set II joints are generally planar with smooth to rough surfaces. Joint spacings range from 1 inch to 5 feet, averaging 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.

No shears or alteration zones were found associated with Joint Set II.

Joint Set III is generally north-south trending, ranging in strike between 340° and 030° with variable dips from 40° east to vertical to 65° west. Set III is a minor set although locally pronounced in the northwest and southwest quadrants. In the northeast quadrant, the average strike and dip are 005° and 60° east. In the southeast, the strike and dip are generally 350° and 65° west (WJ-7).

Fracture and shear zones parallel to Set III were mapped in structural areas GF 6A, GF 6B, and in the "Fingerbuster" (Figure 6.3). At GF 6B, Set III forms numerous open joints on the cliff face. Where present, the Set III joints range in spacing from less than 1 inch in fracture zones to 5 feet, with an average of 1.5 feet. These joints are generally planar to irregular and 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 at the diversion tunnel outlet.

Joint Set IV consists of numerous low angle (dipping less than 40°) joints of various orientations, the strongest trend being 090° (Table 6.2). In all but the northeast quadrant, these joints dip towards the Susitna River at less than 30°. In the northeast quadrant, dips are both towards and away from the river. Set IV joints are planar to irregular, smooth to rough and discontinuous. Spacing is generally 1 to 2 feet when present. No mineralization, shearing, fracture, or alteration zones are associated with this set. Set IV joints probably resulted from stress relief after glacial unloading and/or erosion of the river valley, and therefore should not occur at depth.

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 Joint Sets I and III. No major structures were found associated with Sets II and IV. The Susitna River appears to be joint-controlled at the Watana site. 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 Joint Set I.

(iii) Shears, Fracture Zones, and Alteration Zones

This section defines and discusses shears, fracture, and alteration zones and combinations of these features which are shear/fracture zones and shear/alteration zones mapped at the Watana site. Symbols denoting these features on the geologic sections (Figures 6.4 through 6.8) 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 and discontinuous. Where more than 10 feet wide, both boundaries have been delineated on the geologic map (Figure 6.3) 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 and is characterized by breccia, gouge, and/or slickensides indicating relative movement.

Two types of shears are found at the Watana site. The first type, which is found only in the diorite, is called healed shears and 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 very hard to hard. Figure 6.11 shows a 1-to-2-foot-wide healed sheared zone. 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. 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.

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 (Figure 6.18). 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 20 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 most shears and occur on both the carbonate and chlorite surfaces. These 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. Figure 6.18 is a photograph of a typical shear which is within a fracture zone. These zones will be discussed in more detail in the Fracture Zone and Alteration Zone subsections.

- 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. 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 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). 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. Figure 6.15 is a photograph of an alteration zone within "The Fins". As seen in the figure; the intact diorite is in the upper right and is noticeably darker than the lighter, bleached diorite that is altered and sheared. Iron oxide staining is visible over a 2-to-8-inch-wide carbonate band.

Widths of these alteration zones most often range up to 20 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 (Figure 6.5, see Subsection [iv]). Several shear/alteration zones are exposed in "The Fins" and range from 10 to 55 feet wide.

The carbonate, which is also associated with the alteration zones, occurs as veins or joint filling generally up to 0.5 inches 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 (<2 inches) shears are associated with the alteration zones (Appendix B). 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 site has several significant geologic features which consist of broad areas of shears, fracture zones, alteration zones, and/or combinations of these features. Two of these areas, initially mapped by the COE (45) are called "The Fins" and "Fingerbuster" (Figure 6.3). Other areas or individual structures considered to warrant detailed discussion have been identified on Figure 6.3 by letters GF 1 through GF 8 and are discussed individually below.

- "The Fins"

"The Fins" consists of major zones of shearing and alteration. This feature is located on the north bank of the Susitna River upstream from the proposed diversion tunnel intake portal (Figure 1.2). "The Fins" consists of a 400-foot-wide zone containing a series of northwest trending shear/alteration zones. Gullies formed by erosion of these structures are separated by intact rock bands or ribs ranging from 5 to 50 feet wide.

Three major and numerous minor shear/alteration zones have been mapped in "The Fins." From upstream to downstream, the major zones consist of a 20-foot-wide zone in the area of the diorite and diorite porphyry contact; a 55-foot-wide zone; and a 30-foot-wide zone. These zones are separated by intact competent rock bands or ribs. Large gullies with thick talus have formed in these zones, resulting in poor rock exposure. These zones trend in a northwest-southeast direction and are near vertical. Figure 6.16 is an aerial photograph of "The Fins" looking northwest along the strike. The 55-foot-wide gully (as measured at river level) splits into two branches 20 to 30 feet wide at approximate Elevation 1650. A 10-foot-wide zone of altered and crushed rock is exposed near river level on the east side (Figure 6.15), and there is a 3-foot-wide zone of sheared/fractured and moderately to severely altered rocks on the west side of the main gully. The remainder of the gully is covered by talus. Based on these exposures, it has been assumed that the shear and alteration zones extend across the full 55-foot width of the gully.

There are carbonate veins parallel to these zones and others which transverse them. Carbonate thicknesses range from 0.5 to 8 inches. The veins are fractured but no offsets were noted.

Minor east-west and north-south trending shears also occur in "The Fins." These features are generally less than 1 foot wide. Two north-south trending shears mapped in "The Fins" are 1 foot and 3 feet wide, respectively, and dip 57° to the west. Slickensides on carbonate coatings indicate an oblique sense of movement. Figure 6.14 shows a 3-foot-wide north-south shear. This shear appears to project across the river in the vicinity of the upstream cofferdam and align with a topographic trend on the south bank. Lineations associated with the north-south shears are indicated on Figure 6.16.

The overall trend of "The Fins" is 300 to 310°. Dips are steep to vertical. The extension of this feature to the northwest is inferred from seismic refraction lines SL 81-15, SL 81-15x, and SW-3 which show low seismic velocities (10,000-12,700 feet per second) in bedrock, as well as low bedrock elevation along the projection of "The Fins" (Figure 6.5). In contrast, the bedrock seismic velocity northeast and southwest of this feature is about 18,000 feet per second (Appendices H and I).

Beyond the seismic lines, "The Fins" has been inferred to trend along a topographic low (Figure 6.16). Altered rock found in COE boreholes DR-18, DR-19, and DR-20 in Borrow Site D may also have been drilled in this feature (Figure 5.1). 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 L (Section 6.3[i]), which is the inferred location of "The Fins" structure. Beyond this area, no outcrops or topographic trends could be correlated to this feature. The trace of this feature is also supported by mapping activities performed by Woodward-Clyde Consultants during their seismic studies carried out during 1980-81 (57,58).

- Geologic Feature GF 1

  GF 1 is the region downstream of "The Fins" in the vicinity of the proposed upstream cofferdam and diversion tunnel portals. For discussion purposes, the area has been divided into two subareas: GF 1A on the north bank and GF 1B on the south bank (Figure 6.3).

  Subarea GF 1A contains east-west and northwest-southeast trending shears and fracture zones. The east-west shears are oriented between 280° and 290° with vertical dips. Shear widths are generally 1 foot or less. The northwest-southeast (310 to 320°) trending shears are up to 3 feet wide and are parallel to two fracture zones. These zones are 25 to 30 feet wide and form gullies. These features are likely to be encountered in the proposed diversion tunnels (Figure 6.7), intersecting the tunnels at high angles (Figure 6.3). The most significant structure in GF 1B is a 20-foot-wide frac-

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ture zone trending at 315° and dipping vertically. A 1-foot-wide zone of possible gouge was found in the zone. Approximately 100 feet to the northeast, a 4-inch-wide shear was mapped parallel to this fracture zone. The correlation of the structures in GF 1A with those in GF 1B are uncertain.

- Geologic Feature GF 2

GF 2 (Figure 6.3) is approximately 80 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 steep to the north.

On the north bank, there is no strong topographic expression of the GF 2 structure. A 30-foot-wide gully postulated as a fracture zone was mapped at about Elevation 1700. Joint orientations in this area are similar to those on the south bank. The GF 2 structure was projected farther to the northwest in alignment with a low seismic velocity (14,800 feet per second) zone on SL 80-3 (Appendix I). Based on this evidence, it is likely that this fracture zone will be encountered in the diversion tunnel (Figure 6.7), intersecting the tunnel at an oblique angle.

- Geologic Feature GF 3

GF 3 is located on the south bank (Figure 6.3). This area contains fracture zones and minor shears. These structures strike predominantly at 320° and have vertical to steep northeast dips. A 20-foot-wide fracture zone was mapped in a deep gully paralleling Joint Set I. Parallel to this zone is a 4-to-6-foot wide zone of breccia with heavy carbonate coating. Also in GF 3 is a 3-to-6 foot-wide shear/fracture zone which trends north-south and dips 60° east. No features similar to those in GF 3 were found on the north bank.

- Geologic Feature GF 4

GF 4 consists of two shear/fracture zones (GF 4A and GF 4B), each about 10 feet wide (Figure 6.3). 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 (SL 80-3) are lower (15,000 feet per second) than the usual 18,000 to 20,000 feet per second velocities measured in less fractured diorite. 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 (Figure 6.17). GF 4A has been tentatively correlated with the shears, fracture zones, and alteration zones found in borehole BH-3 (Figure 6.4) 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 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 6.4) at borehole depth 189.0-197.7 feet. The fracture zone is iron oxide stained. The upper three feet of the zone is hydrothermally altered and contains 0.2 foot 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 projection of the GF 4A and GF 4B structures would intersect the proposed diversion tunnels (Figure 6.3) at a high angle.

- Geologic Feature GF 5

GF 5 is located near the proposed dam centerline and consists of fracture zones and minor shears (Figure 6.3). 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 bounded on the downstream side by a 75-foot-high diorite cliff (Figure 6.17). Two northwest trending shears 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 no topographic expression of these features on the north abutment, it has been correlated with several shear and fracture zones intersected in borehole DH-9 (Figure 6.4) and with a 130-foot-wide, low-velocity zone on SW-2 (12,500 fps) (Appendix I). 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. No low-velocity zones were encountered along SL 80-2 (Figure 6.3) that could imply continuation of this feature to the northwest (Appendices H and I).

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 slope, it is correlated with a moderately low (15,000 feet per second) velocity zone along SL 80-3 and a bedrock depression found in borehole DH-25 (Figure 6.8). In this area, overburden thickens from 10 or 15 feet to nearly 80 feet. On the north bank, GF 5 will likely intersect the proposed diversion tunnels (Figure 6.3).

. Geologic Feature GF 6

GF 6 is divided into two subareas: GF 6A on the north bank and GF 6B on the south bank (Figure 6.3). Both subareas are characterized by north-south trending structures. GF 6A is approximately 25 feet wide and occurs in a north-south trending gully whose walls are very closely jointed, severely weathered, possibly altered, and locally friable. A strong north-south trending joint set (Set III) with vertical and steep dips occurs in this area.

Subarea GF 6B is characterized by north-south shears, fracture zones, and open joints; east-west trending open joints; and northwest trending shears (Figure 6.3). These features are exposed in deep gullies in the high rock cliff face on the south side of the river (Figure 6.18). 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 GF 7 below. No direct evidence could be found during this study to correlate GF 6A and GF 6B.

- <u>Geologic Feature GF 7</u>

GF 7 is divided into three subareas: GF 7A on the north bank; GF 7B, which trends across the river from the north bank to the south bank; and GF 7C, which lies between these two areas on the north bank (Figure 6.3). GF 7 is characterized by numerous northwest (290° to 300°) trending, nearly vertical shears. These shears are generally 1 foot or less wide and are often associated with fracture zones up to 10 feet wide.

Subarea GF 7A is about 40 feet wide and lies in a shallow northwest trending gully. An outcrop on the east side of the GF 7A structure at approximate Elevation 1850 is a moderately soft, altered diorite. The extent and orientation of GF 7A are uncertain; however, based on field mapping, it appears to trend in a northwesterly direction.

On the north bank in the andesite porphyry, subarea GF 7B lies in a deep, vegetated gully trending at 290° (Figures 6.3 and 6.19). Exposures in the gully show 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. Figure 6.20 shows where GF 7B intersects the "Fingerbuster" at river level on the north bank (see next subsection). Subarea GF 7B has been projected across the river to correlate with features exposed along the base of the cliffs in area GF 6B (Figure 6.3). GF 7B appears to dip at 75° to the north. This is based on the slope of the cliff face and dips of shears behind and at the base of the cliff. GF 7B was also correlated with a shear zone intersected from 97.8 to 104.0 feet in DH-1 (Figure 6.6). 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. Subarea GF 7B projects to the southeast from the river bank and is exposed in a steep-walled, 10-to-15-foot wide gully at the andesite porphyry/diorite contact at Elevation 1750. GF 7B crosscuts both of these rock types. 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 7B were found beyond this point; however, it has been tentatively correlated to a 10,000-feet-per-second zone on seismic line SW-1 and to shear/fracture zones in DH-23 (Figure 6.5). This correlation is questionable, since the zone was not intersected by BH-8, which lies between these features.

Subarea GF 7C is bounded by the "Fingerbuster," subarea GF 7A and a north-south trending gully on the east side (Figure 6.3). This area has a step-like appearance in section because of a series of east-west trending ridges and gullies between 10 and 20 feet wide. The "steps" trend along the 290° to 300° shears which are parallel to Set I joints in this area. Numerous minor shears in this area have resulted in gullying and erosion. This area was interpreted to be a series of near-surface slumps along the northwest-trending shears. It is assumed that GF 7C extends to near Elevation 2200, where a low-velocity zone was found on SW-2. The size and stability of these blocks will require investigation in subsequent phases of work.

- "Fingerbuster"

The second most prominent structural feature at Watana is the major zone of shears called the "Fingerbuster," located about 2,000 feet downstream of the proposed dam centerline. On the north bank, this structure is partially exposed in a 40-foot-wide gully filled with a deep talus deposit. The andesite porphyry/diorite contact is coincident with this structure to about Elevation 2000. An outcrop in the gully 100 feet above river level is a highly fractured diorite breccia in an andesite matrix. The rock is moderately to severely weathered. Joints are very closely to closely spaced in the gully, trend 330° (Set I) and 0° (Set III), and dip 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 the "Fingerbuster" structure to determine its location at depth. Between borehole depths of 71.2 and 177.1 feet, the borehole intersected a shear/fracture zone which was also coincident with the andesite porphyry/diorite contact at approximately 126 feet (Figure 6.7). 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 "Fingerbuster" to the northwest is inferred to be another shear and fracture zone.

The extension of the "Fingerbuster" 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.

- 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 6.3). This area was delineated during the 1981 field season for a possible underground powerhouse 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 (SL 81-21) was shot along a northeast-southwest trend across the south bank (Figure 6.3). A zone about 1,100 feet long of low seismic velocity in bedrock was found. Velocities were about 12,000 feet per second in this zone and 18,000 feet per second 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 6.5). 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 SL 81-21, 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 6.8). East of DH-28, SW-1 shows zones of alternating high (17,500-20,000 feet per second) and low (12,000-13,000 feet per second) 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 6.5). This observation served to limit the northeastward 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 SL 81-21. The southwest contact was assumed 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 6.5).

(d) Rock Quality Designation

The Rock Quality Designation (RQD) (13) was determined for all rock cores drilled by Acres and COE and is graphically shown on the Summary Logs in Appendix B. Excluded from this series of borings are COE DR-16, DR-17, DR-18, DR-19, DR-20, and DR-22 which were rotary drilled without core recovery and, therefore, no RQDs were obtained. A tabulation of the RQD values is provided in Tables 6.3 and 6.4. As noted in the tables, rock quality encountered in the drilling was generally good to excellent with RQDs averaging between 75 and 90 percent. In general, rock quality improves with depth, with the upper 50 to 80 feet of rock being weathered and more fractured. Below this weathered zone, rock quality is good to excellent with only localized zones of fractured and sheared rock. These zones generally range in thickness from 1 to 5 feet, but can be up to 30 feet. RQDs correlate well with the permeability tests (Section 6.1[f]) which is generally a function of rock quality.

Poor quality rock was found in BH-2 which drilled through part of the "Fingerbuster" shear zone. This borehole was sited downstream from the zone and drilled at an azimuth of 045° and a dip of 55°. As seen in the boring logs, the shear zone was intersected at a borehole depth of approximately 70 feet and continued to a hole length of approximately 100 feet (vertical depth 65 to 80 feet). This zone, which corresponds with the andesite porphyry/diorite contact, consists of highly fractured, severely weathered brecciated and sheared rock. Repeated grouting was required to maintain hole stability. Below this zone, rock quality improved with only localized zones of low RQDs encountered around borehole depth of 200, 210, and 250 feet. Other poor quality rock was encountered in several shallow COE holes (DH-1 and DH-28). These holes were drilled to a depth of less than 125 feet and reflect the poor quality, near surface weathered rock conditions.

In general, weathering appears to be primarily physical in nature, with weathered rock being about 40 feet deep at the damsite. The weathering is light to moderate in joints, with penetration generally less than a inch into the unbroken rock. Shear and fracture zones are considerably more weathered, and many of the shear zones

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exhibit chemical weathering and hydrothermal alteration. Details of these zones are discussed in Section 6.1 (c).

The intact rock is classified as Class B "high strength" and has a high static modulus to compressive strength ratio of 500. Rock overall classification is BH (14).

(e) Rock Properties

Representative NQ (1.77 inches) rock core samples of andesite porphyry, diorite, quartz diorite and granodiorite samples were selected from BH-1, -2, -3, -4, -6, -8, and -12 for laboratory testing. Results of the testing are presented in Tables 6.5 and 6.6 and are discussed below. Since the properties of diorite, quartz diorite, and granodiorite were found to be similar, they have been included under the heading of diorite. Photographs of typical rock testing is shown in Figure 6.21.

(i) Unit Weight

Dry unit weights were determined in conjunction with compression and tensile strength tests. Dioritic rocks averaged 167 pcf and andesite rocks averaged 165 pcf.

(ii) Static Elastic Properties

Elastic properties were measured under unconfined compression using electronic strain gages bonded onto the sample in horizontal and vertical directions. Stress, diametric strain and volumetric strain were calculated and plotted against axial stress from which the tangent modulus at 50 percent failure stress, secant modulus, and Poisson's Ratio were determined. Results are presented in Figure 6.22. An average of all test results shows:

Rock Type	Static Modulus ($x\ 10^6$ psi)	Poisson's Ratio
Andesite	10.2	0.25
Diorite*	9.5	0.23
Combined, all samples	9.64	0.24

*Includes diorite, granodiorite and quartz diorite

(iii) Dynamic Elastic Properties

Compressional (V_p) and shear (V_s) wave velocities were measured on two dioritic samples giving:

Dynamic Modulus ($\times 10^6$ psi)	Poisson's Ratio	Vp (fps)	Vs (fps)
10.1	0.31	19508	10267

(iv) Direct Shear Tests

Three types of direct shear tests were performed:

(1) Natural discontinuity
(2) Polished rock on rock
(3) Polished rock on mortar

Test results are plotted on Figure 6.23. A summary of the results are:

Diorite	Ø Peak	Ø Residual	C (psi)
Natural joint, rough, planar with carbonate, dry	38°	28°	0
Natural discontinuity with inferred cohesion		30°	29
Polished rock on rock, dry	21.5°	18°	0
Polished rock on mortar, dry	44°	31°	0
Polished rock on mortar, dry with inferred cohesion		31°	24

Polished rock on rock tests give a material's lowest friction angle. This angle does not include effects of natural surface undulations or roughness. Therefore, a "waviness angle" is applied to obtain a more representative value for design. This "waviness angle" is based to a large degree on observed field conditions of natural joint surface and site geology.

The results of the natural joint test quoted above show relatively high peak and residual values. Analysis of vertical vs. horizontal displacements shows a 10° incline, which appears to reflect this "waviness angle" for in situ conditions. As noted on Figure 6.23, two possible interpretations of the shear strength are given: a higher peak without cohesion or a lower peak including an apparent cohesion. The results are typical of natural joints and rock on concrete (21).

Diorite on mortar tests show that the shear strength is initially high but decreases to residual values with higher normal loads and greater displacements.

(v) Compressive Strength Testing

Compressive strengths were measured in unconfined compression and by point loading.

- Unconfined Compression

Results of unconfined compressive strength tests show:

Rock Type	Number Of Tests	High (psi)	Low (psi)	Mean ± Standard Deviation (psi)
Andesite	8	26,206	6,100	18361 ± 5978
Diorite	32	29,530	4,473	17593 ± 6080

Both rock types are isotropic and show relatively high strengths. Frequency plots (Figure 6.24) show 90 percent of all cores tested above 10,000 psi and approximately 70 percent of results plotted between 11,755 and 23,736 psi.

- Point Load Testing

Boreholes BH-6 and BH-8 were profiled at 15-to-20-foot intervals using a Terremetrics T-500 point load tester. Frequency plots (Figure 6.25) show 95 percent of all test results are more than 10,000 psi and, assuming a normal distribution, nearly 70 percent of all tests fall within the 18,114-to-38,390-psi range. No distinction between the various rock types could be noted.

These apparent strengths are substantially higher than those defined by unconfined compressive strength tests. The probable cause is that rock strength is proportional to the physical dimension of the test sample. For unconfined compression tests, lower strengths for larger size cores of the same rock are common (23). Since a point load tester tests the minimum volume of rock, higher results would be expected.

Both types of tests, however, show the intact rock to be of high strength with an average to high modulus ratio (BM, BH) (14).

(vi) Tensile Strength

Rock Type	Number of Tests	High (psi)	Low (psi)	Mean ± Standard Deviation (psi)
Andesite	3	1718	1616	1683 ± 58
Diorite	8	2450	602	1906 ± 576

Test results show that intact rock tensile strength (Brazilian Split) is relatively high, which implies a high intact rock shear strength. The lowest strength was obtained on altered diorite sample while sound, competent cores tested at least three times higher.

(vii) Summary

The rock test results presented in this section are considered adequate for preliminary design purposes. Extensive geotechnical work including drilling, down-hole testing, geophysics, exploratory adits, laboratory and in situ testing, will be required before the final design parameters can be determined for each structure. However, tests performed during this, as well as previous studies, show the rock to be of excellent quality for constructing both surface and subsurface hydropower facilities at Watana.

(f) Rock Permeability

Water pressure tests performed both by the COE and Acres (Section 5) confirm that rock permeability at Watana site is controlled by the degree of jointing, fracturing, weathering and permafrost within the bedrock.

Results of permeability tests are graphically shown on the Summary Logs and tabulated in Appendices B and D, respectively. Water pressure testing could not be performed in several zones because of hole caving. In BH-2, testing was terminated at a hole depth of 70 feet, and in BH-12, the bottom 200 feet could not be tested.

The rock permeability does not vary significantly within the site area, generally ranging between 1×10^{-4} cm/sec to 1×10^{-6} cm/sec. As would be expected in fractured rock, high permeabilities are found near the surface with low permeabilities at depth (Figure 6.26). Similarly, high permeabilities are also encountered in the more highly fractured rock zones.

An example of this was found in BH-1 (Appendix B) where higher permeabilities, about 10^{-4} cm/sec, were measured in a zone from 150 to 160 feet, which corresponds to a highly fractured zone with 0-RQDs and low core recovery. Similarly, high permeabilities, about 1.6×10^{-4} cm/sec, were measured in BH-6 at a depth of 464 feet, which corresponds to a soft mineralized zone with 0-RQDs.

In BH-3 and BH-4, at the estimated powerhouse cavern depth of approximately 1450 to 1400 Elevation, permeabilities are low, in the range of 2×10^{-6} cm/sec. The permeability of rock above the powerhouse complex is generally low, ranging between 1×10^{-5} to 1×10^{-6} cm/sec.

Artesian conditions were encountered in BH-12 at a depth of 325 feet, which corresponded with the granodiorite/andesite altered and sheared contact. Because of the structural relationship of these two rock units (see Section 6.1 [b]), higher permeabilities may be expected where this contact is intersected.

Permafrost conditions within the rock have an effect on permeability. Ice-filled joints and fractures prevent water from flowing through the rock mass, thereby giving erroneously low permeability values (Section 6.1 [h]). Thawing methods have, therefore, been developed in those permafrost areas for foundation treatment under the dam and associated structures.

(g) Groundwater

(i) General

As stated in 6.1(b), the Watana damsite lies within a large dome-shaped diorite pluton. Groundwater data for the site is based on borings, installed piezometers, and field observations.

This section will address only the groundwater conditions at the damsite and construction areas. Discussions of the groundwater in the borrow sites and relict channel will be individually addressed in Sections 6.2 and 6.3, respectively, while the groundwater conditions in the reservoir are briefly discussed in Appendix K.

(ii) Damsites

For the most part, the groundwater at the main damsite is confined to open fractures and joints within the bedrock. Therefore, the movement of groundwater is determined by the rock permeability and continuity of these open fractures and joints. Gradients within the damsite proper are downslope towards the Susitna River, with the groundwater generally representing a subdued replica of the topography.

The groundwater regime is complicated at the Watana site by the existence of nearly continuous permafrost on the south bank and possibly intermittent permafrost on the north bank (Section 6.1 [h]).

As a result of the permafrost, the groundwater table is relatively shallow on the left abutment. Boreholes BH-8, BH-12, DH-12, DH-25, and DH-28 all encountered water levels within 10 feet of the surface. Numerous seeps, springs, and wet areas are evident throughout the left bank. This shallow water table is the "thawed" layer perched on top of the permafrost zone. On steeper slopes (Elevation 1900 to river level), groundwater flows through the weathered rock zone and on top of the rock surface beneath the talus slopes.

Groundwater was encountered in two deep boreholes beneath the permafrost on the south bank. In BH-8, the water level was recorded at approximately 170 feet, whereas BH-12 intersected artesian conditions at hole depth 350 feet or approximately 200 feet beneath ground surface. (This depth corresponds with the mapped sheared and altered zone [GF 8] on the left abutment [Figure 6.3]). This hole, which was drilled in 1981, has continuously flowed at several gallons per minute since it was drilled. During its drilling, water was noted flowing from an adjacent borehole (immediately uphill from BH-12) indicating communication along this zone.

Further investigations and instrumentation will be required in subsequent phases of study to accurately define the groundwater conditions in this area.

Groundwater on the north abutment has been monitored by piezometers installed in BH-3 and BH-6. Based on this data, the groundwater table appears to be deep on the north bank. Water levels monitored in BH-6 and BH-3 show the water table to range between 107 to 150 and 280 feet below ground surface, respectively. The fluctuations noted in BH-6 appear to be directly correlative with changing season precipitation.

(iii) Subsurface Structures

Structures such as penstocks, powerhouses, and transformer galleries that will be constructed below the groundwater table will likely experience water inflows through open joints, fractures, and shears. However, rock permeabilities in these areas are expected to be low (Section 6.1 [f]).

(iv) Surface Facilities

As stated in (ii), any surface structure on the south bank can expect to encounter a perched water table on top of the permafrost. Shallow structures on the upper portions of the north bank are likely to be above the water table, while structures near river level will likely intersect the phreatic surface.

The construction of the Emergency Spillway will likely encounter groundwater within the shallow overburden and weathered rock where perched water table and aquicludes can be expected.

Camp facilities are sited within the relict channel and can expect a surface water condition during the summer thaw. The groundwater table in this area is addressed in Section 6.2.

(h) Permafrost

(i) General

The Watana area has been mapped as a zone of discontinuous permafrost (19).

Permafrost features consisting of frozen tills, bimodul and solifluction slides, beaded streams, thermokarst topography, skin flows, collapsed pingos, and thaw lakes are found throughout the region.

Based on regional temperature readings from the Summit and Cantwell, Talkeetna and Curry areas, it appears that the site is very near to the freezing isotherm, which is supported by one year's temperature data for Watana that show an average temperature of approximately 0.5°C (37). These temperatures suggest that the site is in an area where there is no ongoing development of permafrost.

Thermistor readings at the damsite and borrow sites are shown in Figures 6.27 through 6.29. An analysis of this data is contained in the following subsections and Sections 6.2 and 6.3.

(ii) Damsite

As previously stated, permafrost appears widespread throughout the left abutment. All of the seven boreholes drilled on the left abutment, except BH-12, froze back within 30 feet of the surface. Permafrost was measured throughout the full hole depths in DH-12, DH-23, DH-24, DH-28, and to a minimum depth of 175 feet in BH-8 where the instrument was blocked.

A total depth of permafrost in the left abutment is estimated to be 200 to 300 feet. Temperature readings, however, show this to be "warm" permafrost with readings generally ranging between 0 and -1°C (Figure 6.27).

The extent of permafrost in the underlying river alluvium and bedrock is based on information obtained from DH-21 and BH-6. DH-21 drilled by the COE shows apparent permafrost to the top of rock. No deeper readings could be obtained because of hole collapse. BH-6, drilled on the right abutment and inclined beneath the river, shows temperatures below freezing from hole depths ranging from approximately 95 feet to between 200 to 250 feet, or about 100 to 150 feet beneath rock surface (Figure 6.27).

Drilling of the vertical holes by the COE in the river alluvium showed no apparent permafrost in either the alluvium or bedrock. Further investigations will be required, however, in this area to confirm the permafrost conditions.

No permafrost was encountered in any of the seven borings drilled on the right abutment, with the exception of the previously discussed BH-6. The only other instrumented hole on this abutment is BH-3, which shows a very consistent data plot with a minimum temperature of 1.2°C at about 120 feet. Thermal gradients measured in several of the borings show average gradients of about 1°C per 200 to 300 feet with the exception of BH-3 which shows a gradient of 1°C per 550 feet. This lower gradient may be caused by groundwater flows within the rock mass resulting in a decreased temperature.

(iii) <u>Surface Structures</u>

Excavation for surface structures may encounter sporadic "warm" permafrost or annual frost on the right abutment and more or less continuous permafrost on the left abutment. Annual frost penetration appears to be about 8 to 16 feet in the rock and up to 40 to 50 feet in alluvium.

Although no permafrost was found in the areas of the proposed Emergency Spillway, for construction purposes, it should be assumed that localized permafrost may be encountered that would require thawing and foundation treatment.

(iv) <u>Camp and Access Roads</u>

The camp facility has been sited in the general area of the relict channel (Section 6.2). Local areas of permafrost can be expected in this area with zones of deeper seasonal frost encountered beneath the tundra cover.

Permafrost can also be expected locally along the access and construction haul roads in overburden cuts at depths of 0 to 20 feet. Permafrost in the bedrock is not expected to pose any major engineering constraints. Care will be required in designing cut slopes in permafrost terrain to insure long-term slope stability. Further investigation in these areas will be required to accurately define the permafrost conditions.

6.2 - Relict Channels

(a) Watana Relict Channel

(i) Introduction

In 1975, seismic refraction surveys performed by the COE identified a large, deep overburden deposit on the right bank extending between Deadman and Tsusena Creeks. This large, soil-filled depression was interpreted by the COE as a possible relict channel of the Susitna River. Further seismic work was performed in the channel by the COE in 1978 and by Acres in 1980-81. To date, approximately 70,000 linear feet of seismic refraction surveys have been performed in this area. In addition to the seismic work, the COE drilled 8 deep rotary borings in the channel to identify the stratigraphy and to verify the seismic refraction interpretation. Numerous shallower auger holes were drilled in the area during 1980-81 primarily to assess borrow materials. Figures 5.1 and 6.43 show the extent of exploration performed in and adjacent to the channel area.

All of this data has been used in defining the location, configuration, and material properties of the relict channel. The accuracy of the data in defining the extent and configuration of the channel is considered good. Verification of seismic interpretation for top-of-bedrock by the COE's boring showed accuracy within 10 percent for the 1975 data and 5 percent for the 1978 data.

The seismic accuracy of the intermediate soil stratigraphy is not as good, since the principal objective of the surveys was to locate top-of-bedrock. Therefore, the survey technique used was not conducive for accurately detailing the intermediate zones. As a result, the stratigraphy within the channel has been based on very preliminary and widely scattered data point (Figure 6.40).

The following sections provide a detailed discussion of the Watana relict channel.

(ii) Location and Configuration

The approximate location of the relict channel is shown on photographs in Figure 6.30. The upstream entrance to the channel extends from a location approximately 2,000 feet upstream from the damsite, where bedrock drops below maximum pool elevation (2202 feet), to a point more than two miles upstream from Deadman Creek.

The ground surface in the relict channel is flat to gently rolling with a drainage divide trending generally north to northeast through the area which closely corresponds with seismic lines DM-A and DM-B (Figure 6.31).

A top-of-bedrock contour map showing surface topography and projected flow paths through the channel are shown in Figure 6.35. The maximum overburden thickness in the thalweg channel is approximately 450 feet.

A sketch showing the relict channel with and without the overburden removed is shown in Figure 6.30. Under the maximum operating pool level of 2,185 feet, a total of approximately 13,500 feet of the upstream portion of the channel would be inundated with water (Figure 6.31).

The distance between the proposed reservoir and Tsusena Creek along the shortest distance through the channel would be approximately 6,200 feet and 7,700 feet along the thalweg section (Figure 6.33).

An average hydraulic gradient along the thalweg would be about 1:14.

(iii) Geology

The formation of the relict channel and the subsequent diversion of the Susitna River into its present position is likely the result of a sequence of glacial events during the Quaternary Period (Table 4.1).

The Quaternary history of this area is very complex and poorly understood. However, based on work performed by Acres and Woodward-Clyde Consultants (60) during this study, the following geologic events appear to be the most plausible in explaining the existing conditions.

During preglacial times, the Susitna River flowed down the relict channel and into the area of Tsusena Creek. The river in this area followed the path of least resistance, being diverted around the more massive diorite pluton (which underlies the damsite) to the south. The relict channel appears to have followed the softer sheared and fractured rock of "The Fins" structure which is traced through this area (Section 6.1).

Advancement of the Tsusena Creek glacier into this area from the north and northeast resulted in the infilling and diversion of the Susitna River to the south around the ice margin, where it subsequently downcut through the diorite along existing joint sets (Section 6.1). Once below approximate Elevation 1900, the river fell below the entrance to the relict channel. Several glacial advances and retreats through this area resulted in deposition of a thick sequence of glacially derived material within the relict channel. This material consisted of basal till, alluvium, glacial fluvial silts, sands, and gravels and lacustrine clays.

The actual time and number of glacial advances and retreats in this area are unknown. However, this sequence of events appears to be supported by the stratigraphy within the relict channel.

(iv) Stratigraphy

Based on the drilling in, and adjacent to, the relict channel, a total of 11 stratigraphic units have been identified. They have been designated by letters A through K. These units have been differentiated based on texture, structure, color, mode of deposition and stratigraphic position. Although facies changes exist in these units, each represents a unique depositional event. The correlation of the deeper units have been based principally on the eight deep holes drilled by the COE (45). Since these holes were drilled over a large area, additional work will be necessary to confirm these units and their extent. A vertically exaggerated cross section showing these stratigraphic units is presented in Figure 6.33. This section corresponds with the true section shown in Figure 6.31.

These stratigraphic units are discussed below with a detailed stratigraphic column presented in Figure 6.32. Table 6.7 provides a summary of the unit's thickness, type, occurrence, and permeability.

- Unit K

An alluvial deposit, designated as Unit K, is the oldest and deepest Quarternary deposit found in the relict channel area. This unit was only encountered in one borehole at a depth of 292 feet (DR-22). The unit, which is 162 feet thick overlies bedrock, it is composed of boulders, cobbles, and gravels. Increasing amounts of fine material are present in the upper horizons of the unit. Unit K appears to be an extremely dense alluvium that was deposited within the main thalweg of the relict channel, prior to glaciation. No other evidence of this unit was found in the relict channel area.

- Unit J

A dense till, designated as Unit J, is the oldest glacial deposit in the relict channel area. This till generally overlies bedrock, except in the thalweg of the relict channel, where it overlies the older alluvium of Unit K. This till is distinguished by poorly sorted subangular silts, sands, gravels, and cobbles which are highly compacted as a result of being overridden by later ice advances. Hematite and limonite staining is common in the unit. The unit appears to follow the topography of the underlying bedrock surface reaching its maximum thickness in the relict channel of approximately 60 feet (Figure 6.33).

- Unit J'

Unit J' is a localized clean sand and gravel fluvial deposit that is up to 45 feet thick. The unit is distinguished by its clean, sorted, rounded particles and high permeability. Water losses in excess of 50 gallon/feet were noted during drilling of this unit. This unit, which likely represents an interglacial outwash and alluvium, is found only in the relict channel thalweg.

- Unit I

Another till, designated Unit I, overlies Units J and J'. This till, is very similar in texture, composition, density, and color with the underlying Unit J, making distinction between the units difficult. The only noted difference is that Unit J is marked by a 2-to-6-inch layer of sand or silt within the middle of the unit. The average thickness of this unit where drilled is 60 feet.

- Unit H

Unit H is a series of alluvial and outwash deposits which represent a period of interglacial melting. This unit, which is found as channel deposits in topographic lows of Borrow Site D, becomes thicker and more continuous in the buried channel. Unit H likely represents the horizontally discontinuous remnants of an outwash plain cut by alluvial channels. Thickness of the unit in the channel reaches a maximum of 40 feet. Particles are generally sorted and sub-rounded to rounded gravels and sands, which are moderately permeable (Figure 6.33).

- Unit G

  Unit G marks another glacial advance. This unit contains greater amounts of fine material than the other units. In some areas, the material is plastic, containing a large portion of clay size particles with varied lacustrine deposits. Gravel and sand usually are present, often with ice-rafted cobbles and boulders. Such material is typical of tills deposited by either floating ice or in water that is in contact with the ice margin. Other areas have rounded to sub-angular poorly sorted silt, sand, gravel, and cobbles, which are typical of basal glacial tills. Unit G reaches a maximum thickness of 65 feet.

- Units C, E, and F

  A final retreat of the ice in this area is marked by layers of outwash, designated units C, E, and F. These units, which are similar to each other, contain varying amounts of partially sorted and rounded cobbles, gravels, sands, and silts. These units can be distinguished principally through their stratigraphic position. Permeability of these units is generally low to moderate, because of the presence of varying amounts of fines. Since these units were deposited as glacial outwash, they tend to fill in topographic lows and smooth the topography. The upper horizon of the outwash, Unit C, is often absent, possibly having been removed by post-glacial erosion in many areas. Thickness of the outwash in the buried channel area reaches a maximum of 75 feet.

- Unit D

  Unit D occurs locally as well-sorted alluvial, sands, silts, and gravels between outwash C and E. This material in fills channels cut into the outwash surface of Unit E. These channels generally trend southward across the area, toward the present Susitna River. The thickness of these channels is approximately 15 feet.

- Units A and B

Near surface deposits confined to the upper few feet of Unit D are mainly cobbles raised by frost action and organic tundra material (Unit A) in a silty sand matrix (Unit B). These two units are not present in significant thickness and, therefore, have not been shown on the sections.

Based on the stratigraphy presented above, it appears that the relict channel has been overrun by a minimum of two and possibly three glacial advances (Units J, I, and C). Interglacial periods are marked by varying thicknesses of glaciofluvial and paraglacial silts, sands, and gravels with occasional cobbles (Units J', H, C, E, F, D, A, and B).

This glacial sequence indicates that Units I through K have been overridden and consolidated by subsequent glacial readvances.

(v) Groundwater

The groundwater regime in the relict channel is complex because of the presence of intermittent permafrost, aquicludes, perched water tables, and confined aquifers. There are insufficient data to fully document the groundwater conditions in this area, however, the following presents what is currently known regarding the regime. Further detailed investigations will be required to accurately determine the number, extent, flow directions, and permeabilities within the various aquifers.

The relict channel lies within the drainage between Deadman Creek to the east, the Susitna River to the south, and Tsusena Creek to the west and northwest. Groundwater gradients in the unconsolidated sediments of the channel are principally towards Tsusena and Deadman Creeks with the diorite pluton at the damsite acting as a groundwater barrier to the south.

Most of the test pits and auger holes drilled and excavated in the relict channel and Borrow Site D (Section 6.3) encountered water within the upper 10 feet. Those holes that did not encounter water were either in solid frost or in the coarser permeable gravels of Units C through F. The near surface water table appears to be perched on top of the impervious or semipervious Unit G. Therefore, this shallow water table likely reflects the upper seasonal thaw surface overlying this unit.

Artesian conditions were encountered in Unit H suggesting that it is being confined below the low permeable Unit G.

Highly permeable zones were encountered in Units J' and K at depths of 208 to 231 feet and 293 to 375 feet, respectively (DR-22) (Figure 5.1).

In summary, the principal water bearing units within the relict channel appear to be in Units C, D, H, J', and K. The actual permeabilities of these units, however, have not been determined.

(vi) Permafrost

Intermittent permafrost in the relict channel area is evident by localized frost-heave features, cobble paving and isolated spruce cover.

The extent of permafrost within the relict channel and Borrow Site D has been determined by drilling records and thermistor instrumentation installed in various boreholes drilled by the COE and Acres (Tables 3.2 and 5.4 and Figure 5.1). Thermistor readings are presented in Figure 6.28.

Drilling performed by the COE showed only sporadic permafrost in the relict channel area. Borings AP-1 and 2, DR-16 through DR-20 and DR-22 did not show excess amounts of permafrost; whereas borings DR-18 and DR-22 encountered permafrost in Units G and H at depths of 20 to 68 feet and 72 to 110 feet, respectively (Figure 6.33). Thermistor data in these holes show freezing temperatures from approximately 60 to 140 feet below ground surface in both holes.

Permafrost was encountered in 28 of the 44 auger holes drilled in Borrow Site D. Many of these holes showed seasonal frost from near ground surface to approximate depth of 7 feet, with permafrost being encountered from around 12 to 20 feet. However, several holes showed continuous frost/permafrost to the full depth drilled (Appendix F).

No visual ice or excess water (upon thawing) was found within any of the drilled holes below 25 feet. This lack of free ice below 25 feet is supported by the moisture contents of this material, which is near optimum (12 to 14 percent (Section 6.3[d]). The deepest permafrost encounted in the relict channel was at a depth of 240 feet in DR-22 (Figure 5.1). However, the deepest continuous permafrost was about 30 to 40 feet.

The temperatures in the relict channel are fairly uniform with temperatures in the thalweg segment of the channel being close to 1°C. Slightly higher temperatures were measured in DR-22 in the more permeable units of H and J' during the initial reading (Figure 6.28). This likely reflects an unstable temperature condition caused by drilling fluid that was injected into this zone.

Temperature readings in Borrow Site D (Figure 6.28) show temperatures near 1 to 2°C, suggesting a marginal permafrost condition. However, most of these thermistors were installed in the summer/fall of 1981 and, as is common in "warm" permafrost, they have not fully stabilized over such a short time period. Future readings will likely show a shift towards cooler temperatures.

(b) Fog Lakes "Relict" Channel

(i) Introduction

Other areas around the damsite and within the reservoir were investigated during the 1980-81 program to determine whether other buried channels existed that could potentially affect reservoir impoundment.

A complete review of site and regional geologic mapping, reservoir mapping, and airphoto interpretation showed that the only potential buried channel(s) which might be inundated by the Watana Reservoir (other than the Watana Relict Channel (Section 6.2 [a]) is in the area between Quarry Site A immediately upstream from the damsite and Fog Lakes approximately five miles to the east.

In 1981, a 24,000-foot seismic refraction line was run in this area to determine the top-of-rock. Details of this survey are presented in Appendix I. The following sections briefly summarize the results of that survey and the potential impacts of this area to the project.

(ii) Location and Configuration

The location of the seismic line performed in this area is shown in Figure 1 - Appendix I.

The minimum surface elevation along the line is approximately 2280 feet, nearly 80 feet above Maximum Pool Elevation of 2202 feet.

For discussion, the bedrock surface, as shown along the seismic lines, can be divided into 3 sections: the west section, central section, and east section.

The west section of the line extends from the rock outcrop south of Quarry Site A eastward along the line for approximately 2,000 feet. Here, the bedrock surface appears to be a series of ridges and valleys with the deepest bedrock reaching Elevation 2025 or 175 below maximum pool level.

The central section continues for approximately 2 miles easterly. Bedrock in this area is relatively shallow and generally flat to slightly undulating.

Along the western portion of the line in the Fog Lakes area, bedrock drops off rapidly to depths up to 350 feet until it again shallows along the east edge of the line.

The total estimated width of bedrock below maximum pool level along this line is estimated to be about 2,400 feet along the west section near Quarry Site A and 7,100 feet along the east section in the Fog Lakes area.

(iii) Geology

Since no subsurface drilling was performed in this area, soil and rock types and depths to bedrock have been inferred based solely on seismic velocity measurements.

Woodward-Clyde Consultants delineated three general types of soils in this area: (a) a poorly consolidated, saturated glacial deposit; (b) a well-consolidated glacial sediment which may be partially frozen; and (c) an intermittent surficial material ranging up to 50 feet thick.

Several areas along the traverse appear to be buried channels which extend below the proposed reservoir level. The two most prominent areas are near the west end of the traverse and beneath the Fog Lakes Valley (Figures 17, 22, 23 of Appendix I).

The shape of the channel shown on the profile has been conservatively estimated based on marginal arrival time data from distant offsets and from minimum depth calculations.

A number of uncertainties exist in the interpretation, particularly the nature of the 8,000 to 11,000 fps apparent channel fill material. This material could be either permafrost, overconsolidated till, or weathered rock. Future investigations in this area may be warranted to determine the nature of this material and the actual existence of a buried valley.

(iv) Groundwater

The groundwater table in the area appears to be relatively shallow, as evidenced by poor surface drainage and numerous ponds, lakes, and bogs. Drainage of the area is toward the Susitna to the north and Fog Creek, nearly 5 miles, to the south. Groundwater gradients are expected to be steep in the Susitna drainage area and very low (<1 percent) toward Fog Creek.

(v) Permafrost

Permafrost conditions are likely to be sporadic throughout the area, as evidenced by the existence of typical permafrost features to include black spruce, hummocky tundra, perched ponds on hills, and skin flows.

6.3 - Borrow and Quarry Material

The borrow and quarry materials investigation at Watana was directed to:

- further investigate the quantity and material properties of borrow and quarry sources identified in previous studies, and

- locate new potential source areas for those materials considered to have either insufficient reserves or questionable production feasibility.

A total of seven borrow sites and three quarry sites have been identified for dam construction material (A, B, C, D, E, F, H, I, J, and L) (Figure 6.36). Of these, Borrow Sites D and H are considered as potential sources for semipervious to pervious material; Sites C, E, and F for granular material; Sites I and J for pervious gravel; and Quarry Sites A, B, and L for rock fill.

Several of these sites (B, C, and F), previously identified by the COE, were not considered as primary sites for this study because: (1) a more locally available source of material to the damsite; (2) adverse environmental impacts; (3) insufficient quantity; or (4) poor quality of the material. Therefore, no work was performed in these areas during 1980-81. These sites, however, have not been totally eliminated from consideration as alternative sources and are therefore included in this discussion.

Since adequate quality and quantity of quarry rock are readily available adjacent to the damsites, the quarry investigation was principally limited to general field reconnaissance to delineate boundaries of the quarry sites and to determine approximate reserve capacity. This allowed for a more detailed investigation in the borrow sites.

The borrow investigations consisted of seismic refraction surveys, test pits, auger holes, instrumentation, and laboratory testing. The results of this study are discussed below.

Each site is presented in the following sequence:

(i) Proposed use of the material and why the site was selected;

(ii) Location and geology, including topography, geomorphology, vegetation, climatic data, groundwater, permafrost, and stratigraphy;

(iii) Reserves, lithology, and zonation; and

(iv) Engineering properties which include index properties and laboratory test results.

(a) Quarry Site A

(i) Proposed Use

Quarry Site A is a large exposed diorite and andesite porphyry rock knob at the south abutment of the Watana damsite (Figure 6.35). The predominant rock type is diorite. The proposed use for the quarry is for blasted rockfill and riprap.

Quarry Site A was selected based on its apparent good rock quality and close proximity to the damsite.

(ii) Location and Geology

The boundaries of Quarry Site A include the bedrock "knob" from approximate Elevation 2300 to about 2600 (Figure 6.37). The knob covers an area approximately one square mile. Glacial scouring has gouged out east-west swales in the rock (Figure 6.37). These swales likely corresponded with fractured, sheared, and altered zones within the rock body. Overburden ranges from 0 to several feet over the site. Vegetation is limited to scrubby spruce, vines, and tundra, with limited alder growth in the lower areas. Surface water is evident only in isolated deeper swales. Based on information presented in Section 6.1(g), the groundwater table is expected to be deep in this area with an estimated average depth to the water table from 50 to 100 feet. It is likely that the groundwater level will be near the quarry floor during operation, but inflows are expected to be small, diminishing with time.

Although no borings have been drilled in this site, it is likely that permafrost will be encountered as shallow as 5 feet in depth. The permafrost, however, is near the thaw point (see Section 6.2[h]) and, because of the high exposure to sunlight in this area, is expected to dissipate rapidly. The permafrost zones are expected to be more common in the more fractured and sheared zones.

The western portion of the site has been mapped as sheared andesite porphyry (Figure 6.37) with the remainder of the site being gray diorite. Mapping on the northern half of the site in 1980-81 showed the rock to grade between black andesite porphyry and a coarse-grained gray andesite with sections grading into diorite. Despite these lithologic variations, the rock body is relatively homogeneous. Based on airphoto interpretation, severe shearing and alteration appear to be present on the northeast corner of the delineated site area.

(iii) Reserves

The limits denoted in Figure 6.37 are conservatively drawn to include all exposed or partially covered rock which comprises approximately 530 acres. Extension of these limits would likely include areas of deeper overburden. The depth of severe weathering is estimated to be an average of 5 to 10 feet.

The rock exposure in Quarry Site A provided adequate confidence in assessing the quality and quantity of available rockfill necessary for feasibility. Allowing for spoilage of poor quality rock caused by alteration and fracturing, and assuming a minimum bottom elevation of 2300, the estimated volume of sheared or weathered rock is 23 million cubic yards (mcy) and 71 mcy of good quality rock.

Additional rock fill, if required, can be obtained by deepening the quarry to near the proposed dam crest elevation of 2210 without adversely affecting the dam foundation or integrity of the reservoir.

(iv) Engineering Properties

Weathering and freeze-thaw tests were conducted to determine the rock's resistance to severe environmental conditions. Results indicate that the rock is very resistant to abrasion and mechanical breakdown, seldom losing strength or durability in presence of water and demonstrating high resistance to breakdown by freeze-thaw.

Since this rock is of the same parent rock as the damsite, its physical and mechanical properties are expected to be similar to those results presented in Section 6.1(e). The rock is expected to make excellent riprap, rock shell, or road foundation material.

(b) Quarry Site B

(i) Proposed Use

Quarry Site B was identified in previous investigations as a potential rock quarry for dam construction (Figure 6.36 and 6.38). The area was identified based on outcrops exposed between Elevations 1700 and 2000 along the Susitna River and Deadman Creek. During 1980-81 field reconnaissance, mapping and additional seismic refraction surveys were performed in this area.

(ii) Location and Geology

Quarry Site B is located about two miles upstream from the damsite between Elevations 1700 and 2000. This area initially appeared economically attractive because of the short-haul distance and low-haul gradient to the damsite. However, geologic mapping and seismic refraction surveys performed in this area indicate that the rock is interfingered with poor quality sedimentary volcanic and metamorphic rocks (Figure 6.38) with thick overburden in several areas (Appendices H and I).

Vegetation cover is heavy, consisting of dense alder marshes and alder with aspen and black spruce in the higher, drier areas. The entire south-facing side of the site is wet and marshy with numerous permafrost features. The quarry side facing Deadman Creek is dry, with thick till overburden, which appears frozen. Permafrost in the area is expected to be continuous and deep. Surface runoff from Borrow Site D (Section 6.3 [d]) flows southward passing through Quarry Site B.

(iii) Reserves

Because of (a) the deep overburden (as evidenced by seismic lines SL81-18 and 19); (b) generally poor rock quality; and (c) the extreme vegetation and topographic relief, Quarry Site B was not considered as a primary quarry site. Therefore, no reserve quantities were determined for feasibility.

(iv) Engineering Properties

No material property testing was performed for this area.

(c) Borrow Site C

(i) Proposed Use

Borrow Site C was identified in previous studies as a possible source of gravels and sands for filter material (45). Previous explorations in Borrow Site C consisted of three seismic refraction lines and one test pit (39). The 1980-81 investigation identified adequate volumes of granular material much closer to the damsite in Borrow Site E (Section 6.3[e]). Therefore, no additional work was performed in this area during this study.

(ii) Location and Geology

Borrow Site C, as delineated by the COE, extends from a point approximately 4-1/2 miles upstream from Tsusena Butte to the northwest toe of the butte (see Figure 6.39). As seen from the photo on Figure 6.39, the site is a broad glacial valley filled with till and alluvium. Vegetation ranges from alpine tundra on the valley walls to heavy brush and mixed trees at the lower elevations, thinning to mixed grass and tundra near the river and on terraces. The groundwater table is assumed to be a subdued replica of the topography, being shallow on the valley walls with gradients towards the valley floor. Groundwater migration is expected to be rapid through the highly permeable alluvial material. Permafrost may be intermittent.

Based on the test pit and a seismic refraction survey, the stratigraphy appears to consist of over 200 feet of basal till overlain by outwash, and reworked outwash alluvium. The upper 100 to 200 feet of material is believed to be saturated gravels and sands.

(iii) Reserves

Because the site is not currently being considered as a borrow source, no detailed quantity estimate has been made. However, assuming an approximate area of 1,500 acres and an excavation depth of 15 feet above water table, a gravel quantity on the order of 25 mcy can be approximated. Additional quantities may be obtained at depth; however, further studies will be required to determine the volumes.

(iv) Engineering Properties

The test pit and reconnaissance mapping show the material in the floodplain and terraces to be a 4-inch minus, well-washed gravel with approximately 60 percent gravel, 40 percent sand, and negligible fines. The gradations are representative of a clean, well-washed material with a percentage of cobbles and fines at depth.

(d) Borrow Site D

(i) Proposed Use

Borrow Site D was identified in 1975 as a potential primary source for impervious and semipervious material by the COE.

Based on the field studies performed by the COE in 1978 (45), it was tentatively concluded that:

- Borrow Site D had potentially large quantities of clay and silt;
- The deposit was of adequate volume to provide the estimated quantity of material needed for construction; and
- The site had favorable topography and hydrology for borrow development.

As a result of these previous studies, Borrow Site D became a primary site for detailed investigation during the 1980-81 study.

(ii) Location and Geology

Borrow Site D lies on a broad plateau immediately northwest of the Watana damsite. The southern edge of the site lies approximately 1/2 mile northeast of the dam limits and extends eastward towards Deadman Creek for a distance of approximately 3 miles (Figure 6.40). The topography slopes upward from the damsite elevation of 2150 northward to approximate Elevation 2450.

The ground surface has localized benches and swales up to 50 feet in height. The ground surface drops off steeply at the slopes of Deadman Creek and the Susitna River.

As noted in the site photographs shown in Figures 6.30 and 6.40, vegetation is predominantly tundra and sedge grass averaging about one foot thick with isolated strands of spruce trees on the higher and dryer portions of the site.

Climatic conditions are similar to those at the damsite with the exception that the borrow site is more exposed to higher winds and sunlight. The relatively open rolling topography is conductive to drifting and blowing snow, frequently resulting in drifts up to six feet deep.

Surface water and groundwater conditions have been addressed in detail in Section 6.2 - Watana Relict Channel. In summary, the northwest portion of the site has numerous lakes and shallow ponds with the remaining portions of the site having localized standing water perched on either permafrost or impervious soils. Surface runoff is towards Deadman Creek to the northeast and Tsusena Creek to the west. Generally, much of the area is poorly drained, with many of the low-lying areas wet and boggy.

Instrumentation installed throughout the borrow site shows intermittent "warm" permafrost. Temperatures in the permafrost zones are all within the -1°C range. Detailed discussions of permafrost as it relates to specific stratigraphic units within the area have been addressed in Section 6.2. Thermistor plots (Figure 6.28) show annual frost penetration of approximately 15 to 20 feet. Annual amplitude (fluctuation) in ground temperature reaches depths of 20 to 40 feet. The greatest depth of temperature amplitude is in the unfrozen holes, while the permafrost holes reach 20 to 25 feet. This may be caused by either the effect of possibly greater water content at the freezing interface lessening the seasonal energy variations or the thicker vegetation cover in the permafrost area causing better insulation.

Detailed discussion of the borrow site geology are presented in Section 6.2. The distribution of the various stratigraphic units within the borrow site are shown in Figure 6.32.

(iii) Reserves

The boundaries of the borrow site, as shown in Figure 6.40, are somewhat arbitrary, being limited on the south side by the apparent limit of undisturbed material, to the east by Deadman Creek; to the northwest by low topography; and to the north by shallowing bedrock. If further studies indicate the need for additional materials, it may be feasible to extend the borrow site to the northwest and west. Factors to be considered in borrow site expansion are:

- Siting of other facilities in this area;
- Impacts on relict channel;
- Haul distance; and
- Environmental impacts.

The reserve estimates for Borrow Site D have assumed an average material thickness throughout the site limits (Figure 6.40). Based on the currently established boundaries (encompassing about 1,075 acres) and an excavation depth of 120 feet, a total of 200 mcy of material is available.

(iv) Engineering Properties

The laboratory tests performed on materials from Borrow Site D are presented in Appendix F. A tabulation of the samples collected and the test results are presented in Table 6.8.

Grain size distribution within the borrow site ranges from coarse gravels to clay, as shown in the composite grain size curves (Figure 6.41). Groupings of the various soil types are shown in Figure 6.42. Soil gradations, as related to the stratigraphic units within the borrow site (Section 6.2), are shown in Table 6.9. As can be seen in Figure 6.41, almost all of these samples are well graded, ranging from gravel to fine silt and/or clay. Only Unit H (Section 6.2) exhibits a different characteristic, being a more uniform fine sand and silt. Moisture contents range from a low of 6 percent to a high of 42.5 percent with an average of approximately 14 percent. The highest moisture contents are found in Unit G, a fine gray clayey material (Section 6.2).

Atterberg limits show the soil to fall into two basic groups. The first, consisting of Units C, D, E, and F, are basically non or slightly plastic material. The Liquid Limits of these soils are close to their natural moisture content, varying from 13 to 17 percent. These tests are consistent with previous tests by the COE which show the material to be non plastic or slightly plastic in nature. The plasticity index varies from non plastic (NP) to 2. The second group, comprising soil units G, I, and J, have liquid limits ranging from 17 to 39 percent with plasticity indices ranging from NP to 15 with an average of 10.

Specific gravity for the material is 2.71, which is within an expected range for these soils. Permeability tests on samples compacted to Modified and Standard Proctor values at 2 percent above optimum moisture content gave permeabilities on the order of 10^{-6} cm/sec.

Compaction of a composite sample from Borrow Site D was undertaken utilizing both Standard and Modified Proctor Compaction procedures. The Standard Proctor Test (material <No. 4 sieve) shows the material to have a maximum dry density of about 128 pcf at an optimum moisture content of 10.4 percent. Modified Proctor Test results (material <3/4 inch sieve) indicate a maximum dry density of 135 pcf at 7.5 percent moisture.

Modified and Standard Proctor compaction at 2 percent above optimum moisture content give consolidation compressive indices (Cc) of 0.061 and 0.091, respectively.

Shear strength tests give an angle of internal friction (Ø) of 37 degrees, which corresponds with previous COE data.

Pinhole dispersion tests indicated the material to be non-dispersive.

(e) Borrow Site E

(i) Proposed Use

Borrow Site E (Figures 6.43 and 6.36) was identified by the COE as a principal source of concrete aggregate and filter material for the Watana dam. The apparent volume of material and its close proximity to the site made it the primary site for detailed investigations during the 1980-81 program.

(ii) Location and Geology

Borrow Site E is located three miles downstream from the damsite on the north bank at the confluence of Tsusena Creek and the Susitna River (Figure 6.43). The site is a large flat alluvial fan deposit which extends for 12,000 feet east-west and approximately 2,000 feet northward from the Susitna River up Tsusena Creek. Elevation across the site varies from a low of 1410 near river level to 1700 where the alluvial and terrace materials lap against the valley walls to the north (Figure 6.43).

The area is vegetated by dense spruce and some alders, tundra, and isolated brush. Vegetation cover averages about one foot thick underlain by up to four feet of fine silts and volcanic ash.

Groundwater was found to be generally greater than 10 feet deep. Groundwater levels fluctuate up to five feet from winter to summer, indicating a free draining material.

The hydrologic regime shows summer peak flows in the area reaching approximate Elevation 1435-1440 at the north of Tsusena Creek. This elevation corresponds with the limit of scoured and unvegetated river bank. The estimated 50-year flood level is approximately 1,473 feet.

Figure 6.53 presents a generalized stratigraphic section through the borrow site showing the underlying bedrock overlain by a sequence of bouldery till, river and floodplain gravels and sands. As in the case of Borrow Site D, the grain size distribution in Site E varies from boulders to fine silt and clay (Figure 6.45). Within this wide range of soil types, five distinct soil gradations (A through E) can be delineated (Figure 6.46). However, the complex depositional history and the limited exploration performed in this area does not allow for ready correlation of these soil types over the site. Generally, however, the finer silts and sands are found in the upper five feet of the deposit. As noted in the typical sections (Figures 6.43 and 6.53), several abandoned river channels of either the Tsusena Creek or the Susitna River cross cut the site. The infilling and cross cutting of these streams and rivers through the site has resulted in a complex heterogeneous mixing of the materials. Exploration indicates that, although the five principal soil types are persistent within the site, they vary in depth from near surface to approximately 40 to 70 feet.

No permafrost has been encountered in the borrow site, probably because the site has a south-facing exposure and has a continuous thawing effect caused by the flowing river. Seasonal frost, up to 3 to 6 feet deep, was observed in test pits that encountered groundwater (mid-March 1981) and up to at least 13 feet in pits on the northwest side of the site that did not intercept the groundwater table. In areas of shallow groundwater, the frost was almost exclusively confined to the upper shallow sand and silt layers, while dry gravels showed deeper frost penetration. Annual frost penetration may be assumed to be about 3 to 6 feet in silty or clayey soils and at least 11 feet in loose dry gravels.

(iii) Reserves

Quantities were calculated on the basis of known and inferred deposits above and below the current river regime. Assuming an overall surface area of approximately 750 to 800 acres, the estimated quantity of material above river elevation is 34 mcy. An additional volume of 52 mcy is available below river elevation (Figure 6.44) assuming a total maximum depth of excavation of 125 feet in the southwest corner of the borrow site, decreasing to a minimum of 20 feet in the northeast corner.

Approximately 80 percent of the identified material in the borrow site is within the floodplain area, 10 percent in the hillside terraces, and 10 percent in the Tsusena Creek segment.

Average stripping is estimated at one foot of vegetation and three to four feet of fine grained material.

(iv) Engineering Properties

A summary of the samples and laboratory tests performed on selected materials from Borrow Site E are shown in Table 6.10. Details of the laboratory testing are provided in Appendix F. The soil units A through E range from coarse sandy gravel through gravelly sand, silty sand, cobbles and boulders, silty sand and silt (Figure 6.46). Several of these material units correlate well with the material in Sites I and J (Sections 6.3[h]). Moisture contents for the silts range from 25 to 30 percent; sand from 4 to 15 percent; and gravels from 1 to 5 percent. The percentage of material over 6 inches is roughly estimated at 10 percent with the over-12-inch estimated at 5 percent.

Selective mining may be possible to extract particular types of material. Further detailed investigations in this area will be required to accurately define the location and continuity of stratigraphic units.

(f) Borrow Site F

(i) Proposed Use

Borrow Site F was identified by the COE as a potential source of filter material for the main dam. Preliminary work performed by the COE showed the site to have limited quantities of material spread over a large area. For this reason, Borrow Site E became the preferred site, with Borrow Site F being considered as an alternative source for construction material for access roads, runways, and camp construction. No work was performed in this area during the 1980-81 program.

(ii) Location and Geology

Borrow Site F occupies the middle stretch of Tsusena Creek from just above the high waterfall to north of Clark Creek where it abuts Borrow Site C (Figure 6.39). The northeast portion of the valley is confined by the flank of Tsusena

Butte and its talus slopes. The vegetation in the area is mixed spruce and tundra, with isolated areas of undergrowth and alders. Groundwater is expected to be near surface. Limited permafrost is likely to be encountered in north- and west-facing exposures but is expected to thaw readily when exposed during summer months. Deposits above stream level are expected to be fairly well drained with lower areas saturated.

Limited test pits indicate the material in Borrow Site F is the same as that in Borrow Site C (Section 6.3 [c]). The depth of clean sands and gravels is estimated to be approximately 20 to 30 feet, ranging from a shallow 5 feet to a maximum of 40 feet. The area consists of a series of gravel bars and terraces extending up to 1,500 feet away from the stream (Figure 6.39).

(iii) Reserves

No detailed topography was obtained for the site, however, assuming a conservative depth of 20 feet of material, a total volume of approximately 15 to 25 mcy is likely available.

Additional investigation in this area will be required to confirm these volumes.

(iv) Engineering Properties

Test pits excavated by the COE (Figure 6.39) show gravelly sand overlain by a very thin silt and sandy silt cover. A composite gradation curve for material in this site is shown in Figure 6.47. No detailed testing was performed on this material.

(g) Borrow Site H

(i) Proposed Use

Borrow Site H was defined during the 1980-81 field investigation as an alternative site to Borrow Site D for impervious and semipervious material.

(ii) Location and Geology

The topography of Borrow Site H is a generally rolling, sloping towards the Susitna River. Elevations range from 1400 to 2400 across the site and average about 2100 (Figure 6.48). Most of the site is covered by swamps and marshes, indicating poor drainage. The vegetation consists of thick tundra, muskeg, alder, and underbrush growth.

Groundwater and surface water are perched on top of impervious material with numerous seeps and ponded surface water. The extensive coverage of spruce trees may be indicative of a degrading permafrost area. A large ice deposit exists in a slump exposure on the west end of the site. The deposit and associated solifluction flow with a multiple regressive headwall are approximately 100 to 150 feet across and are visible in the photo (Figure 6.48).

Of the eight auger holes drilled in the site, six encountered permafrost at depths ranging from 0 to 14 feet in depth. All the holes but one showed the water table at or near the surface (Appendix F, Figure 6.48). All of the borings had temperature probes installed during the 1981 program; however, the instruments have not yet stabilized (Figure 6.29). Future readings are likely to show a cooling in the temperature plots.

The site stratigraphy consists of an average of 1.5 feet of organics, underlain by 1.5 to 4.5 feet of brown sand or silt material with traces of organics. Below this upper material, most of the holes show mixed silt, sandy silt, and sandy clay to depths of 6 to 13 feet, which in turn is underlain by zones of gravels, gravelly sand, and mixed silts with sand and gravel. A color change from brown to gray occurs at depths of 6 to 28 feet. Insufficient data exist to allow for detailed stratigraphic correlation across the site.

(iii) Reserves

The quantity estimate has assumed a relatively homogeneous mix of material over a surface area of 800 acres, with 5.5 feet of stripping required to remove organics and clean silts and sands. Assuming an estimated usable thickness of 32 feet (based on drilling data) approximately 35 mcy of material is available from this site.

(iv) Engineering Properties

A summary of the samples and laboratory test results from materials from Borrow Site H are shown on Table 6.11. Laboratory test results are contained in Appendix F.

A composite gradation for the borrow site is shown in Figure 6.49. A detailed assessment of the grain size distribution shows three distinct gradation groupings (A through C) (Figure 6.50). Gradation A denotes a gravelly sand, characterized by less than 40 percent fines and a significant fraction exceeding 3/4 inch; B is a silty sand without the generally coarser fraction; and C is a silt

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unit which is generally less than 1 inch in maximum particle size and contains in excess of 40 percent fines.

The Liquid Limit of the material ranges from 17 to 34 percent with an average of 23 percent. Approximately one third of the samples were non plastic. Natural moisture contents ranged from 6 to 23 percent with an average of 13 percent. (One sample gave a moisture content of 53 percent but was not considered representative.)

The Modified Proctor Test, conducted on 3/4-inch minus material, gave a maximum dry density of 141 pcf at 6.9 percent moisture. The Standard Proctor Test, at 10.8 percent moisture on the minus No. 4 material, gave a maximum dry density of 128 pcf.

Permeability tests on samples compacted to Modified and Standard Proctor values at 2 percent above optimum moisture content gave permeabilities on the order of 10^{-6} cm/sec.

Modified and Standard Proctor compaction at 2 percent above optimum moisture content gave a coefficient of consolidation (C_c) of .06 and .09, respectively. The specific gravity of the material is 2.72, which is normal for a glacial till. The undrained shear strength tests run on samples at 95 percent of Modified Proctor density and 2 percent above optimum moisture gave a friction angle of 37 degrees with cohesion of 648 psf.

Pin-hole dispersion tests showed the material was not dispersive.

In conclusion, Borrow Site H material is considered suitable for use as impervious and semipervious fill. However, problems such as wet swampy conditions, permafrost, and the lengthy haul distance to the site may affect the potential use of this site as a borrow source.

(h) Borrow Sites I and J

(i) Proposed Use

Reconnaissance mapping was performed within a 10-mile radius of the damsite to locate potential sources of free-draining gravels for use in the dam shell. The large volume needs of this material requires that the source be relatively close to the damsite and in an area that would minimize environmental impacts during borrowing operations. As a result, the Susitna River valley alluvium was delineated as a potential borrow source.

(ii) Location and Geology

Seismic refraction survey performed across the river channel during 1980-81 indicated large quantities of sands and gravel within the river and floodplain deposits both upstream and downstream from the damsite.

Borrow Site I extends from the western limits of Borrow Site E downstream for a distance of approximately 9 miles, encompassing a wide zone of terrace and floodplain deposits (Figures 6.51 and 6.53).

Borrow Site J extends upstream from the damsite for a distance of approximately 7.6 miles. The site area extends from river bank to river bank and includes several terraces and stream deltas (Figures 6.52 and 6.53).

Borrow Sites I and J are fully within the confines of the Devil Canyon and Watana reservoirs, respectively.

Both sites are in an active fluvial environment. Borrow Site J is flanked by bedrock, talus and till-covered valley walls; while Borrow Site I includes extensive terraces extending several hundred feet up the valley walls above river level.

(iii) Reserves

For purposes of volume calculation, it was assumed that all materials with seismic velocity of 6,500 feet per second represented suitable gravel deposits (Table 6.1). Materials with velocities higher than 6,500 were assumed to be either too bouldery or dense. Not included in the estimate were:

- The river material between the two sites;
- Material between the west boundary of Site J and the downstream area of the damsite; and
- The section from the damsite to Borrow Site E.

This last area was considered to require excessive dredging and could likely affect the hydraulics of the tailwater.

An active slope failure was identified near Borrow Site H (Appendix K). If further studies show that the excavation of river material beneath this slide may result in slope failure, than this section of alluvium will be left in place. In summary, a total of 125 mcy of material were estimated in Borrow Site I extending a distance of 8.5 miles downstream and 75 mcy in Borrow Site J over a distance of 7 miles upstream.

(iv) Engineering Properties

Individual gradation curves from a total of 45 samples taken from 22 test pits are presented in Appendix F and summarized on a composite curve shown on Figure 6.54.

Soil properties determined from laboratory testing are shown in Table 6.12.

Three basic gradations are present within the two sites. These are fine grained silty sand, sand and gravel (Figure 6.55). The fine silty sand fraction was encountered in 25 percent of the test pits and ranged in thickness from 6 inches to 6 feet. The second gradation is a sand which varies from a well-sorted clean sand to a gravelly poorly sorted sand. This type of material was encountered in only 15 percent of the pits, and where present, underlies the silt layer with an average thickness of about 4 feet. The bulk of the samples are of a moderately sorted gravel mixed with from 20 to 40 percent of sand and silt with less than 5 percent silt and clay size fraction. No indication of plasticity in the fines was noted.

(i) Quarry Site L

(i) Proposed Use

Quarry Site L was identified during the 1980-81 program as a source for cofferdam shell material.

(ii) Location and Geology

Quarry Site L is located 400 feet upstream from the proposed upstream cofferdam (Figure 6.56) on the south bank. The site is a rock knob immediately adjacent to the river which is separated from the main valley walls by a topographically low swale that has been mapped as a relict channel (Appendix J).

The rock in the quarry area is diorite along the western portion of the knob with andesitic sills or dikes found farther upstream. The rock exposure facing the river is sound with very few shears or fractures. The vegetation is heavy brush with tall deciduous trees on the knob and aldens with brush in the swale to the south. Little surface water is present on the knob; however, the low lying swale is marshy. Permafrost may be expected to be present throughout the rock mass.

Quarry Site L lies opposite "The Fins" feature which is exposed on the north abutment (Section 6.1[c]); however, extensive mapping in this area shows no apparent shearing or fracture that could be correlative with the extension of this feature.

(iii) Reserves

Because of limited bedrock control, the site has been delineated into two zones for estimating reserves (Figure 6.56). Zone I delimits the total potential reserves based on assumed overburden and rock volumes, while Zone II identifies that volume of rock that, with a high degree of confidence, is known to be present (Figure 6.56). Based on field mapping and airphoto interpretation, the total useable volume of material has been estimated to be 1.3 mcy for Zone I and 1.2 mcy for Zone II, over an area of 20 acres.

(iv) Engineering Properties

No testing was performed on rock samples for Quarry Site L. However, based on field mapping, it appears that the rock properties and quantities will be similar to those at the damsite (Section 6.1[d] and [e]).

TABLE 6.1: WATANA SEISMIC VELOCITY CORRELATIONS

VELOCITY	INFERRED MATERIAL
0-1500	Shallow, loose dry sands, gravels, soil
1500-3900	Moist Gravels, sands, talus, slope wash, generally well drained. Can include loose, drained tills and outwash, unfrozen clays.
3900-4900	Moist alluvial terraces, gravels - occurs predominately as surface terraces or as shallow depth channel fill in relict channel bedrock lows above elevation 2200 - possible beaded stream deposits.
4600-4800	Water
4900-5500	Granular alluvium, saturated, and possible outwash; may be frozen. May represent less bouldery beds of stream alluvium and outwash.
5500-7000	Low velocity saturated gravels, outwash. Also higher velocity active river alluvium and talus velocities. Probably includes majority of frozen alluvium and tills.
7000-10000	Dense tills, alluvium, boulders, and coarse outwash materials. May include frozen clays and gravels. Also highly weathered sheared rock.
10000-15000	Sheared and severely fractured and altered bedrock. Over consolidated tills and/or sedimentary rocks and frozen talus.
15000-20000	Bedrock, velocity represents lower range, fractured and altered rock, while higher velocities are sound rock.
20000+	Sound crystalline bedrock.

TABLE 6.2: WATANA JOINT CHARACTERISTICS*

Joint Set	Site Quadrant	Strike (Range)	Strike (Avg.)	Dip (Range)	Dip (Avg.)	Spacing** (Range)	Spacing** (Avg.)	Surface Conditions: Texture	Surface Conditions: Coating	Remarks
I	All	290°-330°	320°	75°NE-80°SW	90°	1"-15'	2'		Carbonate locally	Parallel to major shears, fracture zones and alteration zones
	NE, SE				80°NE	2"-10'	2'		Carbonate at WJ-6 and WJ-7	
	NW, SW		320°		90°	1"-15'	2'	Planar, smooth to locally rough, continuous	Major carbonate at WJ-4	
	I6 NW, SW		295°		75°NE	1"-15'	2'		Minor carbonate at WJ-9	
II	All	045°-080°	060°	80°SE-80NW	90°	1"-5'	2'	Planar, smooth to rough	Carbonate locally	No shears or alteration zones, minor fracture zone
	NE, SE		050°		85°NW	1"-5'	1.5'	Planar to irregular, smooth to slightly rough	Carbonate at WJ-5	
	NW, SW		065°		90°	2"-5'	2'	Planar, smooth to rough	Carbonate at one outcrop	
III	All	340°-030°	0°	40°E-65°W	60°E	0.5"-5'	1.5'	Planar to irregular, rough	Carbonate locally	Parallel to minor shears and fracture zones
	NE		005°		60°E	2"-2'	1'	Curved, rough	--	Weakly developed
	SE		350°		65°W	6"-4'	1.5'	Planar to irregular, smooth to rough	--	Weakly developed
	NW, SW		345°		60°E	0.5"-5'	2'	Planar to irregular, rough	Carbonate locally	Strongly developed
IV		Variable orientations		Shallow to moderate						
	Strongest Concentrations:									
	NE		080°		10°N	2"-3'	1'			
	SE		090°		25°S			Planar to irregular, smooth to rough, discontinuous	--	Probably stress relief, near surface
			310°		40°NE					
	NW		090°		10°S	1"-3'	2'			
	SW		0°		05°E	6"-10'	2'			
			090°		25°N					

*Surface data only
**When set is present

TABLE 6.3: WATANA RQD SUMMARY

Borehole Ground Surface El. (feet) Top Of Rock El. (feet) Borehole Dip**		DH-1* 1459 1415 V	DH-4* 1462 1384 V	DH-5* 1462 1402 V	DH-6* 1716 1713 V	DH-7* 1716 1708 59°	DH-8* 1910 1894 V	DH-9* 1913 1909 45°	DH-10* 2033 2020 V	DH-11* 2034 2018 45°	DH-12* 1951 1942 V	DH-21* 1480 1407 60°	DH-23* 1952 1947 45°	DH-24* 2061 2054 V	DH-28* 1971 1958 V	BH-1 2050 2032 70°	BH-2 1835 1826 38°	BH-3 2150 2123 55°	BH-4 2185 2174 59°	BH-6 1605 1598 60°	BH-3 1976 1964 60°	BH-12 1966 1949 40°	Total Rock Drilled - Average RQD
Vertical Depth (ft)	RQD																						
0'-50'	Rock Drilled (ft) RQD%	51.4 28%	45.2 66%	47.9 46%	48.9 50%	49.1 48%	54.5 59%	7.0 59%	48.6 21%	70.3 71%	51.6 60%	59.7 85%	70.5 45%	50.9 70%	29.5 36%	52.5 79%	61.2 55%	59.1 75%	56.9 44%	58.5 50%	59.2 43%	81.5 57%	1174.0 56%
50'-150'	"	27.6 45%		69.2 83%	97.2 51%	64.6 60%	79.3 67%	139.5 62%	100.5 68%	144.1 77%	99.9 53%	110.0 85%	41.7 49%	82.1 70%	62.4 10%	104.8 76%	119.8 23%	124.9 96%	115.7 54%	118.4 64%	116.2 75%	151.7 72%	1969.6 65%
150'-250'	"							72.1 44%	34.8 89%	65.0 85%	105.1 77%	121.7 83%				109.6 86%	124.4 54%	120.0 99%	120.8 94%	115.8 86%	114.5 82%	154.0 68%	1257.8 79%
250'-350'	"										33.9 85%	118.3 82%				14.3 73%	85.6 75%	119.9 87%	114.9 99%	115.3 81%	114.6 79%	156.1 62%	872.9 80%
350'-450'	"											109.5 91%						119.5 46%	115.1 99%	114.4 82	114.3 84%	159.3 79%	732.1 79%
450'-550'	"																	120.6 96%	120.0 79%	115.2 71%	117.8 81%	69.3 83%	542.9 82%
550'-650'	"																	125.0 96%	115.1 70%	94.8 79%	102.0 88%		436.9 83%
650'-750'	"																	120.0 96%	114.7 74%				234.7 86%
750'-850	"																	15.0 100%	64.0 95%				79.0 96%
Total Hole Length (feet) Average RQD		79.0 34%	45.2 66%	117.1 68%	146.1 50%	113.7 55%	133.8 64%	278.6 57%	183.9 60%	279.4 78%	290.5 67%	519.2 84%	112.2 47%	133.0 70%	91.9 18%	281.2 80%	391.0 49%	924.0 96%	937.2 80%	732.4 75%	738.6 78%	771.9 70%	7299.9 72%

*COE boreholes
**V = vertical

TABLE 6.4: WATANA - BOREHOLE ROCK QUALITY DISTRIBUTION

Borehole	Rock Drilled (ft)	PERCENTAGE OF CORE IN SPECIFIC RQD RANGES					
		0-25%	25-50%	50-75%	75-90%	90-95%	95-100%
DH-1*	79.0	29	56	8	0	7	0
DH-4*	45.2	16	5	17	52	10	0
DH-5*	117.1	6	15	31	23	3	22
DH-6*	146.1	13	30	44	9	0	4
DH-7*	113.7	13	26	29	29	0	3
DH-8*	133.8	6	11	41	32	8	2
DH-9*	278.6	19	18	25	30	7	1
DH-10*	183.9	25	12	14	23	10	16
DH-11*	279.4	3	5	22	38	17	15
DH-12*	290.5	8	17	29	17	12	17
DH-21*	519.2	0	2	25	22	14	37
DH-23*	112.2	36	22	18	8	9	7
DH-24*	133.0	5	14	42	18	9	12
DH-28*	91.9	61	29	10	0	0	0
BH-1	281.2	2	4	22	26	18	28
BH-2	391.0	24	17	30	19	5	5
BH-3	924.0	7	2	5	12	8	66
BH-4	937.2	6	11	13	9	7	54
BH-6	732.4	5	7	22	33	15	18
BH-8	738.6	3	6	22	30	11	28
BH-12	771.9	6	17	30	19	10	18
Total Rock Drilled	7299.9						

*COE core was relogged from boxes.

TABLE 6.5: WATANA ROCK TEST SUMMARY
DIORITE, QUARTZ-DIORITE, GRANODIORITE

Borehole*	Sample	Borehole Depth (ft)	Compressive Strength (psi)	Unit Weight (pcf)	Tensile Strength (psi)	Other**
BH-1	W-1-41.6	41.6	23,587	167.2		
	W-1-44.2	44.2	23,587	167.7		
	W-1-83.9	83.9		169.2	2,019	
	W-1-134.9	134.9	24,400	168.9		
	W-1-230.3	230.3				$E_D = 10.8 \times 10^6$ psi, $v = 0.29$
BH-2	10-80	313.8	17,487	169.6		
BH-3	W-3-57.9	57.9	10,623	165.6		
	W-3-199.6	199.6	19,632	169.3	1,824	
	W-3-320.7	320.7	20,333	169.2		$E_T = 10.6 \times 10^6$ psi, $v = 0.27$
	W-3-602.2	602.2	4,473	151.0	602	Altered, unit wt. for tensile strength test = 160.5
	W-3-954.8	954.8	11,556	165.9		
BH-4	W-4-90.4	90.4	12,607	165.3		
	W-4-285.8	285.8	14,233	171.9		
	W-4-533.4	533.4	15,665	170.9		
	W-4-535.8	535.8		169.1	1,965	
	W-4-690.9	690.8	14,414	168.5	1,872	$E_T = 9.9 \times 10^6$ psi, $v = 0.24$
	W-4-888.1	888.1	7,650	168.8		Slightly altered
BH-6	80-12	81.65	14,640	166.2		
	80-14	144.6	21,147	166.4		
	80-15	218.1	15,860	167.3		
	80-16	233.0		167.2	2,098	
	80-19	260.7	15,047	164.8		
BH-8	80-28	316.9	16,858	168.3		
	80-29	322.6	28,020	168.3	2,417	
	80-31	327.46	26,996	167.3		
	80-35	468.4	21,160	167.1		
	80-38	480.65	23,358	167.0		$E_D = 9.4 \times 10^6$ psi, $v = 0.33$
BH-12	W-12-328.8	328.8	19,113	165.7	2,450	
	W-12-465.4	465.4	18,707	168.6		
	W-12-657.6	657.6	13,827	164.3		
	Average (Acres)		17,500 $\pm$5,754 SD	167.1	1,906 $\pm$576 SD	
DH-8***	27	44.2	21,450			$E_T = 11.2 \times 10^6$ psi, $v = 0.24$
	28	70.7	29,530			$E_T = 9.49 \times 10^6$ psi, $v = 0.20$
DH-10	29	70.2	20,500			$E_T = 8.60 \times 10^6$ psi, $v = 0.22$
	30	176.5	18,470			$E_T = 9.41 \times 10^6$ psi, $v = 0.23$
DH-11	31	40.15	10,420			$E_T = 9.65 \times 10^6$ psi, $v = 0.27$
	32	84.3	7,610			$E_T = 7.13 \times 10^6$ psi, $v = 0.20$
	Average (All Tests)		17,593 $\pm$6,080 SD			

*Locations shown on Figure 5.1
**E_D = Dynamic modulus
***COE testing

E_T = Tangent modulus at 50% of failure stress
v = Poissons Ratio
SD = Standard deviation

TABLE 6.6: WATANA ROCK TEST SUMMARY - ANDESITE PORPHYRY

Borehole*	Sample	Depth (feet)	Compressive Strength (psi)	Unit Weight (pcf)	Tensile Strength (psi)	Other**
BH-2	1-80	20.5	26,206	165.4		
	2-80	27.05	20,333	166.9		$E_T = 9.9 \times 10^6$ psi, $v = 0.24$
	3-80	45.3	17,283	166.6		$E_T = 10.5 \times 10^6$ psi, $v = 0.27$
	4-80	49.4	15,453	166.4		
	5-80	82.25		162.8	1,718	
	6-80	87.0		165.3	1,715	
BH-4	W-4-14.2	14.2	23,180	165.4		
BH-8	80-22	37.8	19,520	162.6	1,616	
BH-12	W-12-41.1	41.4	18,814	163.7		
BH-12	W-12-96.8	96.8	6,100	162.7		
	Average		18,361 $\pm$5,978 SD	164.8	1,683 $\pm$58 SD	

*Locations shown on Figure 5.1
**E_T = Tangent modulus at 50% of failure stress
v = Poissons Ratio
SD = Standard deviation

TABLE 6.7: QUATERNARY STRATIGRAPHY OF BURIED CHANNEL AREA

	Unit	Maximum Thickness	Material Type	Occurrence	Permeability
A&B	Surficial Deposits	5 feet	Organic silts and sands with cobbles and boulders	Local	Moderate
C	Outwash	18 feet	Silty sand with gravel and cobbles	Often removed by post-glacial erosion	Low to Moderate
D	Alluvium and Fluvial Deposits	15 feet	Sand, silt with occasional gravel	Along courses of former drainage channels in outwash "E"	Moderate
E&F	Outwash	55 feet	Silt, sand, gravel, cobbles, partly sorted	Generally continuous except in limited areas	Low to Moderate
G	Till/waterlain Till	65 feet	Clayey silty sand with gravel and cobbles, often plastic	Continuous, thickest near Deadman Creek	Low
H	Alluvium	40 feet	Silt, sand and gravel, sorted	Buried channel and along limited former drainage channels	Moderate
I	Till	60 feet	Silt, sand, gravel, cobbles poorly sorted	Generally continuous	Low
J	Interglacial	45 feet	Sand, gravel, with occasional silt, sorted	Buried channel only	High
J	Till	60 feet	Silt, sand, gravel cobbles, poorly sorted	Generally continuous	Low
K	Alluvium	160 feet	Gravel, cobbles, boulders, few fines	Buried channel only	High

TABLE 6.8: MATERIAL PROPERTIES - BORROW SITE D

Hole/* Trench Number	Sample Number	Depth (feet) From	To	Lab. Classi-fication	Mechanical Analysis Gravel	Sand	Fine	Atterberg Limits LL	PI	Specific Gravity	W%
AH-D1	1	0	1.5								
	2	1.5	3.0								
	3	3.0	3.5								
	4	4.5	4.75								
	5	6.0	6.75	SM	10	48	42	NV	NP		11.1
	6	8.0	8.75	SM	24	22	54				6.7
	7	10.0	10.75	SM	13	51	36				6.6
	8	15.0	15.75								
AH-D2	3	1.5	2.5	SM	33	38	28	NV	NP		25.7
	4	3.0	3.75	SM	24	41	35	13.9	NP		11.4
	5	4.5	5.25	SM	23	46	31	NV	NP		11.2
	6	6.5	7.0								
	7	8.5	9.0								
	8	15.0	15.75	SC	7	49	44	15.5	2.2		11.3
	9	20.0	20.75	SM-SC	15	46	39	17.5	4.2		9.4
	10	25.0	25.5								
AH-D3	2	.5	.75								
	3	1.5	2.0								
	4	3.0	4.0								
	5	4.5	5.25								
	6	6.5	7.25								
	7	8.5	9.5								
	8	15.0	15.75								
	9	20.0	20.25								
	10	25.0	25.25								
	11	30.0	30.5								
AH-D4	3	1.5	3.0								
	5	4.5	5.0								
	6	6.0	7.5								
	8	7.5	8.0								
AH-D5	3	3.0	3.75								
	4	7.5	9.0	SM	0	88	22				
	5	10.0	11.0	SM	34	47	19				
	6	15.0	16.5	SM	25	52	23				
	7	20.0	21.0								
	8	25.0	25.75								
	9	30.0	31.5	SM	0	75	25	14	NP		13
	10	35.0	36.0	CL-ML	0	55	45	17	14		12
	11	40.0	41.25	CL	8	42	50	23	14		12
	12	45.0	46.0	SM-SC	11	64	25	39	14		9
	13	48.0	48.25								
AH-D6	1	0.0	2.0								
	3	5.0	6.0	SM	10	50	40	15	NP		10
	4	6.5	7.5	SM							8
	5	7.5	8.0								
	6	8.0	9.0	SM	0	76	24	13	NP		12
	7	9.5	10.0	SM							11
	8	15.0	16.0								
	9	20.0	21.5	SP-SC	0	88	12	17	2		12
	10	25.0	26.5	SM	29	38	33	15	NP		9
	11	30.0	30.5								8
	12	35.0	36.0	SM	10	50	40	17	NP		9
	13	40.0	40.6								12
	14	45.0	46.0								
AH-D7	3	5.0	5.5								11
	4	7.0	8.0	SM	20	50	30				12
	5	8.5	9.5	SM							11
	6	15.0	16.5	SM	20	53	27				10
	7	20.0	20.25								6
	8	25.0	25.75	SM	6	71	23				9
	9	35.0	35.25								9
	10	40.0	40.75	SM	0	80	20				9
	11	48.0	48.25								

TABLE 6.8 (Cont'd)

Hole/* Trench Number	Sample Number	Depth (feet)		Lab. Classi-fication	Mechanical Analysis			Atterberg Limits		Specific Gravity	W%
		From	To		Gravel	Sand	Fine	LL	PI		
AH-D8	4	3.5	4.5								
	5	4.5	6.0	SM	18	65	17	14	NP		15
	6	6.0	6.5								
	7	8.0	9.5								
	8	9.5	11.0	SM	0	58	42	14	NP		14
	9	15.0	16.5	SM	12	71	17				13
	10	20.0	20.5								
	11	25.0	25.5	SP	28	61	11	18	5		10
	13	35.0	36.0	ML	10	37	53				13
	15	45.0	45.25								9
	16	50.0	50.25		9	55	36				7
AH-D9	1	0.0	1.0								
	2	1.5	2.5	SM	10	55	35				
	3	3.0	4.0	SM	10	50	40				
	4	4.5	6.0	SM	0	60	40				
	5	6.0	7.5	SM	14	65	21				
	6	7.5	8.5	SM	0	76	23				
	7	9.0	10.5	SM	15	63	22				
	8	15.0	15.5								
	9	20.0	20.5								
	10	25.0	25.9								
	11	30.0	30.5								
	12	35.0	35.4								
	13	40.0	41.0	C-ML	0	8	92	21	NP		21
	14	45.0	46.5	ML	0	17	83	35	8		25
	15	50.0	51.5								
	16	55.0	55.2								
	17	60.0	60.25								
AH-D10	1	0.0	1.0								
	2	1.0	1.5								
	3	2.0	3.0								
	4	3.0	3.5								
	5	4.0	4.5								
	6	5.0	5.5								
	7	6.0	7.5								
	8	7.5	8.5								
	9	15.0	16.0								
	10	20.0	20.5								
	11	25.0	26.0								
	12	30.0	31.0								
	13	40.0	40.33								
AH-D11	3	3.0	4.0								
	4	4.0	6.0								
	5	6.0	7.5								
	6	7.5	9.0								
	7	15.0	16.5								
	8	20.0	21.5								
	9	25.0	25.25								
	10	30.0	31.0								
	11	25.0	36.5								
	13	45.0	45.5								
	15	54.5	54.66								
AH-D12	3	1.5	3.0								
	4	3.0	4.0								
	5	4.5	5.5								
	6	6.0	6.5								
	7	7.5	8.0								
	8	9.0	9.33								
	9	15.0	15.3								
	10	20.0	20.16								
	11	25.0	25.5								

TABLE 6.8 (Cont'd)

Hole/* Trench Number	Sample Number	Depth (feet)		Lab. Classi-fication	Mechanical Analysis			Atterberg Limits		Specific Gravity	W%
		From	To		Gravel	Sand	Fine	LL	PI		
AH-D13	1	0.0	0.5								
	2	0.5	1.5								
	3	3.0	4.0								
	4	4.5	6.0								
	5	6.0	7.5								
	6	7.5	9.0								
	7	15.0	16.25								
	8	20.0	20.66								
	9	25.0	26.5								
	10	30.0	31.0								
	11	35.0	35.5								
	12	38.0	40.0								
	13	45.0	45.5								
AH-D14	2	3.0	4.0								
	3	6.0	7.5								
	4	7.5	9.0								
	5	9.0	10.0								
	6	15.0	16.5								
	7	20.0	20.5								
W-81	D			SP	0	5	95	59	23		
W-81	D				15	40	45			2.71	

*Locations shown on Figure 6.40

TABLE 6.9: GRADATION RESULTS - BORROW AREA D

Soil Unit		Coarser than No. 4 (%)	Between No. 4 and No. 200 (%)	Finer than No. 200 (%)	PI	Unified Soil Classification
Composite	Sample	15	40	45		SM
	Coarse	13	62	25		SM
C & D	Mean	5	60	35	NP	SM
	Fine	0	49	51		ML
	Coarse	32	50	18		SM
E & F	Mean	12	53	35	NP	SM
	Fine	2	48	50		SM-ML
	Coarse	15	57	28		SM
G	Mean	0	45	55	10	ML
	Fine	0	18	82		ML
	Coarse	4	75	21		SM
H	Mean	0	73	27	NP	SM
	Fine	0	68	32		SM
	Coarse	25	55	20		SM
I & J	Mean	15	53	32	7.5	SM
	Fine	5	53	42		SM

PI = Plasticity Index
NP = Non-plastic

TABLE 6.10: MATERIAL PROPERTIES - BORROW SITE E

Hole/* Trench Number	Sample Number	Depth (feet) From	Depth (feet) To	Lab. Classi-fication	Mechanical Analysis Gravel	Mechanical Analysis Sand	Mechanical Analysis Fine	Atterberg Limits LL	Atterberg Limits PI	Specific Gravity	W%
E1	1	2.5	3.0	GP-GM	53	39	8				
	2	7.0	7.5	GP	74	25	1				
E2	1	2.5	3.0	SP	49	49	2				
	2	5.5	6.0	GW	77	22	1				
E3	1	2.5	3.0	GW	78	21	1				
	2	10.5	11.0	GP	74	24	2				
E4	1	3.0	3.5	GP	82	17	1				
	2	10.5	11.0	GP	82	17	1				
E5	1	1.0	2.0	GW	83	16	1				
E6	1	7.5	8.0	SM	25	62	13				
E8	1	2.5	3.0	GW	76	23	1				
	2	6.5	7.0	SP	36	63	1				
E9	1	2.5	3.0	-	0	10	90				
	2	4.5	5.0	SM	22	58	20				
	3	7.0	8.0	GM	-	-	-				
E10A	1	3.5	4.0	GP	63	34	3				
	2	6.5	7.5	SM	0	83	17				
E10B	1	2.0	2.5	GW	64	34	2				
E11	1	1.5	2.0	SM	0	62	38				
	2	5.0	5.5	GP-GM	61	31	8				
E12	1	2.0	2.5	GP-GM	63	31	6				
	2	2.5	3.5	SM	10	52	38				
	3	3.5	4.5	SM	29	47	24				
E14	1	1.0	2.0	SP-SM	0	95	5				
	2	6.0	7.0	SP	69	28	3				
E15	1	3.0	3.5	GW	83	16	1				
E16	1	3.0	3.5	SP	66	32	2				
E17	1	0.5	1.0	-	0	32	68				
	2	3.5	4.0	SM	0	59	41				
	3	10.0	10.5	GP-GM	65	30	5				
E18	1	0.25	0.75	GP	55	43	2				
	2	2.0	2.5	SM	20	52	28				
	3	5.0	5.5	GP	63	36	1				
	4	10.0	10.5	GP	71	27	2				
E19	1	1.0	1.5	SM	0	66	34				
	2	2.5	3.0	SM	0	79	21				
E20	1	1.5	2.0	SM-ML	0	47	53				
	2	3.0	3.5	SP	79	19	2				
	3	7.5	8.5	SM	19	50	31				
	4	11.0	11.5	SP-SM	66	28	6				
E21	1	2.0	2.5	-	0	30	70				
	2	6.5	7.0	GM	85	11	4				
AH-E1	2	0.5	1.0								
	3	1.0	1.5	SM	0	52	48				19.6
	4	2.0	2.5	ML	0	40	60				27.3
	5	4.0	4.25								
	7	6.5	6.75								
	10	12.0	12.5								
	11	15.0	15.25								
	13	23.5	25.0								
AH-E2	2	1.5	2.25								
	3	3.0	3.5								
	4	5.0	5.75								
	5	6.5	7.0								
	6	8.5	9.0								
AH-E3	2	0.5	1.0								
	3	1.0	1.5								
	4	1.5	2.25								
	5	3.0	3.75								
	6	4.5	5.5	SP-SM	38	56	6				4.4
	7	6.5	7.5	GW	60	36	4				0.7
	8	8.5	9.0								
	9	15.0	15.5								
	10	16.5	17.0								

TABLE 6.10 (Cont'd)

Hole/* Trench Number	Sample Number	Depth (feet) From	To	Lab. Classi-fication	Mechanical Analysis Gravel	Sand	Fine	Atterberg Limits LL	PI	Specific Gravity	W%
AH-E4	2	0.5	1.5								
	3	1.5	3.0								
	4	3.0	4.0								
	5	4.0	4.5								
	6	5.0	6.5	SM	2	76	22				17.6
	7	6.5	7.25								
	8	8.0	8.75								
AH-E5	2	1.0	1.5								
	3	1.5	2.0								
	4	2.0	2.5								
	6	4.0	5.25								
	8	6.0	6.75								
	10	7.5	8.5								
	11	9.0	10.25								
AH-E6	2	0.5	1.5								
	3	1.5	3.0								
	6	6.0	7.0								
	7	7.5	8.0								
	8	9.5	9.75								
	10	20.0	20.75								
AH-E7	1	0.0	0.5								
	3	2.0	3.0	GP	61	37	2				2.3
	4	3.0	4.0								
AH-E8	2	0.5	1.5								
	3	1.5	2.0								
	4	3.0	3.75								
AH-E9	1	0.0	1.0								
	2	1.5	2.5	SM	0	71	29				15.7
	3	3.0	3.5								
	5	5.0	5.25								
	6	6.5	8.0	GM	43	40	17				4.4

*Location shown on Figure 6.43.

TABLE 6.11: MATERIAL PROPERTIES - BORROW SITE H

Hole/* Trench Number	Sample Number	Depth (feet) From	Depth (feet) To	Lab. Classi-fication	Mechanical Analysis Gravel	Mechanical Analysis Sand	Mechanical Analysis Fine	Atterberg Limits LL	Atterberg Limits PI	Specific Gravity	W%
AH-H1	1	0.0	1.5		0	75	25				13
	2	1.5	3.0	SM	26	49	25				13
	3	3.0	4.0								16
	4	4.5	6.0	SC	13	66	22	32	17		17
	5	6.0	7.5	CL	14	34	52	34	21		16
	6	7.5	8.5	CL	18	27	55	25	7		12
	7	9.0	10.0								12
	8	15.0	15.5	GM	66	22	12	21	NP		9
	9	20.0	21.5								9
	10	25.0	26.5								
AH-H2	1	0.0	1.5								
	2	1.5	3.0		15	62	23	-	NP		23
	3	3.0	4.0	SM							17
	4	4.5	5.5								20
	5	6.0	7.0		34	31	35	18	NP		7
	6	7.5	8.5	GM							11
	7	9.0	10.0								11
	8	15.0	16.0	SM	24	23	33				10
	9	20.0	20.83	SM	27	41	32	17	NP		9
	10	25.0	25.5								6
	11	30.0	30.75		18	42	40	18	5		8
	12	35.0	35.7	SM-SC							8
	13	40.0	40.75								7
AH-H3	1	0.0	1.5								
	2	1.5	3.0								
	3	3.0	4.0								53
	4	4.5	5.5	SM-SC	14	44	42	18	5		19
	5	6.0	7.0								14
	6	7.5	8.5								
	7	9.5	10.5	SM	7	52	41	-	NP		12
	8	15.0	16.5	SM	17	53	30	14	NP		9
	9	20.0	20.25								
	10	25.0	25.25								
AH-H4	1	0.0	1.5								
	2	1.5	3.0								
	3	3.0	4.5	GC	45	35	20	23	7		16
	4	4.5	5.5								13
	5	6.0	7.0	SM-SC	25	35	40	20	4		15
	6	7.5	8.5								11
	7	15.0	16.0	SM	35	38	27	22	NP		11
	8	20.0	21.0								
	9	25.0	25.5								
AH-H5	1	0.0	1.5								
	2	1.5	3.0								
	3	3.0	4.0								
	4	4.5	6.0	SM-SC	22	36	42	23	6		16
	5	6.0	7.5	SM-SC	0	55	45	22	6		17
	6	7.5	8.5	SM-SC	24	33	33	21	4		9
	7	9.0	9.5		24	33	33	21	4		10
	8	15.0	15.66								
	11	30.0	30.25								
	12	35.0	35.5								
AH-H6	1	0.0	1.5								
	2	1.5	3.0								
	3	3.0	4.5								
	4	4.5	6.0								
	5	6.0	7.0								
	6	7.5	9.0	SM	22	45	33	-	NP		13
	7	9.0	10.5								12
	8	15.0	15.5								
	9	20.0	20.25								
	10	25.0	26.5	SC	10	45	45	23	9		11
	11	30.0	31.0								
	12	35.0	35.5	SM-SC	34	47	19	21	6		8
	13	40.0	40.5								8

TABLE 6.11 (Cont'd)

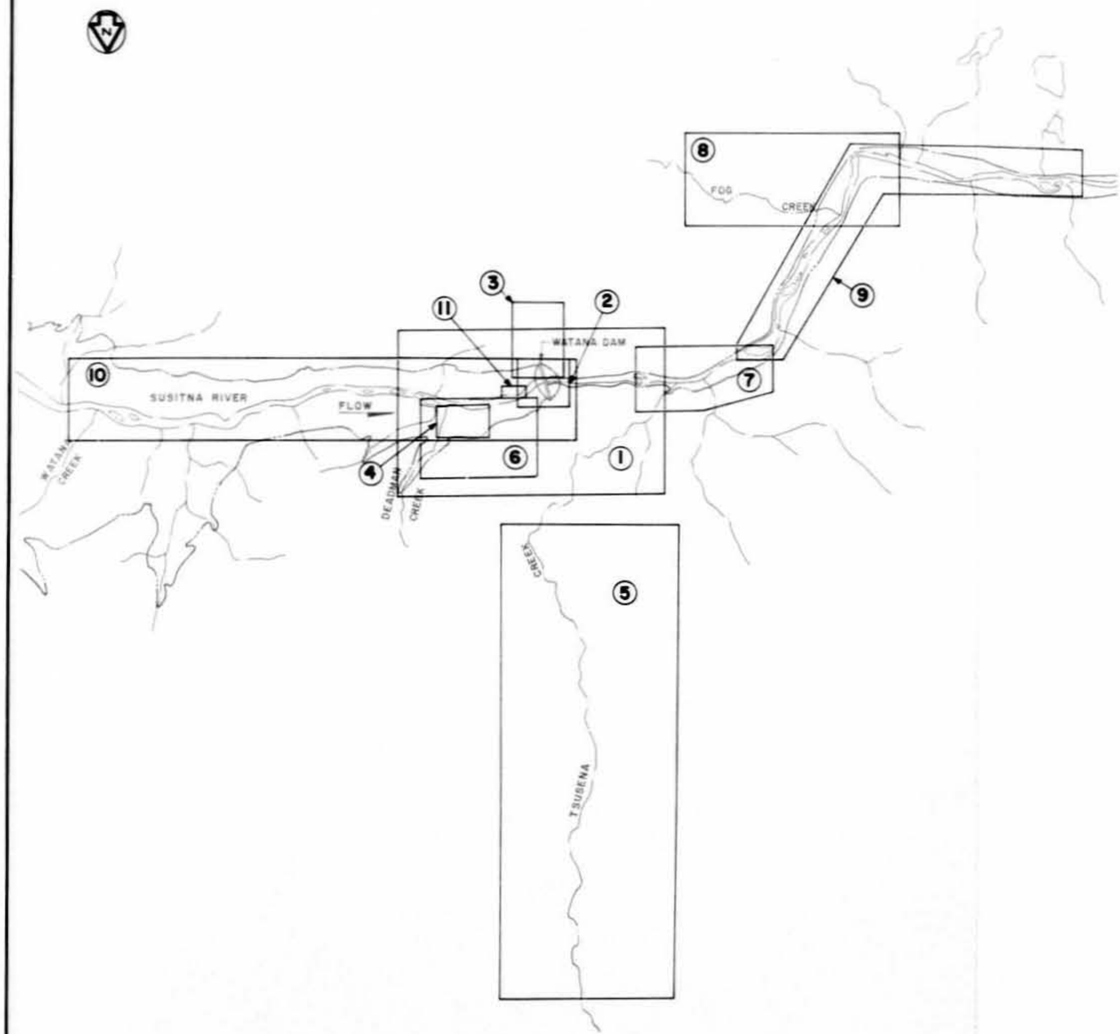
Hole/* Trench Number	Sample Number	Depth (feet)		Lab. Classi-fication	Mechanical Analysis			Atterberg Limits		Specific Gravity	W%
		From	To		Gravel	Sand	Fine	LL	PI		
AH-H7	1	0.0	1.5								
	2	1.5	3.0								
	3	3.0	4.5								
	4	4.5	5.5								
	5	6.0	7.5	MC-CL	12	36	52	17	4		14
	6	7.5	9.0								17
	7	9.0	10.5	CL	7	34	59	29	14		16
	8	15.0	16.5								
	9	20.0	21.5	SC							13
	10	25.0	25.66		22	51	27	33	19		13
	11	25.66	26.5								
	12	30.0	30.6								
AH-H8	1	0.0	1.5								
	2	1.5	3.0								
	3	5.0	6.5								
	4	6.5	7.5					-	NP		14
	5	8.0	9.5	SC	18	40	42	25	11		12
	6	9.5	11.0								13
	7	15.0	16.5	GC	38	26	36	21	7		7
	8	20.0	21.0	GC	40	27	33	21	7		6
	9	25.0	26.0								6
	10	30.0	30.5								
	11	35.0	35.25								
W80-256	H			GC-SC	29	33	38	21.7	9.2		10.9
W80-357	H			GM-SM	27	37	36	17.1	2.5		12.3
W81	H				28	34	38			2.72	
W81	H				43	27	30	23	6		

*Locations shown on Figure 6.48

TABLE 6.12: MATERIAL PROPERTIES - BORROW SITES I AND J

Hole/* Trench Number	Sample Number	Depth (feet) From	To	Lab. Classi-fication	Mechanical Analysis Gravel	Sand	Fine	Atterberg Limits LL	PI	Specific Gravity	W%
TP-R1	1	0.0	1.0								
	2	1.5	2.0	GW	69	29	2				
	3	2.0	3.0								
	4	3.0	3.5	GW	72	26	2				
	5	3.5	4.5	GW	71	27	2				
TP-R2	1	0.0	1.0	GW	77	21	2				
	2	4.5	5.0	GW	79	19	2				
TP-R3	1	1.0	1.5								
	2	4.5	5.0	GW	71	28	1				
TP-R4	1	1.0	1.5								
	2	4.0	4.5	GW	69	30	1				
TP-R5	1	0.5	1.0	GW	64	34	2				
	2	3.0	3.5	GW	68	31	1				
TP-R6	1	1.0	2.0								
	2	2.0	3.0	ML-SM	1	52	47				
TP-R7	1	0.5	1.0	GW	68	31	1				
	2	3.5	4.0	SW	23	76	1				
TP-R8	1	0.5	1.0	GW	72	26	2				
TP-R9	1	0.5	1.0	SM	0	75	25				
TP-R10	1	1.0	1.5	SM	0	70	30				
	2	3.5	4.0	SM-SC	36	50	14				
TP-R11	1	0.5	1.0	GW	67	31	2				
	2	3.5	4.0	GW	70	28	2				
TP-R12	1	0.5	1.0	GW	67	30	3				
	2	4.5	5.0	GW	68	30	2				
TP-R13	1	0.5	1.0								
	2	5.5	6.0	GW	62	36	2				
TP-R14	1	0.5	1.0	GW	64	34	2				
	2	5.5	6.0	GW	64	35	1				
TP-R15	1	1.5	2.0								
	2	5.5	6.0	SM	0	55	45				
TP-R16	1	0.5	1.0	SM	0	63	37				
	2	4.5	5.0	GW-GM	59	35	6				
TP-R17	1	1.0	1.5	GW	73	25	2				
	2	4.0	4.5	GW	59	34	7				
TP-R18	1	1.0	1.5								
	2	4.5	5.0	GW	58	39	3				
TP-R19	1	0.5	1.0								
	2	3.5	4.0	GW	24	73	3				
TP-R20	1	0.5	1.0	SM	3	82	15				
	2	4.5	5.0	GW	62	34	4				
TP-R21	1	0.5	1.0								
	2	4.0	4.5								
TP-R22	1	1.0	1.5	GW-GM	65	33	13				
	2	4.5	5.0	GM	82	17	1				

*Locations shown on Figures 6.51 and 6.52.



INDEX

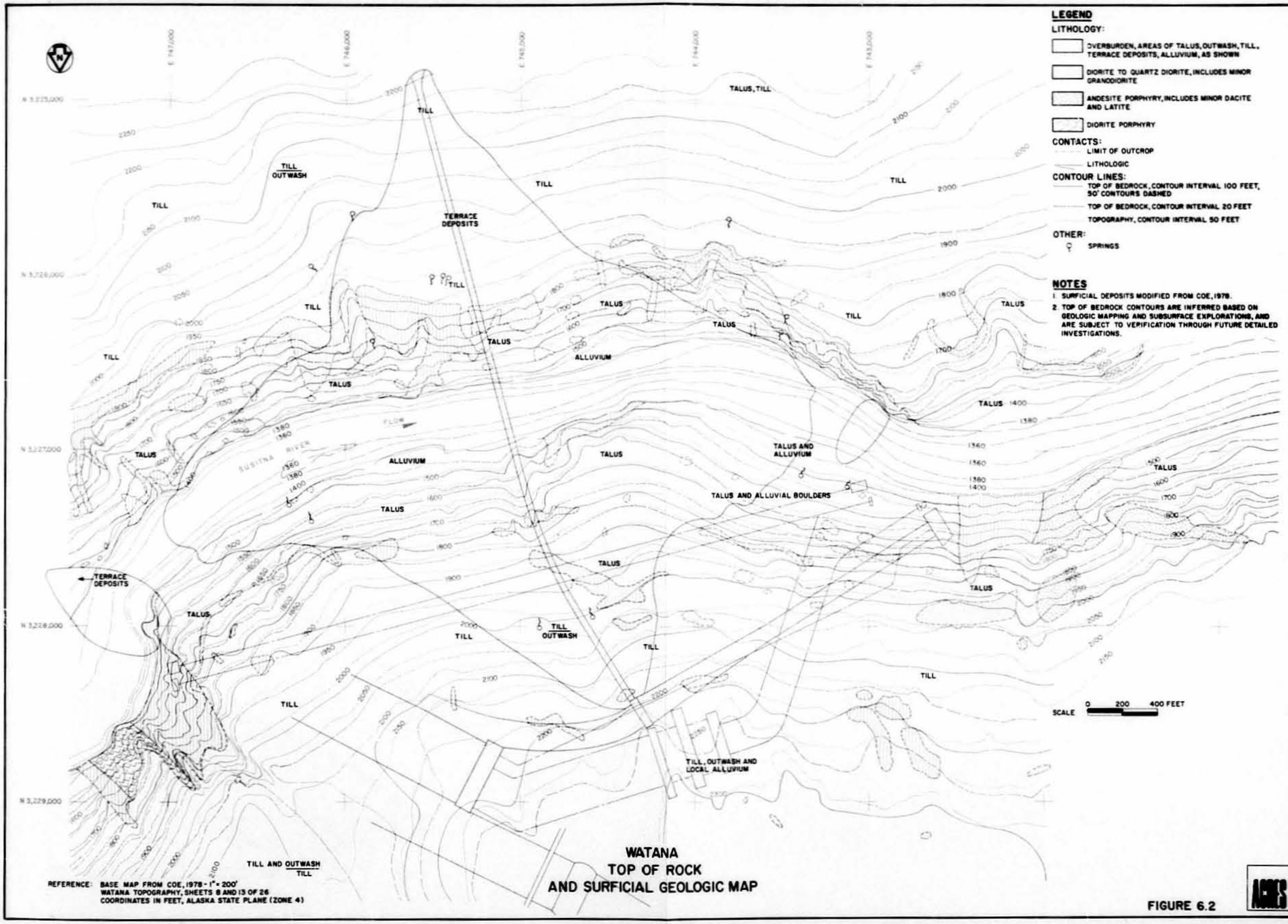
BLOCK NO.	AREA COVERED	SCALE*	FIGURE REFERENCE
1	DAMSITE VICINITY	1"=2500'	FIGURE 5.1 a
	RELICT CHANNEL: TOP OF BEDROCK	1"=2500'	FIGURE 6.35
2	DAMSITE: EXPLORATION	1"=500'	FIGURE 5.1 b
	DAMSITE: TOP OF BEDROCK	1"=500'	FIGURE 6.2
	DAMSITE: GEOLOGIC MAP	1"=500'	FIGURE 6.3
3	QUARRY SITE A	1"=1000'	FIGURE 6.37
4	QUARRY SITE B	1"=500'	FIGURE 6.38
5	BORROW SITES C AND F	1"=5000'	FIGURE 6.39
6	BORROW SITE D	1"=1000'	FIGURE 6.40
7	BORROW SITE E	1"=1000'	FIGURE 6.43
8	BORROW SITE H	1"=2500'	FIGURE 6.48
9	BORROW SITE I	1"=2500'	FIGURE 6.51
10	BORROW SITE J	1"=2500'	FIGURE 6.52
11	QUARRY SITE L	1"=500'	FIGURE 6.56

* REDUCED REPORT FORMAT

SCALE 0 1 2 MILES

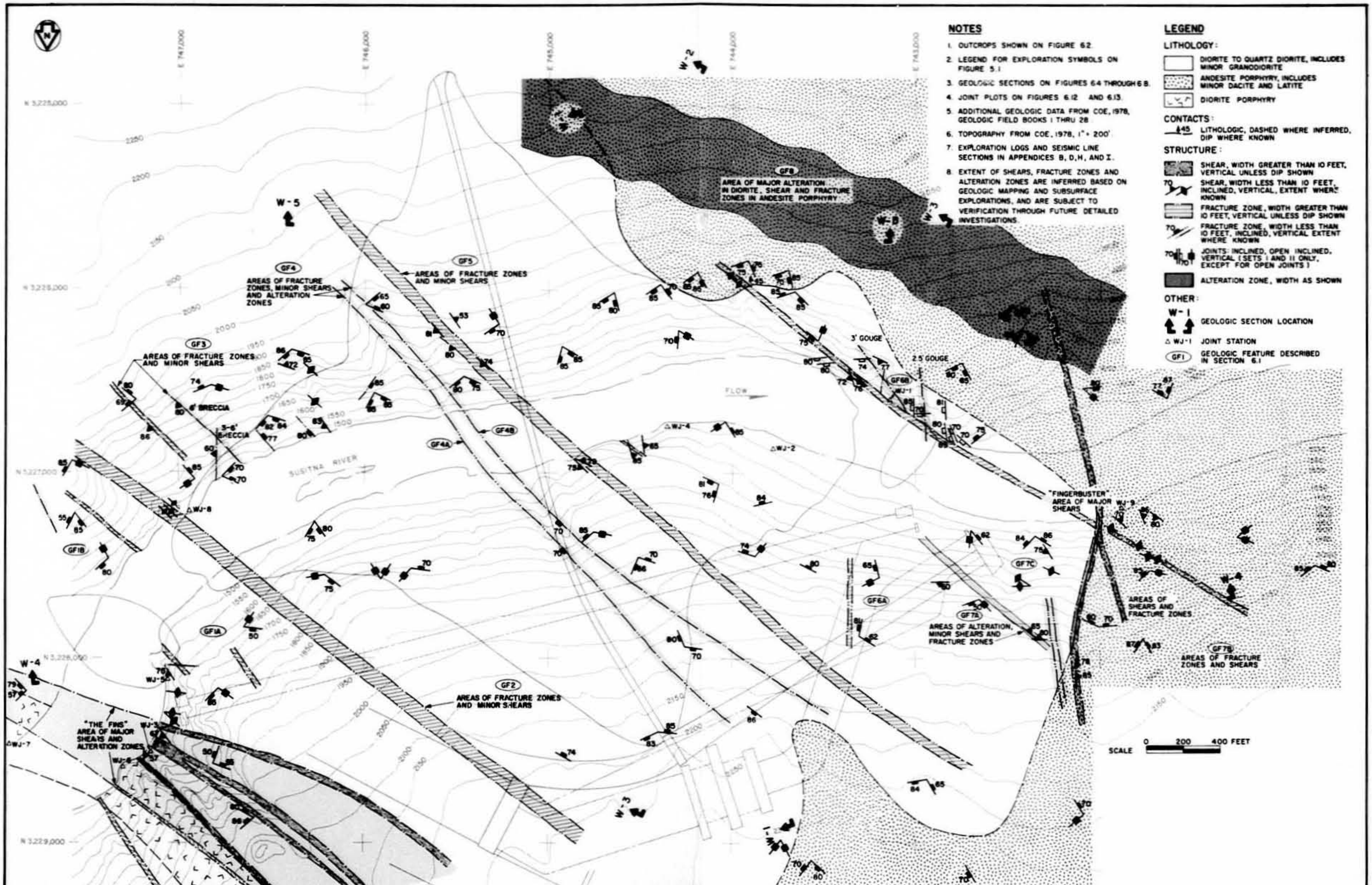
ACRES

FIGURE 6.1



WATANA
TOP OF ROCK
AND SURFICIAL GEOLOGIC MAP

FIGURE 6.2

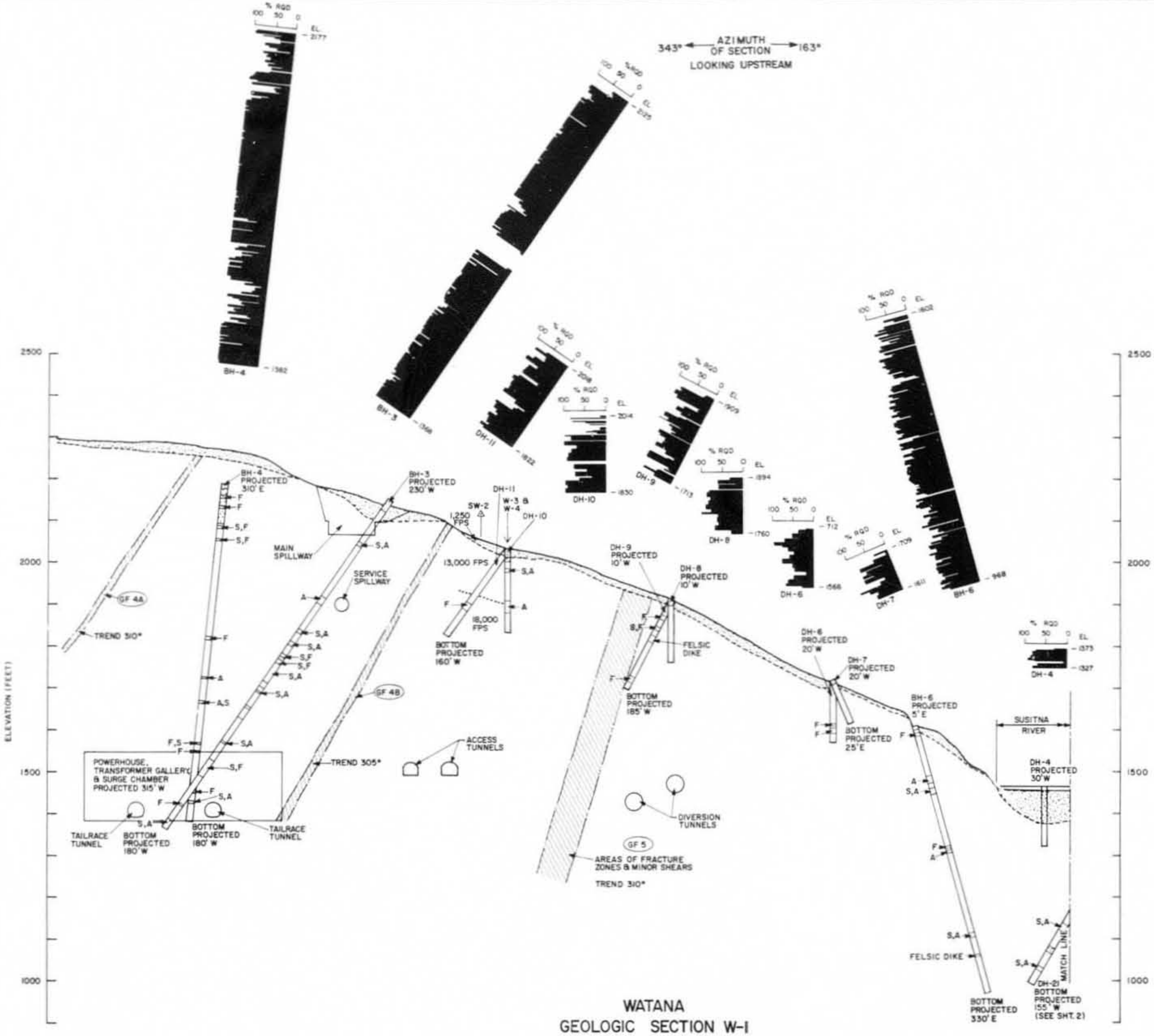


WATANA GEOLOGIC MAP

REFERENCE: BASE MAP FROM COE, 1978 - 1"=200' WATANA TOPOGRAPHY, SHEET 8 & 13 OF 26, COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4)

FIGURE 6.3

ACRES



LEGEND

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

CONTACTS:
- APPROXIMATE TOP OF ROCK
- LITHOLOGIC, 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
- 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 6.1.

NOTES

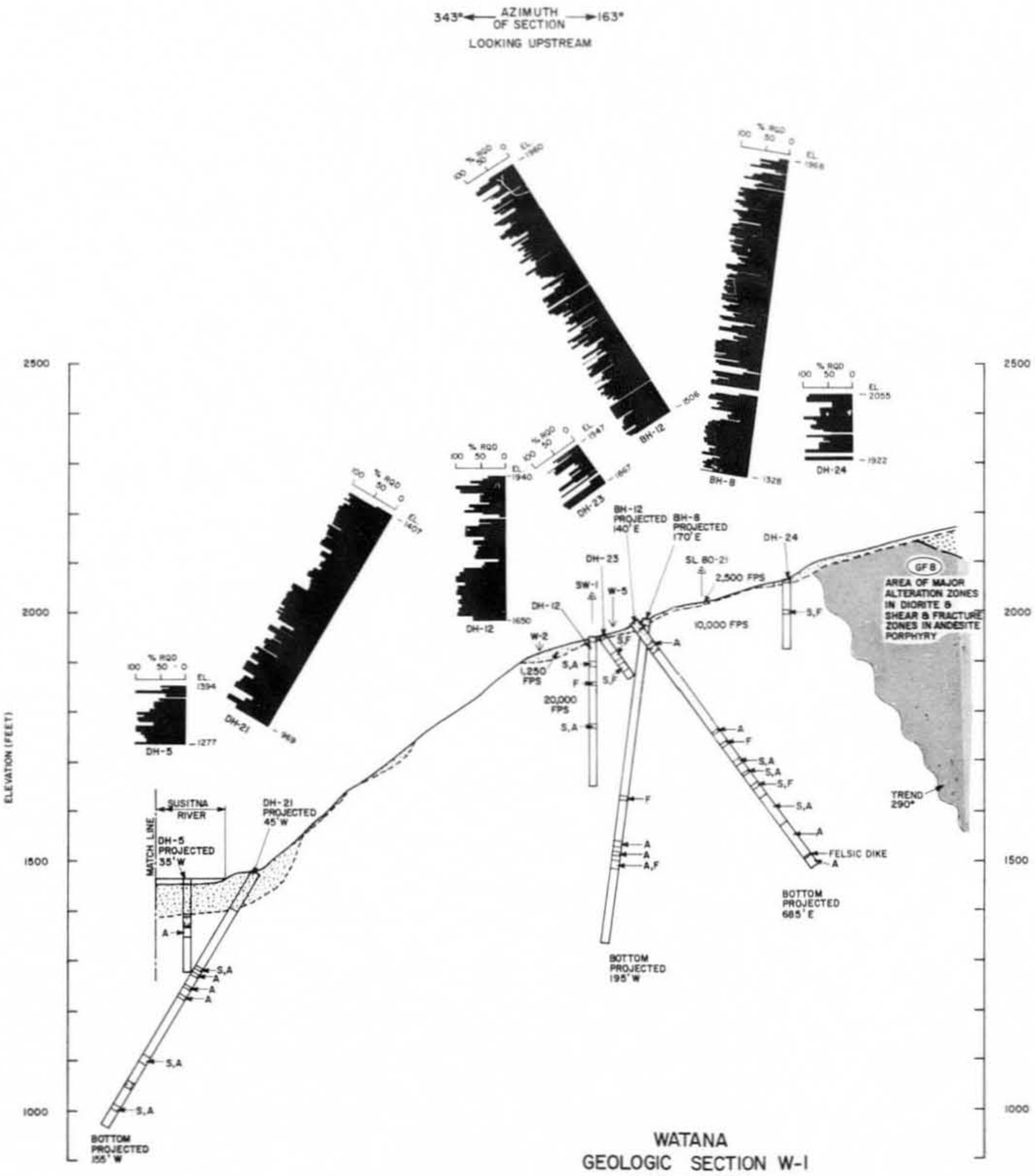
1. SECTION LOCATION SHOWN ON FIGURE 6.3.
2. VERTICAL & HORIZONTAL SCALES EQUAL.
3. SURFACE PROFILE FROM 1" = 200' TOPOGRAPHY, COE, 1978.
4. EXPLORATION LOGS AND SEISMIC LINE SECTIONS SHOWN IN APPENDICIES B,D,H AND I.
5. EXTENT OF SHEARS, FRACTURE ZONES, AND ALTERATION ZONES ARE INFERRED BASED ON GEOLOGIC MAPPING AND SUBSURFACE EXPLORATIONS, AND ARE SUBJECT TO VERIFICATION THROUGH FUTURE DETAILED INVESTIGATIONS.

SCALE 0 100 200 FEET

WATANA
GEOLOGIC SECTION W-1
SHEET 1 OF 2

ACRES

FIGURE 6.4



LEGEND

LITHOLOGY:

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

CONTACTS:

- APPROXIMATE TOP OF ROCK
- LITHOLOGIC, 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
- 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 6.1.

NOTES

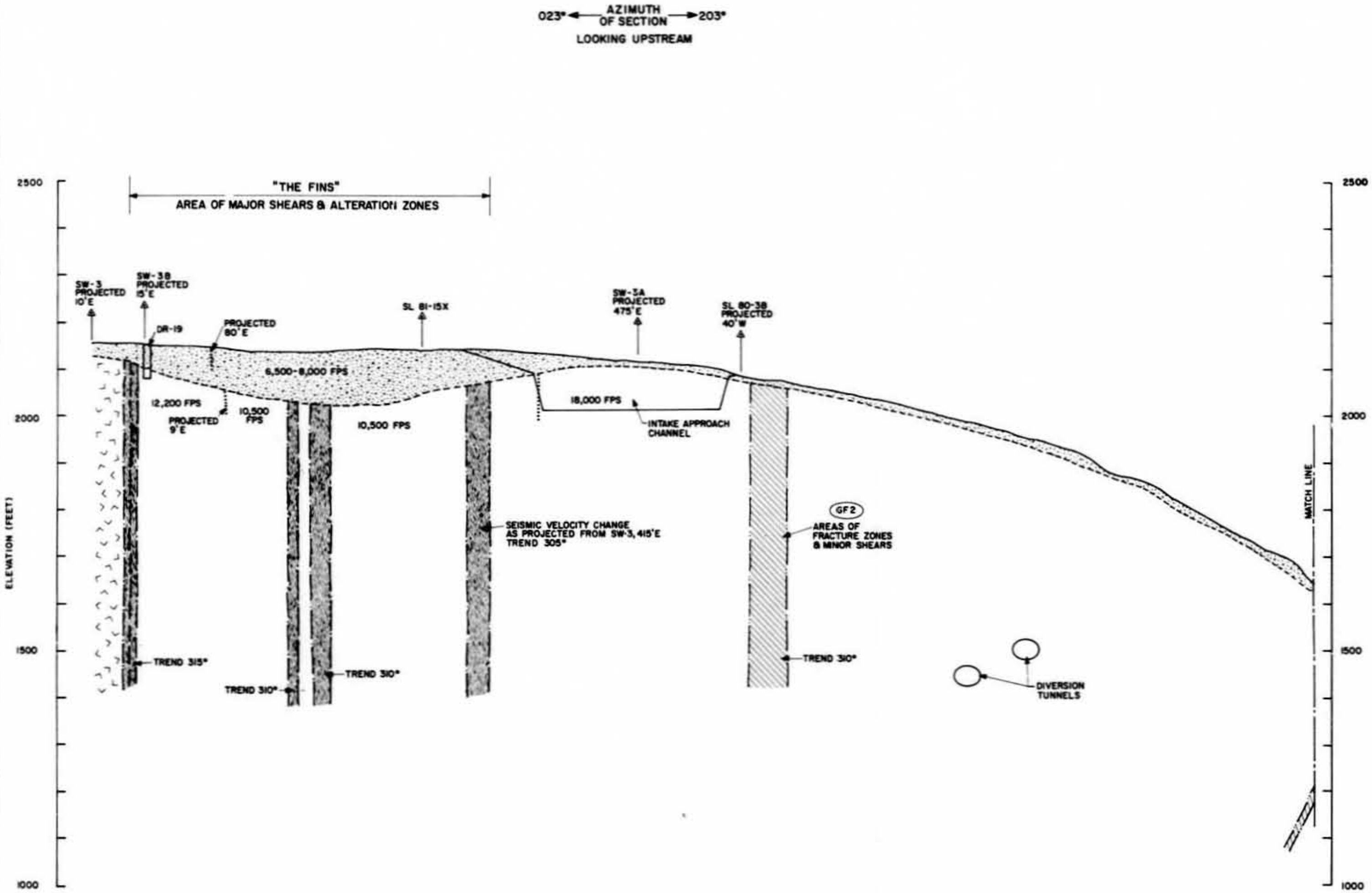
1. SECTION LOCATION SHOWN ON FIGURE 6.3.
2. VERTICAL & HORIZONTAL SCALES EQUAL.
3. SURFACE PROFILE FROM 1" = 200' TOPOGRAPHY, COE, 1978.
4. EXPLORATION LOGS AND SEISMIC LINE SECTIONS SHOWN IN APPENDICES B,D,H AND I.
5. EXTENT OF SHEARS, FRACTURE ZONES, AND ALTERATION ZONES ARE INFERRED BASED ON GEOLOGIC MAPPING AND SUBSURFACE EXPLORATIONS, AND ARE SUBJECT TO VERIFICATION THROUGH FUTURE DETAILED INVESTIGATIONS.

SCALE 0 100 200 FEET

WATANA
GEOLOGIC SECTION W-1
SHEET 2 OF 2

ACRES

FIGURE 6.4



LEGEND

LITHOLOGY:

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

CONTACTS:

- APPROXIMATE TOP OF ROCK
- LITHOLOGIC, 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
- 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 6.1.

NOTES

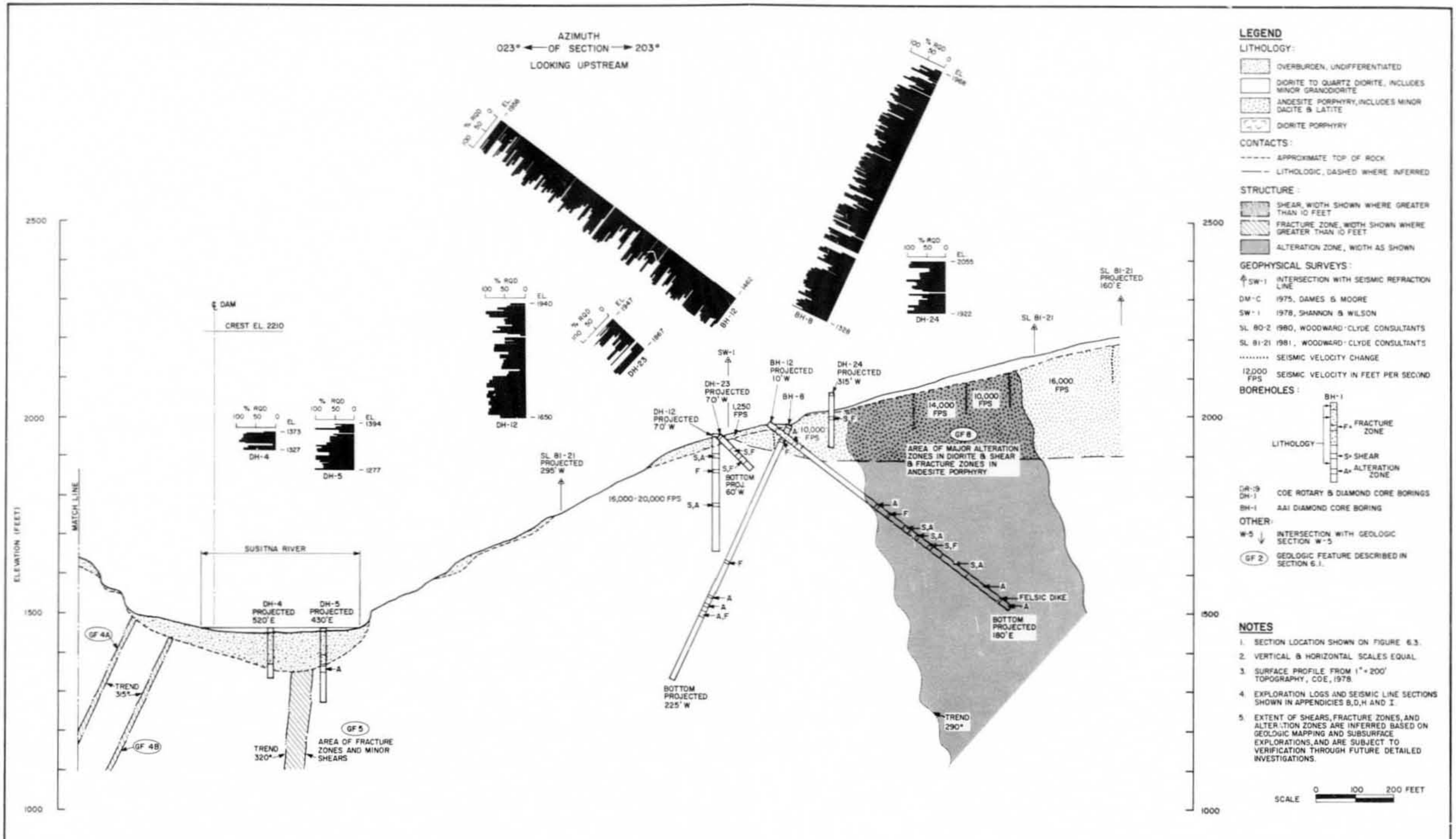
1. SECTION LOCATION SHOWN ON FIGURE 6.3.
2. VERTICAL & HORIZONTAL SCALES EQUAL.
3. SURFACE PROFILE FROM 1" = 200' TOPOGRAPHY, COE, 1978.
4. EXPLORATION LOGS AND SEISMIC LINE SECTIONS SHOWN IN APPENDICIES B,D,H AND I.
5. EXTENT OF SHEARS, FRACTURE ZONES, AND ALTERATION ZONES ARE INFERRED BASED ON GEOLOGIC MAPPING AND SUBSURFACE EXPLORATIONS, AND ARE SUBJECT TO VERIFICATION THROUGH FUTURE DETAILED INVESTIGATIONS.

SCALE 0 100 200 FEET

WATANA
GEOLOGIC SECTION W-2
SHEET 1 OF 2

ACRES

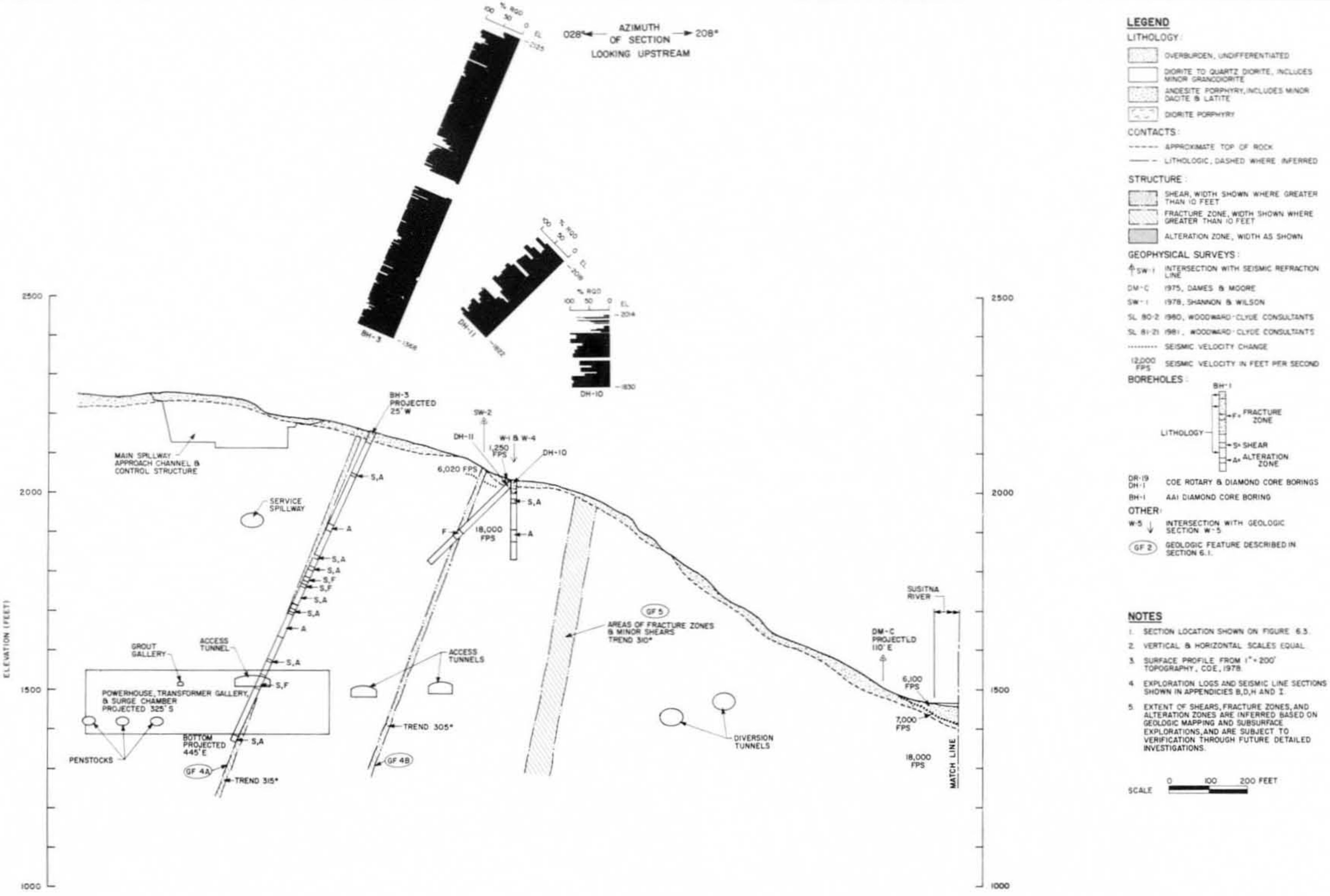
FIGURE 6.5



WATANA
GEOLOGIC SECTION W-2
SHEET 2 OF 2

ACRES

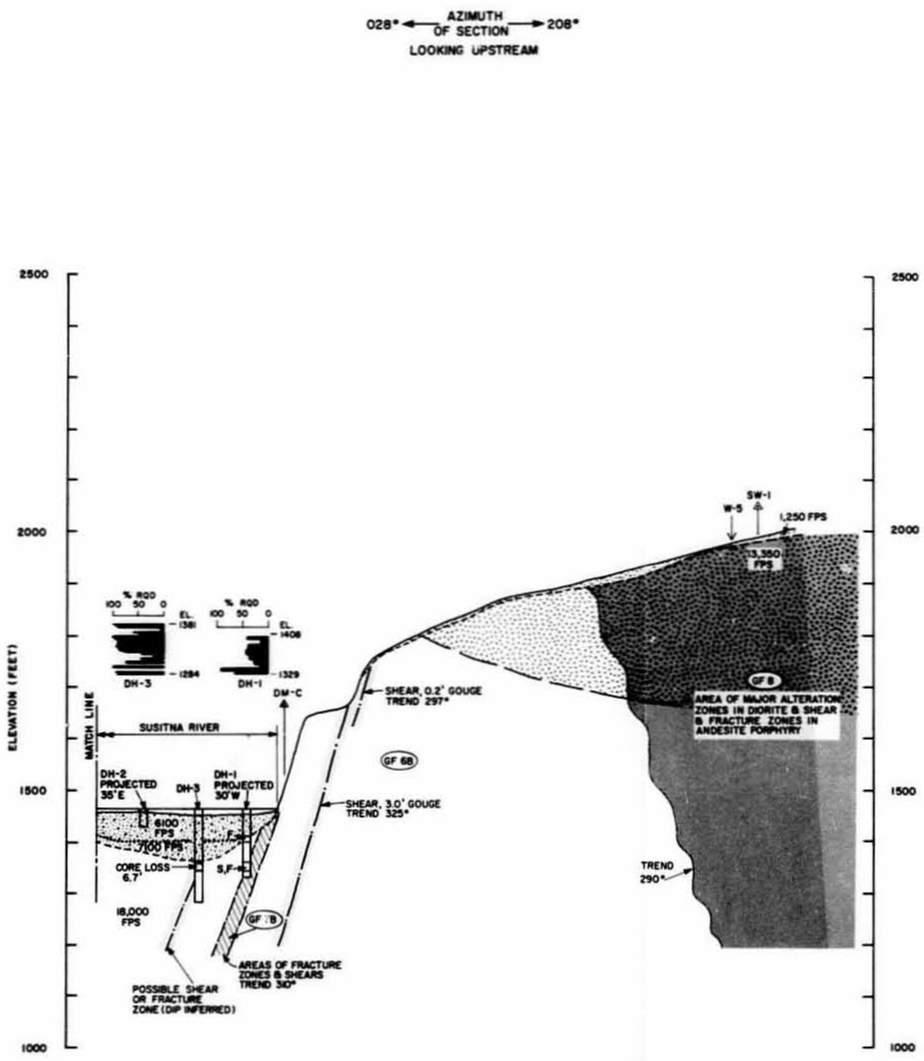
FIGURE 6.5



WATANA
GEOLOGIC SECTION W-3
SHEET 1 OF 2

ACRES

FIGURE 6.6



LEGEND

LITHOLOGY:

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

CONTACTS:

- APPROXIMATE TOP OF ROCK
- LITHOLOGIC, 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
- 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 6.1.

NOTES

1. SECTION LOCATION SHOWN ON FIGURE 6.3.
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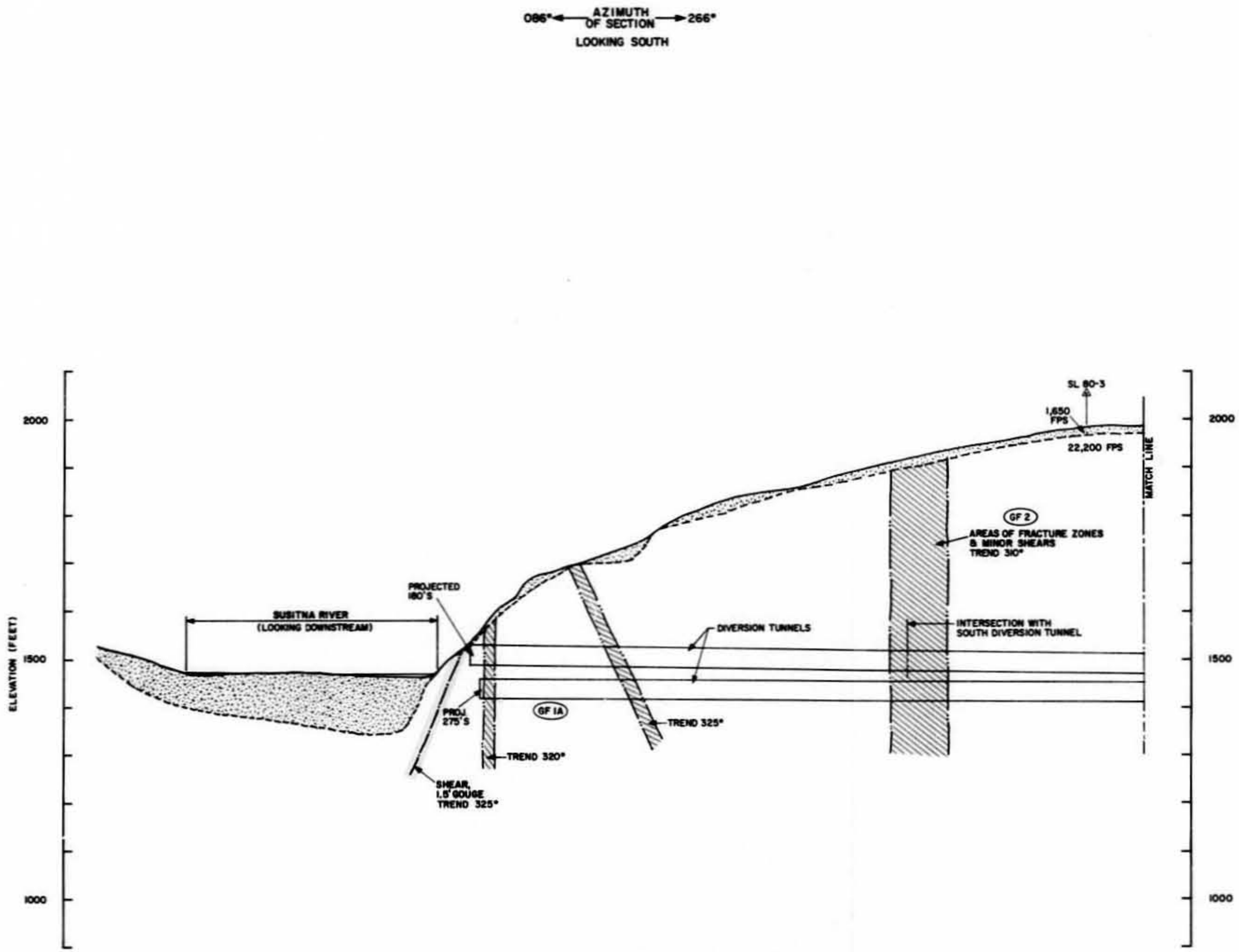
SCALE 0 100 200 FEET

WATANA
GEOLOGIC SECTION W-3
SHEET 2 OF 2

ACRES

FIGURE 6.6



LEGEND

LITHOLOGY:

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

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- SL 81-21 1981, WOODWARD-CLYDE CONSULTANTS
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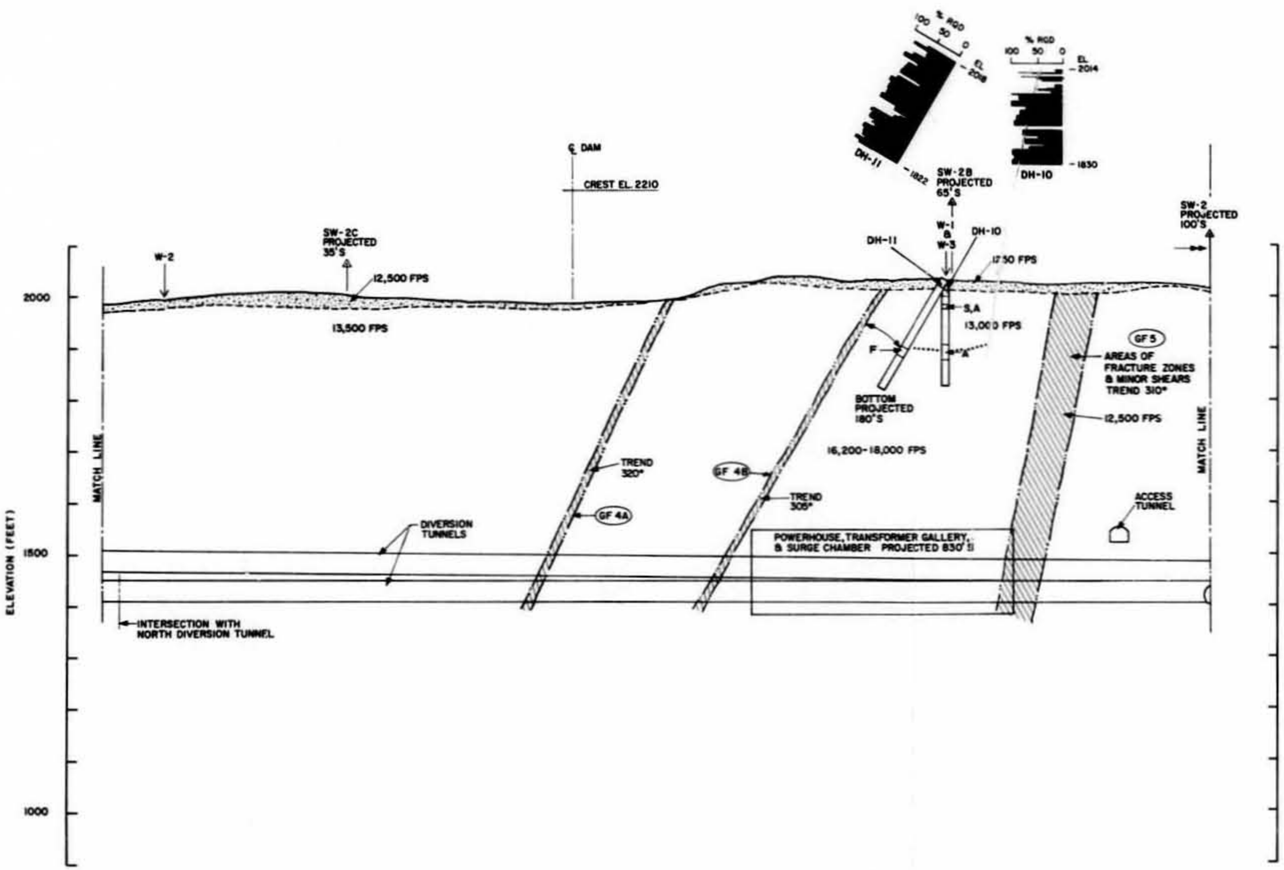
SCALE 0 100 200 FEET

WATANA
GEOLOGIC SECTION W-4
SHEET 1 OF 3

ACRES

FIGURE 6.7



LEGEND

LITHOLOGY:

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

CONTACTS:

- APPROXIMATE TOP OF ROCK
- LITHOLOGIC, DASHED WHERE INFERRED

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- SL 81-21 1981, WOODWARD-CLYDE CONSULTANTS
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- 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 6.1.

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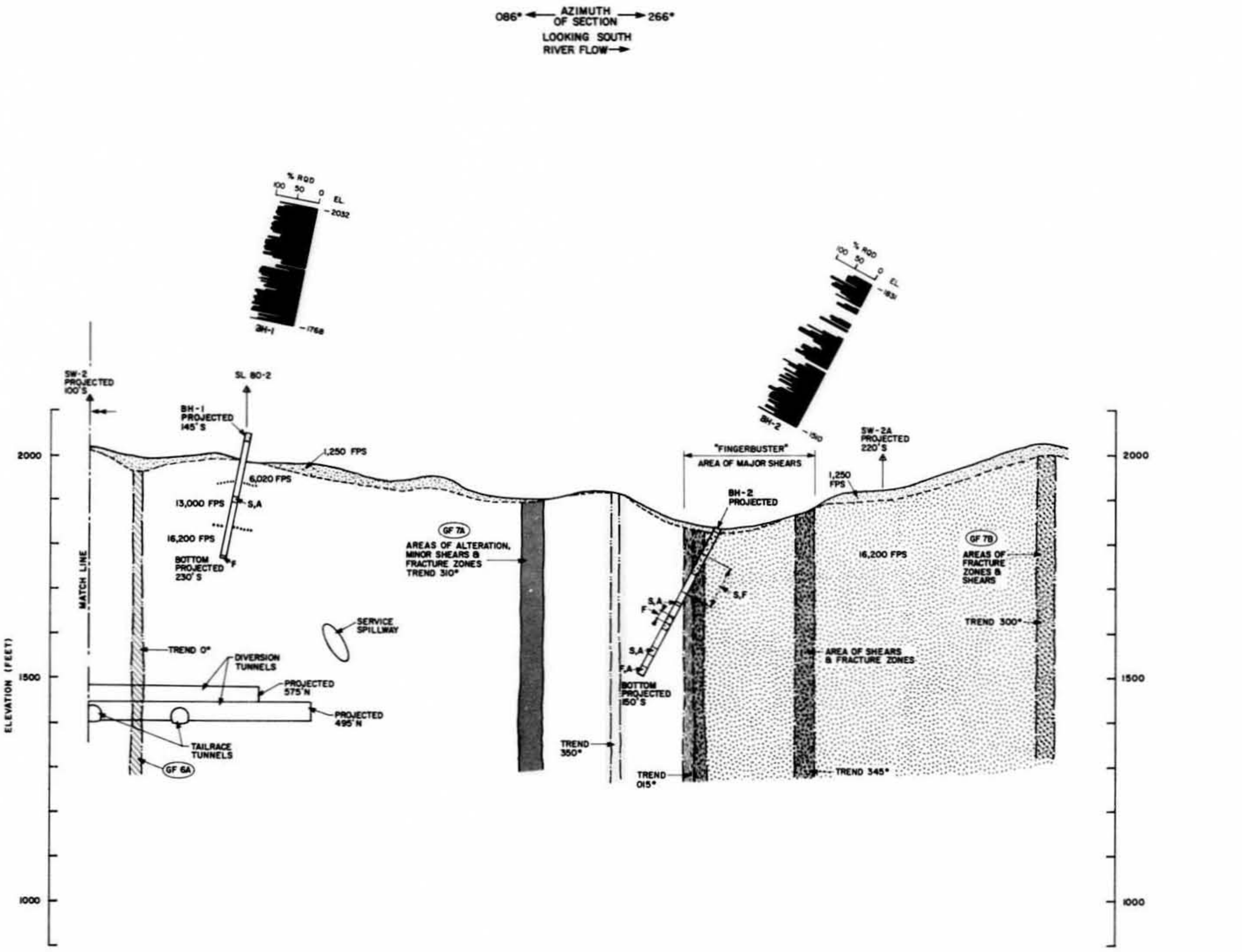
SCALE 0 100 200 FEET

WATANA
GEOLOGIC SECTION W-4
SHEET 2 OF 3

FIGURE 6.7

ACRES



LEGEND

LITHOLOGY:

- OVERBURDEN, UNDIFFERENTIATED
- DIORITE TO QUARTZ DIORITE, INCLUDES MINOR GRANODIORITE
- ANDESITE PORPHYRY, INCLUDES MINOR DACITE & LATITE
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- SL 81-21 1981, WOODWARD-CLYDE CONSULTANTS
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- 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 6.1.

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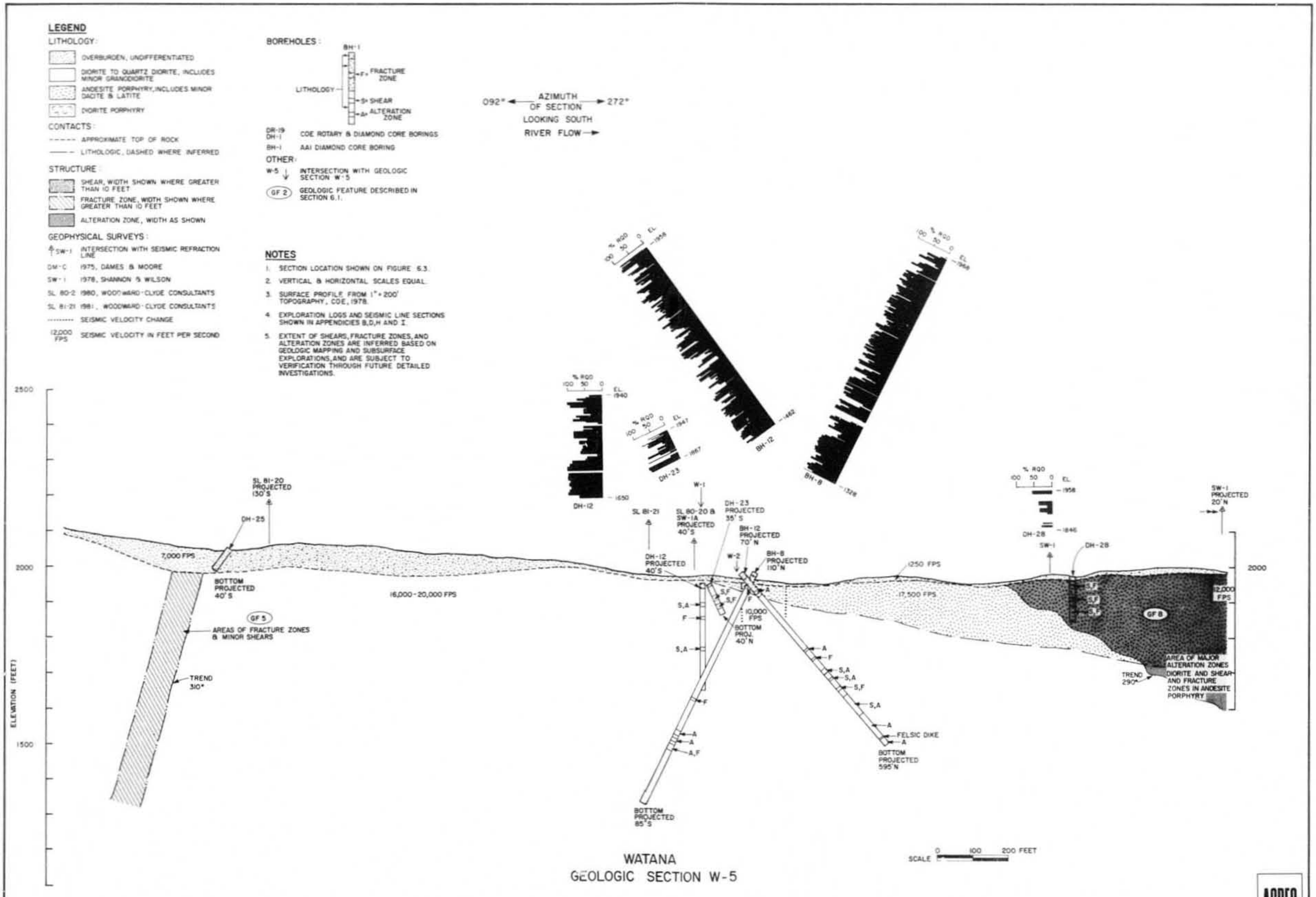
SCALE 0 100 200 FEET

WATANA
GEOLOGIC SECTION W-4
SHEET 3 OF 3

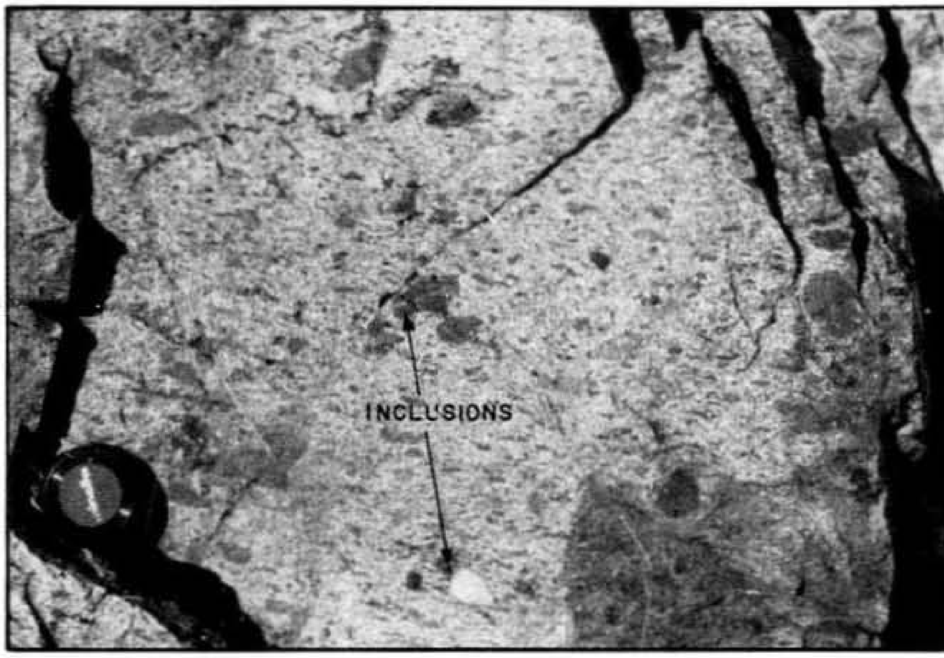
ACRES

FIGURE 6.7



WATANA
GEOLOGIC SECTION W-5

FIGURE 6.8

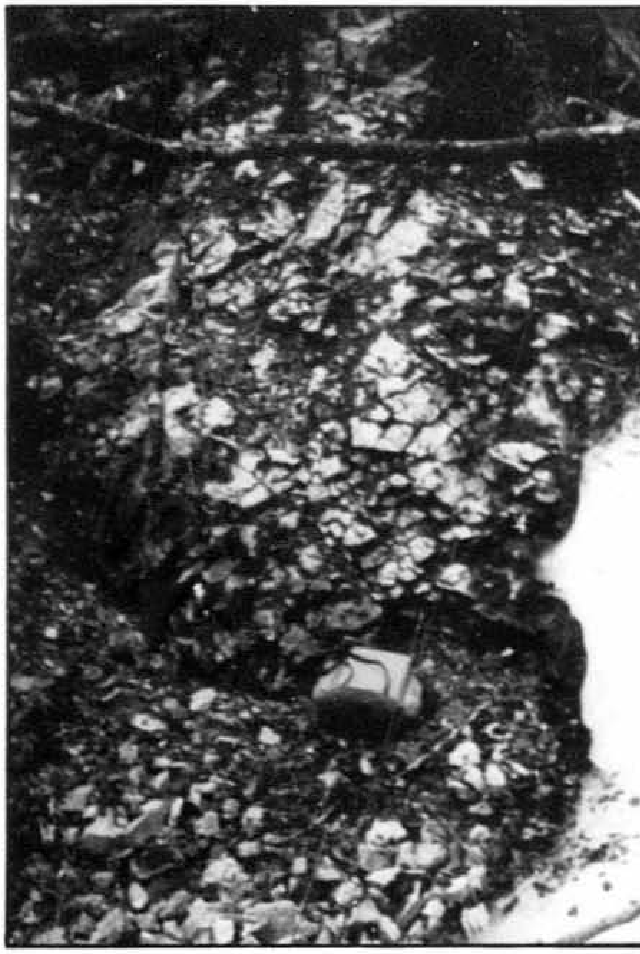


ANDESITE PORPHYRY OUTCROP
RIVER LEVEL - NORTH BANK
"FINGERBUSTER" AREA

WATANA
ANDESITE PORPHYRY FLOW STRUCTURE & INCLUSIONS

FIGURE 6.9

ACRES



ANDESITE PORPHYRY
ABOVE DIORITE OUTCROP
APPROX. EL. 1800 FEET - SOUTH BANK

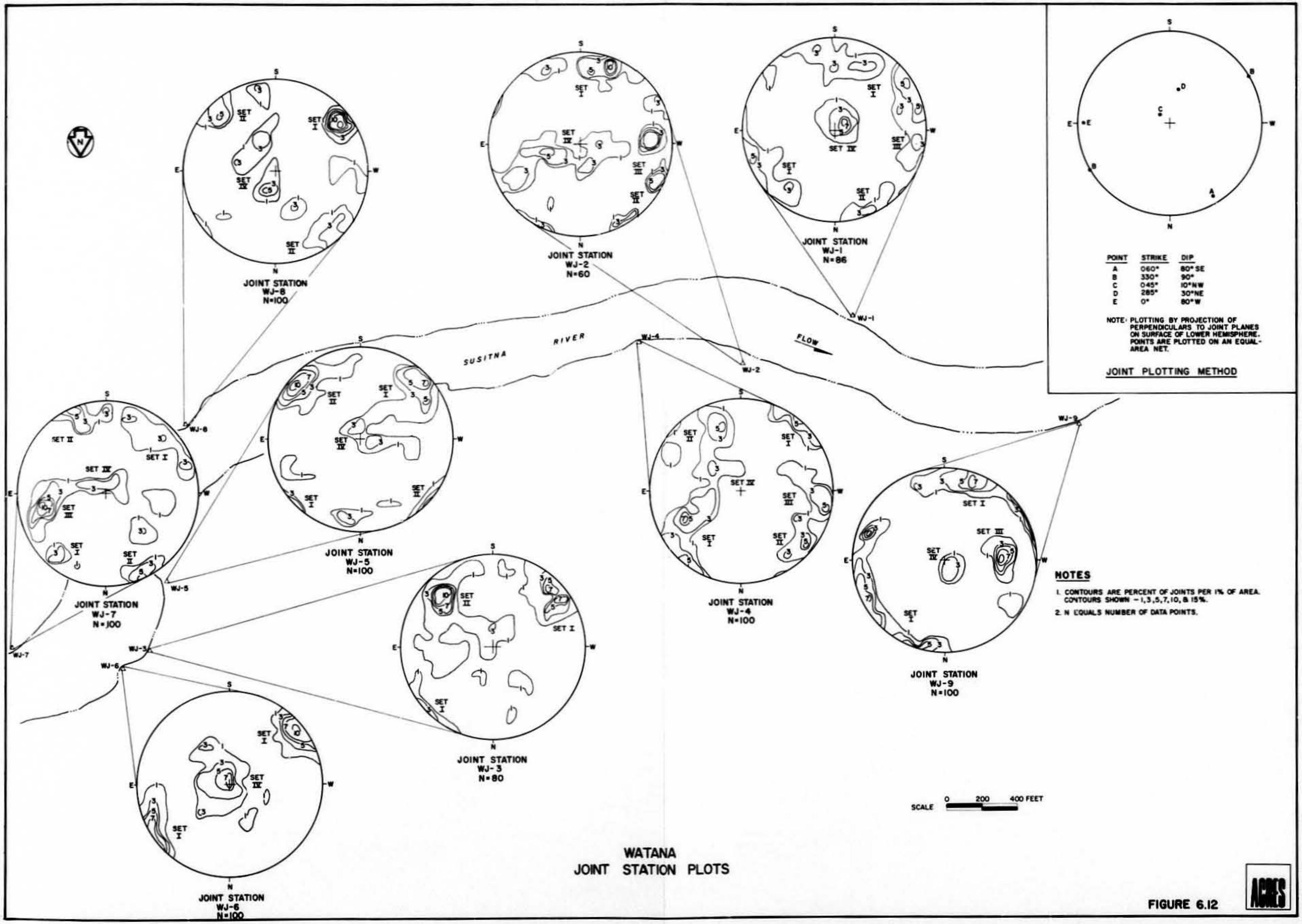
WATANA
FRACTURE ZONE IN ANDESITE PORPHYRY

FIGURE 6.10

WATANA
FELSIC DIKE IN DIORITE

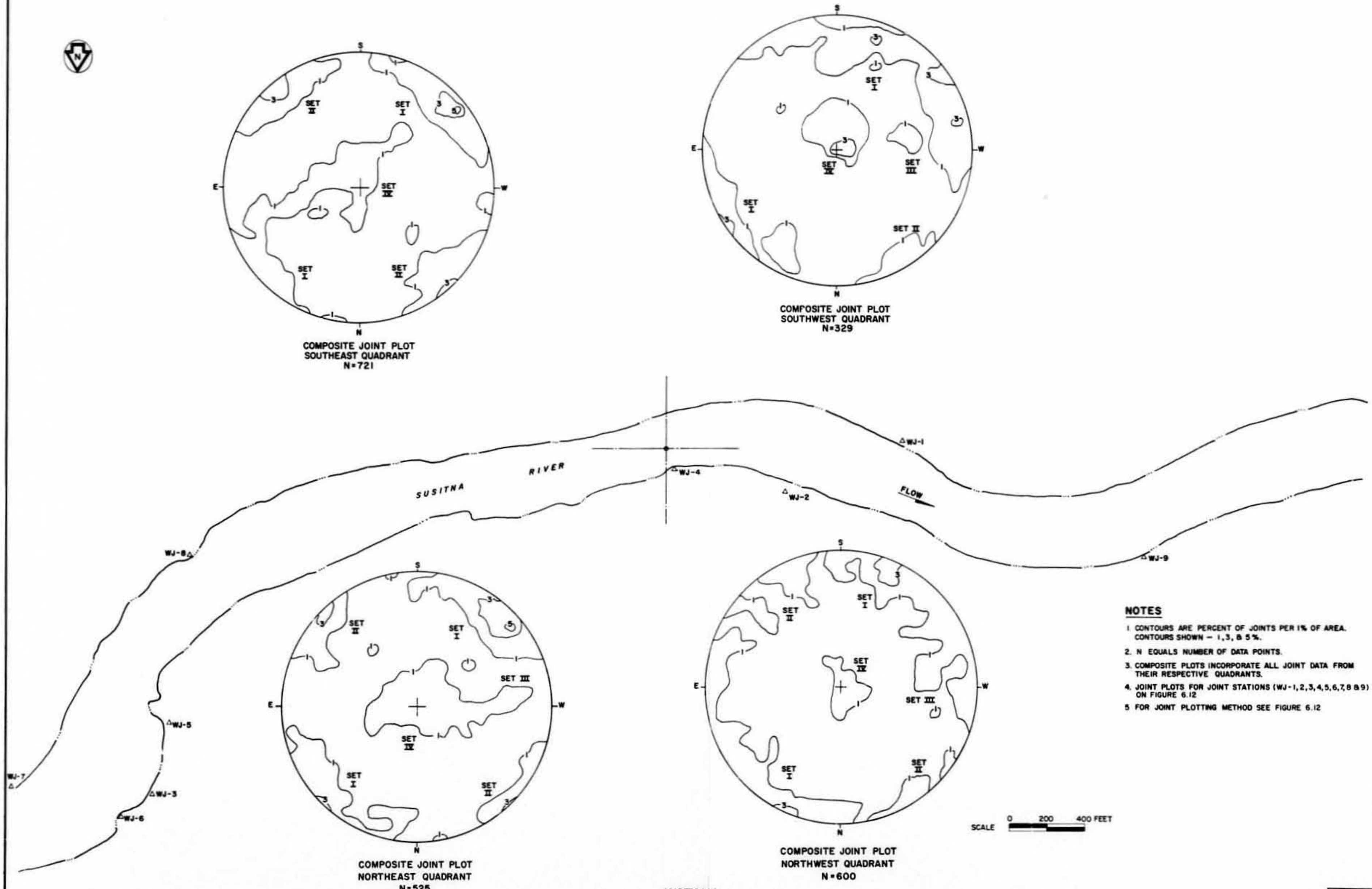
ACRES

FIGURE 6.11



WATANA
JOINT STATION PLOTS

FIGURE 6.12



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 & 9) ON FIGURE 6.12
5. FOR JOINT PLOTTING METHOD SEE FIGURE 6.12

WATANA
COMPOSITE JOINT PLOTS

ACRES

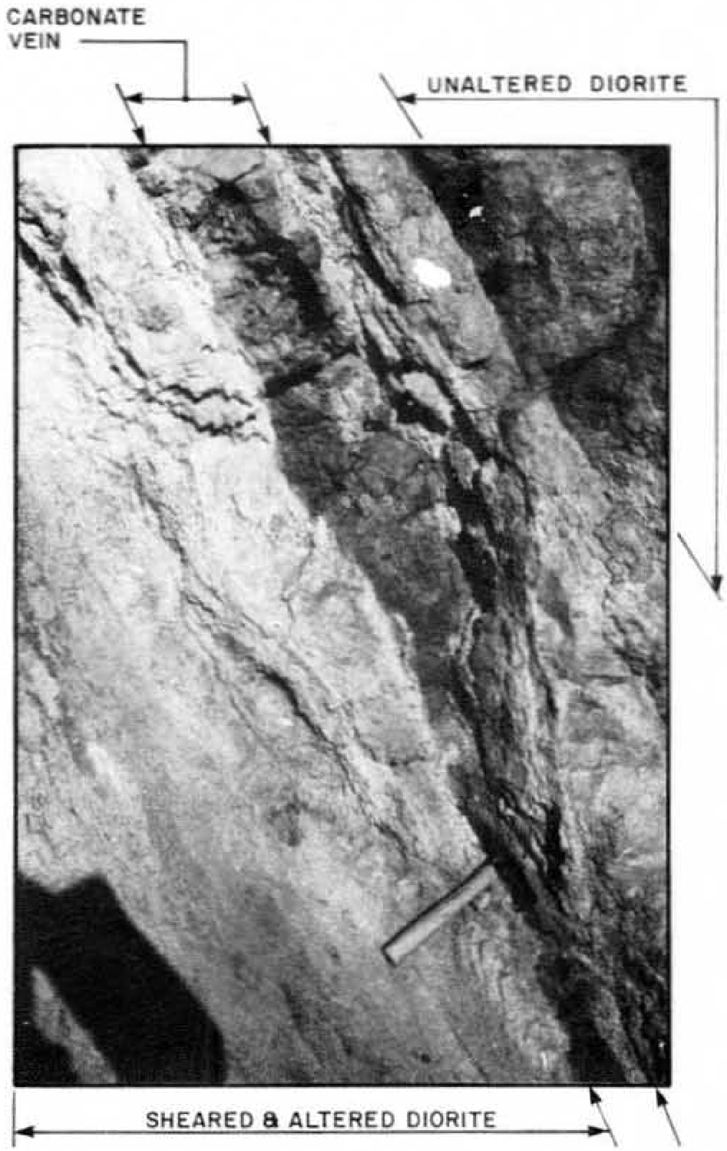
FIGURE 6.13

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

WATANA
TYPICAL SHEAR

FIGURE 6.14

ACRES

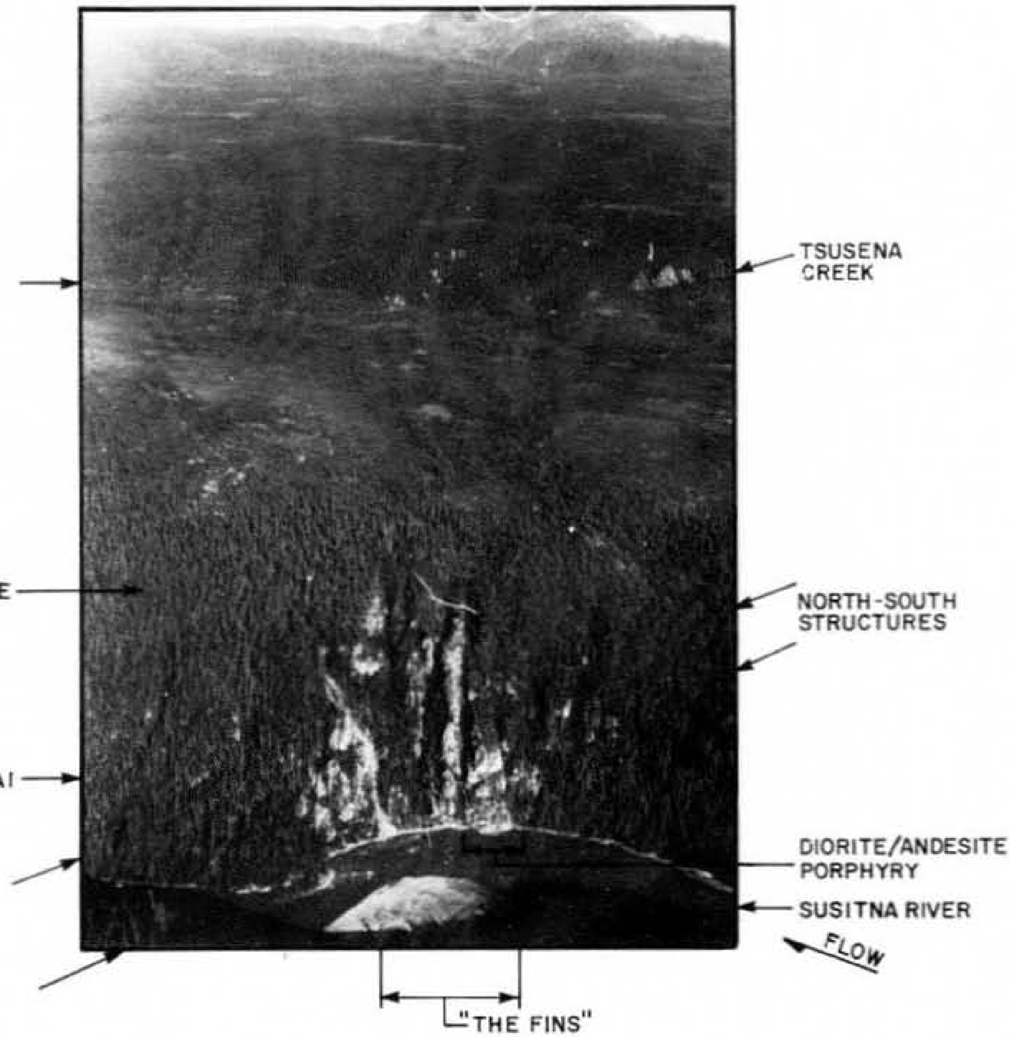


EAST SIDE OF 55 FT. WIDE SHEAR/ALTERATION ZONE
RIVER LEVEL - NORTH BANK "THE FINS" AREA

WATANA
SHEAR/ALTERATION ZONE

ACRES

FIGURE 6.15



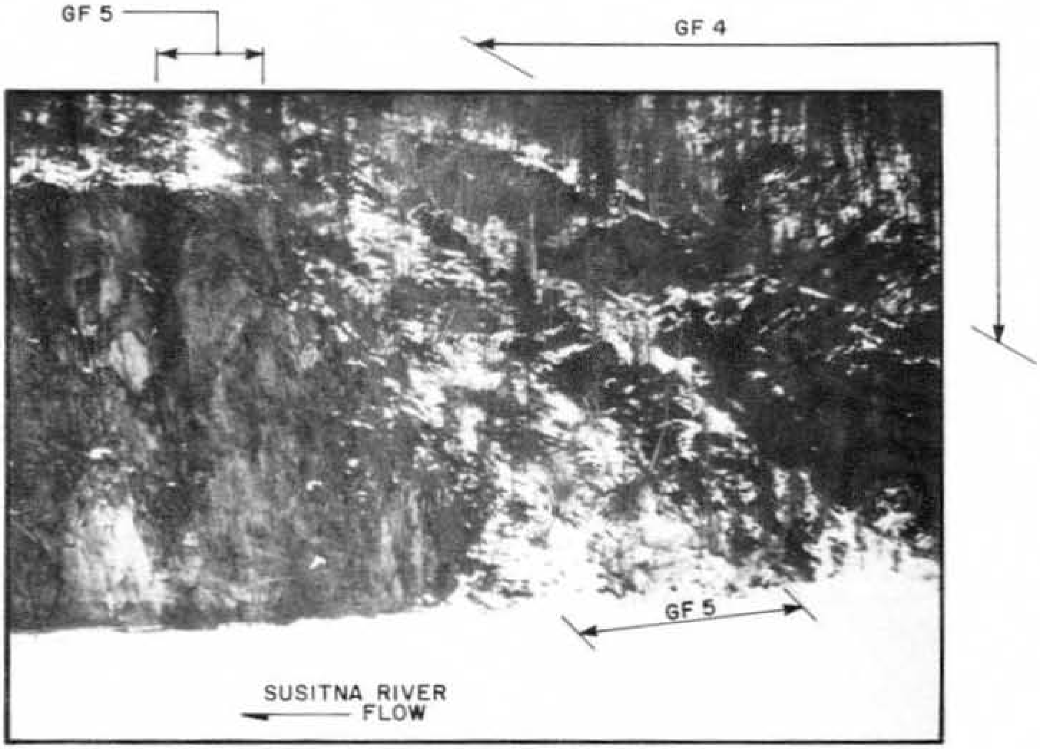
AERIAL VIEW OF "THE FINS"
LOOKING NORTHWEST ALONG STRIKE

NOTE:
GEOLOGIC FEATURES GF AI AND "THE FINS" DISCUSSED IN SECTION 6.1.

WATANA
"THE FINS"

FIGURE 6.16

ACRES



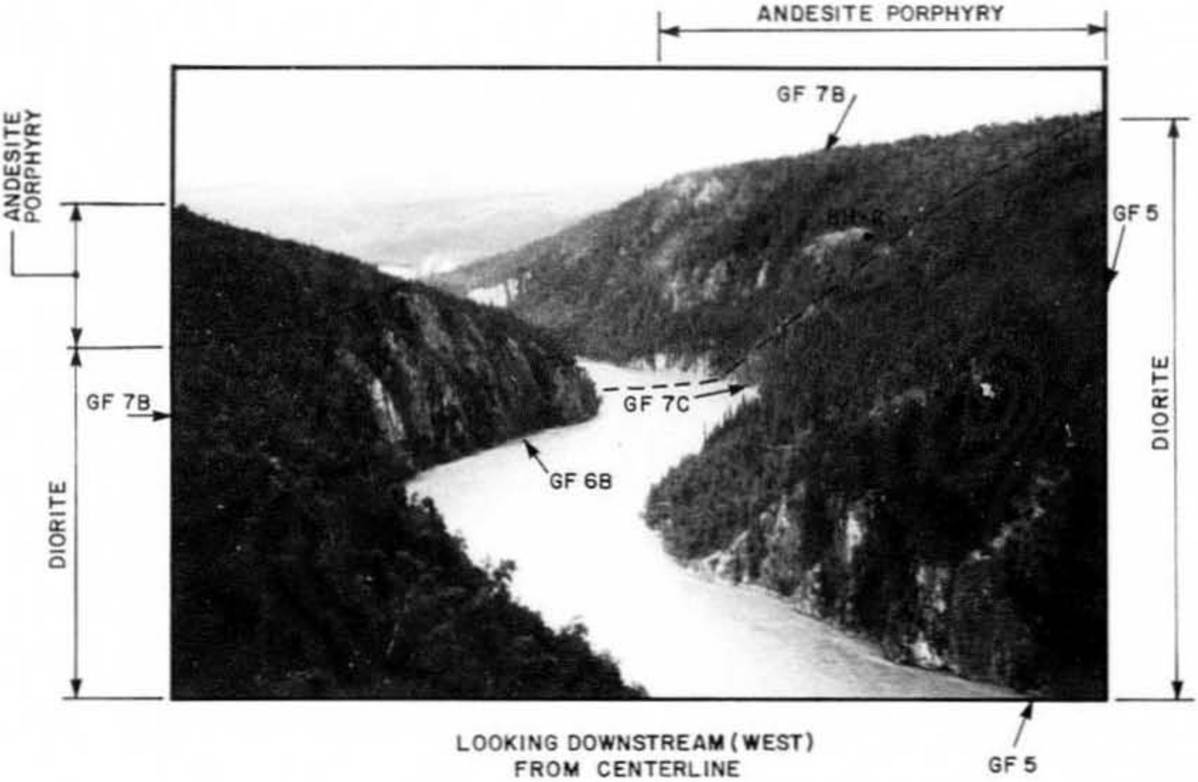
VIEW LOOKING NORTHEAST
NORTH BANK

NOTE:
GEOLOGIC FEATURES GF 4 AND GF 5 DESCRIBED IN SECTION 6.1.

WATANA
GEOLOGIC FEATURES GF 4 AND GF 5

ACRES

FIGURE 6.17



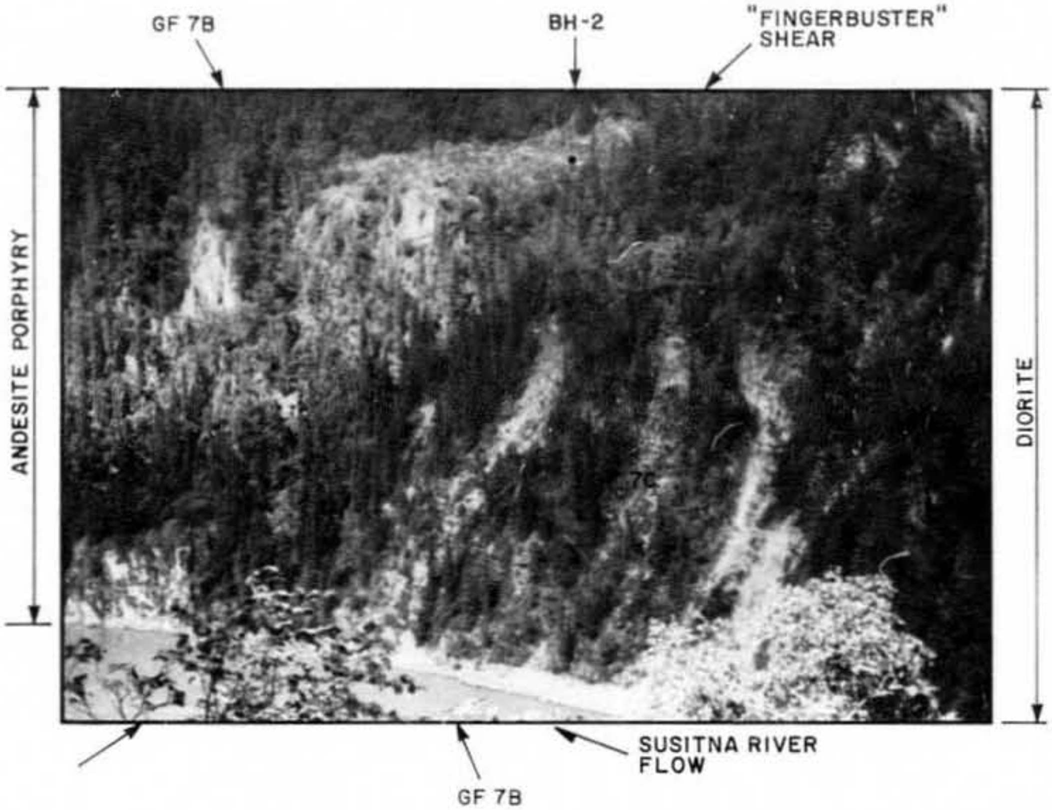
NOTES:

1. GEOLOGIC FEATURES GF 5, GF 6B, GF 7B, AND GF 7C DESCRIBED IN SECTION 6.1.
2. DASHED LINE IS ANDESITE PORPHYRY & DIORITE CONTACT.

WATANA
GEOLOGIC FEATURES DOWNSTREAM OF CENTERLINE

FIGURE 6.18

ACRES



NOTES:

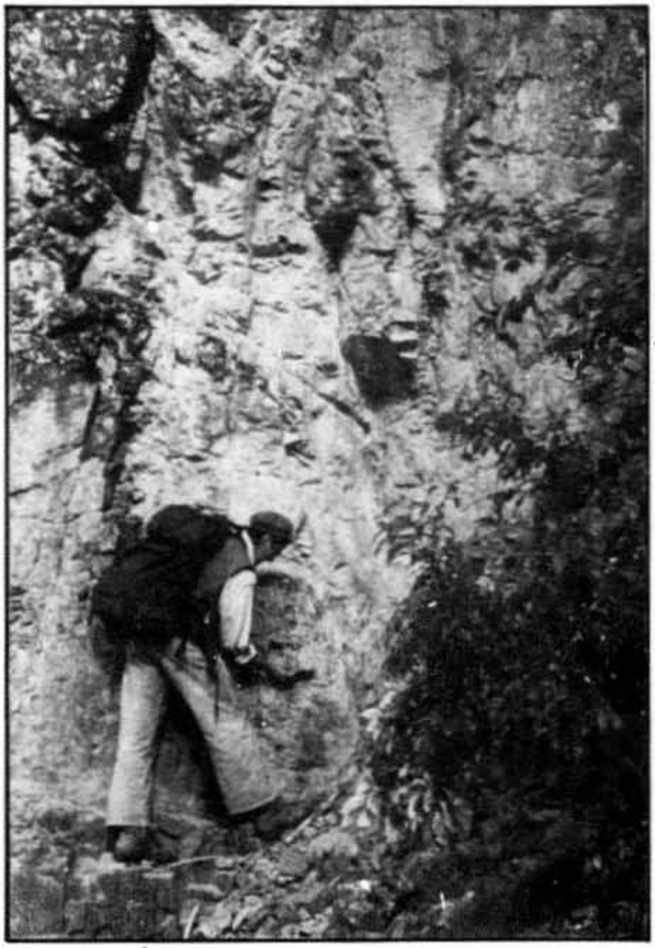
1. GEOLOGIC FEATURES "FINGERBUSTER", GF 7B, AND GF 7C DESCRIBED IN SECTION 6.1.
2. ANDESITE PORPHYRY & DIORITE CONTACT ALONG "FINGERBUSTER" SHEAR.

WATANA
"FINGERBUSTER" AREA
NORTH BANK

FIGURE 6.19

ACRES

GF 7B



"FINGERBUSTER" SHEAR

VIEW LOOKING NORTHWEST
ANDESITE PORPHYRY OUTCROP
RIVER LEVEL - NORTH BANK

NOTE:
GEOLOGIC FEATURES "FINGERBUSTER" AND GF 7B
DESCRIBED IN SECTION 6.1.

WATANA
GEOLOGIC FEATURE GF 7B

FIGURE 6.20

ACRES

TYPICAL COMPRESSION
TEST FAILURE

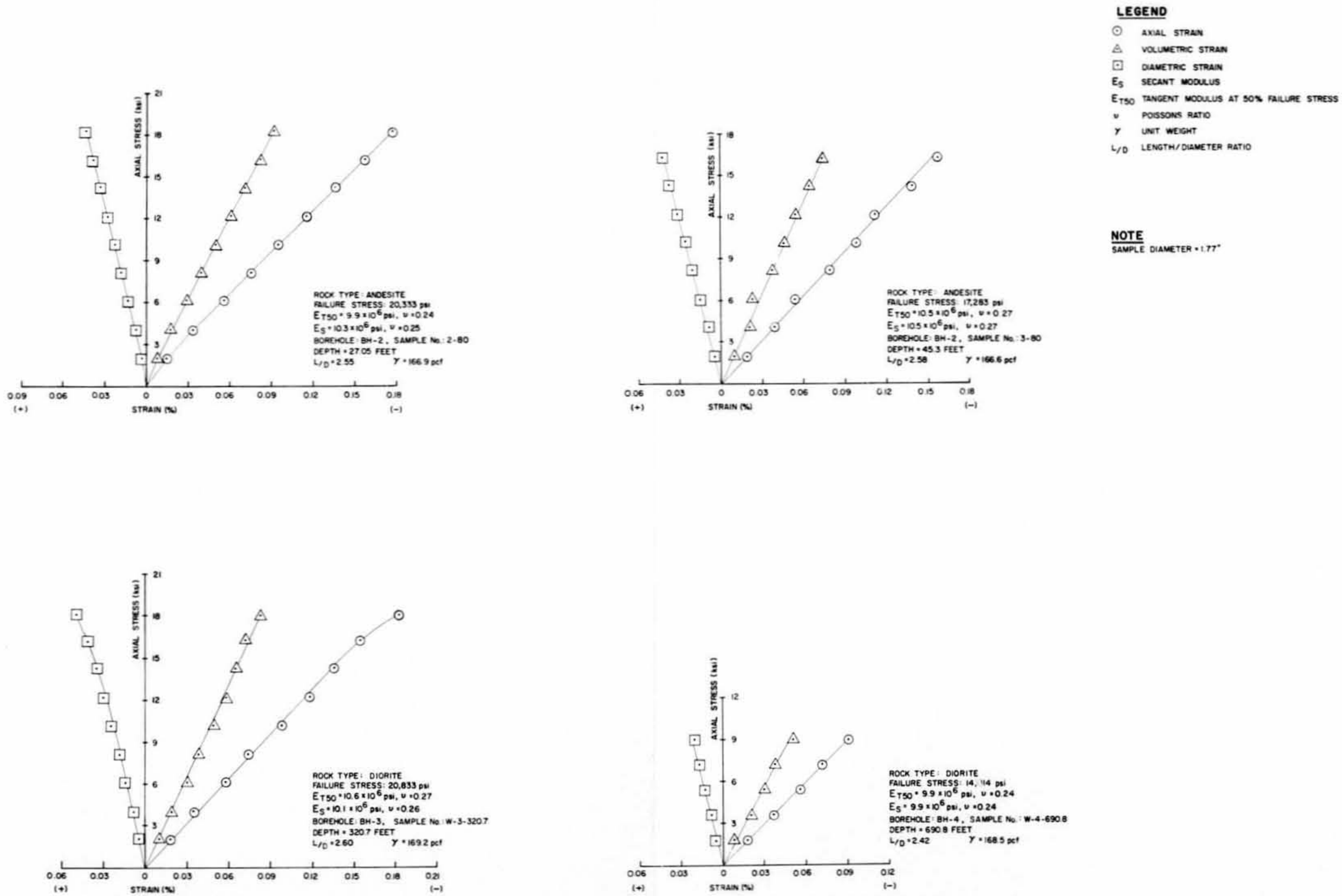
TYPICAL TENSILE
TEST FAILURE

ALTERED DIORITE -
COMPRESSION TEST

ALTERED DIORITE -
TENSILE TEST

WATANA
ROCK TESTS

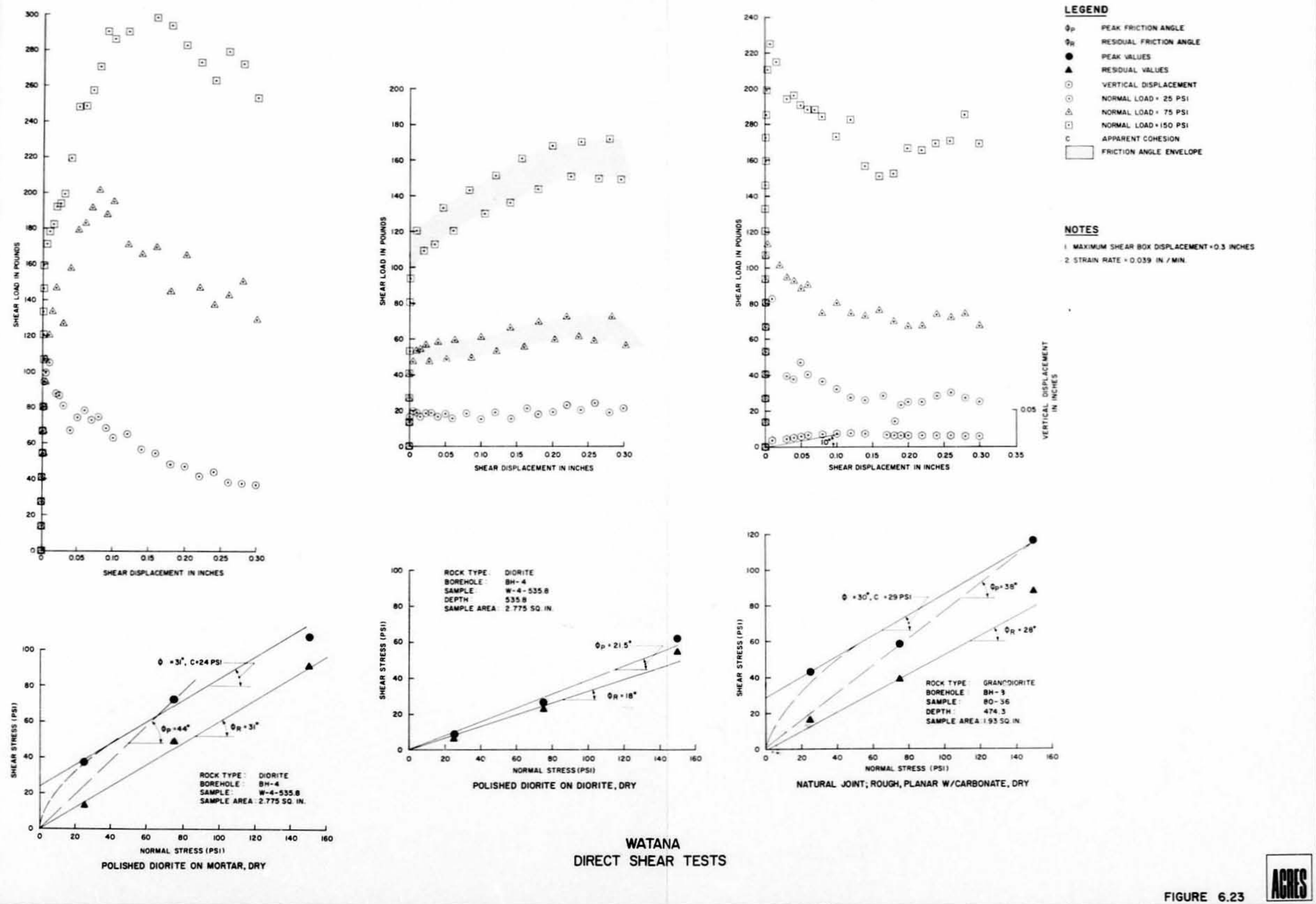
FIGURE 6.21



WATANA
STATIC ELASTIC PROPORTIES
FOR ANDESITE AND DIORITE

ACRES

FIGURE 6.22



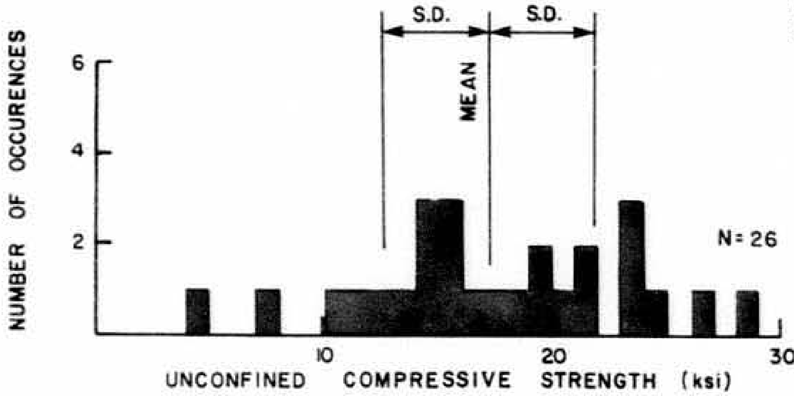
WATANA
DIRECT SHEAR TESTS

FIGURE 6.23

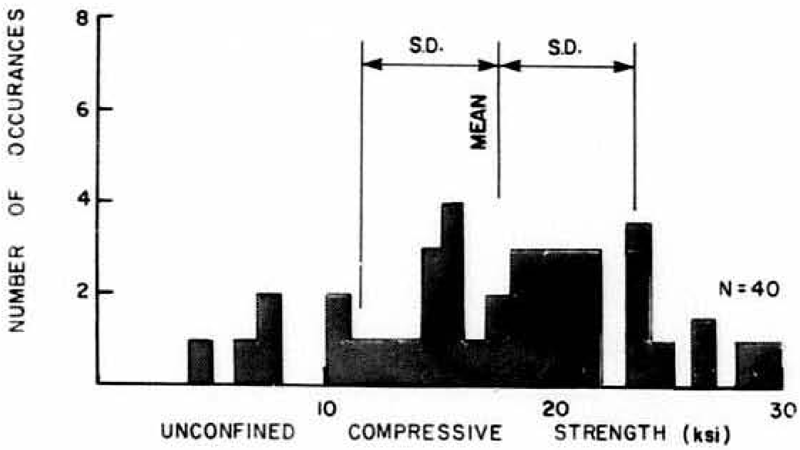
LEGEND

N - NUMBER OF TESTS

S.D. - STANDARD DEVIATION



DIORITE, QUARTZ DIORITE, GRANODIORITE
(AAI)



ALL TESTS (AAI, COE)

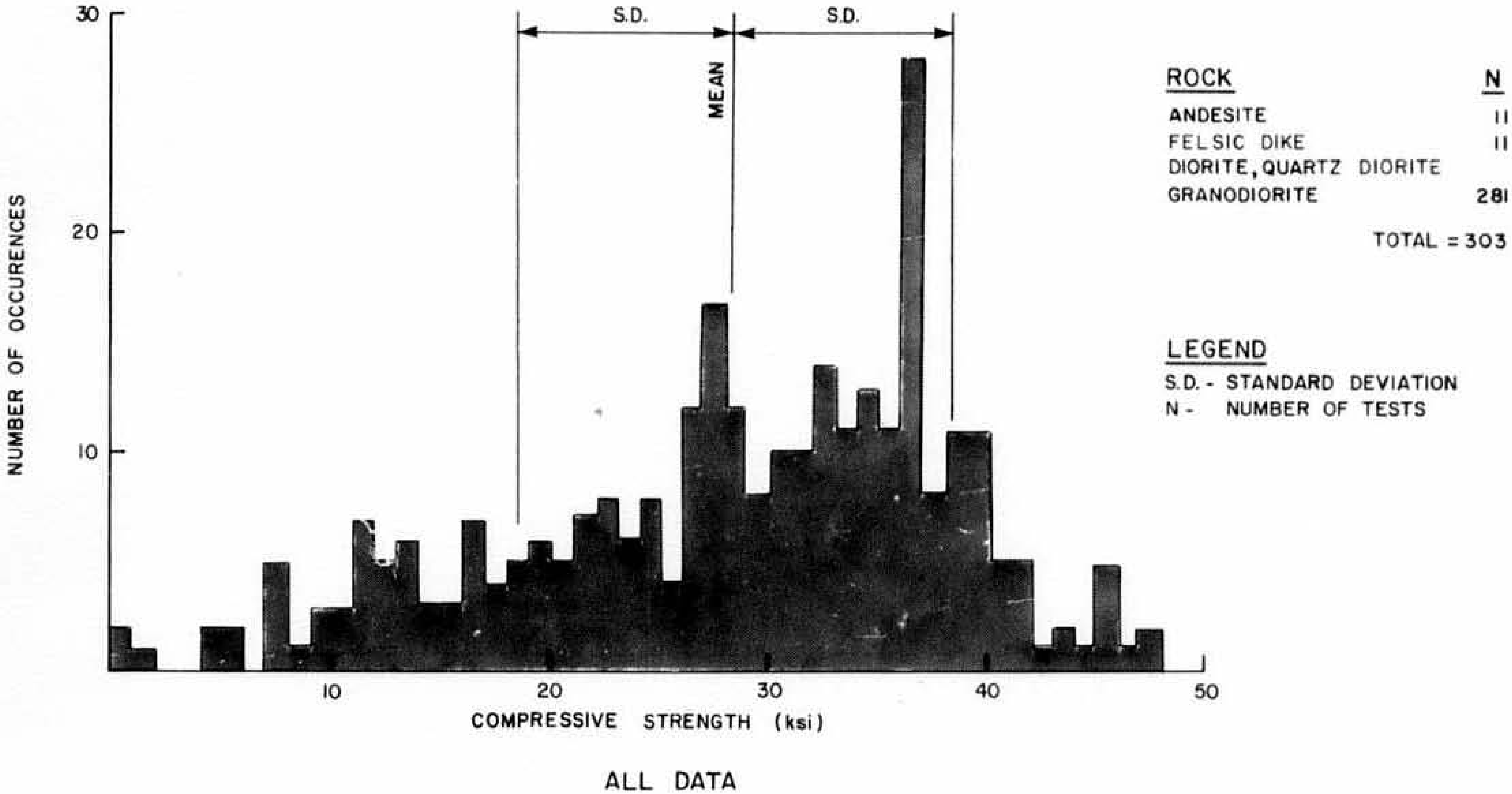
WATANA

UNCONFINED COMPRESSIVE STRENGTH TEST RESULTS

REFERENCE: 78-C-305

FIGURE 6.24

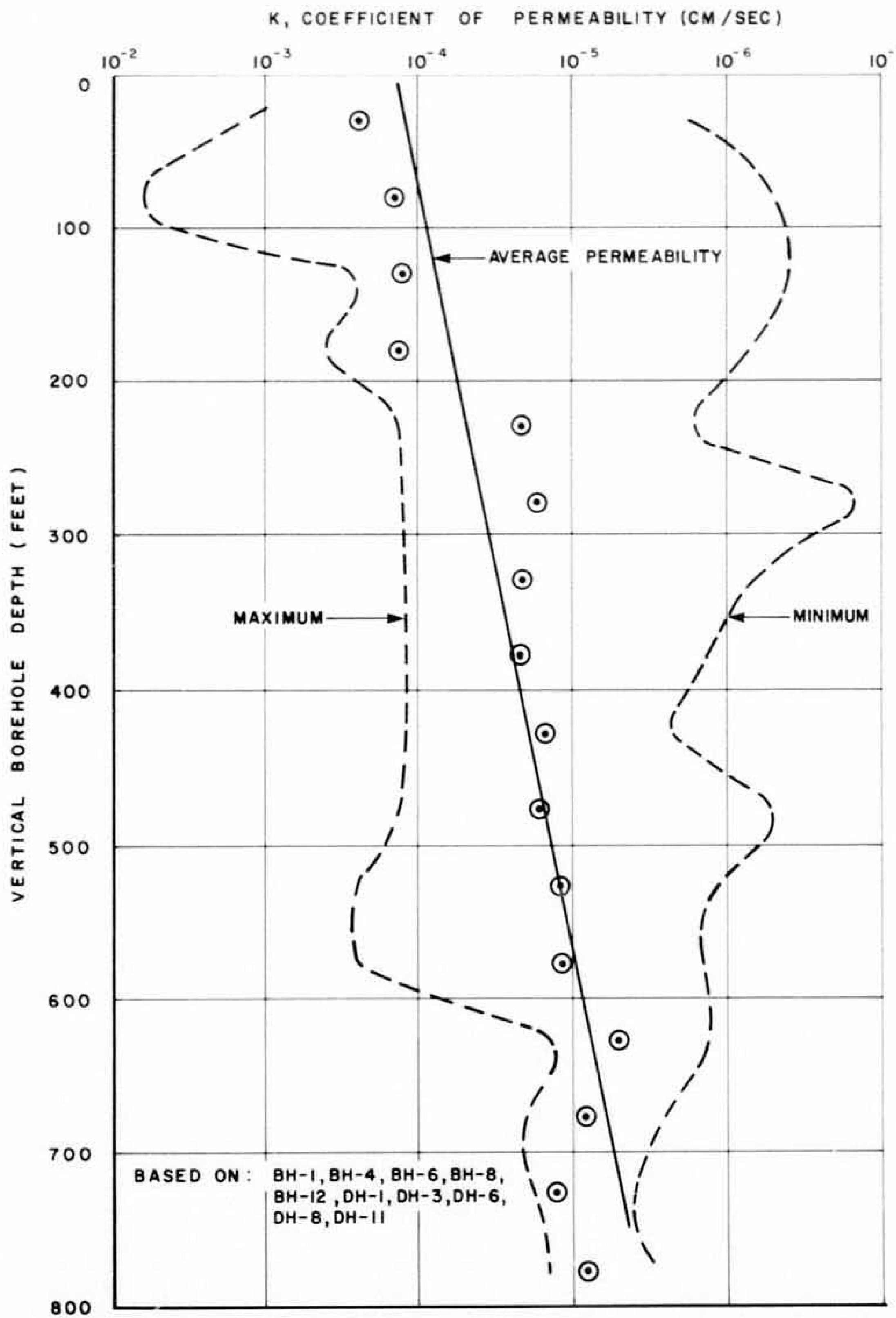
ACRES



WATANA
POINT LOAD TEST DATA

FIGURE 6.25

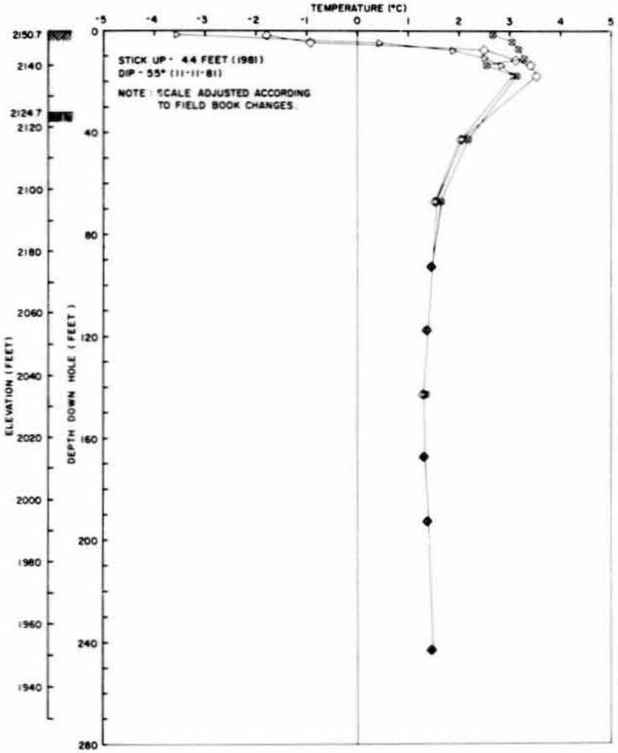
ACRES



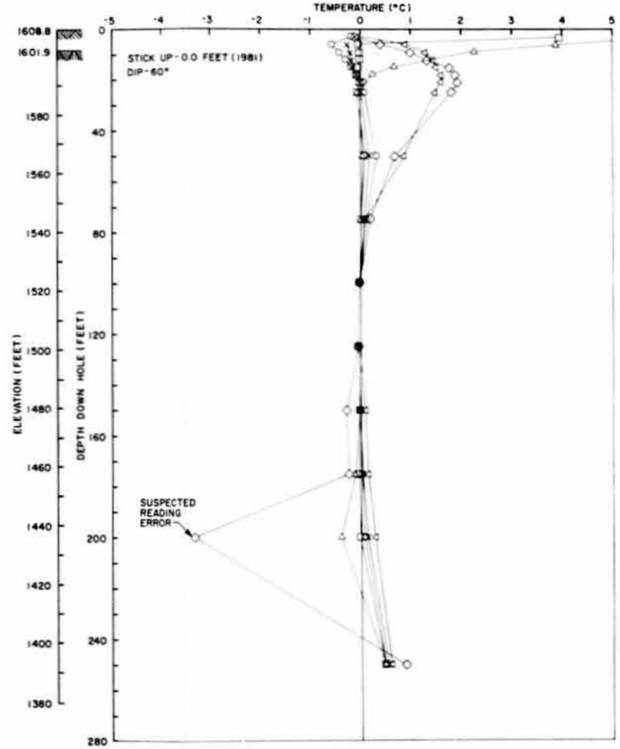
WATANA ROCK PERMEABILITY

ACRES

FIGURE 6.26



BH-3



BH-6

NOTE: DUE TO PROBLEMS ENCOUNTERED IN FIELD MEASUREMENTS, THE FOLLOWING ADJUSTMENTS WERE PERFORMED TO CONFORM TO EXISTING RELIABLE DATA. THESE FIXED LATERAL SHIFTS MAY NOT CORRECT THE FULL MAGNITUDE OF THE DISCREPANCIES.

DATE OF READING	ADJUSTMENT SUBTRACTED FROM CALCULATED READING (°C)
11-21-80	14.92
4-26-81	13.95
5-24-81	14.63
6-25-81	14.54
8-3-81	14.82

LEGEND

LITHOLOGY:

- GROUND SURFACE
- TOP OF ROCK

BOREHOLES:

- AP AUGER BORING — CORPS OF ENGINEERS (1978)
- DH DIAMOND CORE BORING — CORPS OF ENGINEERS (1978)
- DR ROTARY DRILL HOLE — CORPS OF ENGINEERS (1978)
- AH AUGER HOLE — ACRES AMERICAN INCORPORATED (1980 & 1981)
- BH BORE HOLE — ACRES AMERICAN INCORPORATED (1980 & 1981)

DATA SOURCES:

INDEX OF THERMISTOR READING DATES:

- ▽ JULY 30, 1980
- ◁ NOVEMBER 21, 1980
- ○ APRIL 19, 1981
- × MAY 24, 1981
- □ JUNE 24, 1981
- △ AUGUST 3, 1981
- ⊗ NOVEMBER 11, 1981
- • NOVEMBER 13, 1981
- ◇ DECEMBER 9, 1981
- ⊠ DECEMBER 15 & 16, 1981
- ▷ JANUARY 4-7, 1982

CORPS OF ENGINEERS THERMISTOR DATA POINTS. (CONNECTED BY DASHED LINES)

- ○ JULY 11, 1978
- □ AUGUST 10, 1978
- △ AUGUST 23, 1978
- • OCTOBER 25 & 26, 1978
- ◇ NOVEMBER 29 & 30, 1978

NOTES

1. LOCATION OF BORINGS SHOWN ON FIGURES 5.1a, 5.1b AND 6.40.
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 BOX - KEITHLEY 172 A, USED FOR 1980 THRU 1982 READINGS.
5. TOP OF ROCK ELEVATIONS SHOWN ONLY WHEN ENCOUNTERED.
6. BORINGS ARE VERTICAL UNLESS A DIP IS SHOWN.

SCALE

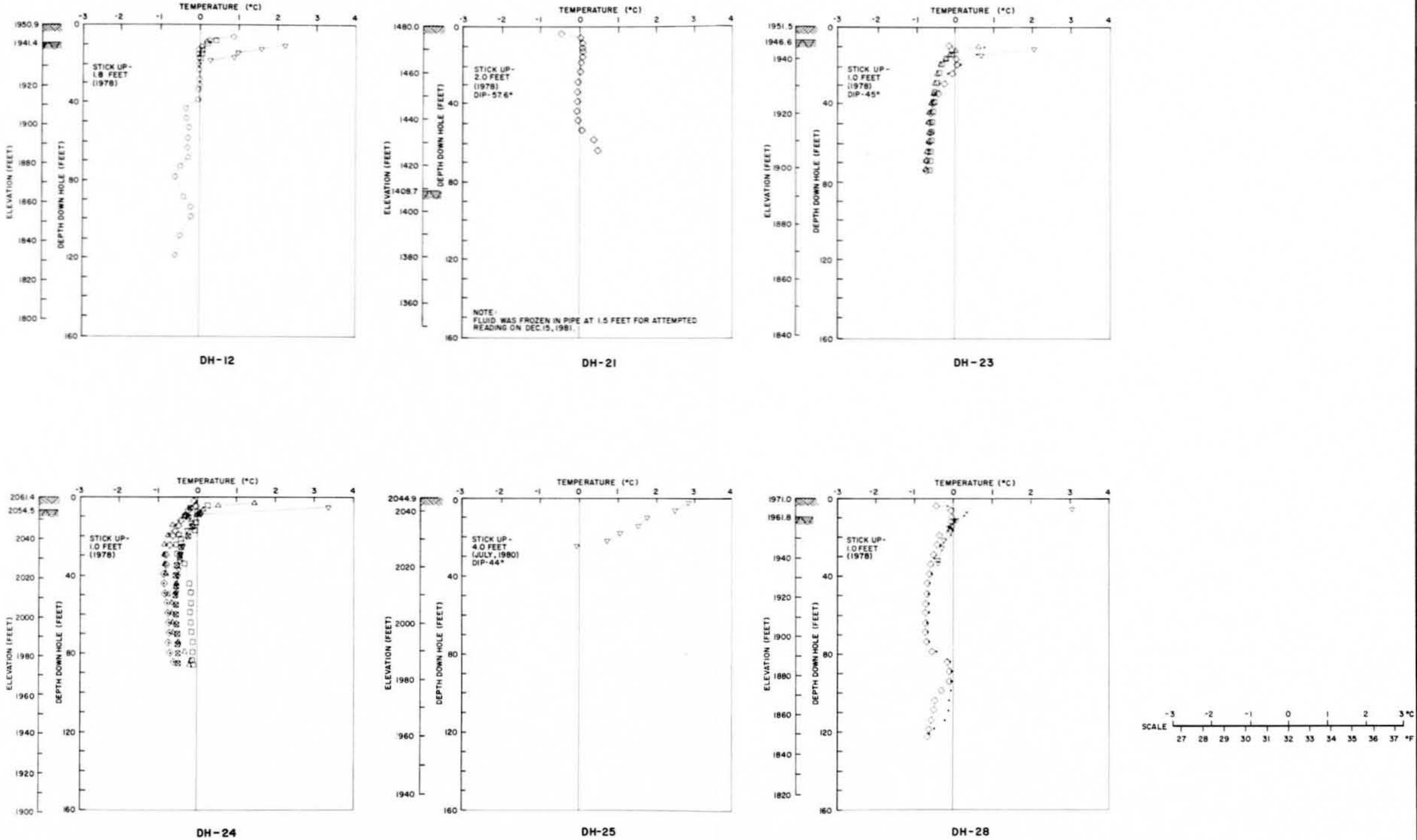
°C	-3	-2	-1	0	1	2	3

°F	27	28	29	30	31	32	33	34	35	36	37

WATANA
THERMISTOR DATA-DAMSITE
SHEET 1 OF 2

FIGURE 6.27

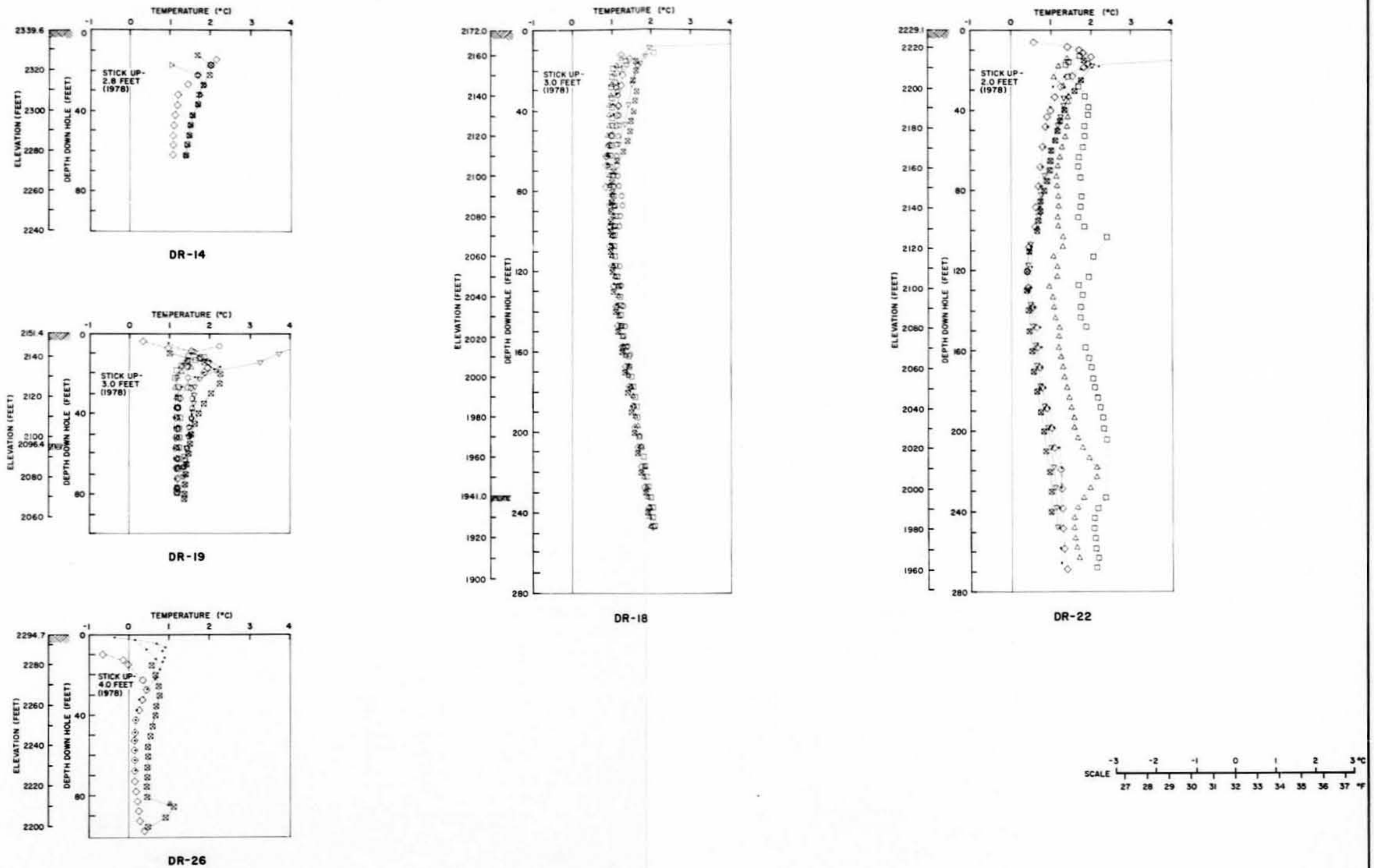
ACRES



WATANA
THERMISTOR DATA DAM SITE
SHEET 2 OF 2

ACRES

FIGURE 6.27

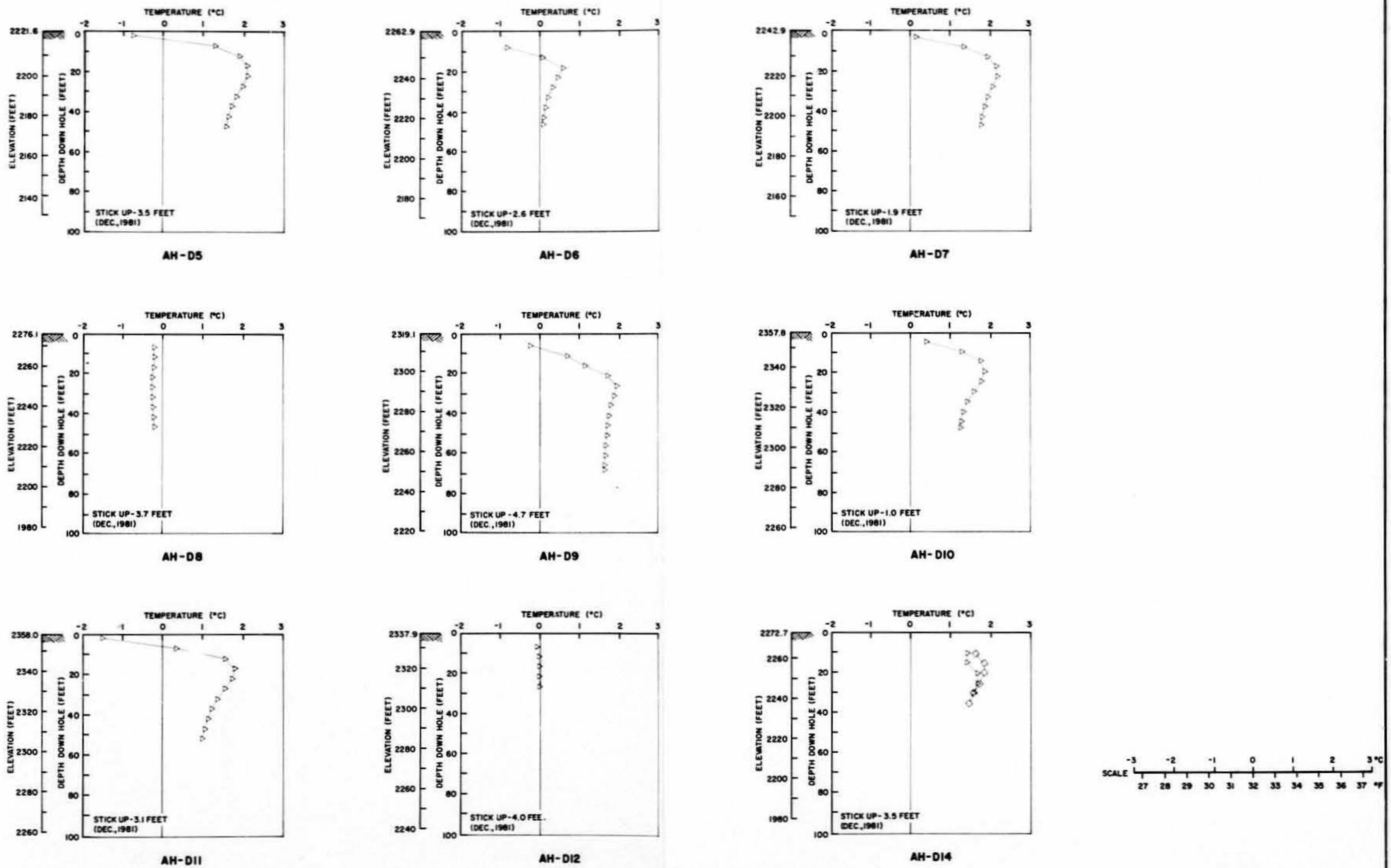


NOTE: TWO SETS OF OCT. 26, 1978 READINGS WERE TAKEN ON TWO DIFFERENT DIAMETER PROBES (DOTS WITH DASHED LINES).

WATANA
THERMISTOR DATA - RELICT CHANNEL
SHEET 1 OF 2

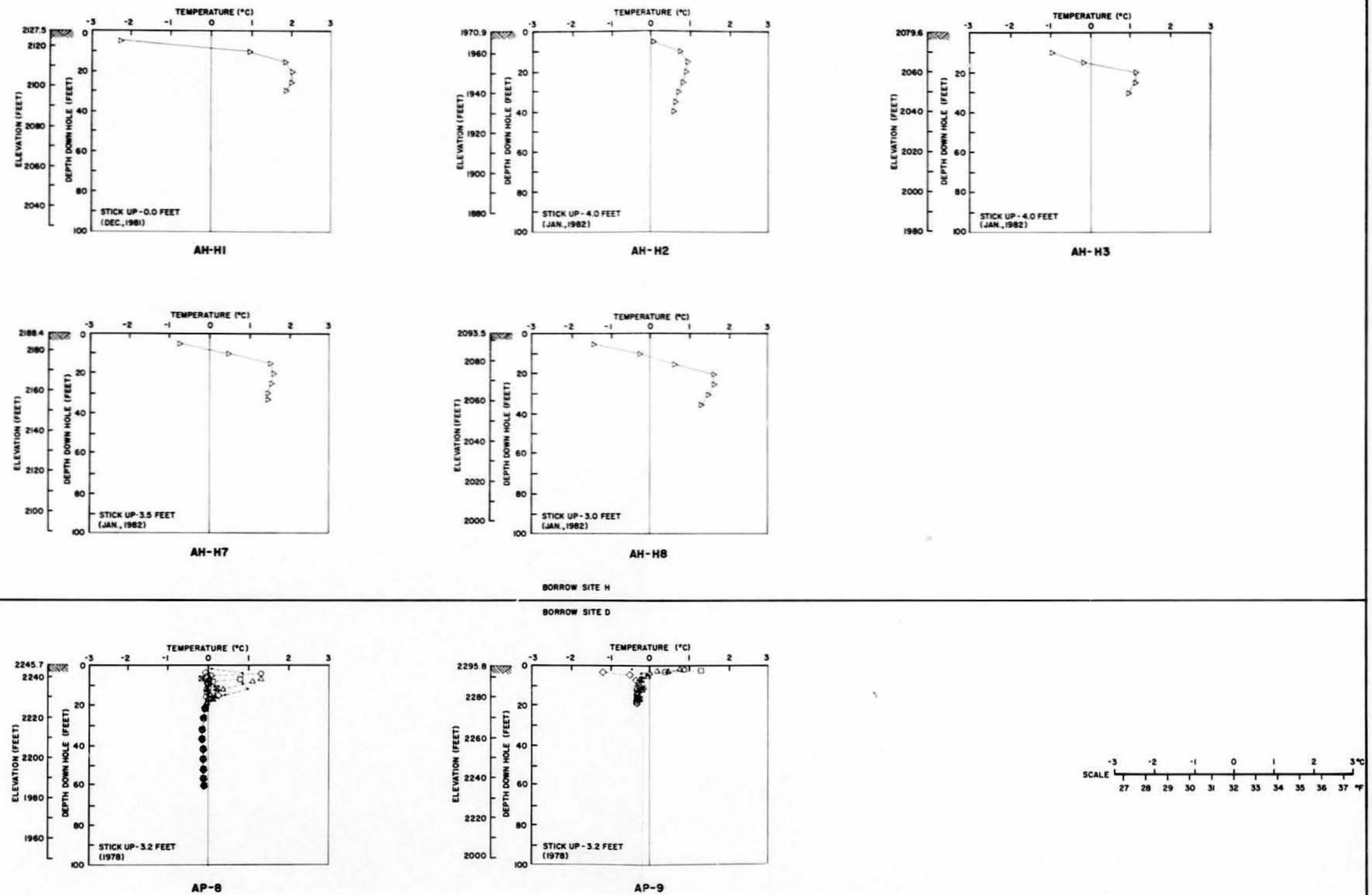
FIGURE 6.28

ACRES



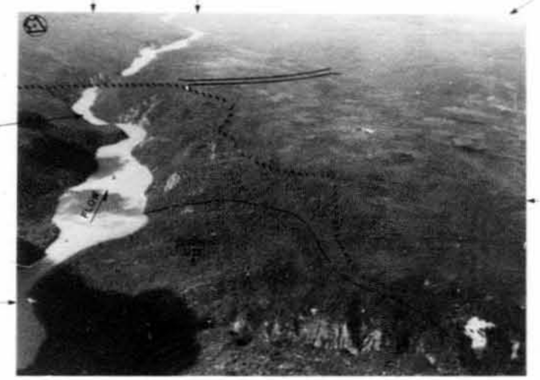
WATANA
THERMISTOR DATA - RELICT CHANNEL
SHEET 2 OF 2

FIGURE 6.28



WATANA
THERMISTOR DATA - BORROW SITE H
& BORROW SITE D

FIGURE 6.29



GENERAL VIEW OF INLET AREA
& WESTERN HALF OF OUTLET ZONE

SHORTEST FLOW PATH

LEGEND

CONTACTS:

APPROXIMATE NORMAL MAXIMUM OPERATING LEVEL, EL 2185'.

POSSIBLE FLOW PATH IF SEDIMENTS ARE PERMEABLE.

NOTES

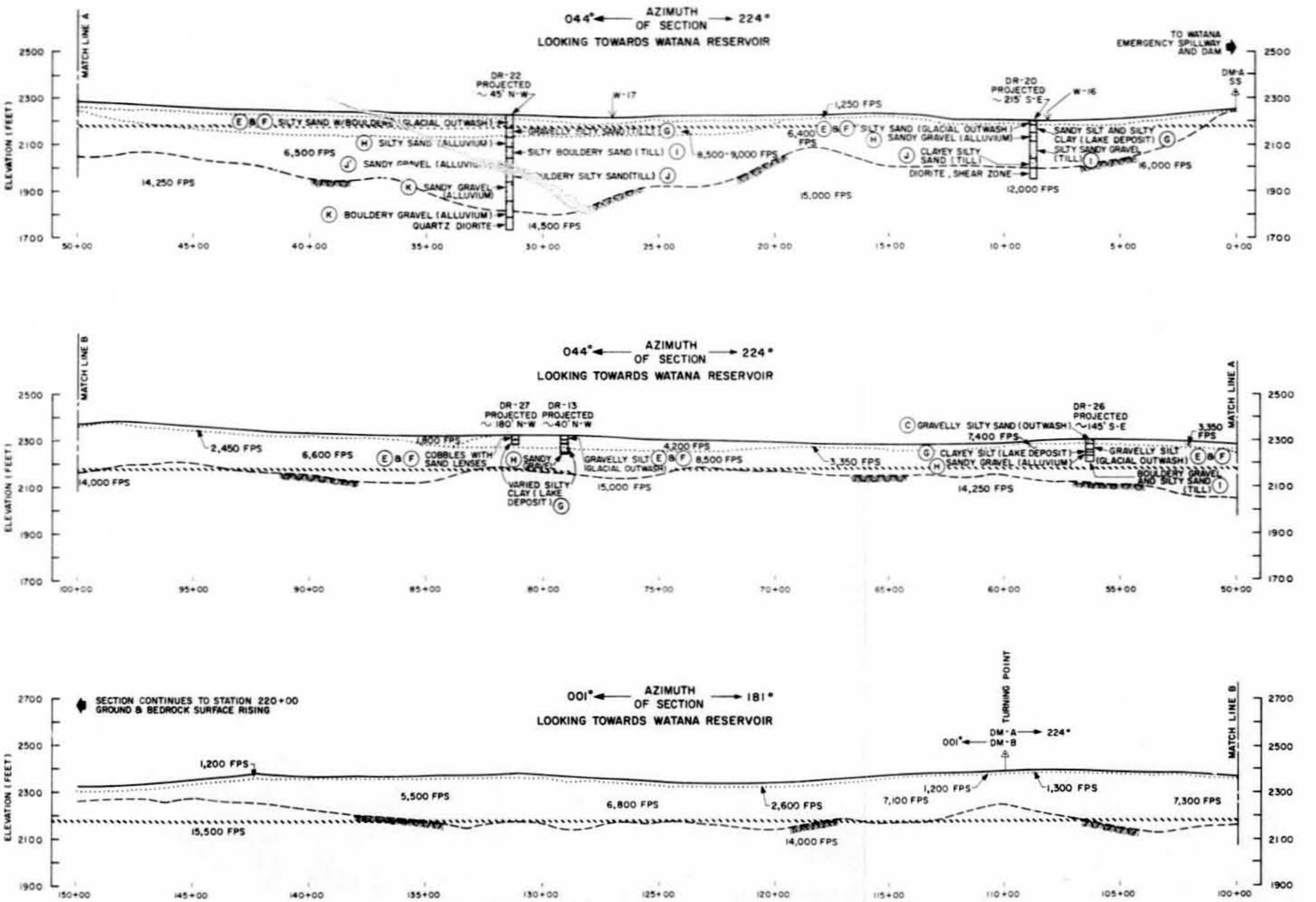
1. RELICT CHANNEL PROFILES SHOWN ON FIGURES 6.31 AND 6.33
2. PHOTO LOCATIONS & RELICT CHANNEL TOP OF ROCK SHOWN ON FIGURES 6.30 AND 6.35
3. PHOTOS TAKEN SUMMER 1980 (LEFT) & SUMMER 1981 (RIGHT).
4. RIGHT PHOTO LOOKS DOWN SHORTEST POTENTIAL FLOW PATH. CLEARED SPOT NEAR CENTER OF PHOTO IS TOPOGRAPHIC LOW, EL. 2200 FEET. PHOTO LOCATION SHOWN ON LEFT PHOTO.
5. ARTISTS SKETCH LOOKS OPPOSITE DIRECTION OF RIGHT PHOTO.

ARTIST'S SKETCH

WATANA
RELICT CHANNEL PHOTOS

FIGURE 6.30

ACRES



LEGEND

LITHOLOGY:

- BEDROCK (INFERRED TO BE DIORITE)
- OVERBURDEN, STRATIGRAPHIC UNITS AS SHOWN

CONTACTS:

- APPROXIMATE TOP OF ROCK
- NORMAL MAXIMUM OPERATING LEVEL EL. 2185

BOREHOLES: DR-20

- (G) STRATIGRAPHY
- DR-20 COE ROTARY DRILL BORING

GEOPHYSICAL SURVEYS:

- DM-A SEISMIC REFRACTION SURVEY END OR TURNING POINT-1975, DAMES & MOORE
- SEISMIC VELOCITY CHANGE
- 12,000 FPS SEISMIC VELOCITY IN FEET PER SECOND

OTHER:

- W-16 INTERSECTION WITH CROSS SECTION W-16

NOTES

1. SECTIONS READ FROM TOP TO LOWER LEFT (STA. 0+00 TO 150+00) SEISMIC LINES DM-A & B
2. SECTION LOCATION SHOWN ON FIGURE 6.35.
3. SECTIONS W-16 & W-17 SHOWN ON FIGURE 6.35.
4. VERTICAL AND HORIZONTAL SCALE EQUAL.
5. SECTION ELEVATIONS FROM COE 1" = 200' TOPOGRAPHY, 1978.
6. SECTION COINCIDES CLOSELY WITH DIVIDE BETWEEN SUSITNA RIVER AND TSUSENA CREEK DRAINAGES. THIS SECTION REPRESENTS NARROWEST RELICT CHANNEL WIDTH WHERE GROUND SURFACE IS ABOVE MAXIMUM POOL ELEVATION.
7. SECTION LIES ON DAMES AND MOORE SEISMIC LINE DM-A AND DM-B, 1975.
8. SEISMIC LINE ELEVATIONS CORRECTED AS PER COE SURVEY AND NPAS AIR PHOTO MAPS, 1978.
9. REFER TO TABLE 6.1 FOR SEISMIC VELOCITY AND MATERIAL CORRELATION.
10. SEE FIGURE 6.32 FOR STRATIGRAPHIC COLUMN AND GENERAL NOTES.

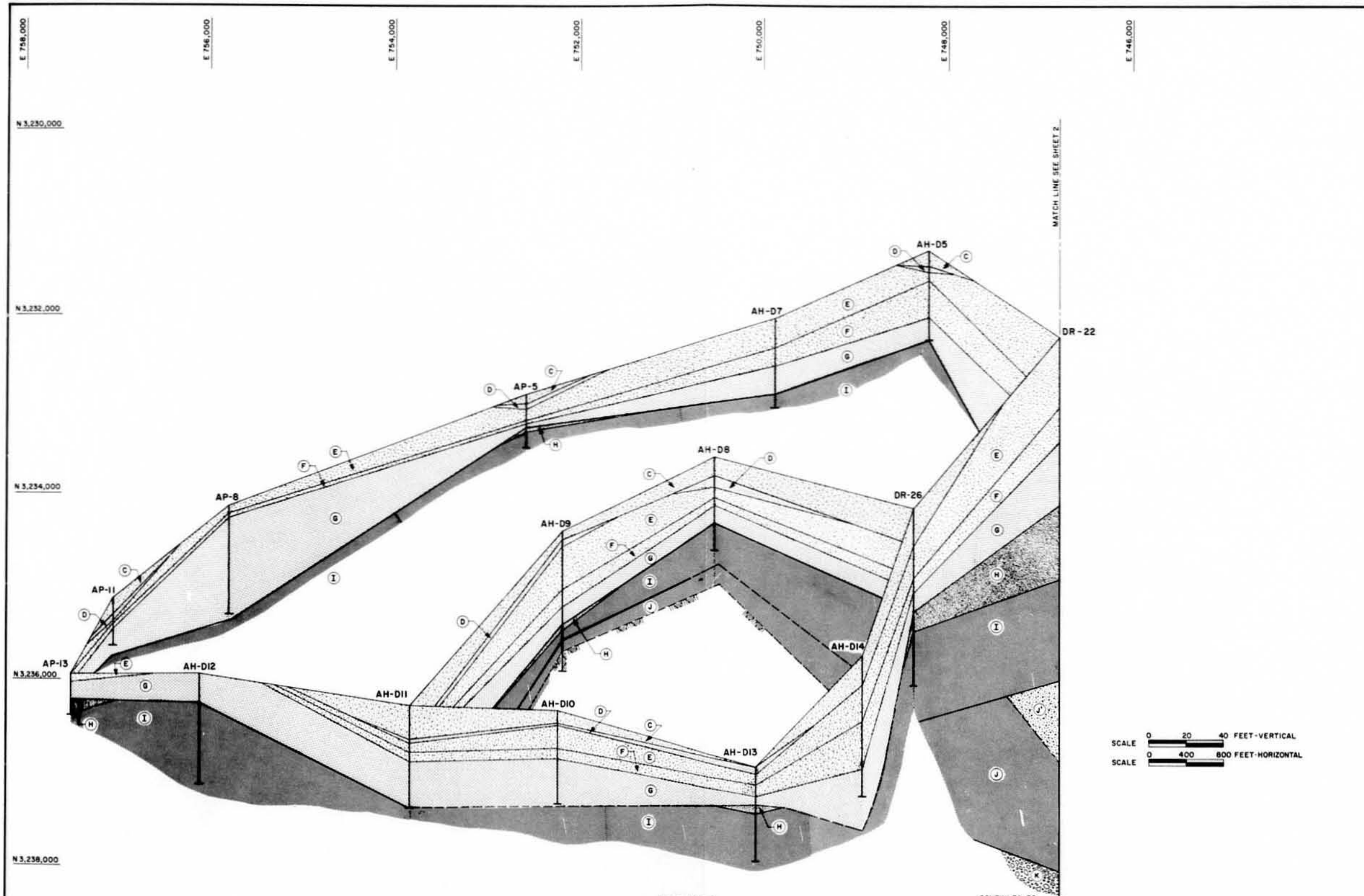
SCALE 0 200 400 FEET

REFERENCE: DAMES & MOORE, 1975. COE, 1979.

WATANA RELICT CHANNEL SECTION

ACRES

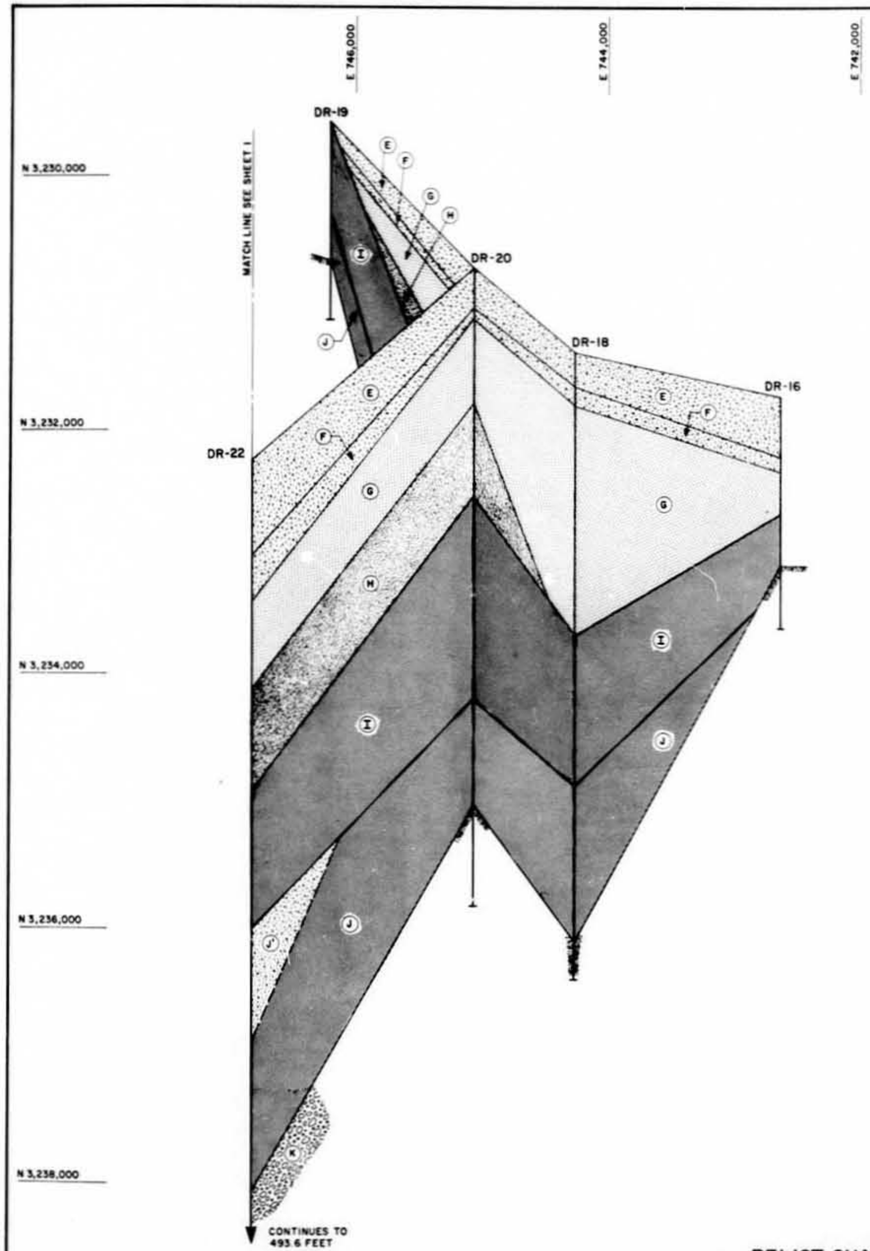
FIGURE 6.31



WATANA
RELICT CHANNEL & BORROW SITE D
STRATIGRAPHIC FENCE DIAGRAM
SHEET 1 OF 2

FIGURE 6.32

ACRES



GENERALIZED STRATIGRAPHIC COLUMN
BORROW SITE D AND RELICT CHANNEL

COLUMN	UNIT:		ESTIMATED THICKNESS:	DESCRIPTION:
	-	SURFICIAL	0 – 5'	BOULDERS, ORGANIC SILTS AND SANDS.
	C	OUTWASH	0 – 18' 12' AVERAGE	SILTY SAND WITH SOME GRAVEL AND OCCASIONAL COBBLES. USUALLY BROWN, BECOMES GRAY IN LIMITED AREAS. THICKEST IN NORTHERN PORTIONS OF AREA. THINNING SOUTHWARD, OFTEN ABSENT NEAR SUSITNA RIVER.
	D	ALLUVIUM & FLUVIAL DEPOSITS	0 – 15'	SAND WITH SOME SILT, OCCASIONAL GRAVEL. GENERALLY BROWN, FOUND ONLY ALONG COURSE OF LIMITED DRAINAGE CHANNELS FORMED IN OUTWASH E. GENERALLY SORTED.
	E & F	OUTWASH	0 – 35' 15' AVERAGE	SAND, SILT, GRAVEL AND COBBLES, PARTLY SORTED, WITH FRAGMENTS SUB-ANGULAR TO ROUNDED. SILT AND SAND LENSES OFTEN PRESENT. BROWN TO GRAY BROWN WITH A COBBLE/BOULDER ZONE OFTEN PRESENT AT THE BASE OF UNIT F. CONTACT BETWEEN E & F IS OFTEN POORLY DEFINED.
	G	TILL/WATERLAIN TILL	2 – 50' 12' AVERAGE	CLAYEY, SILTY SAND, USUALLY GRAY, OFTEN PLASTIC. CONTAINS COBBLES AND GRAVEL IN MANY AREAS. OCCASIONALLY PRESENT AS A LACUSTRINE DEPOSIT SHOWING LAMINATIONS AND/OR VARVES. GENERALLY A TILL DEPOSITED THROUGH OR NEAR STANDING WATER.
	H	ALLUVIUM	0 – 40'	SAND, SILT, GRAVEL, PARTLY TO WELL SORTED. OFTEN ABSENT BETWEEN UNITS G & I. UNIT REPRESENTS PERIOD OF MELTING PRODUCING ALLUVIUM/OUTWASH BETWEEN THESE DEPOSITS. APPEARS AS NARROW BANDS REPRESENTING CHANNEL FILLINGS. THICKEST IN WESTERN PORTION OF THE AREA.
	I & J	TILL	> 10' TO 65' 20' AVERAGE	POORLY SORTED SAND, SILT, GRAVEL AND COBBLES, OCCASIONALLY WITH CLAY. GENERALLY GRAY TO GRAY BROWN. CONTINUITY UNCERTAIN DUE TO LACK OF INFORMATION AT DEPTH. SILT OR SAND LAYER 2 INCHES-6 INCHES THICK OFTEN FOUND IN CENTER OF UNIT I. BASE UNIT ON TOP OF BEDROCK, EXCEPT IN BURIED CHANNEL THALWEG. CONTACT BETWEEN I & J OFTEN POORLY DEFINED, AND LOCALLY INCLUDES AN ALLUVIUM DESIGNATED J'
	J'	ALLUVIUM		
	K	ALLUVIUM	TO 160'	SAND, GRAVEL, COBBLES, BOULDERS, FEW FINES, PERMEABLE. FOUND ONLY IN THALWEG OF BURIED CHANNEL. TOP AT 292 FEET, EXTENDING TO ROCK AT 454 FEET IN DEPTH IN DR-22.
		BEDROCK, DIORITE		

NOTES

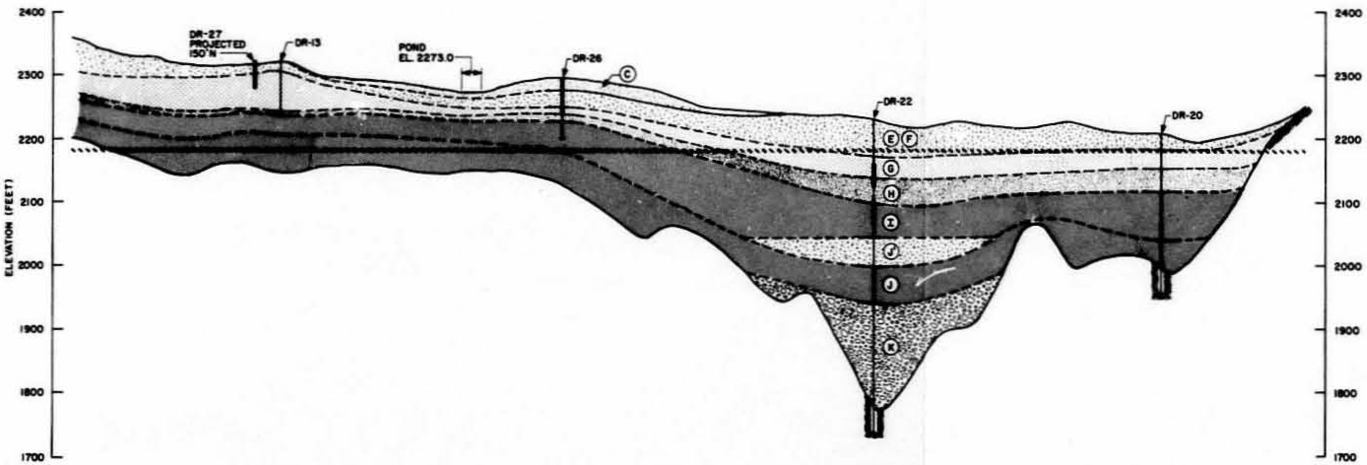
1. EXPLORATION LOCATIONS SHOWN ON FIGURES 5.1 AND 6.40.
2. FOR LEGEND OF SYMBOLS SEE FIGURE 6.33
3. EXPANDED SECTION FROM DR-13 THROUGH DR-20 SHOWN ON FIGURE 6.33.
4. LETTERS USED TO DEFINE UNITS ARE ARBITRARY AND WERE USED FOR CORRELATION PURPOSES.
5. THE ACCURACY AND THICKNESS OF SOIL AND ROCK STRATA IS SUBJECT TO VERIFICATION.
6. THIS FIGURE IS GENERALIZED FOR GRAPHIC PRESENTATION. FOR MORE SPECIFIC INFORMATION REFER TO TEXT AND BORING LOGS.

SCALE 0 20 40 FEET-VERTICAL
SCALE 0 400 800 FEET-HORIZONTAL

WATANA
RELICT CHANNEL & BORROW SITE D
STRATIGRAPHIC FENCE DIAGRAM
SHEET 2 OF 2

FIGURE 6.32

ACRES



LEGEND

LITHOLOGY:

C, E,F, G, H, I, J', J, K

CONTACTS:

—— KNOWN UNIT CONTACT

– – – INFERRED UNIT BOUNDARY

BEDROCK SURFACE WHERE DRILLED.

NORMAL MAXIMUM OPERATING LEVEL EL. 2185

BOREHOLES:

DR-26 COE ROTARY CORE BORINGS

NOTED AS FROZEN DURING DRILLING

NOTES

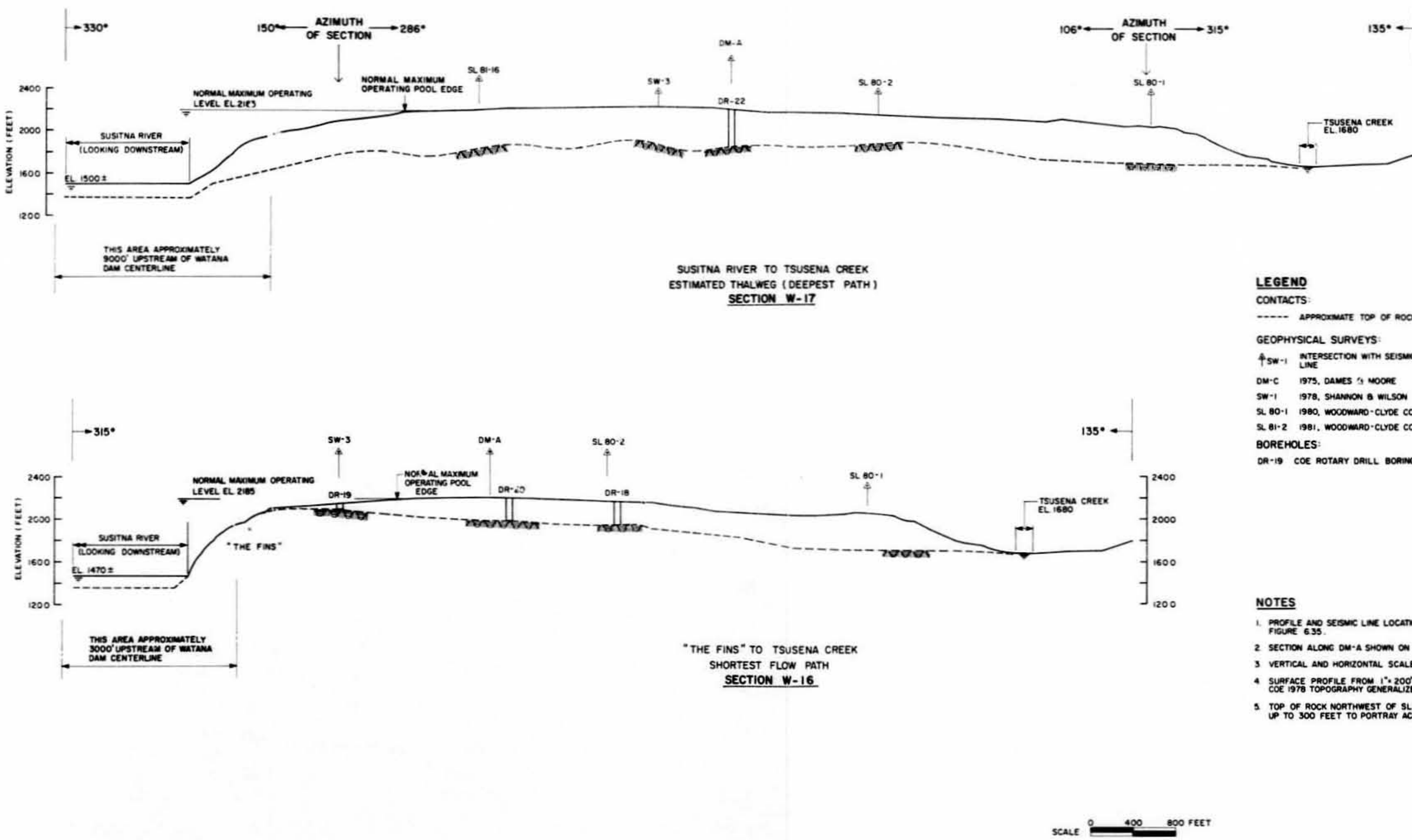
1. SEE FIGURE 6.32 FOR STRATIGRAPHIC COLUMN AND GENERAL NOTES.
2. SEE FIGURE 6.31 FOR TRUE SCALE SECTION OF SAME GENERAL AREA.
3. VERTICAL TO HORIZONTAL SCALES 5:1.
4. PERMAFROST DATA (TEMPERATURE PLOTS ON FIGURE 6.28).
   DR-13 NO TEMPERATURE DATA
   DR-20 NO PERMAFROST
   DR-22 FROZEN 72' TO 110'
   DR-26 FROZEN 19' TO 55'
   DR-27 FROZEN 0' TO 44'
5. BEDROCK ELEVATIONS BASED ON SEISMIC REFRACTION. DATA (FIG. 5.1)
6. THE ACCURACY AND THICKNESS OF SOIL AND ROCK STRATA IS SUBJECT TO VERIFICATION.
7. THIS FIGURE IS GENERALIZED FOR GRAPHIC PRESENTATION. FOR MORE SPECIFIC INFORMATION REFER TO TEXT AND BORING LOGS.

SCALE 0 80 160 FEET VERTICAL

SCALE 0 400 800 FEET HORIZONTAL

WATANA
RELICT CHANNEL-EXPANDED THALWEG SECTION

FIGURE 6.33



LEGEND

CONTACTS:

----- APPROXIMATE TOP OF ROCK

GEOPHYSICAL SURVEYS:

SW-1 INTERSECTION WITH SEISMIC REFRACTION LINE

DM-C 1975, DAMES & MOORE

SW-1 1978, SHANNON & WILSON

SL 80-1 1980, WOODWARD-CLYDE CONSULTANTS

SL 81-2 1981, WOODWARD-CLYDE CONSULTANTS

BOREHOLES:

DR-19 COE ROTARY DRILL BORING

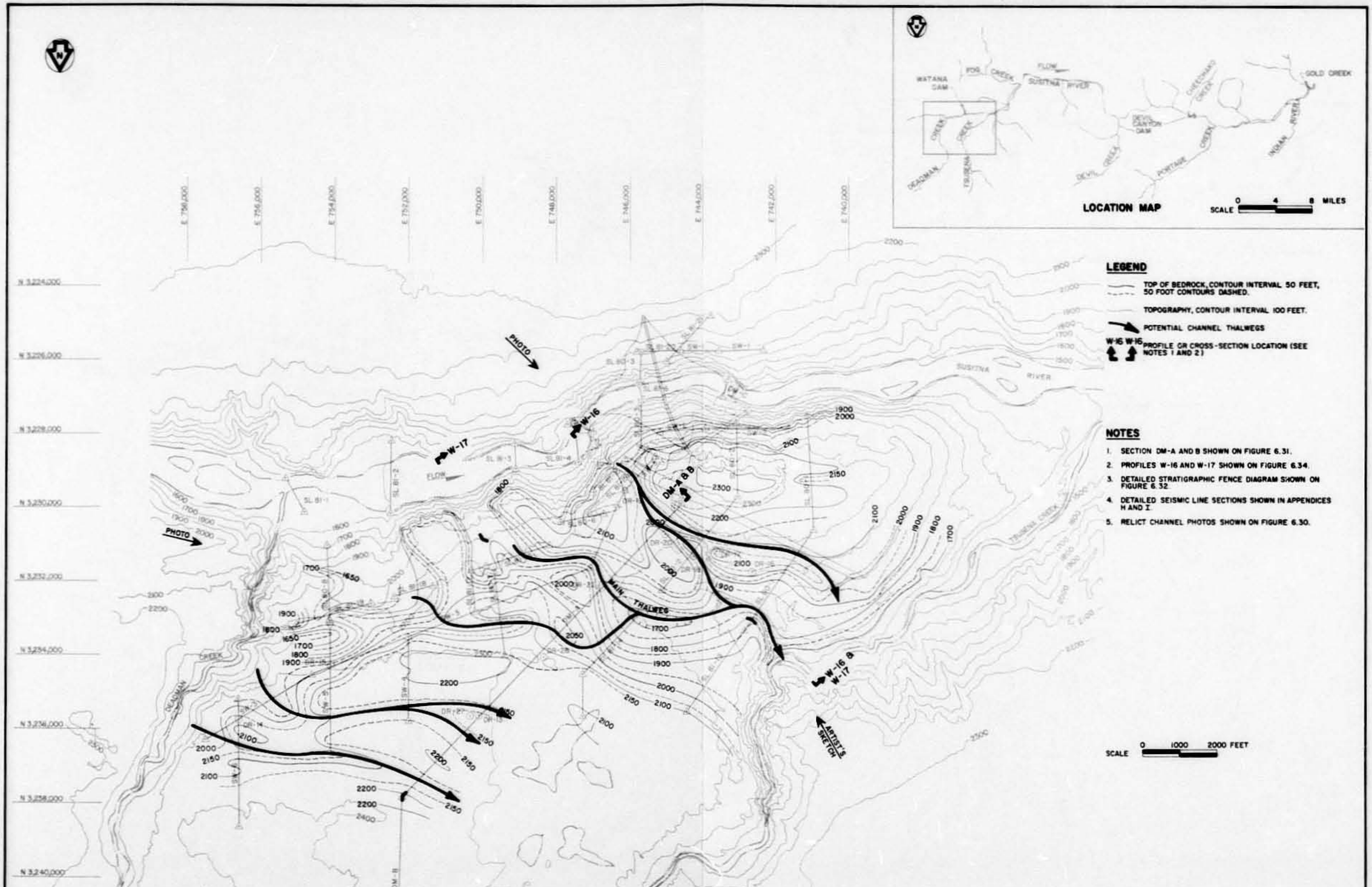
NOTES

1. PROFILE AND SEISMIC LINE LOCATIONS SHOWN ON FIGURE 6.35.
2. SECTION ALONG DM-A SHOWN ON FIGURE 6.31.
3. VERTICAL AND HORIZONTAL SCALE EQUAL.
4. SURFACE PROFILE FROM 1"= 200' TOPOGRAPHY, COE 1978 TOPOGRAPHY GENERALIZED TO ±25 FEET.
5. TOP OF ROCK NORTHWEST OF SL 80-1 IS PROJECTED UP TO 300 FEET TO PORTRAY ACTUAL THALWEG PROFILE.

WATANA
RELICT CHANNEL PROFILES

ACRES

FIGURE 6.34

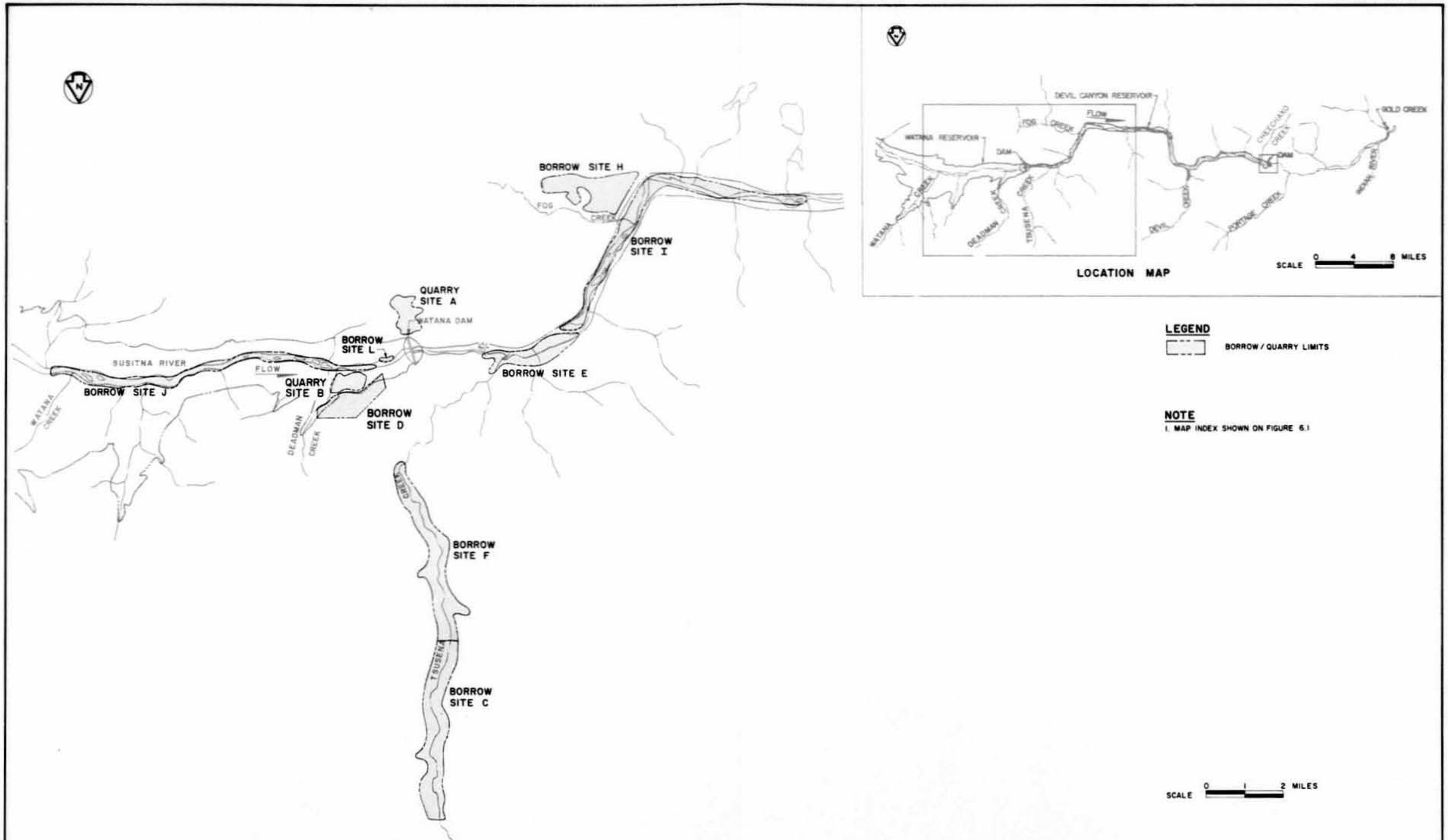


WATANA
RELICT CHANNEL-TOP OF BEDROCK

DM-A & B

FIGURE 6.35

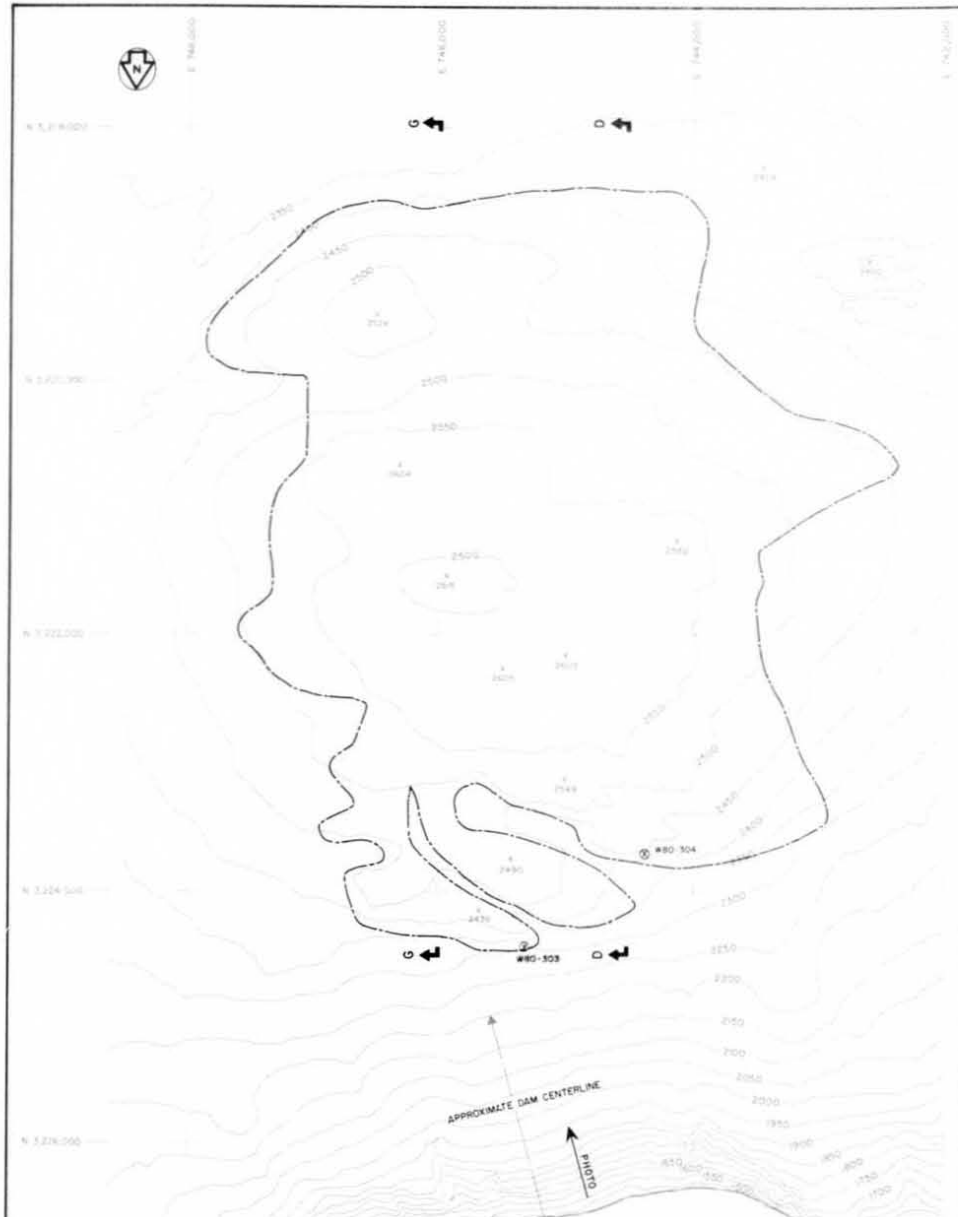
ACRES



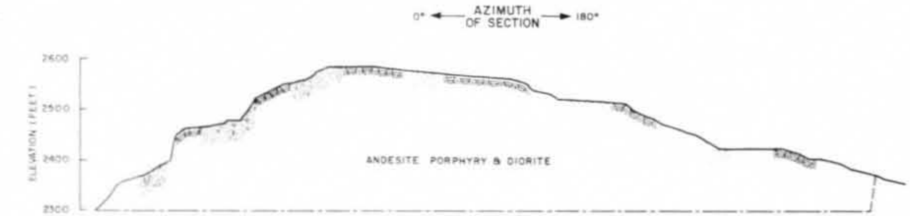
WATANA
BORROW SITE MAP

ACRES

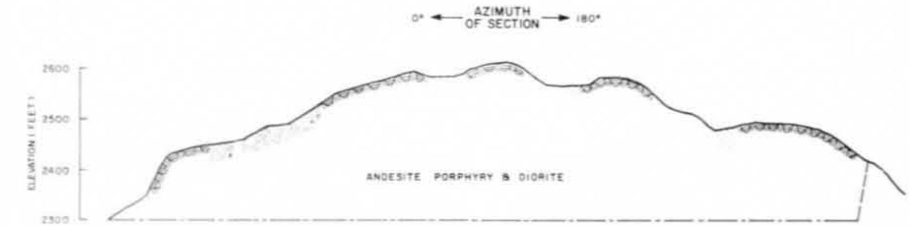
FIGURE 6.36



QUARRY A PLAN



SECTION D-D



SECTION G - G

LEGEND

STRUCTURE

- SUSPECTED FRACTURE ZONE WITH LOCAL SHEARING
- BEDROCK OUTCROP
- SHEAR ZONE

CONTACTS

- MAPPED LIMIT OF BORROW SITE

OTHER

- D D CROSS-SECTION LOCATIONS
- SAMPLE LOCATION (APPROXIMATE)

APPROXIMATE DAM CENTERLINE

NOTES

1. SELECTED TYPICAL SECTIONS SHOWN.
2. VERTICAL SCALE 4 TIMES HORIZONTAL SCALE.
3. 50 FOOT CONTOURS REPRODUCED FROM REFERENCED BASE MAP.
4. CONTOUR INTERVAL 50 FEET
5. QUARRY SITE LIMITS BASED ON PRELIMINARY MAPPING AND IS SUBJECT TO RESULTS OF DESIGN EXPLORATIONS.
6. INTERPRETATION BASED ON AIR PHOTO INTERPRETATION AND RECONNAISSANCE, AND SURFICIAL GEOLOGY MAPPING.
7. PHOTO TAKEN AUGUST, 1981.
8. LITHOLOGY AND CONTACTS WITHIN QUARRY A REQUIRE FUTURE DELINEATION

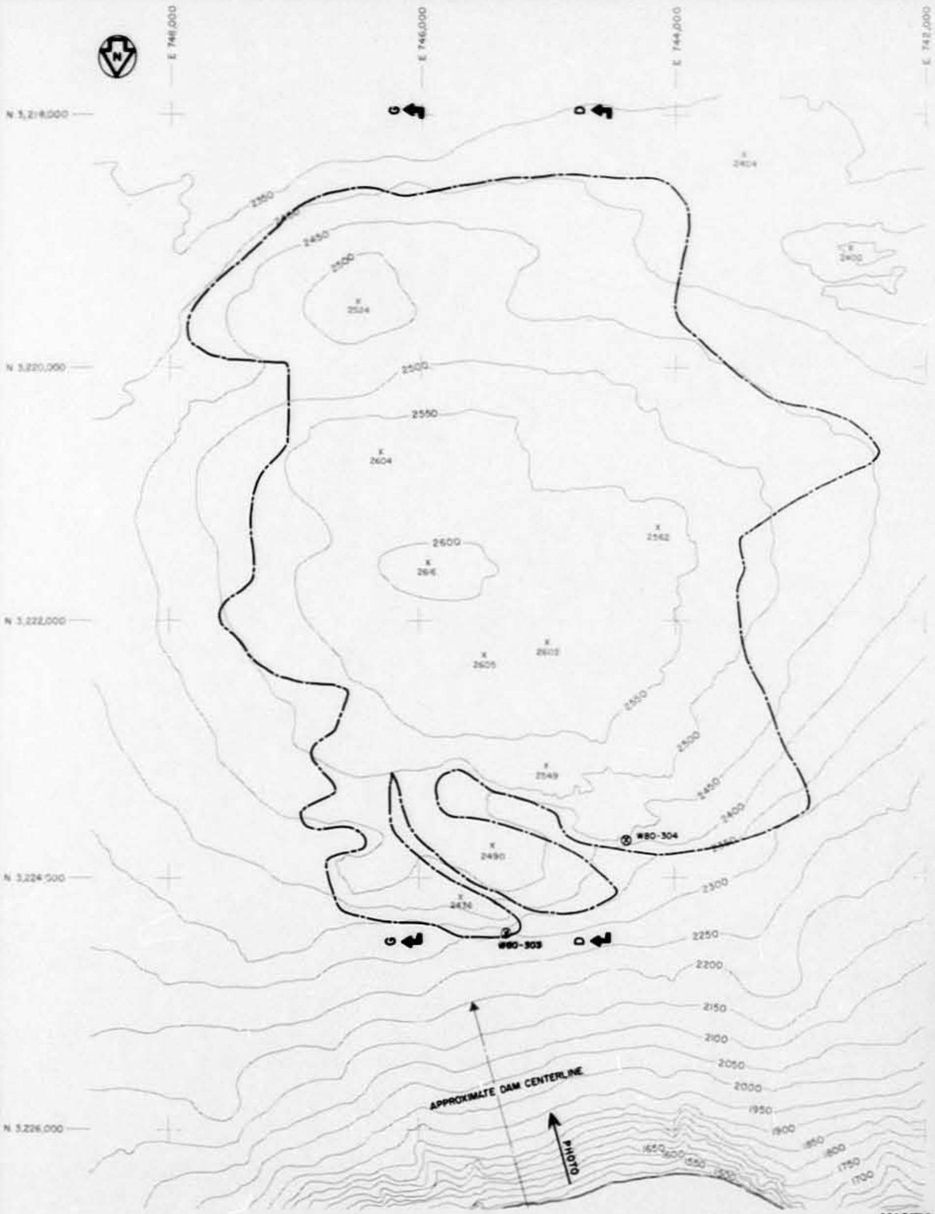
WATANA
QUARRY SITE A PLAN AND SECTIONS

SCALE 0 400 800 FEET

REFERENCE: 1" = 200' TOPOGRAPHY 1978 COE, (NPAS) SHEET 8/26.
1" = 400' TOPOGRAPHY 1981 AAI, (NPAS) SHEET 1 OF 1, FLT. NO. 4-4.

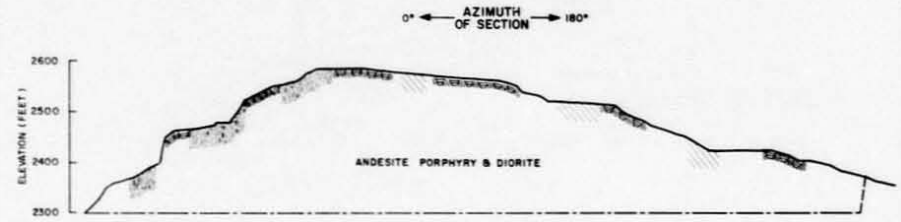
ACRES

FIGURE 6.37

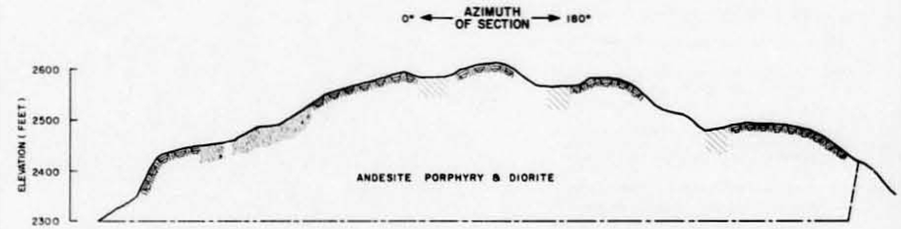


QUARRY A PLAN

REFERENCE : 1" = 200' TOPOGRAPHY 1978 COE, (NPAS) SHEET 8/26.
1" = 400' TOPOGRAPHY 1981 AAI, (NPAS) SHEET 1 OF 1, FLT. NO. 4-4.



SECTION D-D



SECTION G - G

LEGEND

STRUCTURE

SUSPECTED FRACTURE ZONE WITH LOCAL SHEARING

BEDROCK OUTCROP

SHEAR ZONE

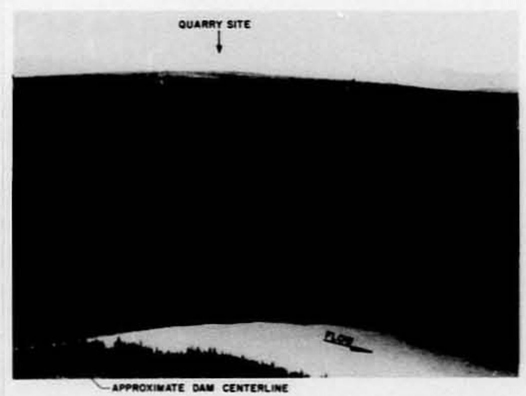
CONTACTS

MAPPED LIMIT OF BORROW SITE

OTHER

D D CROSS-SECTION LOCATIONS

⊗ SAMPLE LOCATION (APPROXIMATE)



NOTES

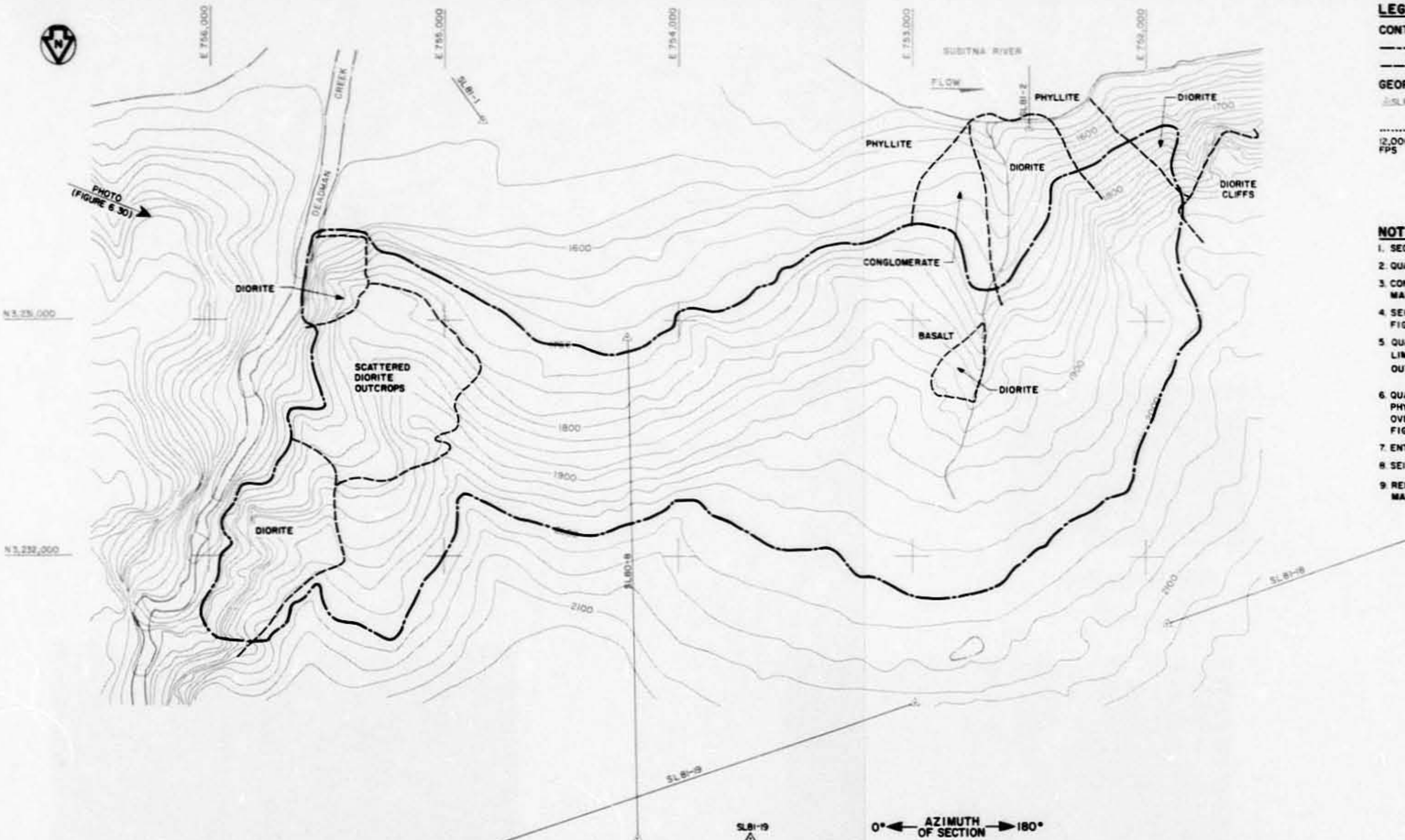
1. SELECTED TYPICAL SECTIONS SHOWN.
2. VERTICAL SCALE 4 TIMES HORIZONTAL SCALE.
3. 50 FOOT CONTOURS REPRODUCED FROM REFERENCED BASE MAP.
4. CONTOUR INTERVAL 50 FEET
5. QUARRY SITE LIMITS BASED ON PRELIMINARY MAPPING AND IS SUBJECT TO RESULTS OF DESIGN EXPLORATIONS.
6. INTERPRETATION BASED ON AIR PHOTO INTERPRETATION AND RECONNAISSANCE, AND SURFICIAL GEOLOGY MAPPING.
7. PHOTO TAKEN AUGUST, 1981.
8. LITHOLOGY AND CONTACTS WITHIN QUARRY A REQUIRE FUTURE DELINEATION

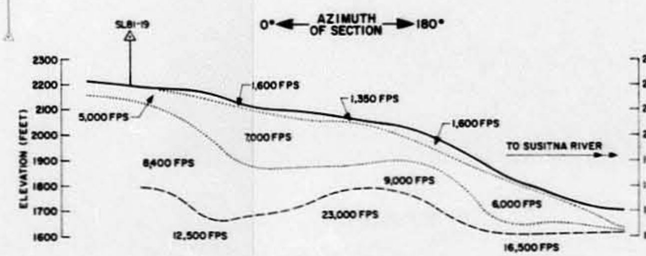
SCALE 0 400 800 FEET

WATANA
QUARRY SITE A PLAN AND SECTIONS

ACRES

FIGURE 6.37





SECTION SL80-8

LEGEND

CONTACTS:

—·— QUARRY SITE LIMITS

——— BEDROCK OUTCROPS

GEOPHYSICAL SUVEYS:

SL81-8 SEISMIC REFRACTION SURVEY END OR TURNING POINT-1980-81, WOODWARD-CLYDE CONSULTANTS

.... SEISMIC VELOCITY CHANGE

12,000 FPS SEISMIC VELOCITY IN FEET PER SECOND

NOTES

1. SECTION LOCATION SHOWN ON PLAN.
2. QUARRY SITE IS SHOWN ON LEFT HAND PHOTO, FIGURE 6.30
3. CONTOUR INTERVAL 25' TRACED FROM REFERENCED BASE MAP.
4. SECTION LIES ON SEISMIC LINE SL80-8 (APPENDIX H, FIGURE 10).
5. QUARRY SITE B LIMITS BASED ON QUARRY SITE LIMITS PROPOSED BY COE, 1978. LIMITS OF ROCK OUTCROP MAPPED BY COE.
6. QUARRY MATERIAL IS DIORITE OUTCROPS WITH SOME PHYLLITE, CONGLOMERATE AND BASALT AT LOWER ELEVATIONS. OVERBURDEN IS TILL AND OUTWASH, SEE BORROW SITE D, FIGURE 6.40.
7. ENTIRE QUARRY SITE LIES WITHIN PROPOSED RESERVOIR LIMITS.
8. SEISMIC REFRACTION DATA SHOWN IN APPENDIXES H AND I.
9. REFER TO TABLE 6.1 FOR SEISMIC VELOCITY AND MATERIAL CORRELATION.

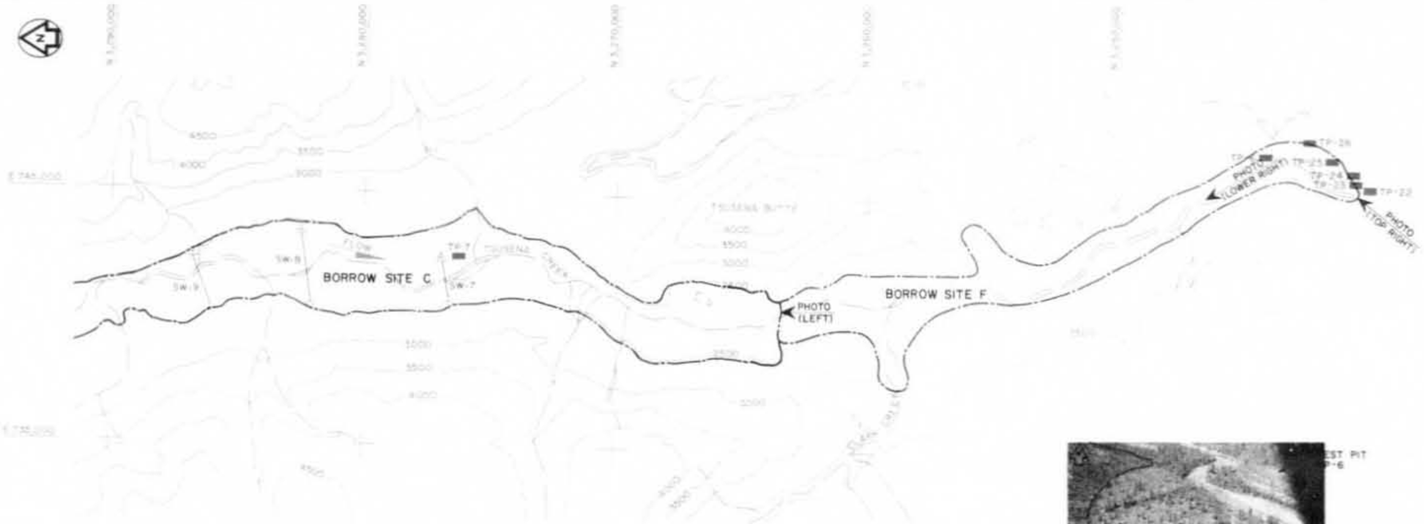
SCALE 0 200 400 FEET

REFERENCES: BASE MAP FROM COE, 1978 - 1" = 200' WATANA TOPOGRAPHY, SHEETS 14 & 15 OF 26, COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4).

WATANA
QUARRY SITE B PLAN AND SECTIONS

ACRES

FIGURE 6.38



LEGEND

CONTACTS:

—·— MATERIAL LIMITS

BOREHOLES AND TEST PITS:

TP-6 1978, COE TEST PITS AND TRENCHES

GEOPHYSICAL SURVEYS:

SW-9 SEISMIC REFRACTION SURVEY END OR TURNING POINT - 1978, SHANNON & WILSON

NOTES

1. CONTOUR INTERVAL 500', TRACED FROM ENLARGED REFERENCED BASE MAP.
2. BORROW SITE LIMITS BASED ON SEISMIC AND AIR PHOTO INTERPRETATION. FINAL MAPPED LIMITS OF BORROW MATERIALS, SUBJECT TO RESULTS OF DESIGN INVESTIGATIONS.
3. BORROW MATERIAL IS COMPRISED OF CLARK AND TSUSENA CREEK HISTORICAL AND RECENT TERRACE DEPOSITS OF GRAVEL AND SAND.
4. ENTIRE BORROW SITE LIMITS LIE OUTSIDE OF PROPOSED RESERVOIR LIMITS.
5. EXPLORATION LOGS AND SEISMIC LINE SECTIONS IN COE, 1978.
6. SEISMIC LINE LOCATIONS REPLOTTED FROM SHANNON & WILSON, 1978 LOCATIONS APPROXIMATED.
7. PHOTOS TAKEN SUMMER OF 1978 AND 1981.

LOWER BORROW SITE F

BORROW SITE C

BORROW SITE C

CLARK CREEK

BORROW SITE C

UPPER BORROW SITE F

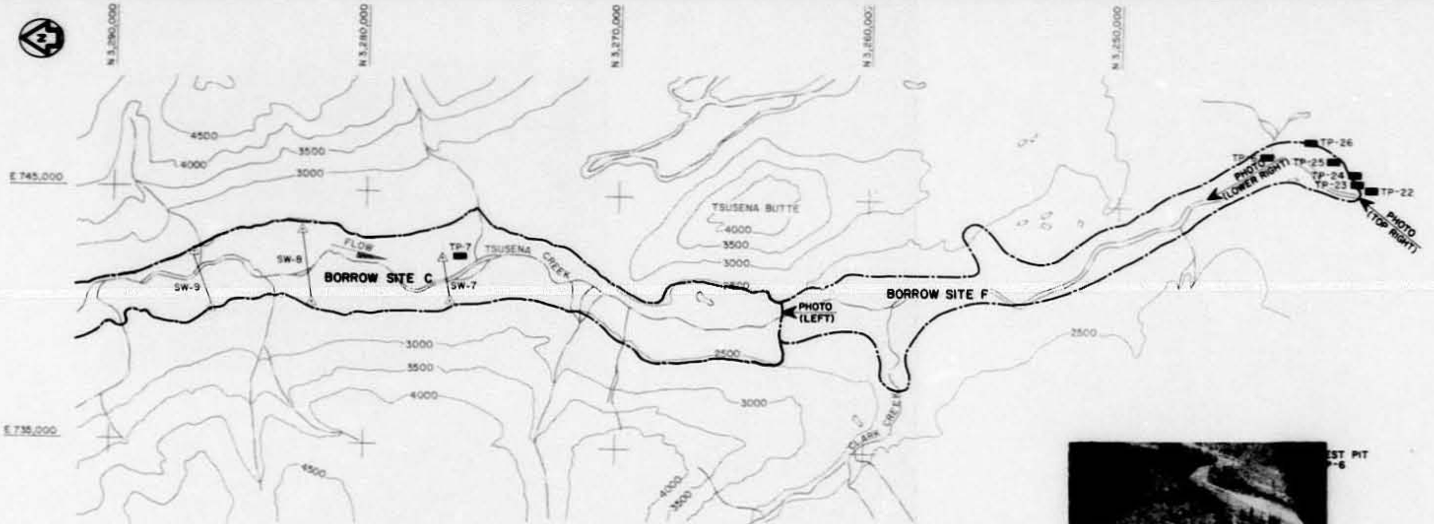
SCALE 0 2000 4000 FEET

REFERENCE: BASE MAP FROM USGS 1:63,360 ALASKA QUADRANGLE, TALKEETNA MOUNTAINS (D-3)
COE, 1978
S & W, 1978
COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4)

WATANA
BORROW SITES C & F

FIGURE 6.39

ACRES



LEGEND

CONTACTS:

—·—·— MATERIAL LIMITS

BOREHOLES AND TEST PITS:

■ TP-6 1978, COE TEST PITS AND TRENCHES

GEOPHYSICAL SURVEYS:

△ SW-9 SEISMIC REFRACTION SURVEY END OR TURNING POINT - 1978, SHANNON & WILSON

NOTES

1. CONTOUR INTERVAL 500', TRACED FROM ENLARGED REFERENCED BASE MAP.
2. BORROW SITE LIMITS BASED ON SEISMIC AND AIR PHOTO INTERPRETATION. FINAL MAPPED LIMITS OF BORROW MATERIALS, SUBJECT TO RESULTS OF DESIGN INVESTIGATIONS.
3. BORROW MATERIAL IS COMPRISED OF CLARK AND TSUSENA CREEK HISTORICAL AND RECENT TERRACE DEPOSITS OF GRAVEL AND SAND.
4. ENTIRE BORROW SITE LIMITS LIE OUTSIDE OF PROPOSED RESERVOIR LIMITS.
5. EXPLORATION LOGS AND SEISMIC LINE SECTIONS IN COE, 1978.
6. SEISMIC LINE LOCATIONS REPLOTTED FROM SHANNON & WILSON, 1978 LOCATIONS APPROXIMATED.
7. PHOTOS TAKEN SUMMER OF 1978 AND 1981.

LOWER BORROW SITE F

SCALE 0 2000 4000 FEET

BORROW SITE C

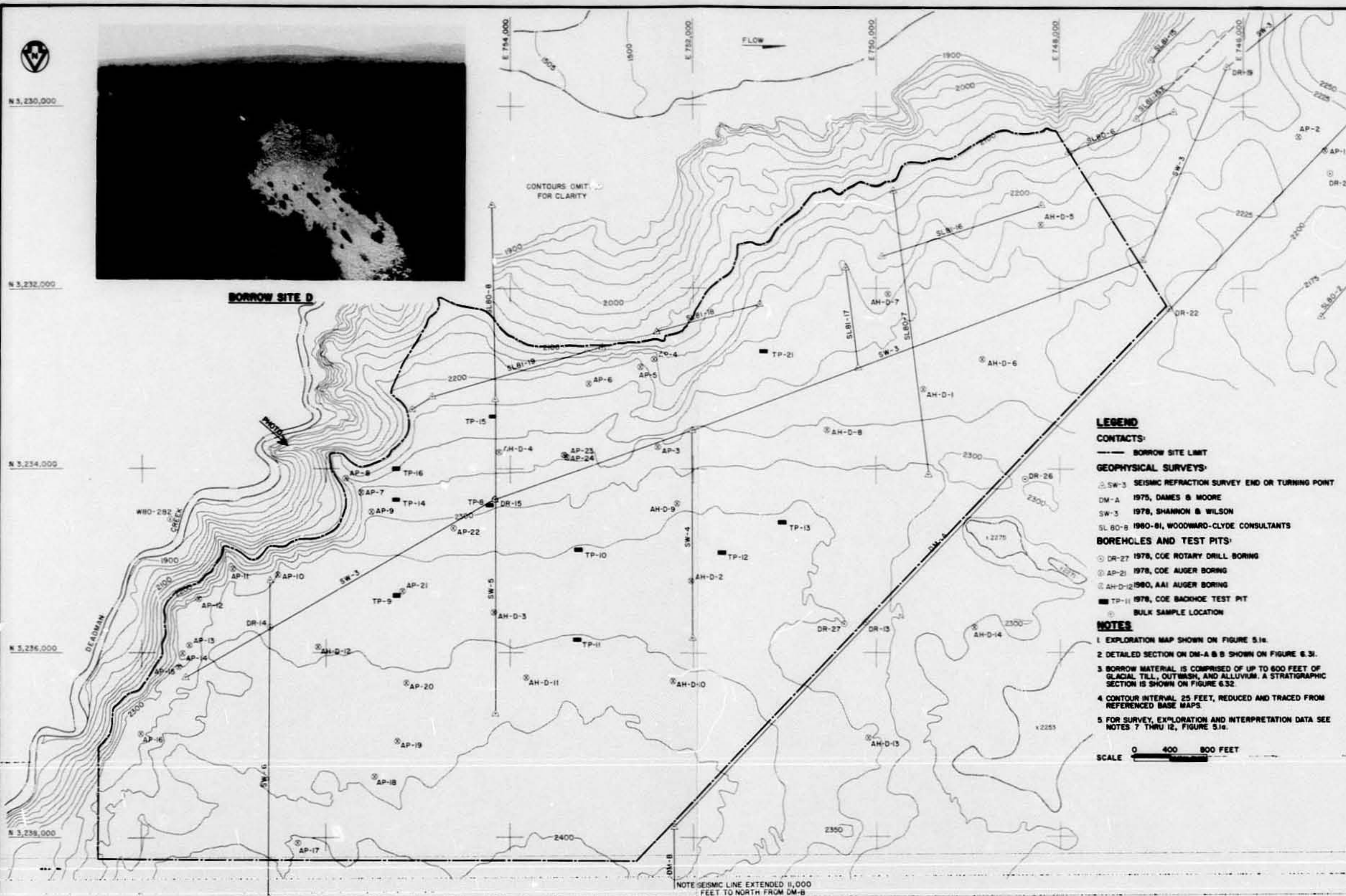
UPPER BORROW SITE F

REFERENCE: BASE MAP FROM USGS 1:63,360 ALASKA QUADRANGLE, TALKEETNA MOUNTAINS (D-3)
COE, 1978
S & W, 1978
COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4)

WATANA
BORROW SITES C & F

ACRES

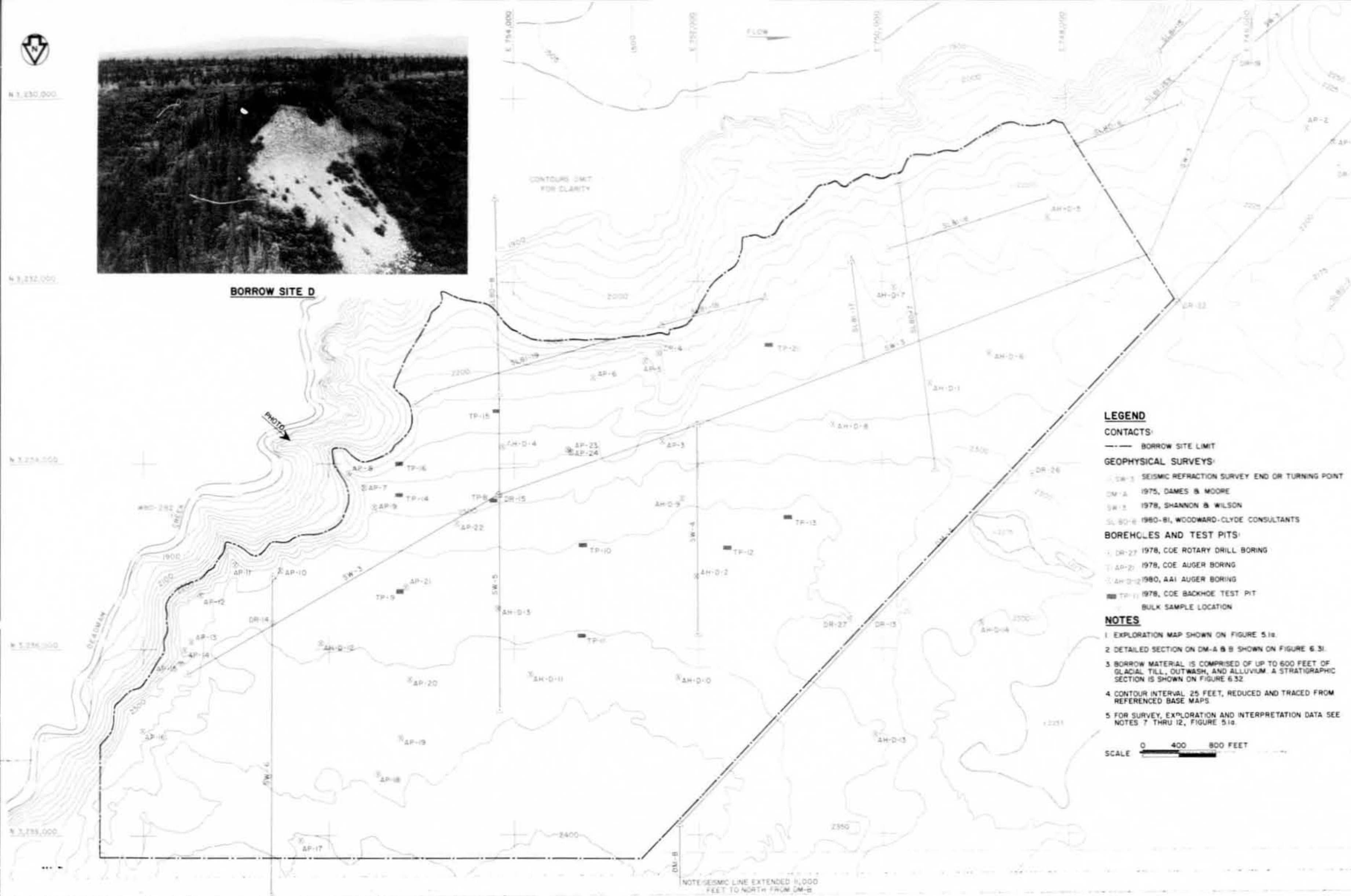
FIGURE 6.39



REFERENCE: BASE MAP FROM 1978, COE - 1" = 200' DAMSITE TOPOGRAPHY, SHEETS 13-15, 18-20 OF 26

WATANA
BORROW SITE D PLAN

FIGURE 6.40

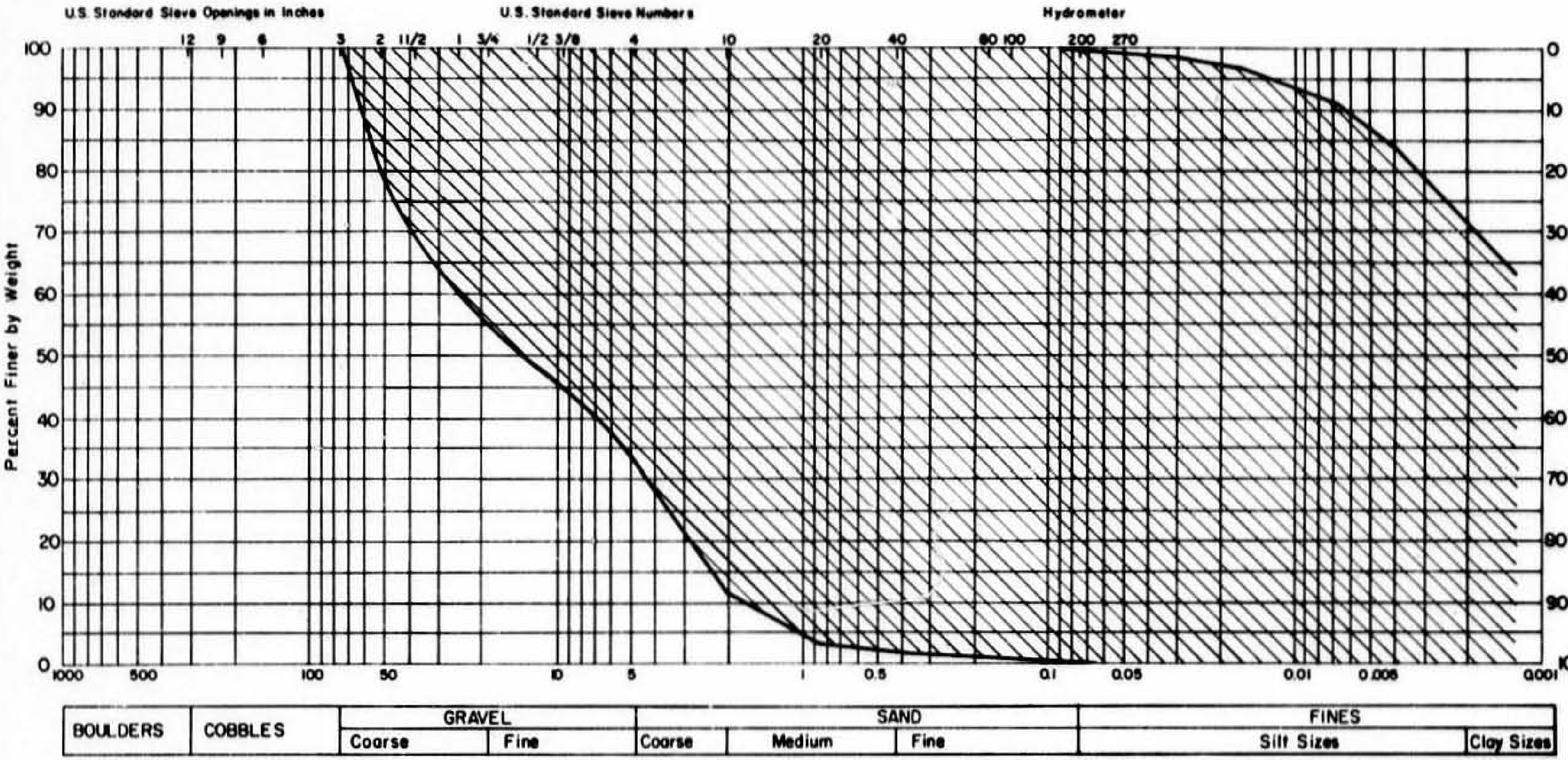


REFERENCE: BASE MAP FROM 1978, COE - 1"=200' DAMSITE TOPOGRAPHY, SHEETS 13-15, 18-20 OF 26.

WATANA
BORROW SITE D PLAN

FIGURE 6.49

ACRES

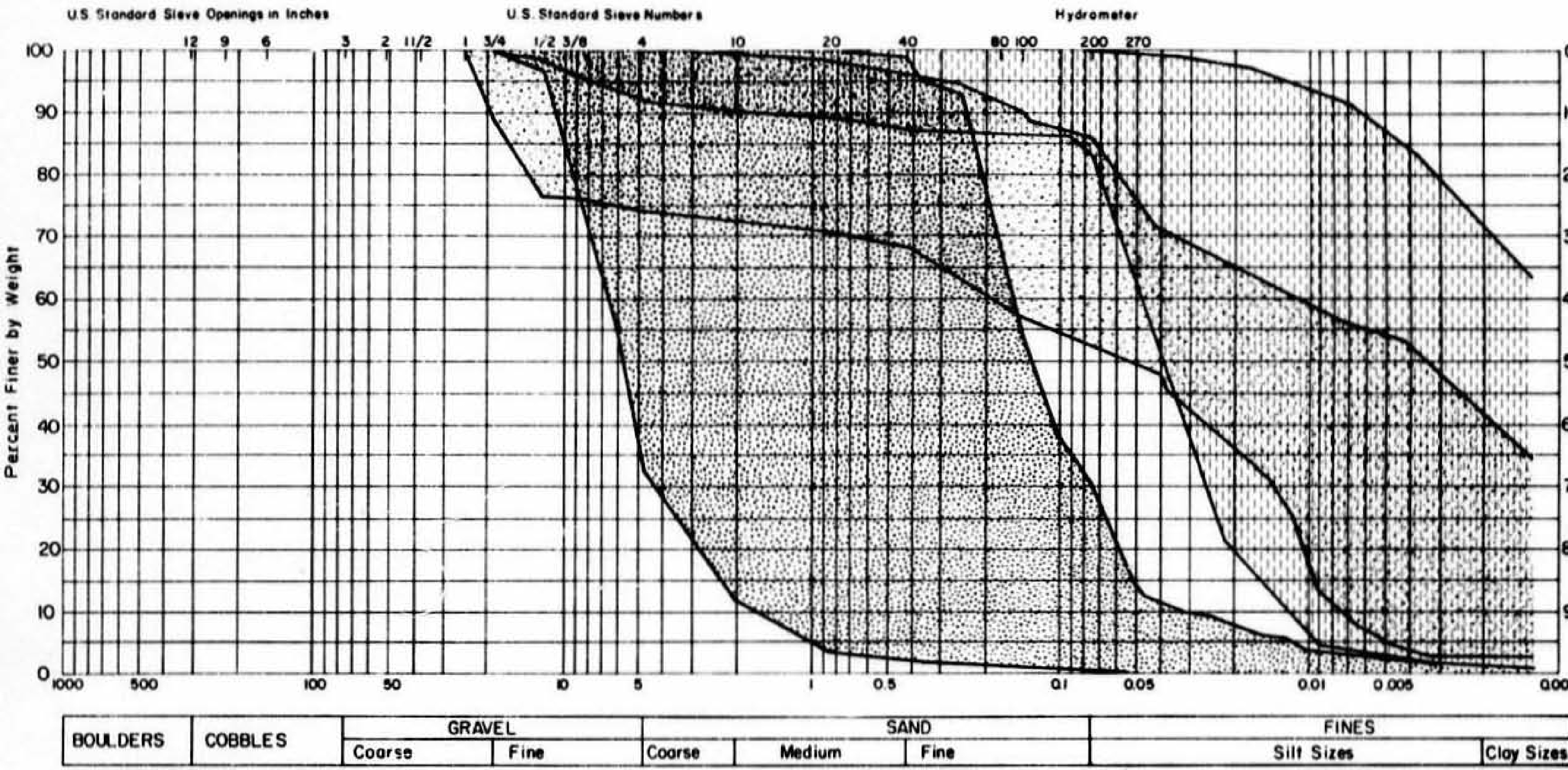


TOTAL NUMBER OF SAMPLES:146

WATANA
BORROW SITE D
RANGE OF GRADATIONS

FIGURE 6.41

ACRES

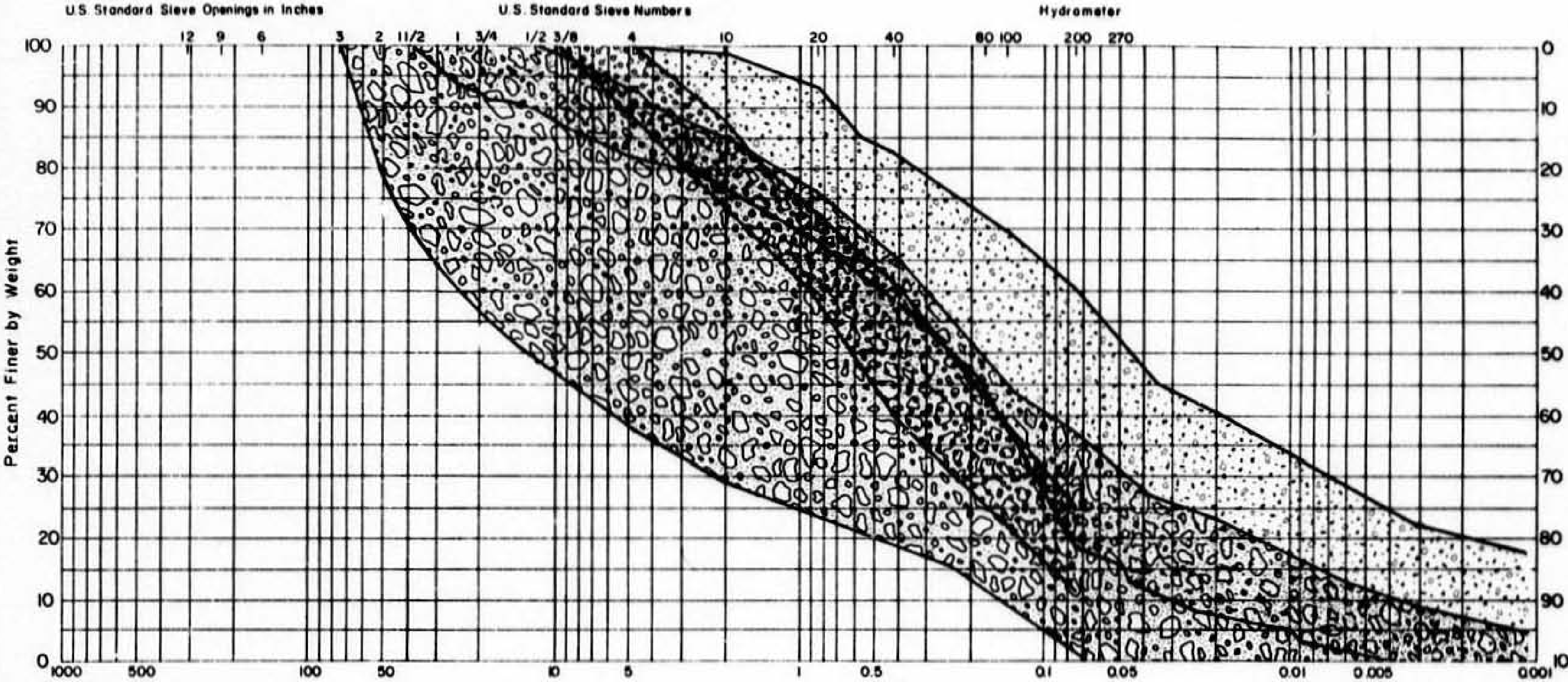


GRADATION TYPE	MATERIAL	NO. OF SAMPLES
1	SILTY CLAY, CLAYEY SILT WITH SAND	14
2	SILTY CLAY WITH SAND AND GRAVEL	24
3	SILTY SAND WITH GRAVEL	9

WATANA
BORROW SITE D
MATERIAL GRADATION TYPES
SHEET 1 OF 2

FIGURE 6.42

ACRES



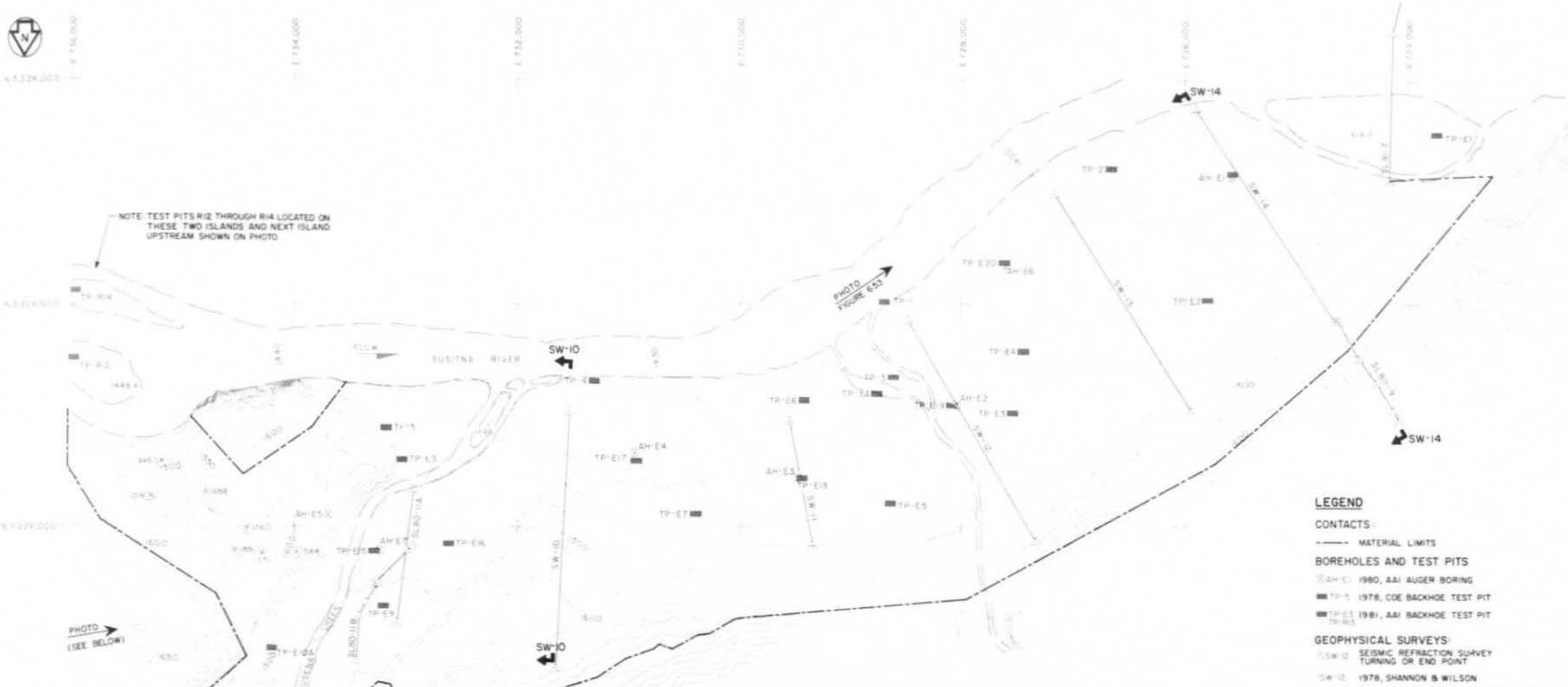
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

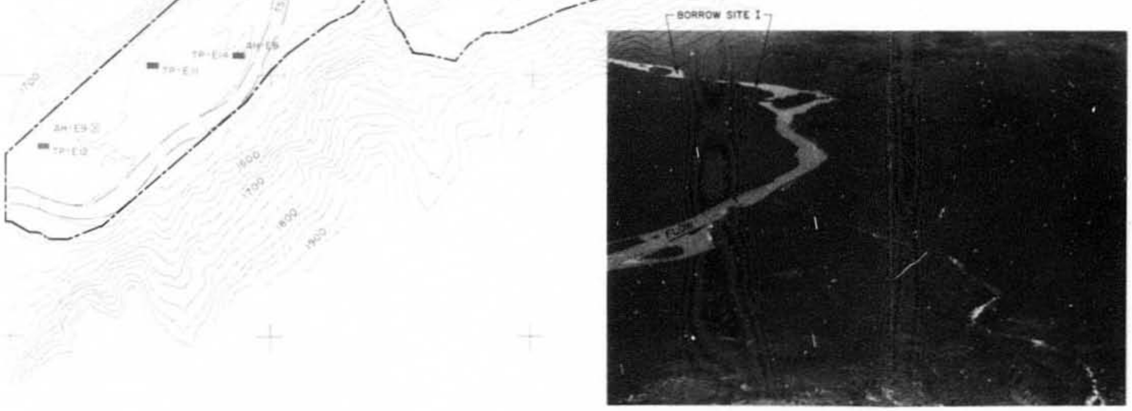
GRADATION TYPE		MATERIAL	NO. OF SAMPLES
	4	SILTY SAND WITH CLAY AND GRAVEL	41
	5	SILTY SAND WITH GRAVEL	8
	6	GRAVELLY SAND, SANDY GRAVEL	50

WATANA
BORROW SITE D
MATERIAL GRADATION TYPES
SHEET 2 OF 2

FIGURE 6.42

ACRES





NOTES

1. TYPICAL SECTIONS AND PHOTOS ARE SHOWN ON FIGURES 6.44 AND 6.53.
2. CONTOUR INTERVAL 25', TRACED AND/OR REDUCED FROM REFERENCED BASE MAPS.
3. "SW" SEISMIC LINE LOCATIONS CORRECTED AS PER S & W ORIGINAL SURVEY NOTES, 1980-81 LOCATIONS PER R & M SURVEYS.
4. MATERIAL LIMITS BASED ON FIELD EXPLORATION, MAPPING AND AIR PHOTO INTERPRETATION. FINAL LIMITS OF BORROW MATERIALS SUBJECT TO RESULTS OF DESIGN INVESTIGATIONS.
5. BORROW LIMITS EXTEND TO SOUTH SHORE OF RIVER, AND ADJOIN BORROW SITE I (FIGURE 6.51) ON WEST END.
6. NORTHERN PORTION OF BORROW SITE EXTENDS ABOVE PROPOSED DEVIL CANYON RESERVOIR LIMITS (1455').
7. EXPLORATION LOGS AND SEISMIC LINE SECTIONS SHOWN IN APPENDICES F, H AND I.

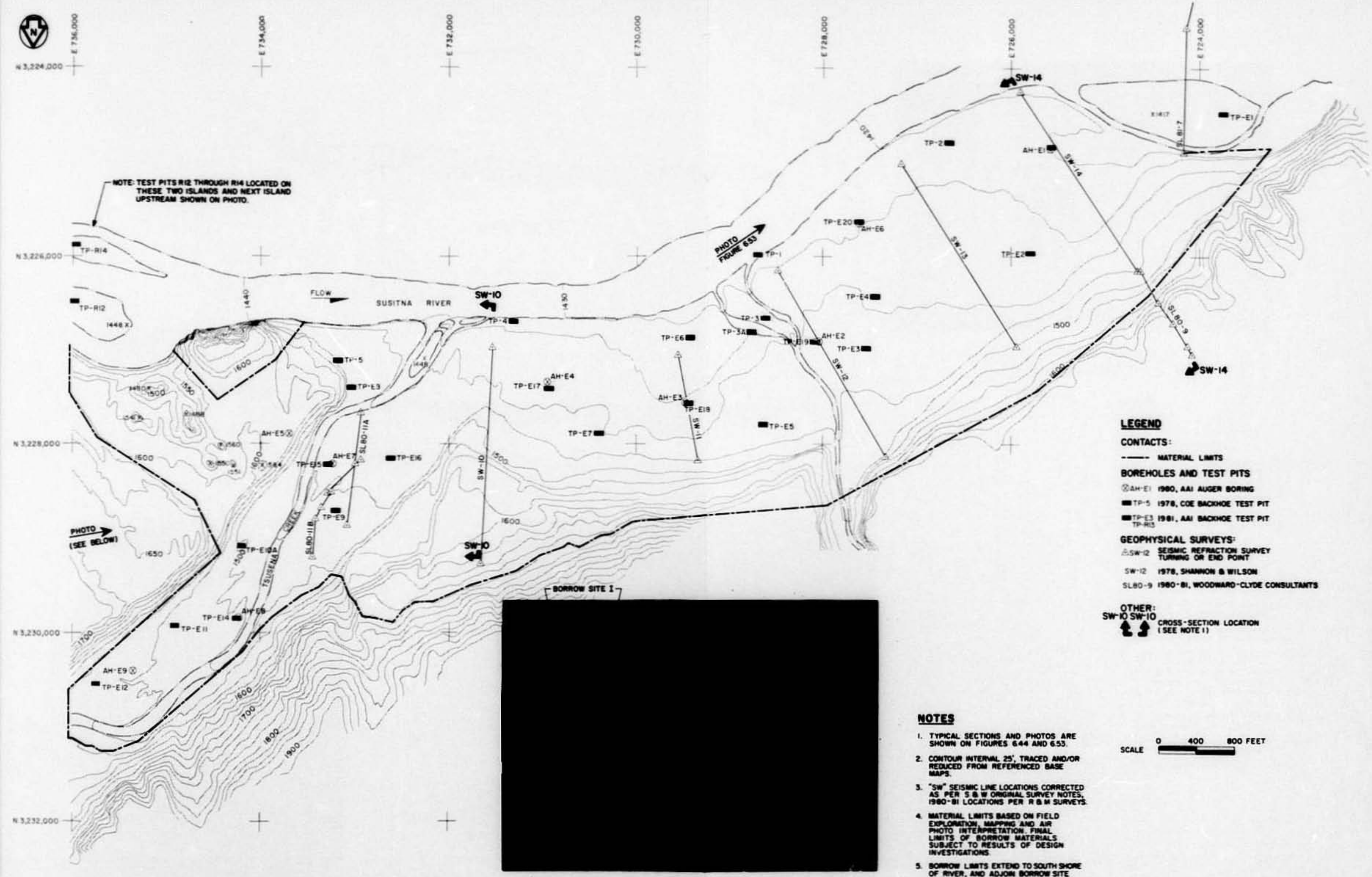
SCALE 0 400 800 FEET

WATANA
BORROW SITE E PLAN

REFERENCES: BASE MAP FROM COE, 1978 - 1" = 200' WATANA TOPOGRAPHY, SHEET 6 & 11 OF 26
R & M, 1981 - 1" = 400' DEVIL CANYON RESERVOIR MAPPING, FLIGHT 5 (6-8), MANUSCRIPT 2
COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4)

ACRES

FIGURE 6.43



LEGEND

CONTACTS:

- - - - MATERIAL LIMITS

BOREHOLES AND TEST PITS

⊗AH-E1 1980, AAI AUGER BORING

■TP-5 1978, COE BACKHOE TEST PIT

■TP-E3 TP-R13 1981, AAI BACKHOE TEST PIT

GEOPHYSICAL SURVEYS:

△SW-12 SEISMIC REFRACTION SURVEY TURNING OR END POINT

SW-12 1978, SHANNON & WILSON

SL80-9 1980-81, WOODWARD-CLYDE CONSULTANTS

OTHER:

SW-10 SW-10 CROSS-SECTION LOCATION (SEE NOTE 1)

SCALE 0 400 800 FEET

NOTES

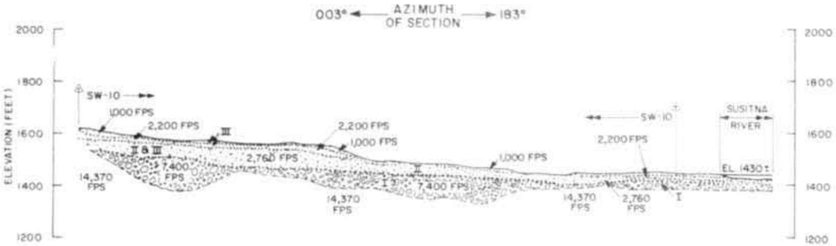
1. TYPICAL SECTIONS AND PHOTOS ARE SHOWN ON FIGURES 6.44 AND 6.53.
2. CONTOUR INTERVAL 25', TRACED AND/OR REDUCED FROM REFERENCED BASE MAPS.
3. "SW" SEISMIC LINE LOCATIONS CORRECTED AS PER S & W ORIGINAL SURVEY NOTES, 1980-81 LOCATIONS PER R & M SURVEYS.
4. MATERIAL LIMITS BASED ON FIELD EXPLORATION, MAPPING AND AIR PHOTO INTERPRETATION. FINAL LIMITS OF BORROW MATERIALS SUBJECT TO RESULTS OF DESIGN INVESTIGATIONS.
5. BORROW LIMITS EXTEND TO SOUTH SHORE OF RIVER, AND ADJOIN BORROW SITE I (FIGURE 6.51) ON WEST END.
6. NORTHERN PORTION OF BORROW SITE EXTENDS ABOVE PROPOSED DEVIL CANYON RESERVOIR LIMITS (1455').
7. EXPLORATION LOGS AND SEISMIC LINE SECTIONS SHOWN IN APPENDICES F, H AND I.

REFERENCES: BASE MAP FROM COE, 1978 - 1" = 200' WATANA TOPOGRAPHY, SHEET 6 & 11 OF 26
R & M, 1981 - 1" = 400' DEVIL CANYON RESERVOIR MAPPING, FLIGHT 5 (6-8), MANUSCRIPT 2
COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4)

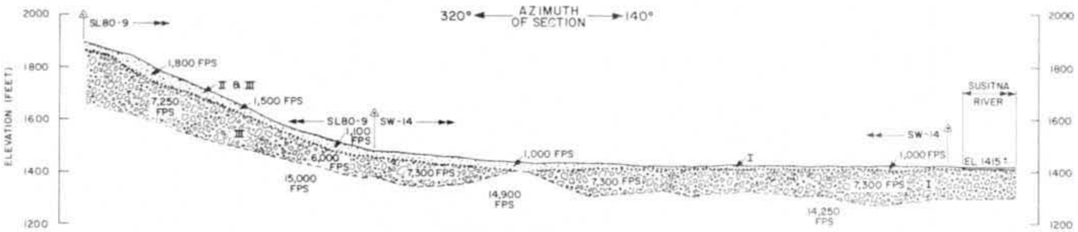
WATANA
BORROW SITE E PLAN

ACRES

FIGURE 6.43



SECTION SW-10



SECTION SW-14 & SL80-9

TYPICAL STREAM-WASHED GRAVEL
SUSITNA FLOODPLAIN, WESTERN SITE E

LEGEND

CONTACTS:

- - - - - APPROXIMATE TOP OF ROCK

GEOPHYSICAL SURVEYS:

SW-10 SEISMIC REFRACTION SURVEY END OR TURNING POINT

SW-10 1978, SHANNON & WILSON

SL 80-9 1980, WOODWARD-CLYDE CONSULTANTS

.... SEISMIC VELOCITY CHANGE

12,000 FPS SEISMIC VELOCITY IN FEET PER SECOND

NOTES

1. SECTION LOCATIONS SHOWN ON FIGURE 6.43
2. ALL SECTIONS LOOKING UPSTREAM (EAST).
3. VERTICAL AND HORIZONTAL SCALES EQUAL.
4. SECTION ELEVATIONS FROM REFERENCED BASE MAPS, TRACED AT 25' CONTOUR INTERVALS.
5. ADDITIONAL PHOTOS AND SKETCHES OF TYPICAL BORROW SITE CONDITIONS SHOWN ON FIGURE 6.53
6. ZONES INDICATE MATERIAL TYPES AS DESCRIBED IN TEXT. INFERRED ORIGINS ARE:
   I. SUSITNA RIVER ALLUVIAL GRAVELS
   II. TSUSENA CREEK BED ALLUVIAL GRAVELS
   III. OUTWASH OR HIGH LEVEL HISTORIC GRAVEL & SAND TERRACES
7. SECTIONS LIE ON SHANNON & WILSON 1978 SEISMIC LINES, COE 1978, AND S & W 1978
8. REFER TO TABLE 6.1 FOR SEISMIC VELOCITY AND MATERIAL CORRELATION.
9. PHOTOS TAKEN APRIL, AUGUST 1981.

ROCK HAMMER FOR SCALE

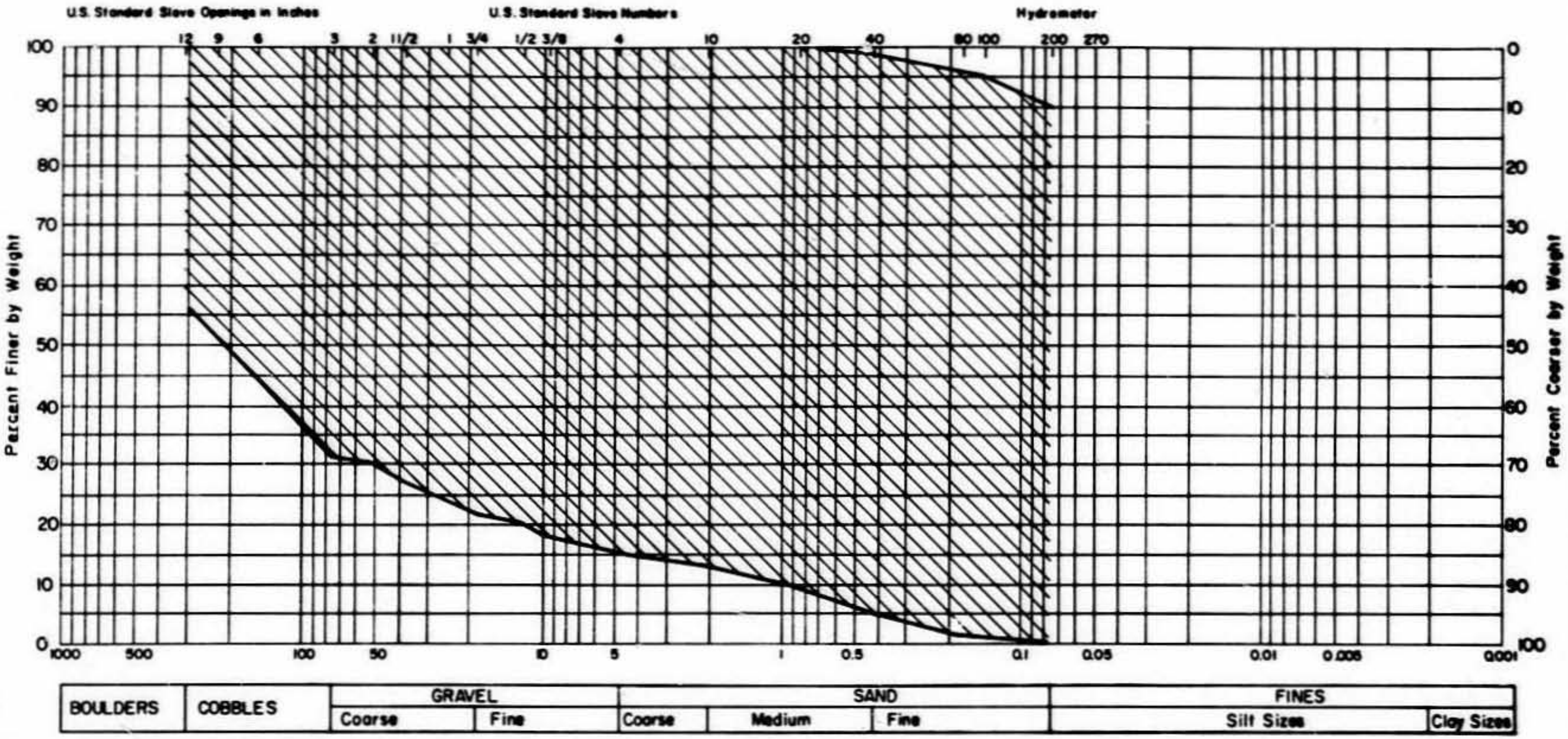
TEST PIT TP-E15
SOUTH WALL SHOWING BOULDER LAYER
OVER SANDY GRAVEL

TEST PIT TP-E15
SAMPLE 1 - WEIGHING & SPLITTING

SCALE 0 200 400 FEET

WATANA
BORROW SITE E SECTIONS

FIGURE 6.44

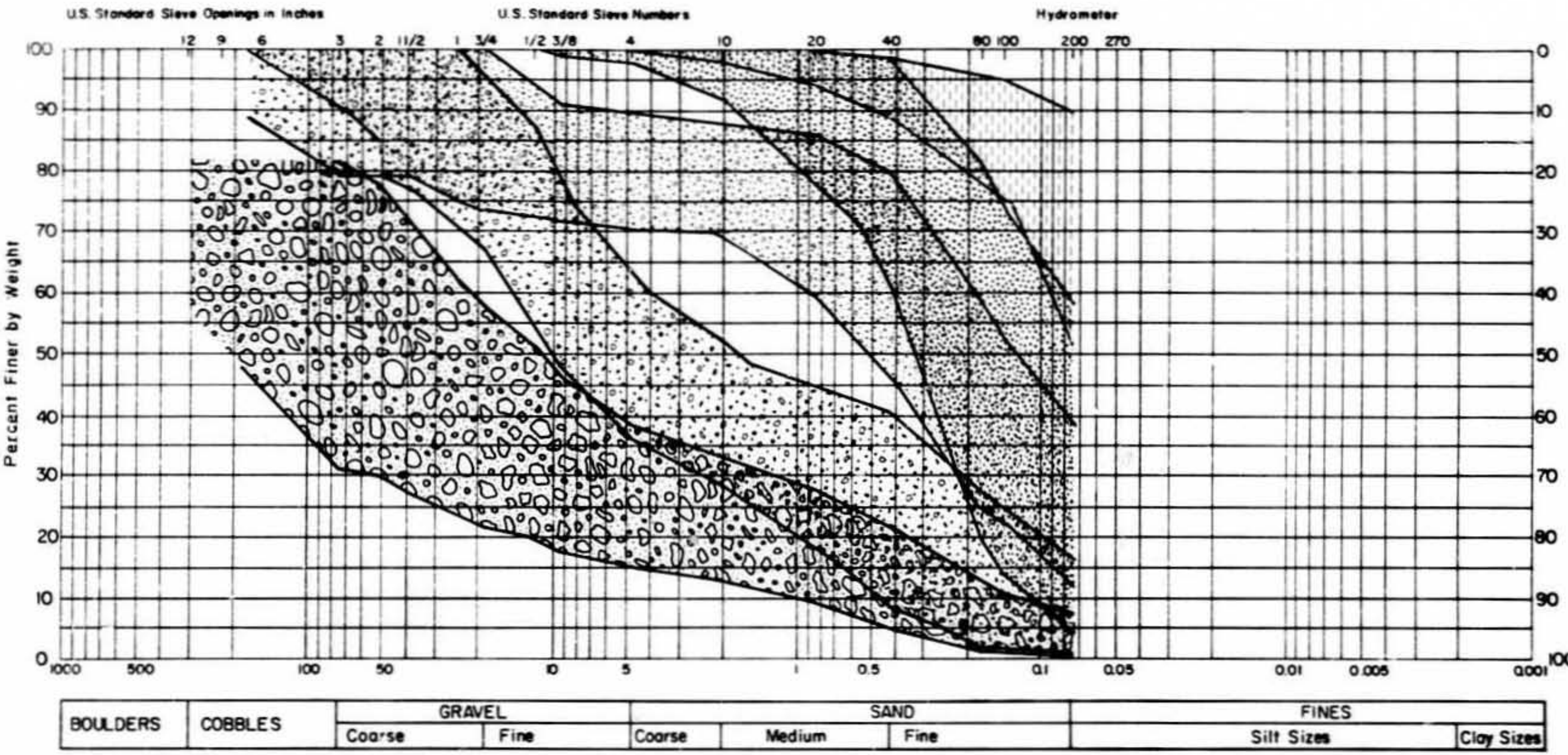


TOTAL NUMBER OF SAMPLES : 50

WATANA
BORROW SITE E
RANGE OF GRADATIONS

ACRES

FIGURE 6.45

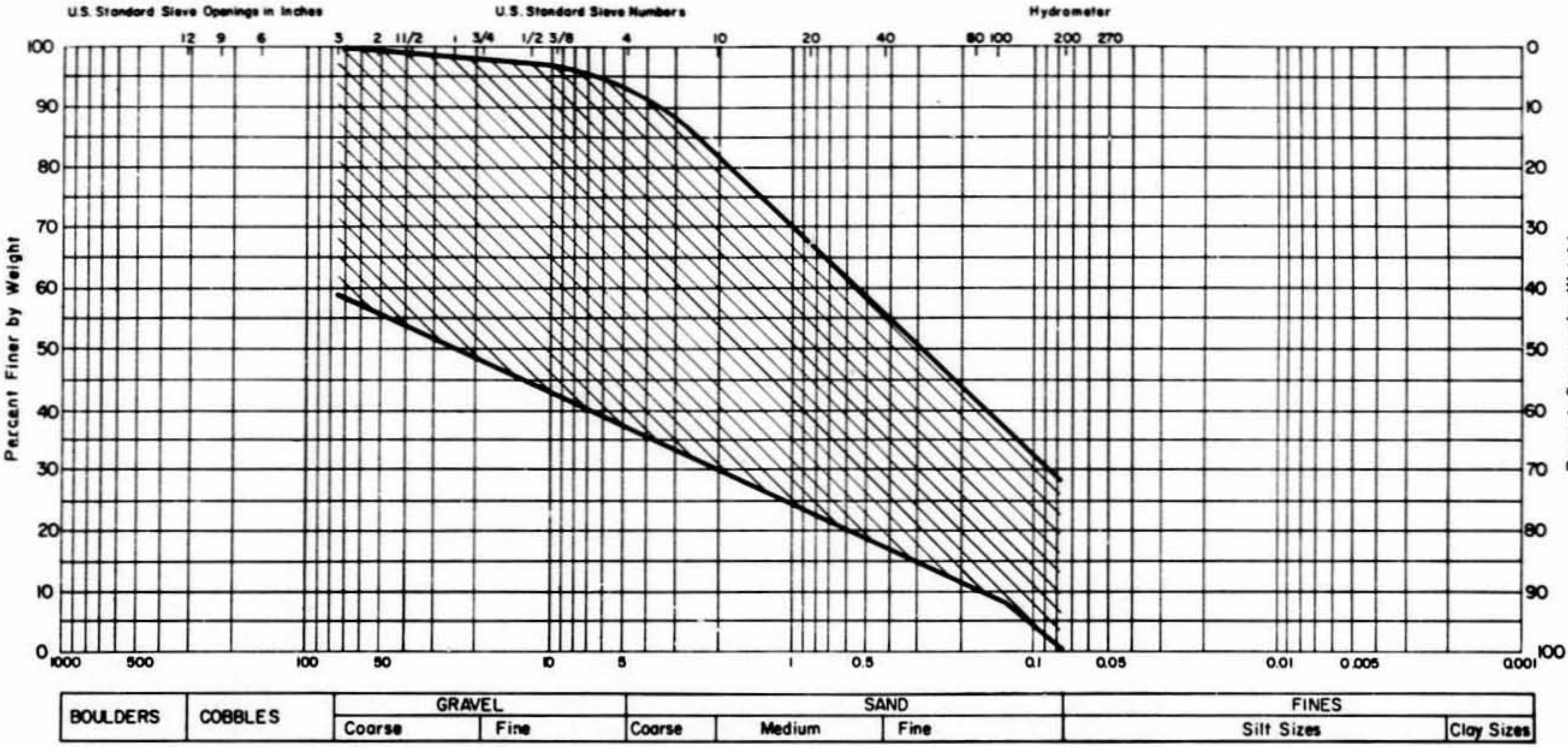


UNIT	MATERIAL	NO. OF SAMPLES
A	SANDY SILT WITH TRACE CLAY	4
B	SILTY SAND	10
C	SILTY SAND WITH CLAY, GRAVF_, COBBLES	6
D	SANDY GRAVEL, GRAVELLY SAND	11
E	SANDY GRAVEL WITH SILT, COBBLES, BOULDERS	19

WATANA
BORROW SITE E
STRATIGRAPHIC UNIT GRADATIONS

FIGURE 6.46

ACRES

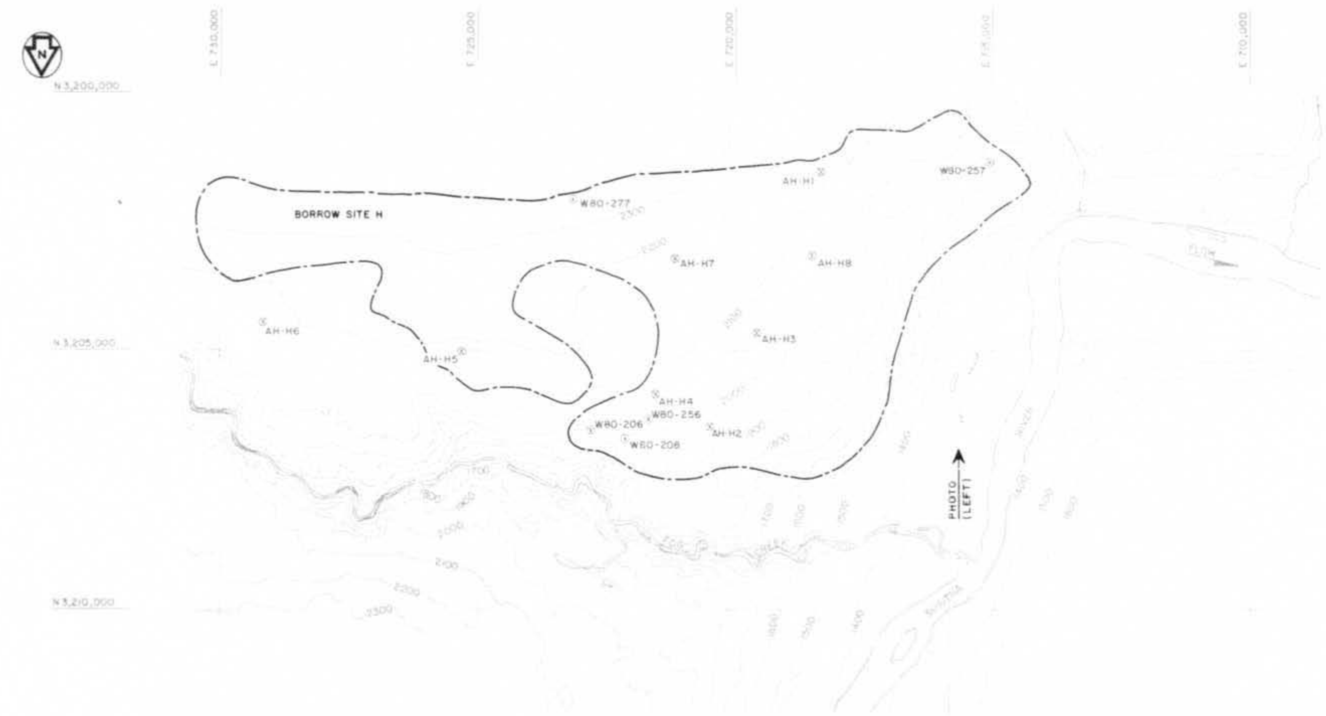


TOTAL NUMBER OF SAMPLES: 10

WATANA
BORROW SITES C & F
RANGE OF GRADATIONS

ACRES

FIGURE 6.47



LEGEND

CONTACTS:

—·—·— MATERIAL LIMIT

BOREHOLES AND TEST PITS:

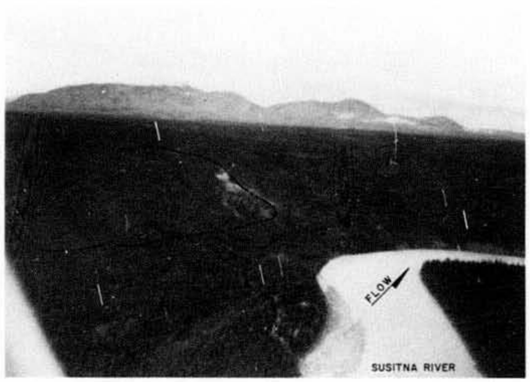
AH-H1 1981, AAI AUGER BORING

SAMPLE LOCATION (APPROXIMATE)

NOTES

1. CONTOUR INTERVAL 100', TRACED FROM ENLARGED REFERENCED BASE MAP.
2. MATERIAL LIMITS BASED ON FIELD AND AIR PHOTO INTERPRETATION. FINAL MAPPED LIMITS OF BORROW SITE SUBJECT TO RESULTS OF DESIGN INVESTIGATIONS.
3. BORROW MATERIAL IS GLACIAL OUTWASH AND TILL OVERLYING BEDROCK. DEPTH TO BEDROCK ESTIMATED TO AVERAGE 40 - 50 FEET.
4. ENTIRE BORROW SITE LIES OUTSIDE OF PROPOSED WATANA AND DEVIL CANYON RESERVOIR LIMITS.
5. EXPLORATION LOGS SHOWN IN APPENDIX F.
6. PHOTOS TAKEN AUGUST 1981 (LEFT), SEPT. 1980 (RIGHT).

SCALE 0 1000 2000 FEET



BORROW SITE H

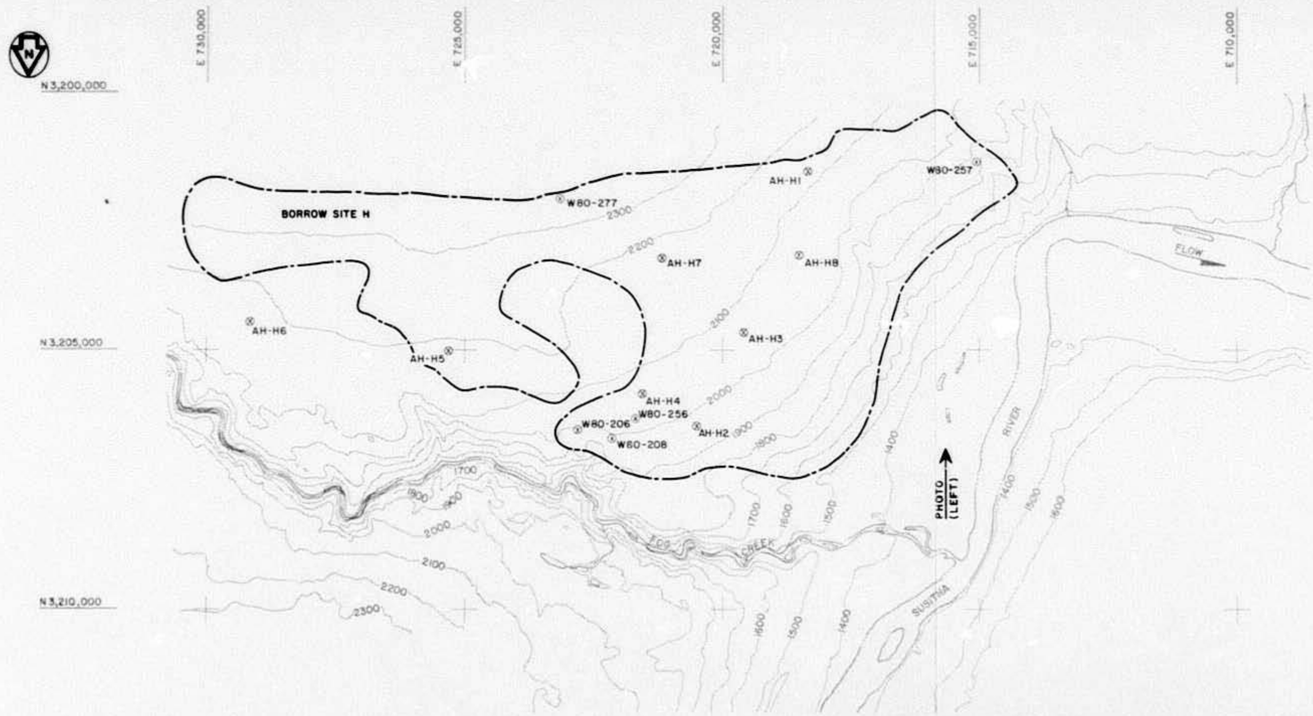
TYPICAL BORROW MATERIAL EXPOSURE

REFERENCES: BASE MAP FROM R & M, 1980 - 1" = 2000' RESERVOIR
COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4)

WATANA
BORROW SITE H PLAN

ACRES

FIGURE 6.48



LEGEND

CONTACTS:

—·—·— MATERIAL LIMIT

BOREHOLES AND TEST PITS:

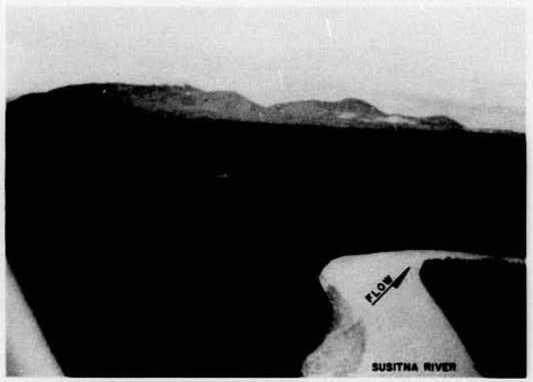
⊗ AH-H1 1981, AAI AUGER BORING

⊙ SAMPLE LOCATION (APPROXIMATE)

NOTES

1. CONTOUR INTERVAL 100', TRACED FROM ENLARGED REFERENCED BASE MAP.
2. MATERIAL LIMITS BASED ON FIELD AND AIR PHOTO INTERPRETATION. FINAL MAPPED LIMITS OF BORROW SITE SUBJECT TO RESULTS OF DESIGN INVESTIGATIONS.
3. BORROW MATERIAL IS GLACIAL OUTWASH AND TILL OVERLYING BEDROCK. DEPTH TO BEDROCK ESTIMATED TO AVERAGE 40 - 50 FEET.
4. ENTIRE BORROW SITE LIES OUTSIDE OF PROPOSED WATANA AND DEVIL CANYON RESERVOIR LIMITS.
5. EXPLORATION LOGS SHOWN IN APPENDIX F.
6. PHOTOS TAKEN AUGUST 1981 (LEFT), SEPT. 1980 (RIGHT).

SCALE 0 1000 2000 FEET



BORROW SITE H

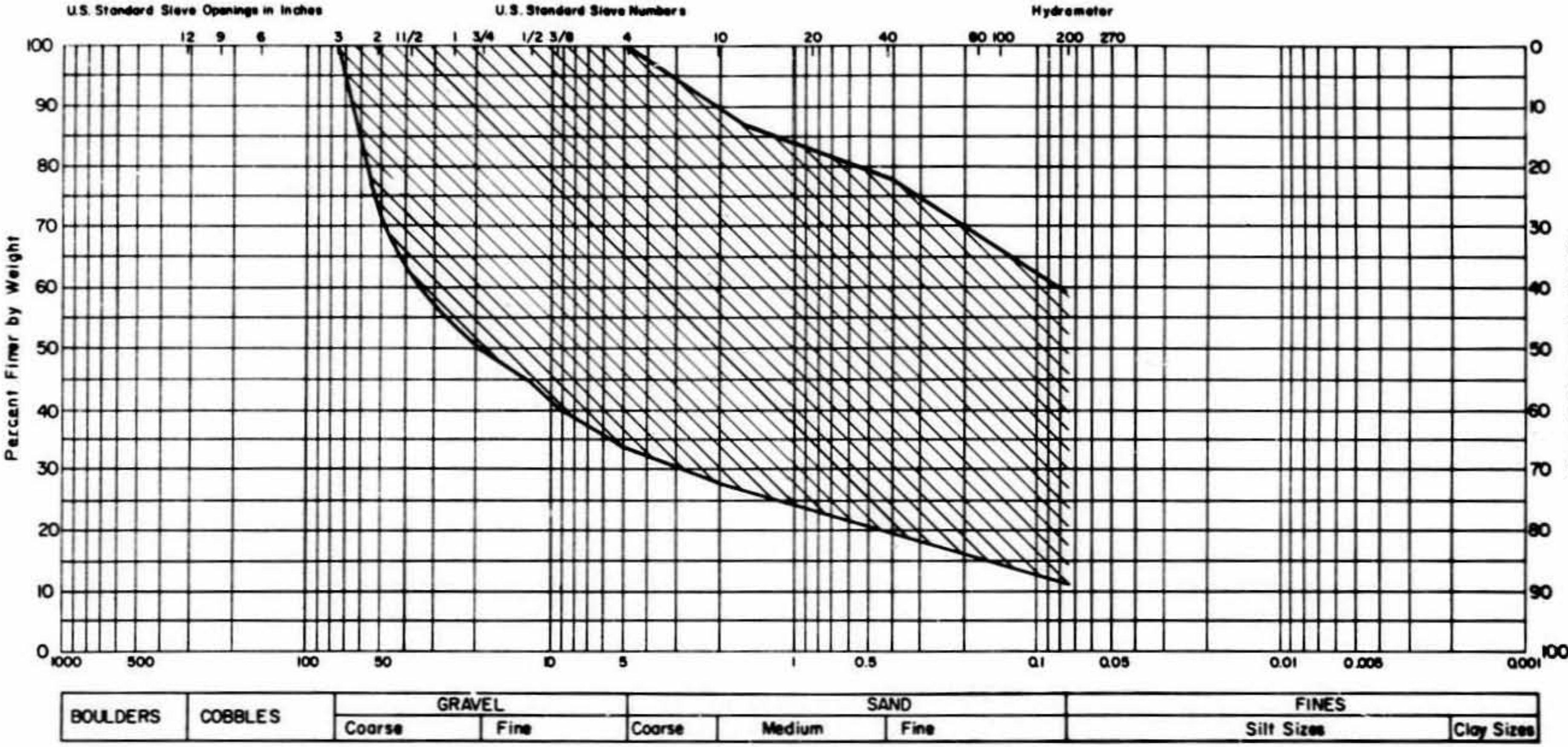
TYPICAL BORROW MATERIAL EXPOSURE

REFERENCES: BASE MAP FROM R & M, 1980 - 1" = 2000' RESERVOIR
COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4)

WATANA
BORROW SITE H PLAN

ACRES

FIGURE 6.48

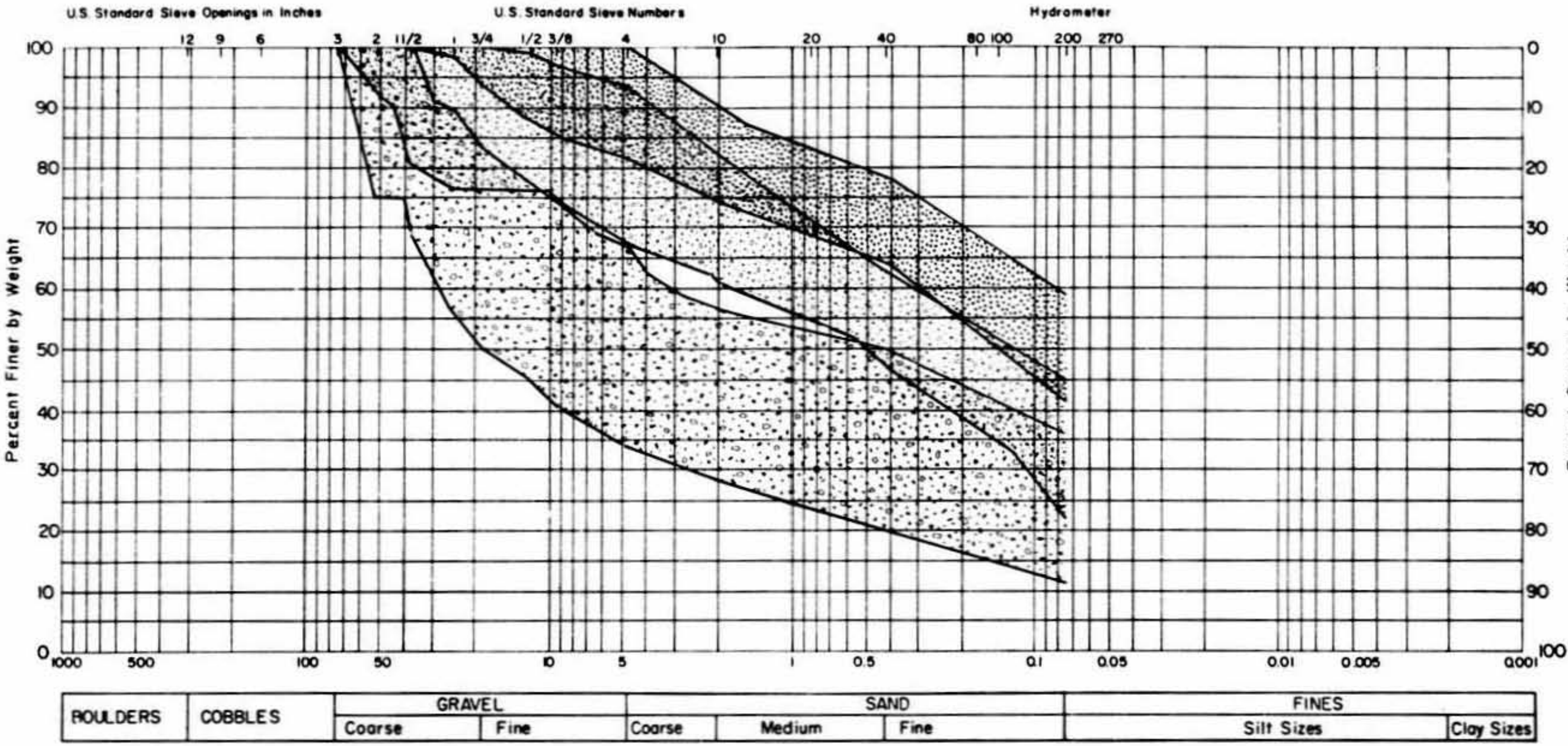


TOTAL NUMBER OF SAMPLES : 49

WATANA
BORROW SITE H
RANGE OF GRADATIONS

FIGURE 6.49

ACRES

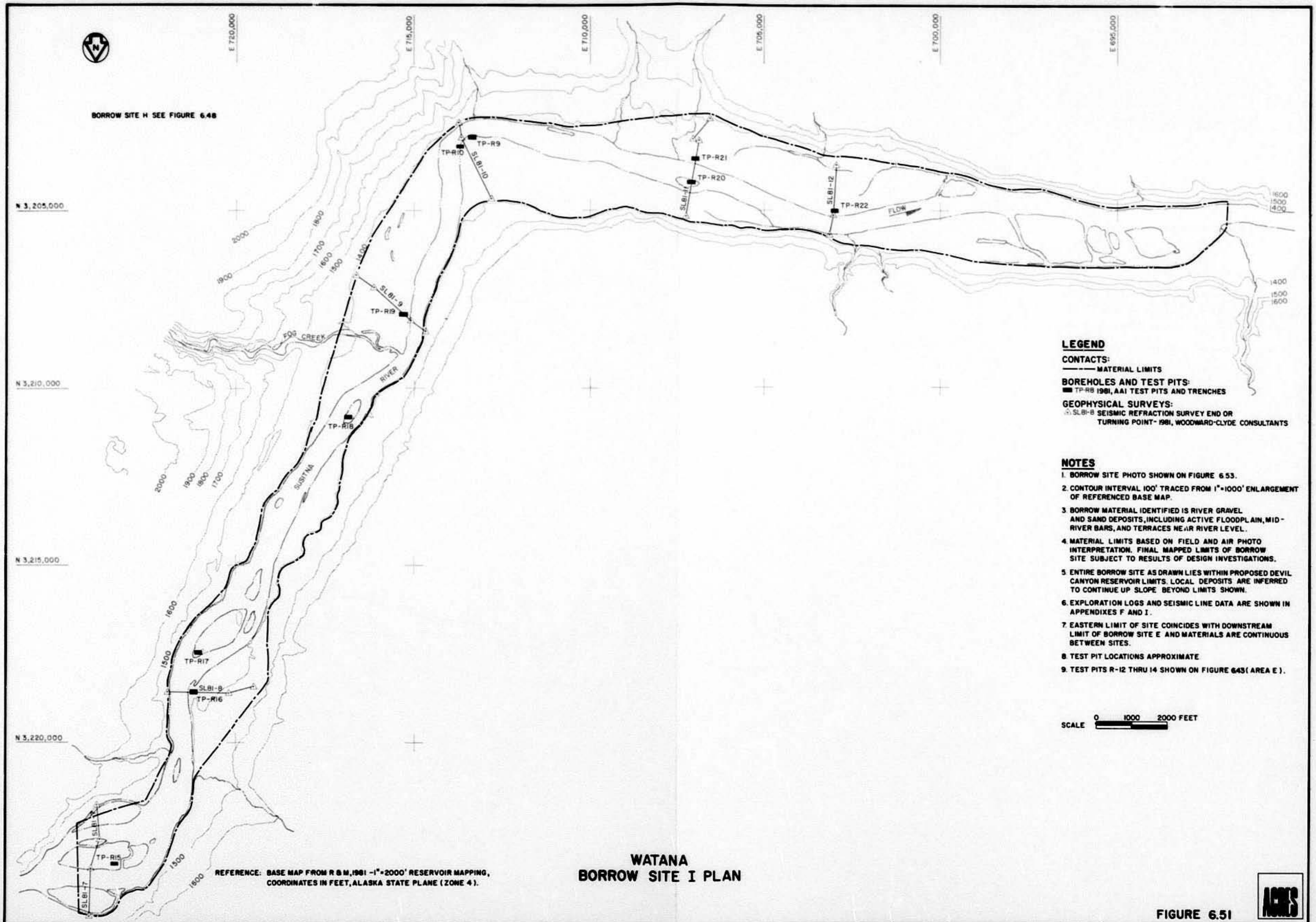


UNIT	MATERIAL	NO. OF SAMPLES
A	SANDY SILT WITH GRAVEL, CLAY	9
B	SILTY SAND WITH GRAVEL	30
C	SANDY GRAVEL	10

WATANA
BORROW SITE H
STRATIGRAPHIC UNIT GRADATIONS

FIGURE 6.50

ACRES



LEGEND

CONTACTS:

MATERIAL LIMITS

BOREHOLES AND TEST PITS:

TP-R8 1981, AAI TEST PITS AND TRENCHES

GEOPHYSICAL SURVEYS:

SL81-8 SEISMIC REFRACTION SURVEY END OR TURNING POINT - 1981, WOODWARD-CLYDE CONSULTANTS

NOTES

1. BORROW SITE PHOTO SHOWN ON FIGURE 6.53.
2. CONTOUR INTERVAL 100' TRACED FROM 1"=1000' ENLARGEMENT OF REFERENCED BASE MAP.
3. BORROW MATERIAL IDENTIFIED IS RIVER GRAVEL AND SAND DEPOSITS, INCLUDING ACTIVE FLOODPLAIN, MID-RIVER BARS, AND TERRACES NEAR RIVER LEVEL.
4. MATERIAL LIMITS BASED ON FIELD AND AIR PHOTO INTERPRETATION. FINAL MAPPED LIMITS OF BORROW SITE SUBJECT TO RESULTS OF DESIGN INVESTIGATIONS.
5. ENTIRE BORROW SITE AS DRAWN LIES WITHIN PROPOSED DEVIL CANYON RESERVOIR LIMITS. LOCAL DEPOSITS ARE INFERRED TO CONTINUE UP SLOPE BEYOND LIMITS SHOWN.
6. EXPLORATION LOGS AND SEISMIC LINE DATA ARE SHOWN IN APPENDIXES F AND I.
7. EASTERN LIMIT OF SITE COINCIDES WITH DOWNSTREAM LIMIT OF BORROW SITE E AND MATERIALS ARE CONTINUOUS BETWEEN SITES.
8. TEST PIT LOCATIONS APPROXIMATE
9. TEST PITS R-12 THRU 14 SHOWN ON FIGURE 643(AREA E).

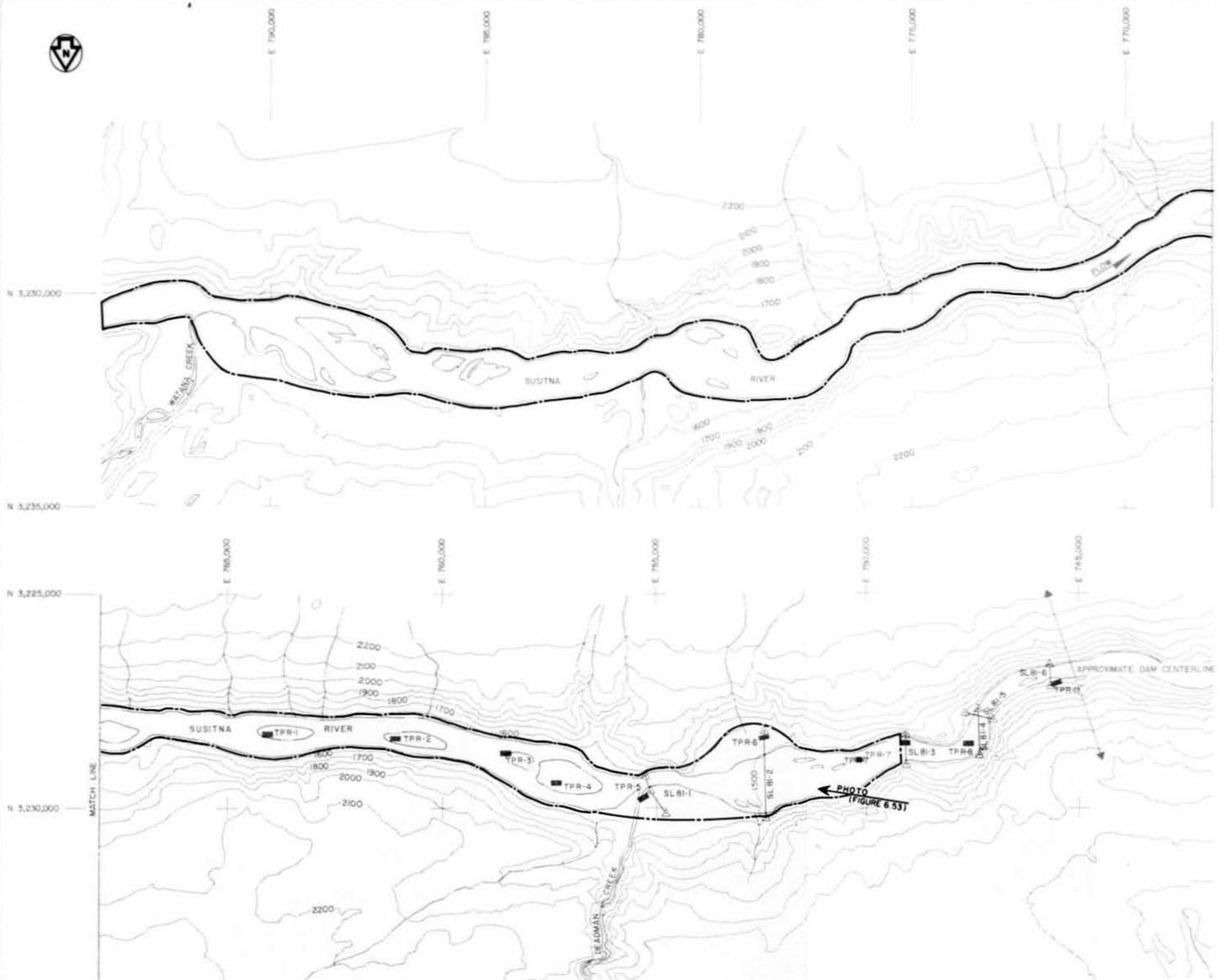
SCALE 0 1000 2000 FEET

REFERENCE: BASE MAP FROM R & M, 1981 - 1"=2000' RESERVOIR MAPPING, COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4).

WATANA
BORROW SITE I PLAN

FIGURE 6.51

ACRES



LEGEND

CONTACTS:

MATERIAL LIMITS

BOREHOLES AND TEST PITS:

TPR-1 1981, AAI TEST PITS AND TRENCHES

GEOPHYSICAL SURVEYS:

SL 81-1 SEISMIC REFRACTION SURVEY END OR TURNING POINT–1981, WOODWARD-CLYDE CONSULTANTS

NOTES

1. SITE PHOTOS WITH SECTION SHOWN ON FIGURE 6.53.
2. CONTOUR INTERVAL 100', TRACED FROM 1" = 1000' ENLARGEMENT OF REFERENCED BASE MAP.
3. BORROW MATERIAL IDENTIFIED AS RIVER GRAVEL AND SANDS, MID-RIVER BARS, AND LIMITED TERRANCES NEAR RIVER LEVEL.
4. MATERIAL LIMITS BASED ON FIELD AND AIR PHOTO INTERPRETATION. FINAL MAPPED LIMITS OF BORROW SITE, SUBJECT TO RESULTS OF FINAL DESIGN INVESTIGATIONS.
5. ENTIRE BORROW SITE LIES WITHIN PROPOSED RESERVOIR LIMITS.
6. EXPLORATION LOGS AND SEISMIC LINE DATA ARE SHOWN IN APPENDICES F AND I.
7. BORROW SITE COULD EXTEND UP TO E 820,000 WITH TOPOGRAPHY AND RIVER CHANNEL CONDITIONS SIMILAR TO THOSE SHOWN BETWEEN E 785,000 AND E 790,000.
8. TEST PIT LOCATIONS APPROXIMATE.

SCALE 0 1000 2000 FEET

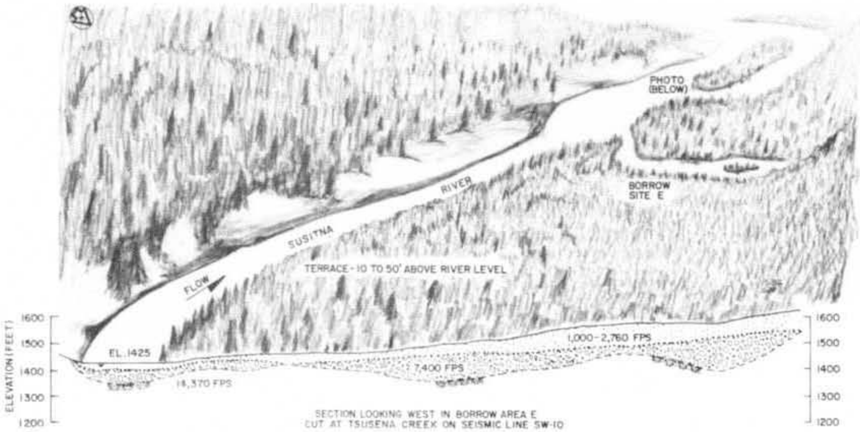
REFERENCE: BASE MAP FROM R & M, 1980-1" = 2000' RESERVOIR MAPPING.
COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4)

WATANA
BORROW SITE J PLAN

ACRES

FIGURE 6.52

BORROW SITE I
(DOWNSTREAM OF WATANA)



WATANA-RIVER ALLUVIUM
TYPICAL SECTION

LEGEND

LITHOLOGY:

- SANDS, GRAVELS ABOVE WATER TABLE
- POSSIBLE COARSER RIVER ALLUVIUM ASSUMED TO BE TILL, PENDING RESULTS OF DESIGN INVESTIGATIONS.
- BEDROCK (DIORITE &/OR ANDESITE FLOWS)

CONTACTS:

- BORROW LIMITS
- ASSUMED TOP OF ROCK

GEOPHYSICAL SURVEYS:

- SEISMIC VELOCITY CHANGE
- 1,000 FPS — SEISMIC VELOCITY IN FEET PER SECOND

NOTES

1. PHOTO LOCATIONS & BORROW SITE MAPS SHOWN ON FIGURE 6.43 (SITE E), FIGURE 6.51 (SITE I), FIGURE 6.52 (SITE J), AND FIGURE 6.53.
2. PHOTOS TAKEN AUGUST 1981.
3. REFER TO TABLE 6.1 FOR SEISMIC VELOCITY AND MATERIAL CORRELATION.
4. VERTICAL SCALE 2 TIMES HORIZONTAL.

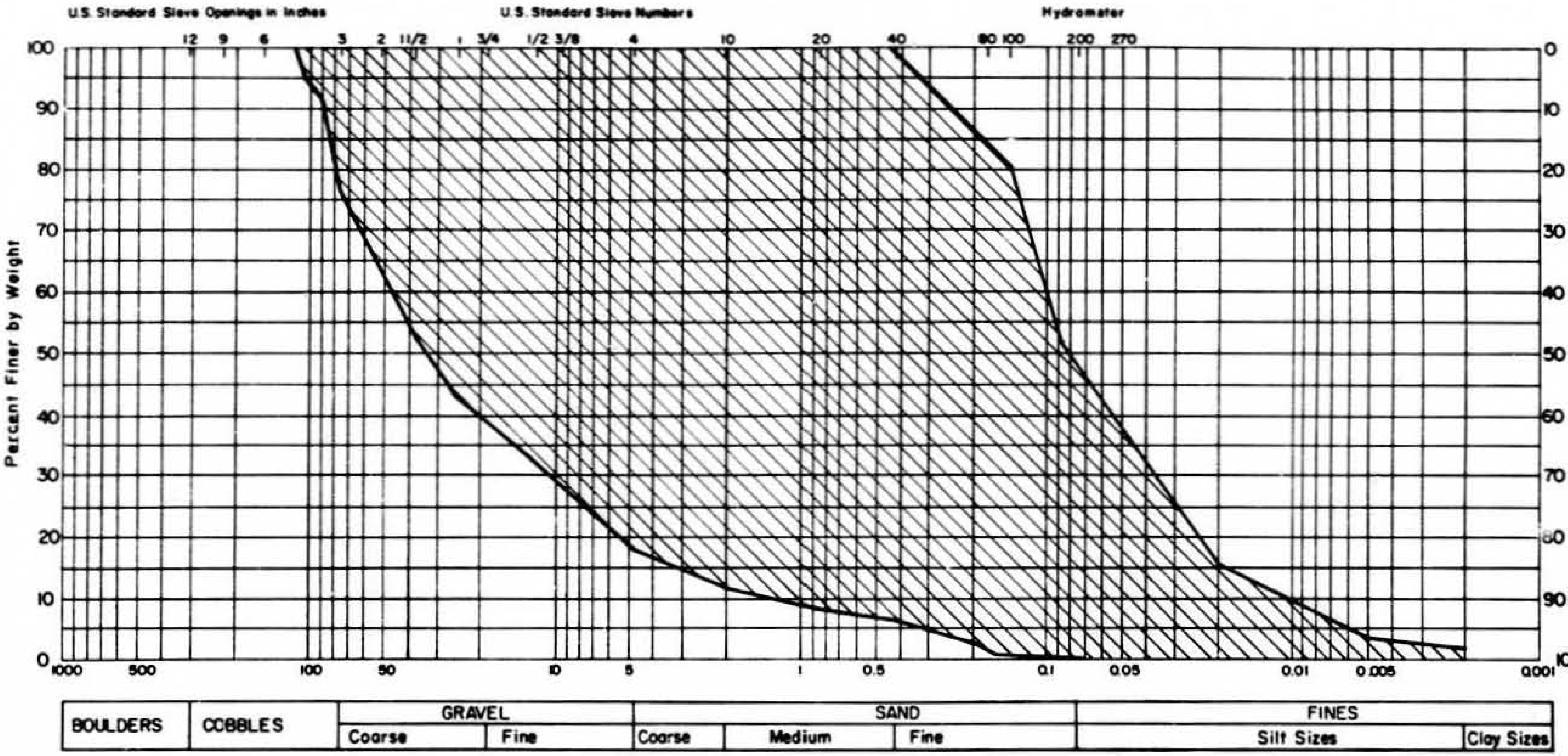
BORROW SITE J
(UPSTREAM OF WATANA)

BORROW SITES I & J
TYPICAL RIVER DEPOSIT
(PHOTO TAKEN IN BORROW SITE E
UPSTREAM OF SITE I
NOTED ON TYPICAL SECTION)

WATANA
BORROW SITES E, I & J
PHOTOS & TYPICAL SECTION

ACRES

FIGURE 6.53

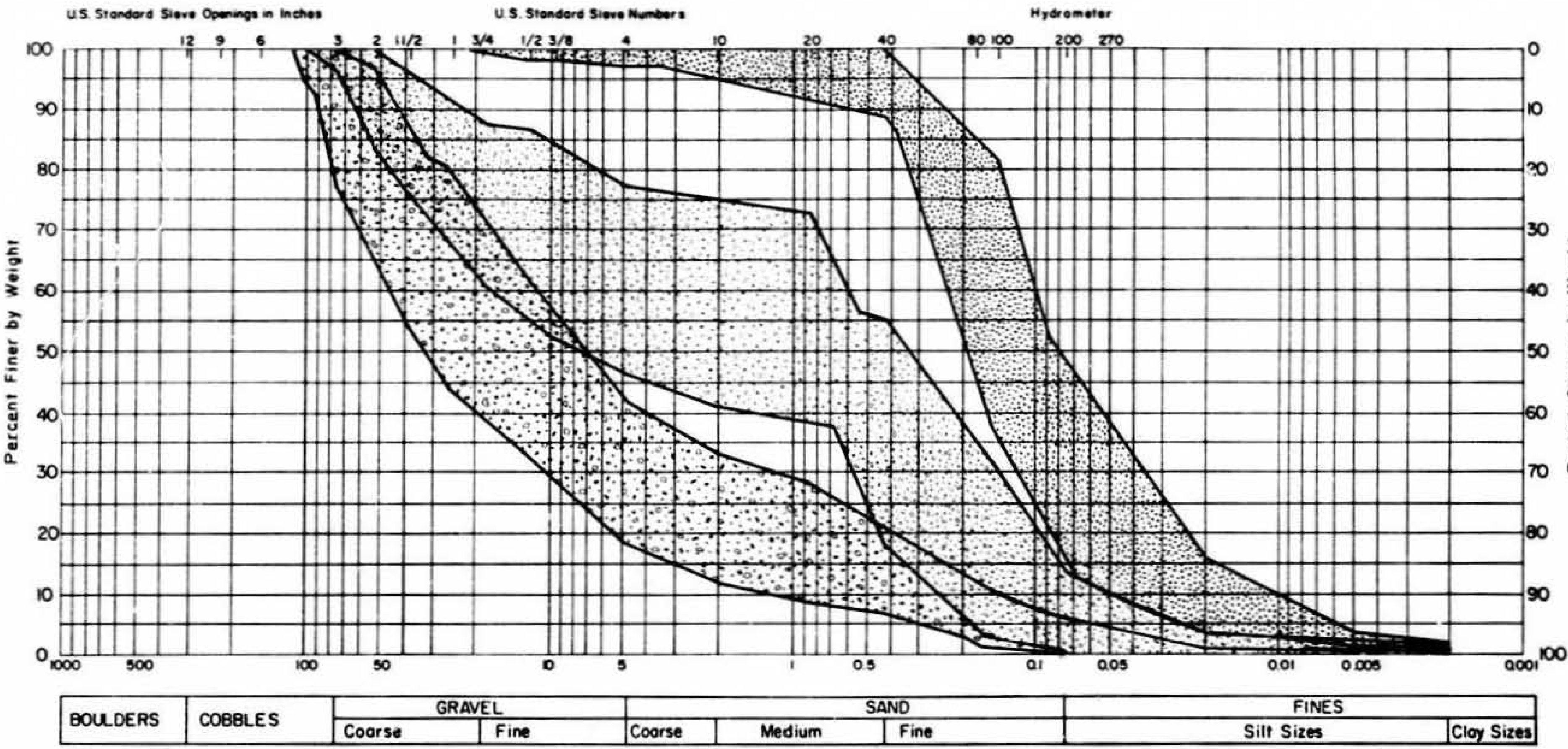


TOTAL NUMBER OF SAMPLES: 35

WATANA
BORROW SITES I & J
RANGE OF GRADATIONS

ACRES

FIGURE 6.54

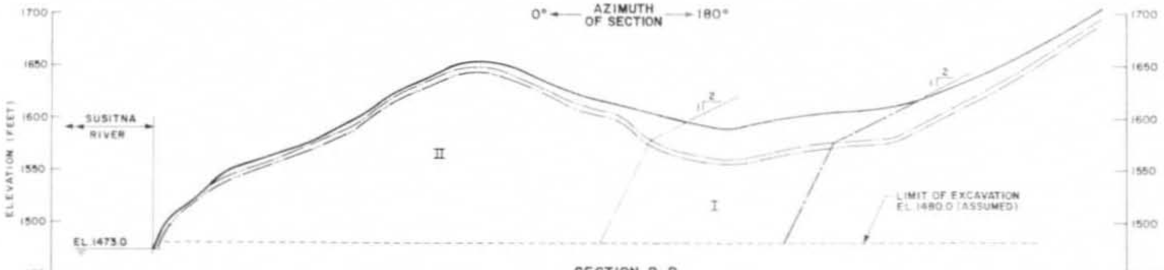


UNIT	MATERIAL	NO. OF SAMPLES
A	SILTY SAND	6
B	SAND	4
C	GRAVEL	25

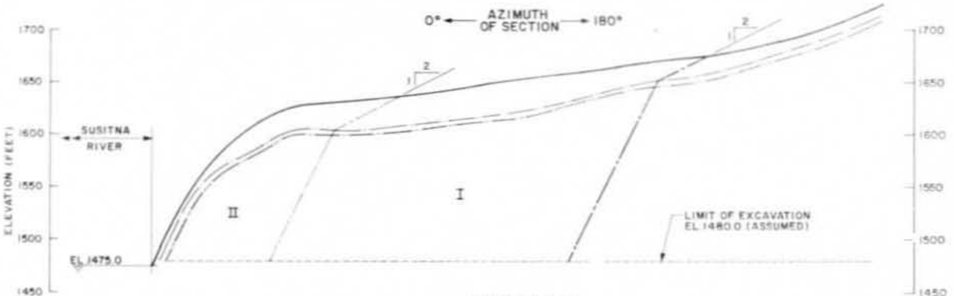
WATANA
BORROW SITES I & J
STRATIGRAPHIC UNIT GRADATIONS

FIGURE 6.55

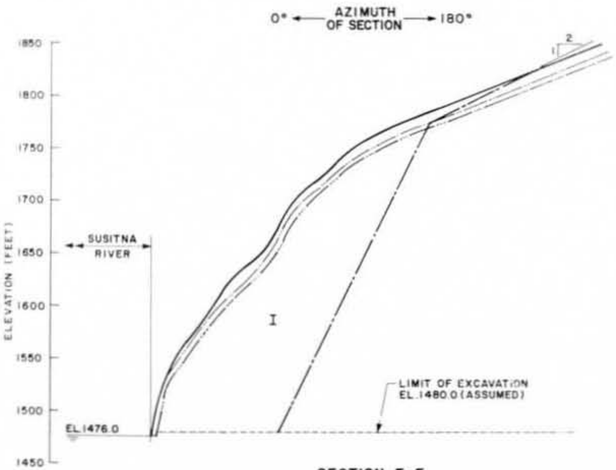
ACRES



SECTION B-B



SECTION D-D



SECTION F-F

REFERENCE: BASE MAP FROM COE, 1978 1"=200' WATANA TOPOGRAPHY, SHEETS 8 & 9 OF 26 COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4)

LEGEND

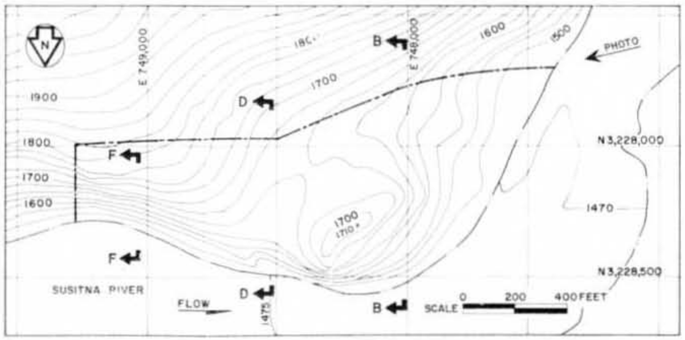
CONTACTS:

- LIMITS OF USABLE ROCK (ASSUMED)
- MATERIAL LIMITS
- APPROXIMATE TOP OF ROCK
- ASSUMED TOP OF SOUND ROCK
- B B CROSS-SECTION LOCATION

NOTES

1. SECTION LOCATIONS SHOWN ON PLAN INSERT.
2. ALL SECTIONS LOOKING UPSTREAM (EAST).
3. VERTICAL AND HORIZONTAL SCALE EQUAL.
4. SURFACE ELEVATIONS FROM 1"=200' TOPOGRAPHY - COE, 1978, TRACED AT 25' CONTOUR INTERVAL.
5. ZONES INDICATE LEVEL OF CONFIDENCE IN ROCK AVAILABILITY AND QUALITY FOR QUARRY USE. ZONE II MAPPED AS DIORITE PORPHYRY, COMPETENT AND BLOCKY. ZONE I INFERRED AVAILABILITY ON BASIS OF OUTCROP EXTENT AND GENERAL SITE GEOLOGY.
6. DEPTH TO ROCK AND WEATHERED ROCK THICKNESS EXTRAPOLATED FROM AIR PHOTO INTERPRETATION AND GENERAL SITE GEOLOGY.
7. MATERIAL LIMITS INFERRED FROM PRELIMINARY MAPPING AND ARE SUBJECT TO REFINEMENT AND VERIFICATION IN DESIGN LEVEL INVESTIGATION.
8. ENTIRE QUARRY SITE LIES WITHIN PROPOSED RESERVOIR LIMITS.
9. ROCK IS INFERRED TO EXTEND TO SOUTH OF AREA LIMITS, BUT QUANTITY AND OVERBURDEN DEPTHS ARE UNKNOWN.
10. LOCATION OF SEISMIC LINES ADJACENT TO QUARRY SITE SHOWN ON FIGURE 5.1b.

QUARRY SITE L PHOTO



PLAN

SCALE 0 50 100 FEET

WATANA
QUARRY SITE L PLAN AND SECTIONS

ACRES

FIGURE 6.56

7 - RESULTS OF GEOTECHNICAL INVESTIGATION - DEVIL CANYON

7.1 - Devil Canyon Damsite

This section discusses the results of a geological and geotechnical investigation performed at the Devil Canyon site. This section is presented in two subsections: 7.1 - Devil Canyon Damsite and 7.2 - Borrow and Quarry Sources and Materials. Location of maps presented in this section are shown on Index Map Figure 7.1.

(a) Overburden Conditions

(i) General

The proposed Devil Canyon damsite occupies a narrow deep gorge on the Susitna River approximately 26 miles downstream from the Watana site at river mile 152 (Figure 4.1). The terrain is one of a glacially scoured mountain area with many deeply incised tributaries cutting down through the steep canyon walls to river level. The overburden within the region generally consists of less than one foot of organics over a veneer of glacial outwash and reworked tills, mixed with talus on the steeper slopes. Glacially scoured bedrock knobs and ridges form a fairly pronounced topography with a grain paralleling the river. A map showing the inferred top-of-bedrock elevations and existing surface topography is shown in Figure 7.2.

Geologic profiles at the damsite and borrow sites is presented in Section 7.1 (b). Much of the interpretation used in preparation of these maps and figures have been based on seismic velocities of various soil and rock types. Results of the seismic refraction surveys performed for this study are presented in Appendices H and I, while surveys performed in previous studies are contained in referenced reports (12,39,57, and 59). For clarity, Table 7.1 provides a correlation of seismic velocities with soil and rock types that have been used in this study.

(ii) Damsite

The bedrock at Devil Canyon is well exposed along the canyon walls from the entrance of the gorge immediately upstream from the proposed damsite to Portage Creek downstream. On the upper abutments, overburden consists primarily of weathered rock and talus mixed with shallow outwash and reworked tills averaging approximately 10 feet thick (28).

On the 50° to 90° slopes in the gorge, overburden ranges from zero up to perhaps 30 feet thick. Overburden in these areas consist of scattered debris on rock ledges and talus slopes. These talus slopes, which extend into the river, are generally confined to gullies within the gorge walls.

Although the high river flows (up to 35 fps) prohibited sampling, it is assumed that the channel alluvium consists of unstratified talus blocks and boulders mixed within a matrix of smaller rock fragments, gravels, and sand. Total depth-to-bedrock in the channel beneath the proposed damsite and cofferdams is estimated to be approximately 60 feet, of which 20 to 30 feet is water and 30 feet river alluvium. The maximum depth of river alluvium was calculated based on USBR drill holes DH-12, DH-13, DH-14, and the 1981 Borehole 5a, which crossed beneath the river (Table 5.2).

Portal structures for diversion tunnels and intakes will be placed in areas of shallow overburden.

Upstream from the damsite, beneath Borrow Site G, bedrock appears to drop-off sharply with overburden reaching depths up to 300 feet. This area is discussed in a subsequent section.

(iii) Surface Structure Sites

Proposed surface structures on the north abutment are expected to encounter the same general soil conditions as at the damsite, with overburden averaging about 10 feet or less, and comprising mostly talus with isolated outwash materials. Any structures on the south abutment would encounter similar conditions as those which exist at the saddle damsite (Section 7.1[a][v]).

(iv) Emergency Spillway

The proposed emergency spillway lies to the south of the damsite on an east-west trending ridge of exposed partially covered bedrock (Figure 7.2).

In general, overburden is expected to be less than 10 feet thick along the proposed east-west spillway alignment. However, where the proposed spillway turns northward (approximately 2,000 feet downstream from the dam centerline) the structure will cross a relict channel, which contains up to 80 feet of alluvium (Section 7.1[a][v]).

(v) Saddle Dam

The overburden at the surface in the proposed saddle dam and emergency spillway area (Figure 7.2) consists primarily of reworked glacial till. The areas of steep topography have isolated talus deposits and include a number of shallow (<10 feet) weathered bedrock zones.

Beneath the lakes, where the proposed saddle dam is sited, bedrock drops off into a deep, overburden-filled trough (Figure 7.2). Based on seismic and borehole data, the stratigraphy in the channel appears to comprise approximately 10 to 20 feet of outwash (sandy, bouldery till), underlain in the deeper sections by stratified layers of sand and gravel. This underlying material appears more compact and clean than the overlying surficial deposit (51).

Maximum overburden depth in the channel area, as determined by borings and seismic refraction lines (Figure 5.2), is 86 feet, with an average of about 40 feet at the saddle damsite. It is postulated that this deep bedrock trough represents a relict channel of the Susitna River (Appendix J). Drilling in this channel shows the material to be dense and relatively impervious. The existence of several lakes on top of this channel (perched at about 75 feet above rock level) demonstrates the overall impermeable nature of this material.

(vi) Camp Areas

Although detailed investigations were not conducted at the proposed campsite area located approximately 7,000 feet downstream from the dam, reconnaissance mapping suggests that bedrock is near surface. Where bedrock is not exposed, overburden is expected to be an average of 5 to 10 feet thick, consisting of sandy, bouldery outwash with localized zones up to 40 feet deep. The only areas around the damsite expected to have very deep overburden are: (a) the upper reaches of creeks from Elevation 1500 to 1800, (b) areas of pond water, and (c) the relict channel (Figure 7.2). Localized clean sand and gravel deposits will probably be scarce throughout the area.

(b) Lithology

(i) Introduction

The bedrock in the Devil Canyon damsite is exposed along the canyon walls of Cheechako Creek and the Susitna River and in scattered outcrops throughout the area (Figure 7.3).

Bedrock at the site is a Cretaceous age (Table 4.1) sequence of interbedded argillite and graywacke which lies on the western side of a Tertiary age granodiorite pluton. The argillite and graywacke have been intruded by felsic and mafic dikes of uncertain age. These rocks have not been assigned formational names, but rather have been given lithologic names for mapping and correlation purposes. Rock names are based on the classification of Travis (43).

The lithology and structure of the Devil Canyon site are shown on a geologic map (Figure 7.3) and geologic sections DC-1 through DC-7 (Figures 7.4 through 7.10). The geologic interpretations are based on field mapping, borehole and seismic refraction data (Section 5). The locations of the proposed civil structures are shown on the geologic map and sections.

Rock exposures in Devil Canyon are nearly continuous along the canyon walls; however, above the break in slope at about Elevation 1400, rock exposures are more limited. Access in this area is very difficult due because of steep slopes. Because of this lack of exposures, the extent of geologic features could not be determined. Future subsurface explorations will be required to verify areas of inferred geology. In general, only structures more than 1 foot wide are shown on the map unless otherwise noted.

Geologic features mapped at the surface were correlated, where possible, to similar features in the boreholes and on seismic profiles. These features are shown on the geologic sections (Figures 7.4 through 7.10). Areas of insufficient subsurface data required extrapolation of geologic features to depth based on mapped surface orientations. For simplicity, borehole data are limited to features 5 feet or greater in thickness. For more detailed information, see Appendices C and E for borehole logs and pressure testing details, and Appendices H and I for seismic refraction surveys. The geologic sections have been oriented to make best use of the available geologic data.

Approximately 1,200 joints were mapped at the site. This information was used in developing the statistical joint plots shown in Figure 7.13. On the geologic map (Figure 7.3) only representative joints from the two major joint sets are shown.

Details of the lithology and structure at the Devil Canyon site are presented in the following sections.

(ii) Granodiorite

The granodiorite is located primarily to the east and south of the site (Figure 4.1). The closest occurrence in the damsite area is approximately 3,500 feet to the southeast, where the contact with the argillite and graywacke is exposed in Cheechako Creek. The contact zone extends over an area up to about 100 feet wide which contains large argillite and graywacke blocks intruded by the granodiorite. Contacts are generally sharp with thin fracture zones on either side.

The granodiorite is light gray and fine to medium grained. It contains quartz, biotite, plagioclase and orthoclase feldspars. Where exposed, the rock is fresh and hard to very hard and massive. The granodiorite has been intruded by both mafic and felsic dikes.

The extent and depth of the pluton beneath the site is not certain nor is the dip of the contact known. In BH-2, a quartz diorite and granodiorite intrusive were intersected from Elevation 663.0 to the end of the borehole at Elevation 645.7 (Figure 7.5). The fine grained groundmass and coarser phenocrysts of this granodiorite are similar to a diorite dike intersected in BH-7. It is uncertain whether the material intersected in BH-2 is a dike or part of the main pluton.

(iii) Argillite and Graywacke

The rock underlying the Devil Canyon site is a slightly metamorphosed sequence of interbedded argillite and graywacke. The argillite is a medium to dark gray, very fine to fine grained argillaceous rock. The argillite is very thinly bedded, hard and generally fresh. Petrographic analyses show that the argillite is composed of subrounded to elongate grains of primarily quartz and biotite with minor iron oxides, pyrite, organic material, amphiboles, and carbonate (53). Some euhedral biotite flakes up to 0.12 mm were observed. Elongated grains are parallel to the bedding.

The graywacke is light to medium gray occasionally varying to a dark reddish gray. The rock consists of fine to medium grained sand-sized grains in a very fine grained argillaceous matrix. Beds are often graded. Zones of coarse grained lithic conglomerate are found locally. Where mapped, these zones are less than 100 feet thick. However, in BH-1, coarse grained material was encountered between borehole depths 331 to 750 feet (Appendix C). Since this hole was drilled at an angle to bedding, the apparent thickness is greater than the true thickness of the unit. Petrographic analyses show the graywacke is similar to the argillite and composed of quartz, feldspar, and biotite with minor iron oxides, pyrite and organic material. Pyrite and other sulphides are generally less than 1 percent, but locally range up to 5 percent of the rock mass in both the argillite and graywacke.

The argillite and graywacke interbeds range from less than 1 inch to greater than 10 feet thick, but are generally less than 6 inches. Figure 7.11 is a photograph of the typical interbedded argillite and graywacke found at the site. Contacts between the beds are sharp and tight with bedding parallel to foliation. The generally weak foliation is better developed in the argillite than the graywacke because of the effect of grain size. Foliation, as described here, refers to the planar structure of the rock resulting from the parallel alignment of platy and elongate grains. In most boreholes and in some outcrops, the foliation has developed a phyllitic sheen in the argillite beds. Bedding/foliation strikes northeast with dips to the southeast of generally 50° to 70°. The dip of the bedding/foliation is shown on the geologic map and sections. On the geologic sections, the apparent dip is indicated where appropriate.

A minor secondary foliation was found subparallel to the main foliation.

The argillite and graywacke have been injected with numerous quartz veins and stringers. Stringers are defined as quartz injections less than 0.5 inches thick. Veins are quartz injections greater than 0.5 inches thick, while veins are greater than 1 foot wide. At least two episodes of injection have been observed. The first episode consists of quartz veins and stringers parallel and subparallel to the bedding/foliation. These veins and stringers, which may have been injected before or during deformation, have been stretched, folded, and occasionally offset along foliation planes. The contacts of the veins and stringers with the bedrock are tight and very hard. The veins and stringers occur either singly or in groups measuring up to 10 feet wide in outcrops and up to 30 feet along the boreholes. In these zones, the amount of quartz is as much as 20 to 40 percent of the whole rock. In general, however, these zones are less than 1 foot wide. These veins and stringers are good quality rock with high RQDs.

The second episode of quartz intrusion is represented by undeformed, post-deformational quartz veins which cut across the bedding/foliation and the quartz intrusions of the first episode. These veins also contain iron and lead sulphide mineralization. These quartz veins are associated with very closely to closely fractured rock. RQDs are usually slightly lower in these zones than the surrounding rock. Most of the veins are less than 2 feet wide.

Although quartz veins and stringers of both episodes are encountered in all boreholes, they are most numerous in boreholes BH-1, BH-2 and BH-4. Quartz veins and stringers associated with the second episode of intrusion are found in both felsic and mafic dikes.

(iv) Dikes

The argillite and graywacke at Devil Canyon have been intruded by a series of mafic and felsic dikes (Figures 7.3, 7.4, 7.5, and 7.10). The mafic dikes are designated M 1 through M 4, while felsic dikes are designated F 1 through F 8. Geologic technical climbers were used to map the location and extent of these features along the canyon walls from the mouth of the canyon downstream to about the locations of DH-12 and DH-14 (Figure 7.3). The dikes generally occur in topographic lows or gullies. Some of these gullies had been misinterpreted by previous investigations to be shear zones. A survey control of the locations of four dikes (M 1, M 2, M 3, and F 4) in the damsite area was performed for the purpose of insuring an adequate correlation across the Susitna River. A magnetometer survey, performed on the south bank, was unsuccessful in tracing their extent beneath the overburden away from the gorge walls.

Four mafic dikes were mapped in the damsite area. Dikes M 1, M 2 and M 3, are in the area of the powerhouse and the diversion tunnels, while M 4 is located approximately 2,000 feet downstream from the dam centerline (Figure 7.3).

Strikes of the mafic dikes are approximately northwest-southeast, crosscutting the bedding/foliation and trending parallel to Joint Set I (Section 7.1[c]). Dips are vertical to steep to the northeast and southwest. The mafic dikes are generally dark green to dark gray, fine grained, fresh to slightly weathered, and hard. They consist primarily of feldspar in a fibrous groundmass with accessory pyroxene, biotite, hornblende, and calcite. In BH-1 and BH-2 mafic dikes contain from 5 to 10 percent euhedral, white, radiating zeolites up to 0.2 inches in diameter. The mafic dikes have been classified as diabase. Joint spacing in the dikes is very close to close with slickensides and chlorite on most surfaces. Because of the joint spacing, the dikes tend to erode more readily than the surrounding argillite and graywacke resulting in their forming talus-filled gullies. Dike widths vary within the same dike ranging from 2 to 10 feet.

The borders of these dikes are generally finer grained with "chill zones" usually 0.5 to 1 foot wide. Contact metamorphism is evident in the argillite and graywacke adjacent to the dike. Fractured and shear zones ranging from 1 to 10 feet but generally less than 5 feet wide, are frequently found immediately adjacent to the contact.

The felsic dikes are light yellowish-gray to gray and aphanitic to medium grained, but generally fine grained. They range from rhyolite to granodiorite in composition and contain quartz phenocrysts. The felsic dikes are generally iron oxide stained and, at the surface, are slightly to moderately weathered. At depth, they are fresh and hard. Because of the very close to closely spaced joints, the felsic dikes tend to erode readily and form talus-filled gullies. Figure 7.12 is an aerial view of the site showing the gullies in which the dikes occur.

The contacts are healed, but with secondary localized shearing or fracturing at or near the contact. Chilled margins up to 3 feet wide are evident in the larger dikes, with contact metamorphism in the argillite and graywacke.

The orientation of the majority of felsic dikes is predominantly northwest and north, with vertical to steep dips to the east and west. These dikes are generally parallel to Joint Set I (Section 7.1[c]) and cut across the bedding/foliation. Several small felsic dikes, however, were noted in the borings to be parallel to the bedding/foliation.

The width of the felsic dikes varies from 2 to 60 feet, but in the immediate site area is less than 10 feet. The widest dikes are found upstream from BH-5a and from approximately 2,500 feet downstream from the dam centerline (Figure 7.3). The widest felsic dike at the site is exposed on the north bank of the river north of Borrow Site G (Figure 7.3). This dike is up to 60 feet wide but pinches out to less than 10 feet at either end of the outcrop. The trend is northwestward with a 75° dip to the northeast. The dike is light gray but weathers to a yellow-orange caused by iron oxide staining. Grain size is fine with fine to medium grained quartz phenocrysts.

(c) Structure

(i) Introduction

This section discusses geologic structures at the Devil Canyon site and their relation to the proposed dam location and tunnel routes. The section is divided into two subsections. The first discusses joints and joint sets while the second discusses shear and fracture zones.

(ii) Joints

The orientation of major and minor joint sets was recorded at all outcrops, as well as the condition of the joint surfaces, spacing, and any mineralization or coating. Four joint stations (DCJ-1 through DCJ-4) were also selected for detailed joint measurements (Figure 7.13) in areas considered to be representative of all joint sets.

One hundred joints were recorded at each of the stations except DCJ-1 where 93 joints were recorded. For each station, joint measurements were plotted on the lower hemisphere of a Schmidt equal-area stereonet at 1, 3, 5, 7, 10, and 15 percent contours (Figure 7.13). The plotting method is described in Figure 6.12.

In addition to the joint station plots, composite joint plots were constructed from joint stations and outcrop data. Composite plots were constructed for the north and south banks and are shown on Figure 7.13.

Four joint sets were mapped at the Devil Canyon site and are identified on both composite and joint station plots. Sets I and II are major sets which occur throughout the site area, while Sets III and IV are less prominent but are locally strong. Table 7.2 is a summary of joint set orientations, dips, spacings, surface conditions, and structural relations. Each joint set is discussed below.

This discussion is based primarily on surface jointing, as it was not possible to correlate between joint in outcrop and those encountered at depth in the borehole. Jointing in boreholes is discussed in a later section.

Joint Set I is the most prominent set at the site. The trend is northwest (340°) with vertical to steep dips to the northeast and southwest. On the south bank, the average dip is vertical, while on the north bank, the average dip is 80° to the northeast. Joint spacings vary from 0.5 inch in fracture zones up to 10 feet, with an average spacing from 1.5 feet to 2 feet. These joints are planar and smooth with occasional iron oxide staining and carbonate coating. Set I joints are very continuous and range from tight to open. Open joints are well developed on the south bank and can be traced horizontally for over 150 feet. These joints are open up to 8 inches at the surface. Set I joints are parallel to most of the shears, fracture zones, and dikes in the site area.

A subsidiary joint set, Ib, to Set I was found locally at DCJ-4 and possibly at DCJ-1 (Figure 7.13). This set strikes northwest (320°) and dips 55° to the northeast.

Joint Set II includes joints parallel and subparallel to the bedding/foliation planes. This set strikes generally northeastward but ranges from 020° to 100°. The average trends on the north and south banks are 065° and 075°, respectively. Dips are southeast, averaging 55° on both banks. Joint spacings are generally 1 to 2 feet. The joint surface conditions are variable, from planar to curved and smooth to rough, as a result of folds and crenulations on the bedding/folation planes. No mineralization was found on joint surfaces at outcrops; however, in the boreholes, these joints are often coated with chlorite. Set II joints are generally tight but tend to be open on the north bank near river level owing to stress relief. Slopes on the north bank are parallel or subparallel to Set II. In the damsite area, the course of the Susitna River at the damsite parallels this joint set.

Major and minor shears are associated with Set II joints and are discussed in the following section (Shears and Fracture Zones). A subsidiary joint set, IIb, was mapped at DCJ-1 and DCJ-4. This subset trends north-northeast at 015° with steep (75° to 85°) dips to the southeast.

Joint Set III is a minor set, although locally well developed. A similar set was described by the USBR (51) in the vicinity of DCJ-3 on the south bank (Figure 7.13). Set III is northeast trending with moderate to steep dips to the northwest. On the north bank, the average strike and dip are 060° and 80° to the northwest, while on the south bank, the strike and dip average 025° and 65° northwest. The Set III joints are planar to irregular and smooth to rough, with spacings generally 3 feet. Occasional traces of iron oxide and carbonate are found on the joint surfaces. Both open and closed joints have been found in Set III. Open joints are most common on the north bank, particularly above Elevation 1400 near DCJ-3, where cliffs have formed parallel to Set III. The continuity of Set III joints could not be determined.

Block failures and slumping on the south abutment appear to be associated with Joint Set III. A large block was mapped between DH-1 and DH-10 on the south side on a 10-foot deep northeast trending depression. Other loose blocks related to this set have been observed to extend at least 25 feet below the canyon rim. Attempts by the USBR to excavate rock benches into the abutment to determine the extent of slumping were inconclusive. However, it is likely to assume that detached blocks may extend up to 50 feet back from the gorge walls.

Joint Set IV consists of numerous low angle (dipping less than 40°) joints. The strongest trend of Set IV joints is northeast and east, with low angle dips to both the north and south. The southerly dips are best developed on the north bank at DCJ-3. A strong northerly dip is evident at DCJ-1 on the south bank and DCJ-2 and DCJ-4 on the north bank (Figure 7.13). DCJ-2 shows both dip directions; however, the northerly dip is the strongest. A secondary low angle set trends northwestward with dips to the northeast. This set is best developed at DCJ-1 and DCJ-2.

Locally, the canyon slopes are failing along joint planes and sliding or slumping towards the river. On the north bank, most movement is along the Set II (bedding/foliation) joints which parallel and dip toward the river. Slopes are generally subparallel to these joints, with slopes generally at 40° to 50° (Figures 7.6 and 7.8). On the south bank, slopes are steeper (60° to 80°) and are controlled by the intersection of Sets I, III and IV.

Areas of open joints that could affect engineering design were identified at the Devil Canyon site. Open joints of Set I were mapped at several areas on the south bank particularly east of Borehole DH-1 where four open joints were traced southeastward up to 150 feet from the edge of the canyon (Figure 7.3). These joints are up to 6 inches wide with undetermined depth. Borehole BH-3 (Figure 7.3) was drilled northeastward toward the cliff face to intersect open joints at depth. Zones up to 10 feet wide of open and jointed rock were encountered along the length of the borehole to a vertical depth of over 100 feet (approximate Elevation 1300).

Drill water was lost at a depth of 122.4 feet along the hole and never regained. RQDs for BH-3 were low, particularly near the bottom of the hole as it neared the cliff face (Figure 7.6). Open joints were also encountered in USBR Boreholes DH-1, DH-8, and DH-9 which were drilled subparallel and across Set I. High water losses and low RQDs were also encountered in these holes which reflected this open jointing.

- Shears and Fracture Zones

This section discusses the shear and fracture zones mapped at the Devil Canyon site. These features are shown on the geologic map and geologic sections (Figures 7.4 through 7.10).

- Shears

Shears are structures having breccia, gouge and/or slickensides indicating relative movement. Both healed and unhealed shears were found at the site. Healed shears consist of an argillite and/or graywacke breccia within a quartz matrix. These zones may represent syndepositional deformation that has subsequently been lithified and healed into a hard competent rock. These zones, therefore, do not represent a structural weakness or discontinuity in the rock mass. These features were most evident in Boreholes BH-1, BH-2, and BH-4. The largest healed shear was found in BH-4 (Figure 7.6) from 221.0 to 252.0 feet. This zone consists of argillite breccia in a zone of highly folded and stretched quartz veins which were intruded by additional quartz veins. Recoveries and RQDs are high, generally greater than 90 percent, through these healed shears, with permeabilities on the order of less than 10^{-6} cm/sec.

The second type of shear found in both surface exposures and boreholes consists of unhealed breccia and gouge. The gouge is light gray to tan clay. Breccia consists of coarse to fine sand size fragments in a clay and/or silt matrix. Gouge and breccia are generally soft and friable, and occur in zones normally 0.1 to 1 foot wide. The thickest gouge and breccia was up to 3 feet in BH-7. Chlorite/talc and carbonate mineralization are associated with the shears. Slickensides are common and occur on the chlorite surfaces. These shears are generally associated with fracture zones. Where they are coincident, they have been denoted as shear/fracture zones.

- Fracture Zones

Fracture zones are areas of very close to closely spaced (less than 1 foot) jointed rock. Fracture zones are found in both outcrop and boreholes. As with the shears, both healed and unhealed fracture zones are common. In outcrop, both healed and unhealed fracture zones range from less than 1 foot up to 20 feet wide, but are generally less than 5 feet. In the boreholes, fracture zones range from less than 1 foot to 60 feet but are generally less than 5 feet as measured along borehole length. Healed fracture zones consist of irregular and discontinuous fractures filled with quartz or carbonate mineralization. These zones are tight with permeabilities consistent with the surrounding rock. Unhealed fracture zones often have chlorite/talc, carbonate, or quartz on joint surfaces. Fracture zones tend to form topographic lows or gullies because of their erodibility. Gullies formed by some of these zones are shown on an aerial photograph of the site (Figure 7.12).

(iv) Significant Geologic Features

The Devil Canyon site has several significant geologic features which include shears, fracture zones, dikes, and open joints. Dikes and joints have been discussed in previous sections. The features discussed in this section are: (a) northeast trending shears in the saddle dam area (GF 1); (b) a series of northwest trending shears and fracture zones (GF 2 through GF 11); (c) the bedrock low beneath Borrow Site G; and (d) rock conditions beneath the Susitna River (Figures 7.3).

- Geologic Feature GF 1

GF 1 is located on the south bank approximately 1,000 feet from the Susitna River (Figure 7.3). The shear has been mapped as passing beneath the proposed saddle dam nearly parallel to the Susitna River. The shear was first postulated by USBR (28 and 57) based on several vertical boreholes (DH-6 and DH-15) which penetrated sheared and fractured bedrock in this area (Figure 7.3). The shear was inferred to strike northeastward along a topograhic depression beneath two ponds and dip northwest towards the river. Subsequent seismic refraction work by the COE (39 and 45) in this area indicated a bedrock low (Figure 5.2) and a low seismic velocity zone in the bedrock across this feature (Figure 7.10). These low velocities (10,700 feet per second) occurred from 25 feet south of DH-4 to 60 feet south of DH-7, whereas velocities at the north and south ends of the line were about 19,000 feet per second. During this investigation, three additional seismic lines (SL 80-12, -13 and -15) were run and two boreholes (BH-4 and BH-7) drilled to define the nature and extent of this shear zone (Appendix B and H).

The seismic data confirmed the existence of a bedrock low in this region with the top of bedrock being as deep as Elevation 1250 (Appendix H). A low seismic bedrock velocity (12,380 feet per second) was interpreted along SL 80-13 beneath the pond. Bedrock velocities to the north and south of this anomally were on the order of 16,800 and 18,800 fps, respectively. BH-4 and BH-7 were angle drilled southward and northward, respectively, to intersect this postulated shear. No shearing was encountered in BH-4; however, BH-7 intersected a highly sheared and fractured argillite and graywacke from a hole depth of 87.0 to 130.7 feet. Zones of breccia and gouge up to 3 feet wide were encountered within a 40-foot wide fracture zone. Rock fragments were coated with chlorite and slickensides. Core recoveries were low and RQDs were 0 percent (Figure 7.6). Permeabilities in this zone were generally 10^{-4} cm/sec. Based on this borehole data, the dip of the shear is inferred to be parallel or subparallel to the bedding/foliation at approximately 65° to the south. It is likely that the shear follows the topographic low to the west as shown on Figure 7.3. The extent of the shear in an easterly direction is unknown.

Additional work will be required in subsequent phases to more accurately delineate the extent of this feature.

- Northwest Trending Shears and Fracture Zones

A series of northwest trending shears and fracture zones, parallel to Joint Set I, were mapped in the damsite area (Figure 7.3). Many of the shears previously identified by the USBR were found to be mafic or felsic dikes of which some have associated shearing at the contact (Section 7.1[b][iv]). Figure 7.12 is an aerial view of the site on which the locations of some of these features are indicated. GF 2 is a shear and fracture zone that ranges from 15 to 18 feet wide as mapped at river level on the north bank (Figure 7.3). The zone trends 345° with an 80° northeast dip. Based on the projection of its strike and dip, GF 2 was correlated with a fracture zone in BH-2 at 601.2 to 621.0 feet (Figure 7.5). This zone consists of planar, smooth joints and irregular, discontinuous fractures. Many joints and fractures are coated with talc and carbonate. RQDs in the zone range from 75 percent to 90 percent with low permeabilities (less than 10^{-5} cm/sec). No evidence of GF 2 could be found on the south bank.

GF 3 (Figure 7.3) parallels GF 2 approximately 100 feet to the west. As mapped on the north bank, GF 3 is 5 to 10 feet wide and coincides with mafic dike M 2. GF 3 has been tentatively correlated with a fracture zone in the upper portion of BH-1 from 80.1 to 108.5 feet. This shear/fracture zone consists of irregular and discontinuous joints and fractures which are carbonate coated and iron oxide stained with traces of silt and slickensides.

RQDs are very low, ranging from 8 to 57 percent with permeabilities on the order of 10^{-4} to 10^{-5} cm/sec. On the north bank, GF 3 has been correlated with a shear/fracture zone in a narrow gully.

Shear/fracture zone GF 4 occurs about 350 feet downstream from GF 3 (Figure 7.3). This zone contains up to 1.5 feet of clay gouge. This zone may correlate with a bedrock dropoff on seismic line SL 81-22. GF 4 projects northward across the river into a gully where it appears to splay. This splayed zone may correlate with a small shear/fracture zone near the bottom of BH-1 from borehole depths of 678.9 to 683.8. This zone consists of planar, smooth joints with irregular and discontinuous fractures. RQDs are low (25 percent and 60 percent); however, permeability measurements are 10^{-6} cm/sec indicating the general tightness of the zone.

Shear/fracture zone GF 5 is a small, apparently discontinuous zone located on the north bank near DH-13 (Figure 7.3). The zone occurs in a narrow gully with very close to close spaced northwest-trending joints. GF 5 was also intersected in DH-13 at a borehole depth of 93.3 feet where it is partially healed with carbonate, and quartz RQDs in this zone are 0 percent.

Shear/fracture zone GF 6 was mapped in a deep gully on the south bank of the river (Figure 7.12). The zone trends northwest, dipping 75° to the west. GF 6 consists of a 2-to-3 foot-wide fracture zone with 3 to 4 inches of light gray to black clay gouge. This zone was intersected by DH-10 between 101.1 and 117.8 feet. No gouge was recovered; however, the joints have occasional slickensides and are chlorite coated. Minor carbonate and iron oxide is also present in the zone. RQDs are generally zero throughout the zone. No pressure testing was done in the borehole; however, reports by the USBR showed no severe water loss during drilling. GF 6 has been tentatively projected to the north bank.

Downstream from GF 6, four other northwest trending shear/fracture zones (GF 7, 8, 9, and 10) had been previously mapped by the USBR. No evidence for these zones could be found during the 1980-81 mapping program. However, the mapping in this area was performed during winter when many areas were covered with snow and ice.

- Bedrock Low Beneath Borrow Site G

Seismic lines SW-15 and SW-16 performed by Shannon & Wilson (39) for the COE in Borrow Site G showed a marked dropoff in bedrock elevation and seismic velocities along the east end of the seismic lines (Figures 7.2 and 7.9).

As noted from the figures, the bedrock surface is inferred in this area to drop off more than 200 feet along a west to east traverse across Borrow Site G. Land access restriction imposed during this study prohibited any further investigation of this area. Possible explanations for this apparent anamalous bedrock dropoff could be attributed to misinterpretation of the seismic data wherein the lower velocity material could be either a highly fractured rock in lieu of till or offset of the rock surface by faulting. The latter interpretation is unlikely in that the work performed by Woodward-Clyde Consultants (60) for this project evaluated lineaments in this area and concluded that there was no compelling evidence for a fault.

Further exploration will be required in subsequent phases of the investigation to better define the bedrock conditions in this area.

- Bedrock Conditions Beneath Susitna River

The presence of geologic structures beneath the present course of the Susitna River was examined by both the USBR (51) and Acres. A series of angle boreholes were drilled by the USBR from both the north and south banks at river level (Figure 5.2).

Several of these boreholes (DH-11, -11A, -11B, -11C, -14 and -14A) "daylighted" into the river requiring them to be redrilled at a steeper angle. RQDs in most of the river holes was generally greater than 60 percent with permeabilities less than 10^{-4} cm/sec. These low values are primarily attributed to open joints and fractures in the shallow weathered bedrock zone.

Minor fracture and shear zones were encountered in several of the boreholes (DH-11 and DH-14 series and BH-5a); however, these were limited in nature and could not be correlated between borings. No indication was found from the investigation to suggest either faulting or fracturing parallel to the course of the river.

To support this conclusion, the dikes on both abutments were surveyed and showed no noticeable offsets across the river.

(v) Geology Along Proposed Long Tailrace Tunnel

- Introduction

This section discusses the lithology and structure along the proposed long tailrace tunnel for the Devil Canyon damsite. Reconnaissance mapping was done along the Susitna River from about 2,500 feet to 10,000 feet downstream from the site. Rock exposures are nearly continuous from the damsite to the bend in the river where the proposed portal area is located (Figure 7.14). From that point downstream, outcrops are scattered and poorly exposed.

- Lithology

As in the area of the main dam, the lithology along the proposed tailrace consists of interbedded argillite and graywacke which have been intruded by mafic and felsic dikes. The argillite is medium to dark gray, very fine to fine grained argillaceous rock with occasional grains of fine to medium sand. The graywacke is light to medium gray and consists of fine to medium grain-size grains in a very fine grained argillaceous matrix. The interbeds of argillite and graywacke are generally 6 inches thick. Contacts between beds are sharp and tight.

Bedding is parallel to a weakly developed foliation. Bedding/foliation strikes generally northeast with moderate dips to the southeast (Figure 7.14). This secondary foliation (which is poorly developed at the damsite) is locally well developed near the proposed tunnel portal. The secondary foliation strikes nearly north-south with high angle dips to the northwest. The argillite and graywacke have been intruded by numerous quartz veins and stringers as at the damsite (Section 7.1[b]).

Felsic and mafic dikes were mapped in outcrops along the river and to the north of the tunnel route. The lithology and structure of these dikes are similar to those found at the damsite. The felsic dikes consist of two varieties: rhyolite and granodiorite. The rhyolite dikes are light yellowish gray to gray. The texture is aphanitic to fine grained with fine to medium grained quartz phenocrysts. The granodiorite dikes are primarily medium grained plagioclase phenocyrsts in a fine grained groundmass of plagioclase, orthoclase, biotite and quartz. The felsic dikes are generally slightly to moderately weathered, medium hard, with very close to closely spaced joints. Iron oxide staining is common. Widths are generally 10 to 20 feet. Contacts with argillite and graywacke are generally fractured and/or sheared. Up to 3-foot-wide contact metamorphic zones are common in the adjacent argillite and graywacke. The felsic dikes strike northwest and northeast.

Mafic dikes are generally dark green to dark gray. These dikes are fresh to slightly weathered and hard. Mafic dikes are composed of feldspar in a fibrous groundmass with accessory pyroxene, biotite, hornblende, and calcite. These dikes are generally 2 to 10 feet wide and trend northwest with high angle to vertical dips. Like the felsic dikes, the mafic dike contacts are generally sheared and/or fractured. Joint spacing is very close to closely spaced.

A nearly 200-foot-wide outcrop of granodiorite was mapped approximately 4,000 feet north of the river at Elevation 2100. It is not known whether this feature is a large dike or part of the granodiorite pluton surrounding the site (Section 4).

- Structures

Joint sets and shear/fracture zones similar to those mapped at the damsite are likely to occur along the tailrace tunnel.

The four joint sets identified at the damsite (Section 7.1[c]) continue downstream; however, variations in orientation and dip occur. Table 7.3 is a list of joint characteristics for joints along the tailrace tunnel.

Joint Set I is northwest trending with a moderate to high angle dips to the northeast and southwest. The average strike and dip of this set in the tailrace area is 325° and 70° northeast, respectively, which differs slightly from its average orientation in the damsite of 340° and 80° northeast. Spacings are highly variable but average about 1.5 feet. The river flows parallel to this set in the vicinity of the outlet portal.

Joint Set II includes joints parallel and subparallel to the bedding/foliation planes. This set strikes 065° with moderate (60°) dips to the southeast. The strike is essentially the same as at the damsite, although the dip is slightly steeper.

Joint Set III strikes nearly north-south at an average of 022°. Dips are variable from 63° east to 84° west. The strike of Set III is similar to that found on the south bank of the damsite; but about 30° more northerly than the average strike found on the north bank (Table 7.2). Dips are generally similar to those at the damsite. Set III joints are well developed in the vicinity of the outlet portal.

Joint Set IV consists of low-angle (dipping less than 40°) joints of various orientations. Those in the vicinity of the tailrace tunnel are similar to those described in Section 7.1 (c) and Table 7.2.

Although no shears or fracture zones were found during the reconnaissance mapping downstream from the damsite, it is anticipated that several such features will be encountered along the tunnel. These shears and fracture zones will likely be less than 10 feet wide and spaced from 300 to 500 feet apart (Section 7.1[c]).

(d) Rock Quality Designation

The Rock Quality Designation (RQD) for all cored holes drilled by Acres and the USBR are presented on the Summary Logs in Appendix C. A tabulation of the RQD values with hole depth is contained in Tables 7.4 and 7.5.

The overall nature of Devil Canyon rock is that of a very hard, brittle rock. Little difference is found in rock quality between the argillite and graywacke. Based on analysis of the RQD values, the rock is classified as "good" to "excellent."

Overall average RQD for 12 boreholes drilled previously by the USBR and 7 boreholes by Acres during 1980-81 in the damsite area is 76 percent (Table 7.4). For the most part, the USBR cores show slightly lower RQDs than the rock drilled by Acres. This is likely attributed to several factors including poor drilling problems and core breakage during handling and transport. Similarly, most of the USBR cores were shallow holes (<150 feet) and reflect lower RQDs found in near surface weathered and fractured zones. As noted in Table 7.4, RQD values tend to increase with depth.

The depth of weathering varies from near surface to 80 feet deep and is mainly evidenced by a high degree of fracturing with joint staining and minor mineralization.

Lower RQD values were encountered in BH-3 (Table 7.4). This hole was drilled on the left abutment and inclined northward to intersect a series of open joints along the gorge walls. Other zones of lower RQDs were found in sheared and highly fractured rock, i.e., BH-7 (Appendix C).

In summary, over 70 percent of the rock drilled during the 1980-81 program had RQD values ranging from 75 to 100 percent with only 8 percent having RQDs less than 25 percent. The intact rock at Devil Canyon has been classified as high strength with an average modulus ratio and classification of BM (14,16).

(e) Rock Properties

Representative NQ (1.77) core samples of agrillite and graywacke were selected from BH-1, 2, 3, 5a, 5b, and 7 (Figure 7.15). Results of the testing program are presented in Tables 7.6 and 7.7 and are discussed below. Representative photos of rock tests are shown in Figure 7.15.

(i) Unit Weight

Dry unit weights, measured in conjunction with both tensile and compressive strength tests, gave an average unit weight of 170 pcf for both the argillite and graywacke.

(ii) Static Elastic Properties

Elastic properties were measured using electronic strain gages bonded onto the sample in axial and circumferentially directions. Stress, diametric strain, and volumetric strain were computed and plotted against axial strain from which secant modulus, tangent modulus at 50 percent failure stress, and Poisson's Ratio were determined. Results are presented in Figure 7.16. An average of all test results show:

Rock Type	No. of Tests	Static Modulus ($x\ 10^6$ psi)	Poisson's Ratio
Argillite	7	9.74	0.21
Graywacke	6	10.32	0.19
Combined	13	10.0	0.20

(iii) Dynamic Elastic Properties

Compressional (V_p) and shear (V_s) wave velocities in fps for both argillite and graywacke were determined and dynamic moduli and Poisson's Ratio computed. Results averaged:

Rock Type	Number of Tests	Vp (fps)	Vs (fps)
Argillite	2	20,015	11,520
Graywacke	2	19,280	11,310

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An average of all test results show:

Rock Type	Number of Tests	Dynamic Modulus ($x10^6$ psi)	Dynamic Poisson's Ratio
Argillite	6	10.62	0.13
Graywacke	5	11.09	0.22
Combined	11	10.8	0.17

(iv) Direct Shear Tests

The following types of direct shear tests were performed on both argillite and graywacke:

- natural discontinuity
- polished rock on rock
- polished rock on mortar

Test results are plotted in Figure 7.17. A summary of the results is as follows:

Argillite	Ø Peak	Ø Residual	C (psi)
- natural discontinuity	27.5°	23°	0
- polished rock on rock, dry	21.5°	19.5°	0
- polished rock on mortar, dry	31°	25°	0
Graywacke			
- natural discontinuity	25°	23°	0
- natural discontinuity using inferred cohesive intercept	--	22°	6
- polished rock on rock, dry	25°	23°	0
	21.5°	18°	0
	16°	10°	0
- polished rock on rock, wet	20°	15°	0
- polished rock on mortar, dry	31°	27°	90
- polished rock on mortar, dry with bond broken with inferred cohesive intercept	--	27°	6

Polished rock on rock tests give a material's lowest friction angle. This angle ignores effects of natural surface undulations or roughness. Therefore, a "waviness angle" is applied to obtain a more representative value for design. This "waviness angle" is based to a large degree on observed field conditions of natural joint surface and site geology.

For this study, natural surface friction angles were based on a slick, chloritized, natural discontinuity in argillite and a smooth, planar, partially open natural joint in graywacke. These discontinuities, which represent unfavorable conditions, have been considered as lower limit values.

Shear strength of rock against concrete was simulated by sliding a polished graywacke and argillite core against mortar. As noted above, these results gave peak Ø values of 30° and Ø residual between 20° and 26°. It should be noted that normal rock foundations are rough, giving friction angles of 35° or higher.

As noted in Figure 7.17, lower friction angles were obtained under the 150 psi normal load test for rock on mortar tests. The 150 psi load test is the highest load in a sequence of three tests performed on the same sample. Therefore, it is likely that the previous shear tests performed on the sample resulted in the surfaces degrading and approaching a residual characteristic, thereby giving a lower result.

Data plots for direct shear tests of polished rock surfaces show an oscillation of the shear load with displacement of the rock surface. This indicates that the movement of the rock surface, relative to each other, was not uniform. The shear stress reaches a peak after which movement takes place. The shear stress drops to a residual value but then builds up to a subsequent peak value. This cycle repeats itself over the full extent of the displacement range.

The upper and lower bounds of the plotted points are believed to represent the peak and residual friction angles for polished surfaces.

Direct shear test data presented here should be considered only as a preliminary estimate of design parameters. The final determination of design friction angles will require a comprehensive knowledge of the geologic structure and friction angles for each discontinuity as they relate to each engineered facility.

(v) Compressive Strength Testing

Compressive strengths were measured by both unconfined compression and point loading methods.

- Unconfined Compression

Results of unconfined compressive strength tests show:

Rock Type	Number of Tests	High (psi)	Low (psi)	Mean ± Standard Deviation (psi)
Argillite	21	32,940	8,017	19,792 ± 6,533
Graywacke	16	36,570	4,066*	22,755 ± 8,600

*Failure along healed joints

Both rock types are variable in strength with higher strengths reflecting "intact" rock and lower strengths reflecting cores with inherent weaknesses such as foliation, healed joints, etc. The foliation within the rock makes the rock slightly anisotropic. Frequency plots (Figure 7.18) show 90 percent of the combined test results are greater than 12,000 psi and, assuming a normal distribution, approximately 70 percent of all tests fall within the standard deviation, i.e., between 12,925 and 28,235 psi.

- Point Load Testing

Rock strength for BH-1 and BH-2 core was tested at 15- to 20-foot intervals using a Terremetrics T-500 point load tester. Statistical data analysis give:

Rock Type	Number of Tests	Mean ± Standard Deviation (psi)
Graywacke	33	21,973 ± 5,745
Interbedded argillite and graywacke	163	21,579 ± 6,752
All tests	338	22,393 ± 6,842

Frequency plots are presented as Figure 7.19. In comparison with the unconfined test, these tests gave slightly higher values. The probable cause for this is that rock strength is proportional to the physical dimensions of the tested sample. For unconfined compression tests, lower strengths are generally found for the larger diameter samples (23). Similar effects are also noted in the Watana test results.

Both types of tests, however, indicate a high strength rock. Combining the compressive strength and elastic properties for both the argillite and graywacke gives a high strength rock with an average static modulus to compressive strength ratio (BM)(14).

(vi) Tensile Strength

Rock Type	Number of Tests (psi)	High (psi)	Low (psi)	Mean ± Standard Deviation (psi)
Argillite	4	3944	3018	3410 ± 390
Graywacke	5	5071	1471	2960 ± 1515

Argillite test results (Brazilian Split) were relatively uniform while graywacke results were variable. These tests show high intact rock tensile strength, which implies high intact rock shear strengths.

(vii) Summary

The rock test results presented in this section are considered adequate for preliminary design purposes. Extensive geotechnical work including drilling, down hole testing, geophysics, exploratory adits, laboratory and in situ testing, will be required before the final design parameters can be determined for each structure. However, tests performed during this, as well as previous studies, show the rock to be of excellent quality for constructing both surface and subsurface facilities at Devil Canyon.

(f) Rock Permeability

Water pressure tests were carried out in all seven holes drilled by Acres. Results of the permeability tests are shown graphically on the summary logs in Appendix C with test results tabulated in Appendix E. At several locations (BH-4 at depths 90 to 140 feet), tests could not be completed because of equipment problems.

Water pressure tests performed by the USBR and Acres (Section 5) confirm that rock permeability at the Devil Canyon damsite is controlled by the degree of jointing, fracturing, and weathering within the bedrock.

The rock permeability does not vary significantly within the site area, generally ranging at 1×10^{-4} and 1×10^{-6} cm/sec with lower permeabilities generally at depth and higher permeabilities in the more highly fractured rock zones. A summary of permeability with depth is shown in Figure 7.20. Permafrost has not been observed at Devil Canyon and therefore will not affect permeability.

(g) Groundwater

The damsite is located in a "young" geomorphic terrain which is characterized by high relief and immature drainage systems. As stated in Section 7.1 (f), groundwater flows are confined to the fractures and joints within the bedrock. Based on piezometer readings and water level readings taken during drilling, it appears that the groundwater table is a subdued replica of the surface topography with groundwater gradients steeper near the river and lakes. Water level readings performed in BH-1 and BH-2 have given relatively constant levels during 1980-81 with depths of approximately 150 feet and 0 feet beneath the ground surface, respectively. Other readings taken in BH-4 and BH-7 on the left abutment correspond closely with the lake level. Groundwater levels are expected to be variable throughout the site, controlled principally by the extent of fracturing within the rock mass.

Some seeps have been noted in the gorge walls indicating groundwater migration through open joints and fractures. These seeps, however, are relatively small. No seeps were noted above the break in slope.

(h) Permafrost

(i) General

Climatological data collected during 1980-81 near the site indicate that the damsite average temperature may be slightly above freezing, about 1°C. According to published data, the Devil Canyon site is within a zone of discontinuous permafrost (19). The localized climatic conditions at the site may, however, be more severe than suggested because of the high relief and the deep gorge which receives very little sunlight.

Despite the apparent severe weather conditions, no direct evidence has been found in or around the damsite to suggest the presence of significant amounts of permafrost (36).

(ii) Damsite

During drilling and test pitting, special care was taken to observe any evidence of permafrost, and none was found. Thermistor strings 250 feet long were installed in BH-1, 2, and 4 (Figure 7.19) and showed excellent stabilization in BH-1 and 2 and fair-to-good stabilization in BH-4. The ground temperatures were all recorded between 1.7°C and 4.4°C at depth. BH-1 and BH-2 on the north abutment have very similar readings, showing the depth of annual amplitude reaching a depth of approximately 50 feet, with minimum ground temperatures of 1.7 to 2.1°C occurring from

60 to 130 feet below surface topography. Below that depth, both holes show a consistent warming trend that probably reflects the natural geothermal gradient. Geothermal gradients appear to be average, showing about 1°C per 300 feet (1°F per 166 feet) (24).

(iii) Emergency Spillway

The emergency spillway area is not expected to have any permafrost in rock, and only sporatic frost in the overburden. In the downstream outlet area, where overburden may reach 75 feet or more, remnant permafrost lenses in the till may be expected. Annual frost penetration is expected to be about 10 to 15 feet.

(iv) Saddle Dam

The thermal regime in the saddle dam area is similar to the damsite, as shown by the thermistor log of BH-4 (Figure 7.21). Based on these data and auger drilling in this area, no evidence of permafrost was found. Because BH-4 was angled under the lake, the thermistor string extends only approximately 175 feet below the top of the alluvium. The apparent 1.5° variation in downhole temperature (4.4°C in August to a low of 3.1° in December) could reflect changes in lake temperature through the year as water migrated from the lake through open joints and fractures around this section of borehole. The apparent subzero temperatures at depth were noted as erratic and inconsistent when the readings were taken. Therefore, the May 24, 1981 reading at 200 feet has been neglected. Likewise, the erratic and fluctuating readings on one of the 250-foot-depth thermistors, with total failure on the latest set of readings, make this a suspect data point (Figure 7.21).

Additional instrumentation will be required in this area to further define the subsurface thermal regime.

(v) Camp Areas

Based on auger holes and USBR investigations, permafrost should be expected to occur in the proposed camp area as localized small lenses or zones within the overburden. Annual frost heaving can be expected in the overburden.

(vii) Access Roads

Access and construction roads can be expected to encounter scattered permafrost lenses and pockets. The annual frost penetration is likely to cause heaving in much of the alluvial material, particularly the clayey moraines and thin outwash deposits. Groundwater flow, where encountered, may cause seasonal "icing," which could disrupt drainage. Further investigations of permafrost and foundation conditions along the proposed access roads will be required in subsequent studies.

7.2 - Borrow and Quarry Material

The borrow investigations at Devil Canyon were performed with the use of auger drilling, test trenching, field mapping, seismic refraction and air photo interpretation as described in Section 5.

The objectives of the 1980-81 investigation were to:

- define the limits of previously identified borrow sites;
- identify new borrow sites; and
- determine material properties and volumes.

The information collected during this investigation has been combined with data from previous investigations to develop a comprehensive data base for each borrow and quarry site. One borrow site and one quarry site were identified for this study. Borrow Site G was investigated as a source for concrete aggregate and Quarry Site K for rockfill. Despite detailed reconnaissance mapping around the site, no local source for impervious or semipervious material could be found. As a result, Borrow Site D (Section 6.3) has been delineated as the principal source for this material. Further investigations may identify a more locally available source. The following sections provide a detailed discussion of the borrow and quarry sites for the Devil Canyon development.

(a) Borrow Site G

(i) Proposed Use

Borrow Site G was previously identified by the USBR and investigated to a limited extent by the COE (45,51) as a primary source for concrete aggregate. Because of its close proximity to the damsite and apparent large volume of material, it became a principal area for investigation during the 1980-81 program. The scope of the 1980-81 investigation in this borrow site is discussed in Section 5 and shown in Figure 7.22.

(ii) Location and Geology

Borrow Site G is located approximately 1,000 feet upstream from the proposed damsite. The area delineated as Borrow Site G is a large flat fan or terrace that extends outward from the south bank of the river for a distance of approximately 2,000 feet. The site extends for a distance of approximately 2,000 feet. The site extends for a distance of approximately 1,200 feet east-west (Figure 7.22). Cheechako Creek exits from a gorge and discharges into the Susitna River at the eastern edge of the borrow site. The fan is generally flat-lying at Elevation 1000, approximately 80 feet above river level. Higher terrace levels that form part of the borrow site are found along the southern edge of the site above Elevation 1100.

Vegetation is scattered brush with mixed deciduous trees found on the floodplain and fan portions. On the southern hillside portion of the borrow site, heavy vegetation is evident with dense trees and underbrush (Figure 7.22). The ground cover averages up to 0.5 foot in thickness and is generally underlain by 1 to a maximum of 6.5 feet of silts and silty sands. This silt layer averages 1.5 feet thick on the flat-lying deposits, and up to 2 feet thick on the hillsides above Elevation 950.

No groundwater was encountered in any of the explorations. The high permeability of the material provides for rapid drainage of the water to the river. Annual frost penetration can be expected to be from 6 to 15 feet. No permafrost has been encountered in the area.

The borrow material has been classified into four basic types, based on the interpretation of field mapping and explorations. The four types of material or zones, as identified on the map (Figure 7.22), are: Susitna River alluvial gravels and sand (Zone I), ancient terraces (Zone II), Cheechako Creek alluvium (Zone III), and talus (Zone IV).

The large fan deposits are a combination of rounded alluvial fan and river terrace gravels composed of various volcanic and metamorphic rocks and some sedimentary rock pebbles. This material is well-washed alluvial material. Zone I has been divided into two subzones, the upper (Ia) being generally a sandy layer about 20 feet thick, underlain by a thick sandy gravel (Ib) that has been inferred by seismic refraction (39) to extend well below river level. A section on the west side of the fan is shown in Figure 7.22. The ancient terraces (Zone II) are probably similar in origin to Zone I, but being higher on the banks, they likely represent a higher river energy environment; hence, the gradations are expected to be less uniform with more cobble size material. The material in Zones I and II is believed to be generally uniform over a wide range and depth with a trend towards coarser materials with depth. The Cheechako Creek alluvium (Zone III) is bouldery with some angular particles.

The talus (Zone IV) comprises argillite and graywacke derived from the bluffs immediately above the fan. This is composed of the same type rock as the damsite.

(iii) Reserves

The borrow site quantities were broken down into zones as shown on the typical sections based on the exploration logs and test trench sections shown in Appendix G (Figure 7.22).

Based on these data, the quantities of fine sands and gravels in Zones Ia and Ib above river level have been estimated to be approximately 1.1 and 1.9 mcy, respectively. Additional quantities could be obtained by excavating below river level. The quantity of material in Zone II is tentatively estimated to be approximately 2 mcy. This, however, has been based on an inferred depth to bedrock. If bedrock is shallower than estimated, this quantity would be less.

Zone III material is estimated at 1.1 mcy, while Zone IV is 55,000 mcy. Zone IV quantities are too small to warrant consideration as a borrow material.

An estimate of the total quantity of borrow material is about 3 mcy with an additional 3 mcy potentially available from inferred resources. The increase in river level caused by diversion during construction may affect the quantity of available material from this site. Therefore, further work will be required in subsequent studies to accurately determine available quantities and methods and schedules for excavation.

(iv) Engineering Properties

A detailed petrologic description of the material was performed by the USBR (52) and Kachadoorian (29) and, therefore, have not been repeated here. In summary, the deposit is a gravel and sand source composed of rounded granitic and volcanic gravels, with a few boulders up to 3 feet in diameter. Deteriorated materials comprise about 8 to 10 percent of the samples.

Testing performed by the USBR (52) indicates that about 2 to 4 percent of the material was considered adverse material for concrete aggregate.

Results of the laboratory tests performed for the project are summarized in Table 7.8. A composite grain size curve showing the wide range of gradations in Borrow Site G is shown in Figure 7.24. A more detailed breakdown of the various stratigraphic unit gradations is shown in Figure 7.25. Units identified in Figure 7.25 correspond with those units mapped in the test trenches (Appendix G). In summary, two distinct grain sizes are found in the site: (1) from the auger holes (Unit D), a fairly uniform, well sorted coarse sand with low fine content and (2) from the test trenches (Unit Z), a fairly well-graded gravelly sand averaging 10 percent passing No. 22 sieve. The principal reason that the auger drilling did not encounter the coarser material is likely reflective of the sampling technique where the auger sampling could not recover the coarser fractions.

A finer silty layer (Unit C) overlies much of the borrow site. Samples from the higher elevations are more sandy than those from the fan area.

Based on observed conditions, the grain sizes from the trenches are considered more representative of the material in Borrow Site G at depth, while the finer fraction represents the near surface material. The specific gravity testing gave values ranging between 2.33 and 2.87 with natural water content ranging from a low of 3.7 to a high of 30.9 percent with an average of around 12 to 15 percent. Dry and wet density ranges from a low of 90 through 143 and 95 through 153 pcf, respectively.

(b) Quarry Site K

(i) Proposed Use

Quarry Site K was identified during this study as a source for rockfill for the construction of the proposed saddle dam on the left abutment.

(ii) Location and Geology

The proposed quarry site is approximately 5,300 feet south of the saddle damsite, at approximate Elevation 1900 (Figure 7.26). The site consists of an east-west face of exposed rock cliffs extending to 200 feet in height. Vegetation is limited to tundra and scattered scrub trees.

Drainage in the area is excellent with runoff around the proposed quarry site being diverted to the north and east toward Cheechako Creek. The groundwater table is expected to be low and confined to open fractures and shears.

The bedrock is a white-gray to pink-gray, medium grained, biotite granodiorite similar to that at the Watana damsite (Section 6). The rock has undergone slight metamorphism and contains inclusions of the argillite country rock with local gneissic texture. The rock is generally massive and blocky, as evidenced by large, blocky, talus slopes at the base of the cliffs.

The rock is probably part of a larger batholith of probable Tertiary age which has intruded the sedimentary rocks at the damsite (Section 4).

(iii) Reserves

The limits that have been defined for the quarry site (Figure 7.26) have been based on rock exposure. Additional material covered by shallow overburden is likely to be available, if required. However, since the need for rock fill is expected to be small, no attempt was made to extend the quarry site to its maximum limits. The primary quarry site is east of Cheechako Creek (Figure 7.26). This area was selected primarily because of its close proximity to the damsite and high cliff faces which is conducive to rapid quarrying. The low area west of the site was not included because of possible poor quality sheared rock. A secondary (backup) quarry source (Figure 7.26) was delineated west of the primary site. Because of the extensive exposure of excellent quality rock in this area, additional exploration was not considered necessary for this study.

The approximate volume of rock determined to be available in the primary site is about 2.5 mcy per 50 feet of excavated depth, or approximately 7.5 mcy within about a 30-acre area. The alternative backup site to the west of Quarry K has been estimated to contain an additional 35 mcy for 150 feet of depth, covering some 145 acres.

(iv) Engineering Properties

The granodiorite was selected over the more locally available argillite and graywacke because of the uncertainty about the durability of the argillite and graywacke under severe climatic conditions.

The properties of the granodiorite are expected to be similar to those found at the Watana damsite (Section 6.1[e]).

Freeze-thaw and wet-drying (absorption) tests performed on rock types similar to those found on Quarry K by the COE (49) exhibited freeze-thaw losses of <1 percent at 200 cycles and absorption losses of 0.3 percent. Both tests showed the rock to be extremely sound and competent.

TABLE 7.1: DEVIL CANYON SEISMIC VELOCITY CORRELATIONS

VELOCITY Feet per Second (fps)	INFERRED MATERIAL
	Shallow sands, gravels, soil - dry surficial including denser gravels, sand, talus and slopewash, generally well drained.
3000-4000	Dry gravels and gravelly sand could include frozen alluvium and slopewash if present.
4000-5000	Saturated and/or frozen (if present) material from classifications above.
5000-7000	Saturated coarse materials including gravels, outwash, till.
7000-9000	Dense gravels, tills, reworked tills and possible highly weathered bedrock.
9000-12000	Rock, highly weathered, open fractured and/or sheared.
12000-14000	Rock, weathered, fractured or sheared but not necessarily openly fractured.
14000-17000	Bedrock, slightly weathered.
17000-19000+	Bedrock, very sound, tight, only slightly weathered.

Reference: 39, 51, 57, and 59.

TABLE 7.2: DEVIL CANYON JOINT CHARACTERISTICS*

Joint Set	Location	Strike (Range)	Strike (Avg.)	Dip (Range)	Dip (Avg.)	Spacing** (Range)	Spacing** (Avg.)	Surface Conditions: Texture	Surface Conditions: Coating	Remarks
I	North Bank	320°-0°	345°	60°NE-70°SW	80°NE	0.5"-10'	1.5'	Planar, smooth, occasional rough, continuous	Occasional iron oxide and carbonate	Parallel to shears, fracture zones and most dikes. Major stress relief, open joints on south bank. Ib found locally
	Ib DCJ-4		320°		55°NE					
	South Bank	310°-350°	340°	60°NE-75°SW	90°	0.5"-5'	2'			
II	North Bank	040°-090°	065°	40°-75°SE	55°SE	6"-3'	2'	Planar to curved, smooth to rough	None	Parallel and sub-parallel to bedding/ foliation. Some open to 6" near river level. Parallel to major and minor shears. IIb is found locally.
	IIb DCJ-4		015°		85°SE					
	South Bank	020°-100°	075°	30°-75°SE	55°SE	2"-6'	1'			
	IIb DCJ-1		015°		75°SE	2"-5'	1.5'			
III	North Bank	045°-080°	060°	50°NW-70°SE	80°NW	4"-10'	3'	Planar to irregular, smooth to rough, tight to open joints	Occasional iron oxide and carbonate	Occurs locally, cliff former above Elevation 1400 on the north bank
	South Bank	015°-045°	025°	68°-80°NW	65°NW	6"-10'	3'			Locally open joints
IV	North Bank	Variable orientations		Shallow to moderate		3"-8'	2'	Planar, rough, discontinuous	Occasional iron oxide and carbonate	Probably stress relief, near surface
	Strongest Concentrations:									
	Composite		060°		15°SE					
	DCJ-2		060°		30°NW					
	DCJ-3		090°		10°S					
	DCJ-4		045°		25°NW					
	South Bank	Variable orientations		Shallow to moderate						
	Strongest Concentrations:									
	Composite		050°		25°NW					
			330°		20°NE					
			330°		15°SW	1"-8'	2'			
			060°		40°NW					
	DCJ-1		345°		15°NE					

*Surface joints only
**Where present

TABLE 7.3: DEVIL CANYON TAILRACE TUNNEL - JOINT CHARACTERISTICS*

Joint Set	Strike (Range)	Strike (Avg.)	Dip (Range)	Dip (Avg.)	Spacing** (Range)	Spacing** (Avg.)	Surface Conditions: Texture	Surface Conditions: Coating	Remarks
I	284°-355°	325°	50°NE-55°SW	70°NE	0.5"-10'	1.5'	Planar, smooth, occasional rough, continuous	Occasional iron oxide and carbonate	Parallel to shears, fracture zones and most dikes
II	052°-085°	065°	37°SE-80°SE	60°SE	2"-5'	2'	Planar to curved, smooth to rough	None	Parallel and subparallel to bedding/foliation. Minor shears
III	006°-038°	022°	63°E-84°W	--	4"-10'	3'	Planar to irregular, smooth to rough	Occasional iron oxide and carbonate	Locally well developed
IV***	Variable		less than 40°				Planar, rough, discontinuous	Occasional iron oxide and carbonate	Probably stress relief, near surface

*Surface joints only
**When present
***See Table 7.2

TABLE 7.4: DEVIL CANYON RQD SUMMARY

Borehole*		BH-1	BH-2	BH-3	BH-4	BH-5a	BH-5b	BH-7	DH-1*	DH-8*	DH-9*	DH-10*	DH-11c*	DH-12*	DH-12a*	DH-13*	DH-13a*	DH-14a*	DH-14b*	DH-14c*	
Ground Surface El.(ft)		1415	1214	1405	1353	980	980	1335	1419.7	1448.3	1424	1425	893	896	896		912	903	902	903	Total Rock
Top of Rock El.(ft)		1404	1212	--	1346	--	--	--	1419.7	1448.3	1424	1425	893	896	896		912	903	902	903	Drilled -
Borehole Dip		67°	60°	32°	60°	45°	45°	50°	45°	30°	45°	52°	57°	60°	45°	45°	37°	53°	60°	55°	Average RQD
Vertical Depth (ft)	RQD																				
0'-50'	Rock Drilled (ft) RQD%	52.7 66%	60.2 79%	94.3 82%	58.2 87%	72.5 64%	71.8 63%	66.2 61%	72.5 67%	99.3 69%	72.5 77%	63.1 63%	31.7 67%	50.0 65%	73.1 79%	49.3 28%	73.9 56%	45.4 75%	60.0 72%	62.0 58%	1228.7 68%
50'-150'	"	107.0 65%	113.4 72%	187.6 76%	113.8 98%	138.7 79%	128.5 82%	134.8 60%	42.2 60%	49.2 88%	12.5 10%	57.6 50%	91.5 54%	48.7 71%	48.6 82%	59.7 11%		53.2 73%	82.1 71%	19.3 17%	1488.4 69%
150'-250'	"	108.8 87%	116.4 90%	101.7 46%	117.9 89%	143.2 81%		141.2 88%													729.2 81%
250'-350'	"	111.1 86%	115.1 87%		114.3 90%	142.2 88%		143.4 85%													626.1 87%
350'-450'	"	110.0 90%	117.2 94%		84.5 95%	101.3 84%															413.0 91%
450'-550'	"	107.7 96%	116.2 85%																		223.9 90%
550'-650'	"	106.6 89%	15.0 96%																		121.6 90%
650'-750'	"	34.5 85%																			34.5 85%
Total Hole Length (ft) Average Hole RQD		738.4 84%	653.5 85%	383.6 69%	488.7 92%	597.9 81%	200.3 75%	485.6 76%	114.7 64%	148.5 75%	85.0 67%	120.7 57%	123.2 58%	98.7 68%	121.7 80%	109.0 19%	73.9 56%	98.6 74%	142.1 71%	81.3 48%	4865.4 76%

*USBR boreholes

TABLE 7.5: DEVIL CANYON - BOREHOLE ROCK QUALITY DISTRIBUTION

Borehole	Rock Drilled (ft)	PERCENTAGE OF CORE IN SPECIFIC RQD RANGES					
		0-25%	25-50%	50-75%	75-90%	90-95%	95-100%
BH-1	738.4	2	6	14	21	13	44
BH-2	653.5	4	4	13	21	14	44
BH-3	383.6	25	18	13	24	13	6
BH-4	488.7	1	2	4	13	16	64
BH-5A	597.9	6	6	10	27	21	30
BH-5B	200.3	9	3	26	36	15	11
BH-7	485.6	11	5	9	30	18	27
DH-1*	114.7	9	23	31	8	8	21
DH-5*	30.7	16	15	22	16	30	1
DH-6*	20.4	91	9	0	0	0	0
DH-8*	148.5	6	10	24	30	8	22
DH-9*	85.0	16	9	13	33	11	18
DH-10*	120.7	17	18	31	24	10	0
DH-11*	31.2	22	14	12	52	0	0
DH-11A*	28.3	0	0	27	28	28	17
DH-1B*	33.9	14	15	8	30	16	17
DH-11C*	123.2	11	32	30	21	1	5
DH-12*	98.7	5	15	39	20	11	10
DH-12A*	121.7	4	9	10	24	18	35
DH-13*	109.0	71	14	15	0	0	0
DH-13A*	73.9	14	22	37	3	8	16
DH-14A*	98.6	11	9	20	18	20	22
DH-14B*	142.1	9	12	24	16	8	31
DH-14C*	81.3	27	15	35	15	5	3
Total Rock Drilled (feet)	5009.9						

* USBR core was relogged from boxes. Several holes have core missing.

TABLE 7.6: DEVIL CANYON ROCK TEST SUMMARY - MAFIC DIKES AND ARGILLITE

Borehole	Sample	Borehole Depth (ft)	Compressive Strength (psi)	Unit Weight (pcf)	Tensile Strength (psi)	Other*
Mafic Dike						
BH-1	80-43	294.5	13,420	159.8		
BH-3	D-3-350.4	350.4	9,472	165.7		
Argillite						
BH-2	80-65	247.3	24,400	168.5		
	80-66	273.0	8,017	168.6		$E_T = 4.4 \times 10^6$ psi, v = 0.20
	80-67	288.7		168.8	3,350	
	80-68	305.5				
	80-69	343.1	28,467	167.9		
	80-76	313.1	27,635	168.8		
	80-77	319.0	10,229	169.0		
BH-3	D-3-83.9	83.9	14,589	170.4		
	D-3-89.6	89.6	17,487	170.9	3,018	$E_T = 11.8 \times 10^6$ psi
	D-3-127.3	127.3				$E_D = 11.3 \times 10^6$ psi, v = 0.19
BH-4	80-55	268.95	17,893	169.6		
	80-56	273.5	25,213	171.7		
	80-60	366.85	15,047	170.9		
BH-5a	D-5A-231.3	231.3	16,227	170.1	3,944	$E_T = 12.7 \times 10^6$ psi, v = 0.19
	D-5A-269.1	269.1				$E_D = 12.7 \times 10^6$ psi, v = 0.30
	D-5A-271.1	271.1	26,840	170.0		
BH-5b	D-5B-149.9	149.9	18,722	170.7		
	D-5B-155.2	155.2		168.2	3,329	
	D-5B-183.4	183.4	16,227	167.8		
BH-7	D-7-174.6	174.6	26,840	168.8		
	D-7-178.1	178.1	21,457	169.2		
	D-7-319.5	319.5	32,940	168.7		
	Average (Acres)		20,484 ±6,935 SD	170.1	3,410 ± 390 SD	
DH-4	4-46.8	46.8				$E_D = 11.6 \times 10^6$ psi, v = 0.07
	4-50.0	50.0	12,910			$E_S = 9.4 \times 10^6$ psi, v = 0.16
						$E_D = 10.2 \times 10^6$ psi, v = 0.04
	4-50.4	50.4	15,980			$E_S = 11.1 \times 10^6$ psi, v = 0.17
	4-51.3	51.3		170.4		Absorption = 0.09, Porosity = 0.24,
DH-8	8-89.6	89.6	16,660	171.6		$E_S = 9.9 \times 10^6$ psi, v = 0.22,
						$E_D = 8.27 \times 10^6$ psi, v = 0.02
						Absorption = 0.08, Porosity = 0.21,
DH-12	12-44.5	44.5	21,860	169.7		$E_S = 8.9 \times 10^6$ psi, v = 0.30,
						$E_D = 9.62 \times 10^6$ psi, v = 0.13
						Absorption = 0.04, Porosity = 0.12
	Average (All Tests)		19,792 ±6,533 SD			

*E_D = Dynamic modulus
*E_T = Tangent modulus at 50% failure stress
*E_S = Secant modulus
*v = Poissons Ratio
SD = Standard deviation

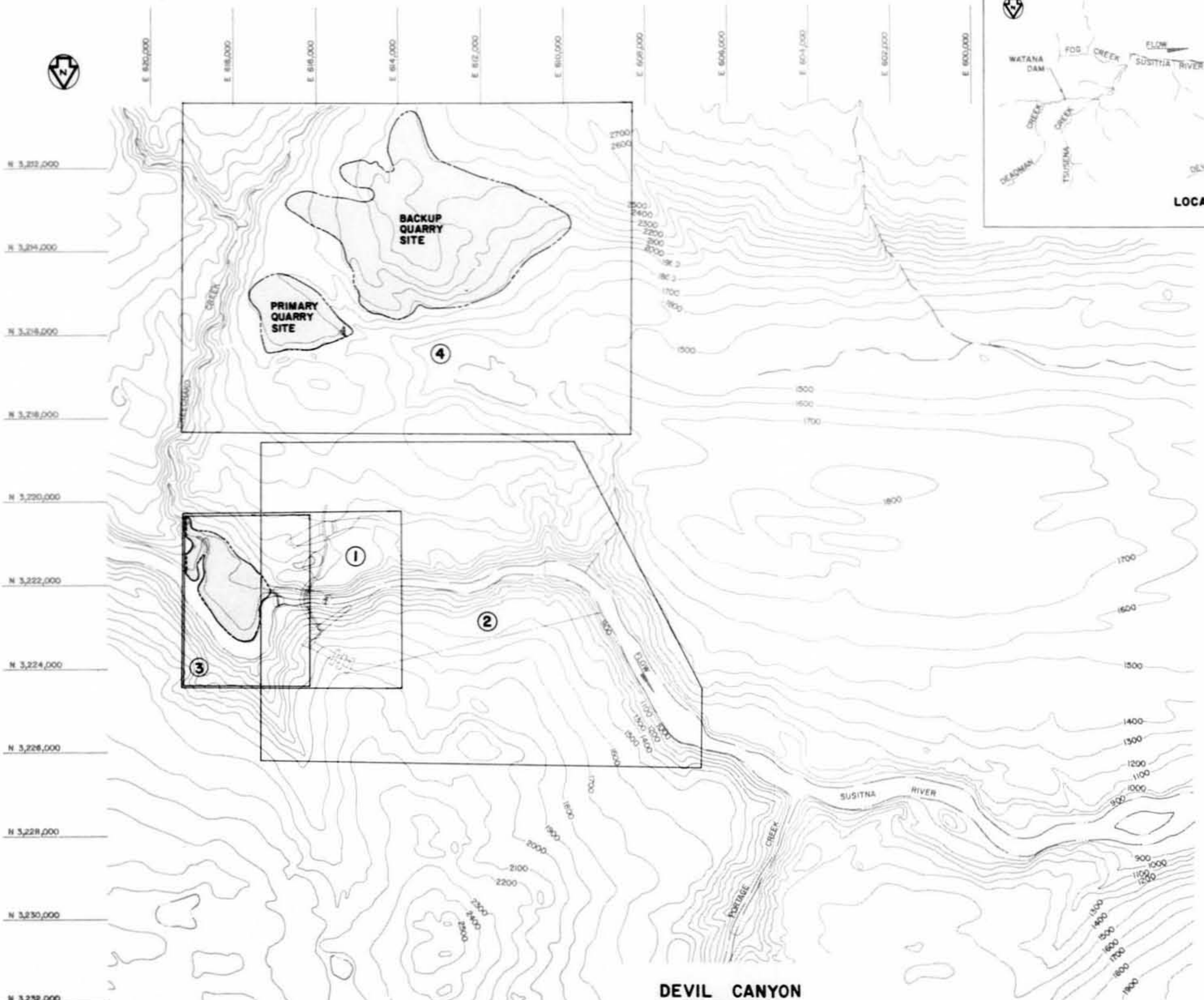
TABLE 7.7: DEVIL CANYON ROCK TEST SUMMARY - GRAYWACKE

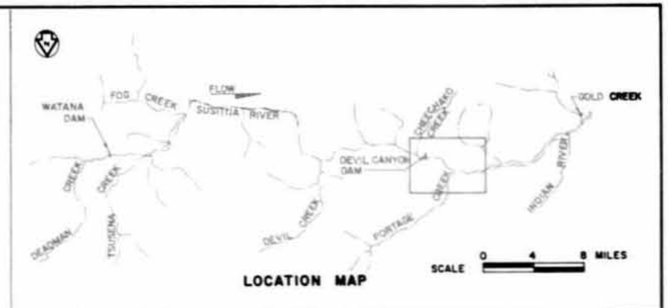
Borehole	Sample	Borehole Depth (ft)	Compressive Strength (psi)	Unit Weight (pcf)	Tensile Strength (psi)	Other*
BH-1	80-42	281.8	14,589	160.4	1,471	
	80-44	440.5	29,463	168.8		
	80-45	449.5	28,467	169.8		
	80-48	510.65	23,453	168.6		E_T = 11.6 x 10^6 psi, v = 0.22
	80-73	429.2	27,726	167.8		
	80-52	571.0	14,556	168.1	2,547	
	80-53	581.2		167.8	5,071	
	80-47	505.5				E_D = 11.3 x 10^6 psi, v = 0.22
	80-50	536.3				E_D = 11.7 x 10^6 psi, v = 0.26
BH-2	80-62	186.4	4,066	165.7		
	80-63	195.5	14,655	168.1		
	80-71	445.2	13,420	169.2		E_T = 9.7 x 10^6 psi, v = 0.19
BH-3	D-3-276.0	276.0	28,398	180.4		E_T = 10.9 x 10^6 psi, v = 0.23
BH-4	80-54	252.5	29,114	169.6	2,761+	
	80-59	351.3	21,960	170.1		
	80-78	378.05	18,908	169.3		
	Average (Acres)		20,598 ±7,925 SD	168.8	2,960 ±1,515 SD	
DH-12A	12A-80.1	80.1	28,450	173.5		E_s = 9.2 x 10^6 psi, v = 0.16, E_D = 8.98 x 10^6 psi, v = 0.15, Absorption = 0.08, Porosity = 0.24
	12A-123.8	123.8	31,280	173.5		E_s = 10.2 x 10^6 psi, v = 0.18, E_D = 12.09 x 10^6 psi, v = 0.21, Absorption = 0.12, Porosity = 0.33
	12A-143.9	143.9	36,570	171.6		E_s = 10.3 x 10^6 psi, v = 0.16, E_D = 11.4 x 10^6 psi, v = 0.25, Absorption = 0.07, Porosity = 0.21
	Average (All Tests)		22,755 ±8,600	169.5		

*E_D = Dynamic modulus
*E_T = Tangent modulus at 50% of failure stress
*E_S = Secant modulus
*v = Poissons ratio
SD = Standard deviation

TABLE 7.8: MATERIAL PROPERTIES - BORROW SITE G

Hole/ Trench Number	Sample Number	Depth		Lab. Classi- fication	Mechanical Analysis			Atterberg Limits		Specific Gravity	W%
		From	To		Gravel	Sand	Fine	LL	PI		
TTG-1	2	5.0	-	SP	65	34	1			2.73	
	3	16.0	-	SP	84	15	1			2.76	
	4	25.5	-	SW	77	20	3			2.72	
	5	37.0	-	SP	55	43	2			2.76	
TTG-2	1	2.5	-	ML	0	85	15			2.82	
	2	6.0	-	SP	1	98	1			2.78	
	3	6.5	-	GP	62	36	2			2.87	
	4	8.0	-	GP	84	14	2			2.86	
	5	15.0	-	GP	88	11	1			2.87	
	8	18.0	-	GP	80	19	1			2.79	
	9	24.5	-	GP	79	20	1			2.33	
AHG-9	4-8	3.0	10.5	SW-SM	18	71	11			2.54	
	14	45.0	46.5	SW	66	32	2			2.53	3.7
	15	50.0	51.5	SM	0	96	4			2.79	6.8
AHG-10	3-5	1.5	6.0	SM	0	64	36			2.63	
	4	3.0	4.5								30.9
	5	4.5	6.0								15.7
	6-8	6.0	9.0	SW	0	91	9			2.64	
	6	6.0	7.5								11.7
	7	7.5	8.5								22.9
AHG-11	6-7	6.5	9.5	SW-SM	17	65	18				
	6	6.5	8.0								16.3
	7	8.0	9.5								14.7
	8-11	15.0	31.0	SM	34	52	14				
	8	14.0	16.5								11.2
AHG-12	5-6	4.0	6.0	SW	34	62	2				
	7-9	6.0	9.5	SW-SM	53	39	8				
	7	6.0	7.5								6.8
	8	7.5	8.5								7.1
AHG-13	4-7	3.5	9.5	SW-SM	7	82	11				
	7	8.0	9.5								25.5
	4	3.5	5.0								24.7
	5	5.0	6.5								18.0
	6	6.5	8.0								20.2
	8	15.0	16.5	ML	0	24	76				
	9	20.0	21.5	SM	40	35	25				
	10,12	25.0	32.0	SW-SM	33	56	11				
AHG-14	8,9	6.0	9.0	SM	22	64	14				
	9	7.5	9.0								9.2
	10	9.0	10.5	SW-SM	20	72	8				9.9
	11	15.0	16.0	SW-SM	41	52	7				
	12	20.0	21.5	SW-SM	25	68	7				7.0
	13	25.0	26.5	CL	4	13	83	49	16		23.5





LOCATION MAP

INDEX

BLOCK NO.	AREA COVERED	* SCALE	FIGURE REFERENCE
1	DAMSITE: EXPLORATION	1"=500'	FIGURE 5.2
	TOP OF BEDROCK	1"=500'	FIGURE 7.2
	GEOLOGIC MAP	1"=500'	FIGURE 7.3
2	TAILRACE AREA	1"=1000'	FIGURE 7.14
3	BORROW SITE G	1"=500'	FIGURE 7.22
4	QUARRY SITE K	1"=1000'	FIGURE 7.26

LEGEND

BORROW / QUARRY SITE LIMITS

* SCALE AFTER REDUCTION

NOTES

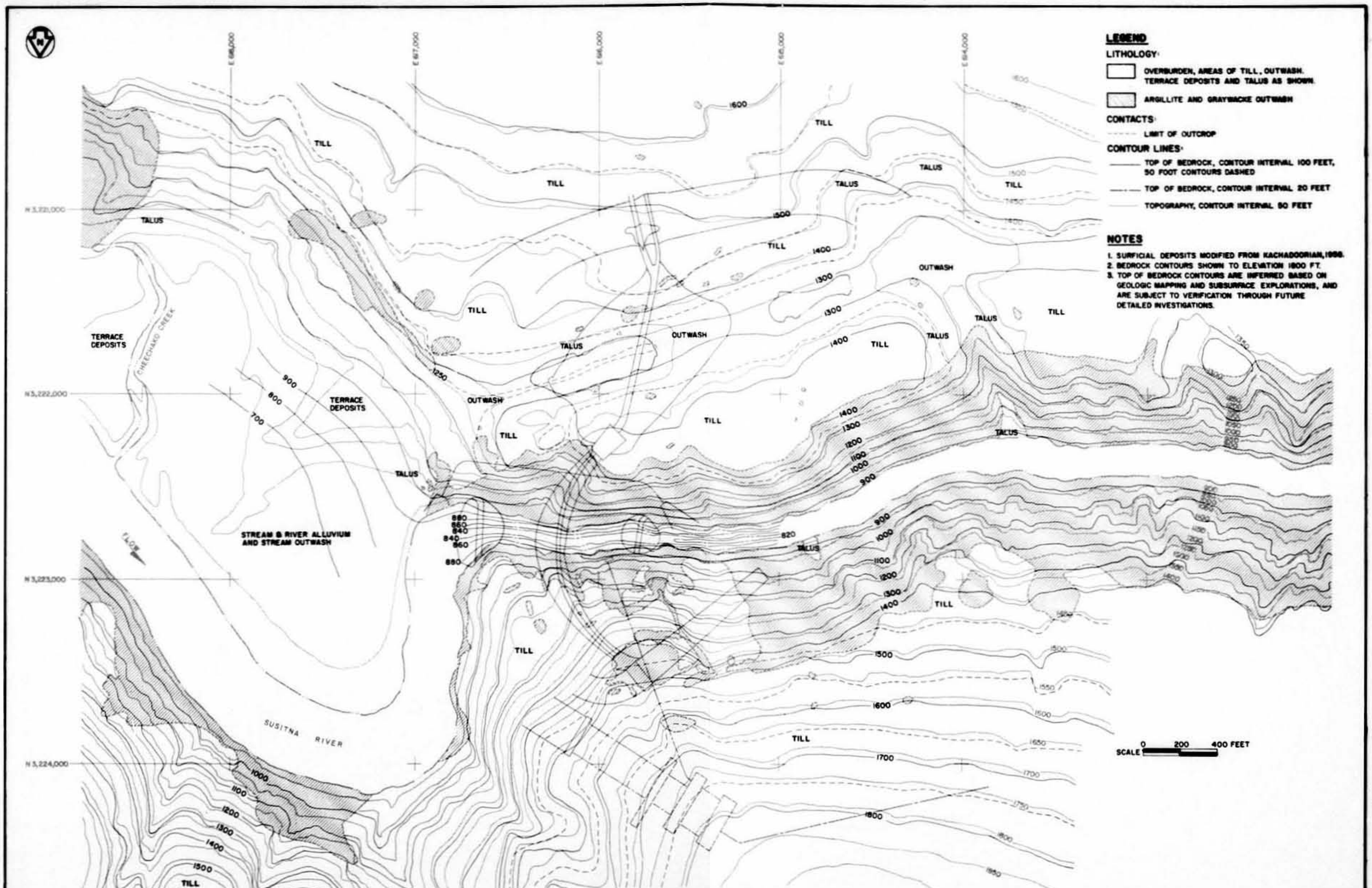
1. TOPOGRAPHY AND DETAILS SHOWN ON INDIVIDUAL FIGURES.

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

DEVIL CANYON INDEX MAP

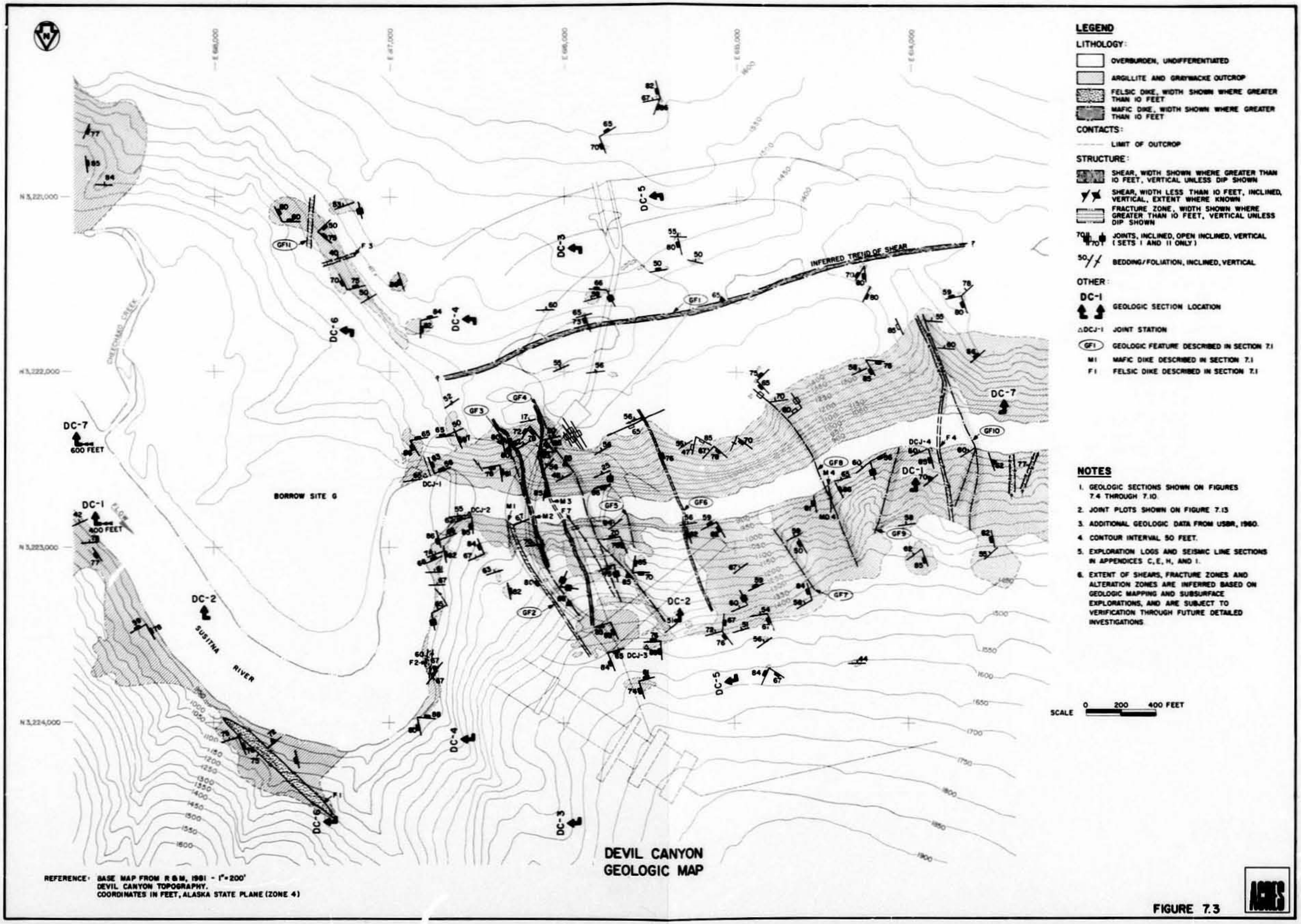
ACRES

FIGURE 7.1



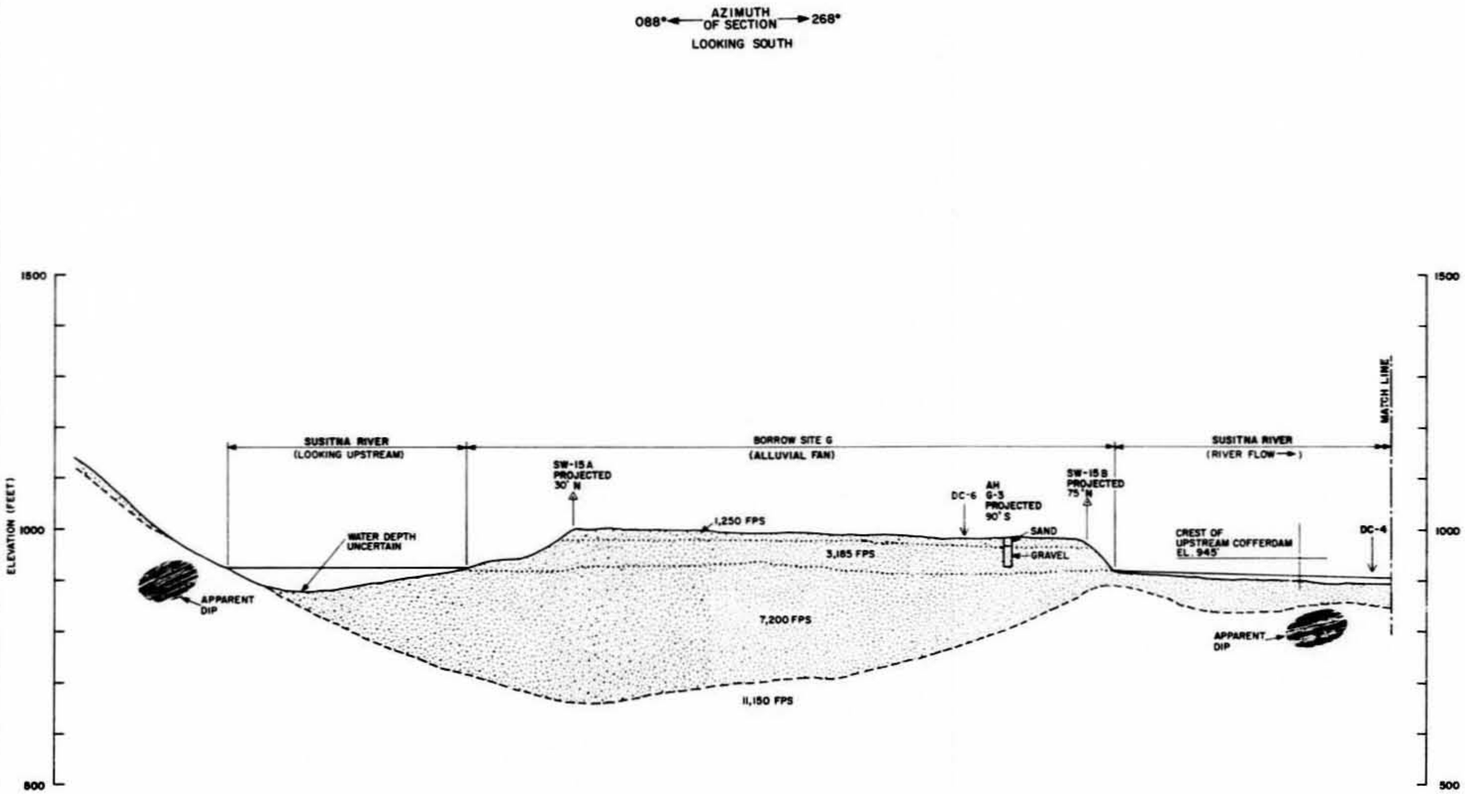
DEVIL CANYON
TOP OF BEDROCK
AND SURFICIAL GEOLOGIC MAP

FIGURE 7.2



DEVIL CANYON
GEOLOGIC MAP

FIGURE 7.3



LEGEND

LITHOLOGY:

- OVERBURDEN, UNDIFFERENTIATED
- ARGILLITE AND GRAYWACKE
- INFERRED ORIENTATION OF BEDDING/ FOLIATION, APPARENT DIP WHERE NOTED
- FELSIC DIKE, WIDTH SHOWN WHERE GREATER THAN 10 FEET
- MAFIC DIKE, WIDTH SHOWN WHERE GREATER THAN 10 FEET

CONTACTS:

- APPROXIMATE TOP OF ROCK
- LITHOLOGIC, DASHED WHERE INFERRED

STRUCTURE:

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

GEOPHYSICAL SURVEYS:

- SW-15 INTERSECTION WITH SEISMIC REFRACTION LINE
- SW-15 1978, SHANNON & WILSON
- SL 80-13 1980, WOODWARD-CLYDE CONSULTANTS
- SL81-22 1981, WOODWARD-CLYDE CONSULTANTS
- SEISMIC VELOCITY CHANGE
- 12,000 FPS SEISMIC VELOCITY IN FEET PER SECOND

BOREHOLES:

BH-1
LITHOLOGY
F= FRACTURE ZONE
S= SHEAR

- DH-1 USBR DIAMOND CORE BORING
- BH-1 AAI DIAMOND CORE BORING
- AH-G1 AAI AUGER HOLE

OTHER:

- DC-1 INTERSECTION WITH GEOLOGIC SECTION DC-1
- GF1 GEOLOGIC FEATURE DESCRIBED IN SECTION 7.1.
- M1 MAFIC DIKE DESCRIBED IN SECTION 7.1.
- F1 FELSIC DIKE DESCRIBED IN SECTION 7.1.

NOTES

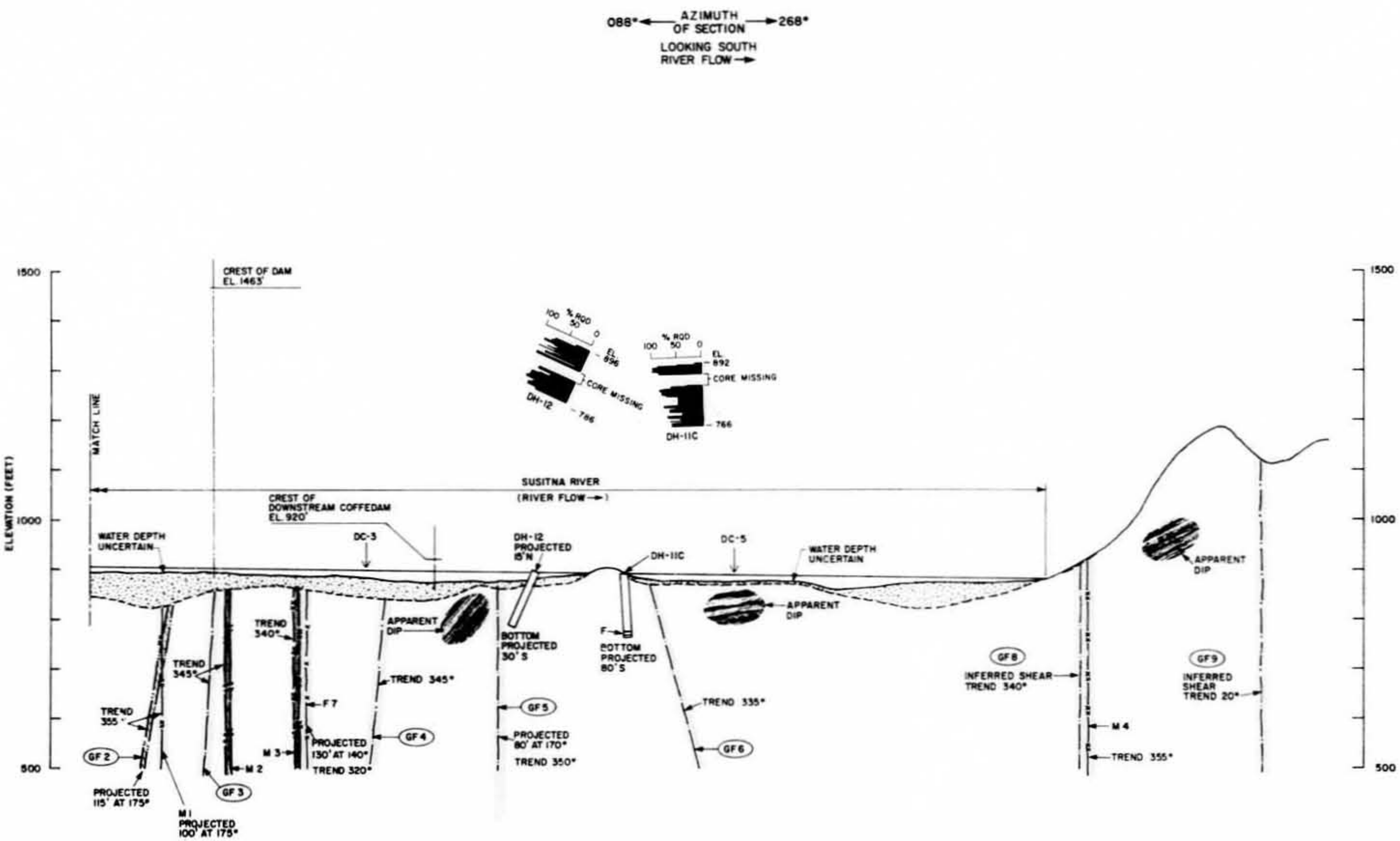
1. SECTION LOCATION SHOWN ON FIGURE 7.3.
2. VERTICAL & HORIZONTAL SCALES EQUAL.
3. SURFACE PROFILE FROM 1" = 200' TOPOGRAPHY, R&M, 1981.
4. EXPLORATION LOGS AND SEISMIC LINE SECTIONS SHOWN IN APPENDICIES C,E,H AND I.
5. EXTENT OF SHEARS, FRACTURE ZONES, AND ALTERATION ZONES ARE INFERRED BASED ON GEOLOGIC MAPPING AND SUBSURFACE EXPLORATIONS, AND ARE SUBJECT TO VERIFICATION THROUGH FUTURE DETAILED INVESTIGATIONS.

SCALE 0 100 200 FEET

DEVIL CANYON
GEOLOGIC SECTION DC-1
SHEET 1 OF 2

ACRES

FIGURE 7.4



LEGEND

LITHOLOGY:

- OVERBURDEN, UNDIFFERENTIATED
- ARGILLITE AND GRAYWACKE
- INFERRED ORIENTATION OF BEDDING/FOLIATION, APPARENT DIP WHERE NOTED
- FELSIC DIKE, WIDTH SHOWN WHERE GREATER THAN 10 FEET
- MAFIC DIKE, WIDTH SHOWN WHERE GREATER THAN 10 FEET

CONTACTS:

- APPROXIMATE TOP OF ROCK
- LITHOLOGIC, DASHED WHERE INFERRED

STRUCTURE:

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

GEOPHYSICAL SURVEYS:

- SW-15 INTERSECTION WITH SEISMIC REFRACTION LINE
- SW-15 1978, SHANNON & WILSON
- SL 80-13 1980, WOODWARD-CLYDE CONSULTANTS
- SL81-22 1981, WOODWARD-CLYDE CONSULTANTS
- SEISMIC VELOCITY CHANGE
- 12,000 FPS SEISMIC VELOCITY IN FEET PER SECOND

BOREHOLES:

BH-1
LITHOLOGY
F = FRACTURE ZONE
S = SHEAR

- DH-1 USBR DIAMOND CORE BORING
- BH-1 AAI DIAMOND CORE BORING
- AH-G1 AAI AUGER HOLE

OTHER:

- DC-1 INTERSECTION WITH GEOLOGIC SECTION DC-1
- GF1 GEOLOGIC FEATURE DESCRIBED IN SECTION 7.1.
- M1 MAFIC DIKE DESCRIBED IN SECTION 7.1.
- F1 FELSIC DIKE DESCRIBED IN SECTION 7.1.

NOTES

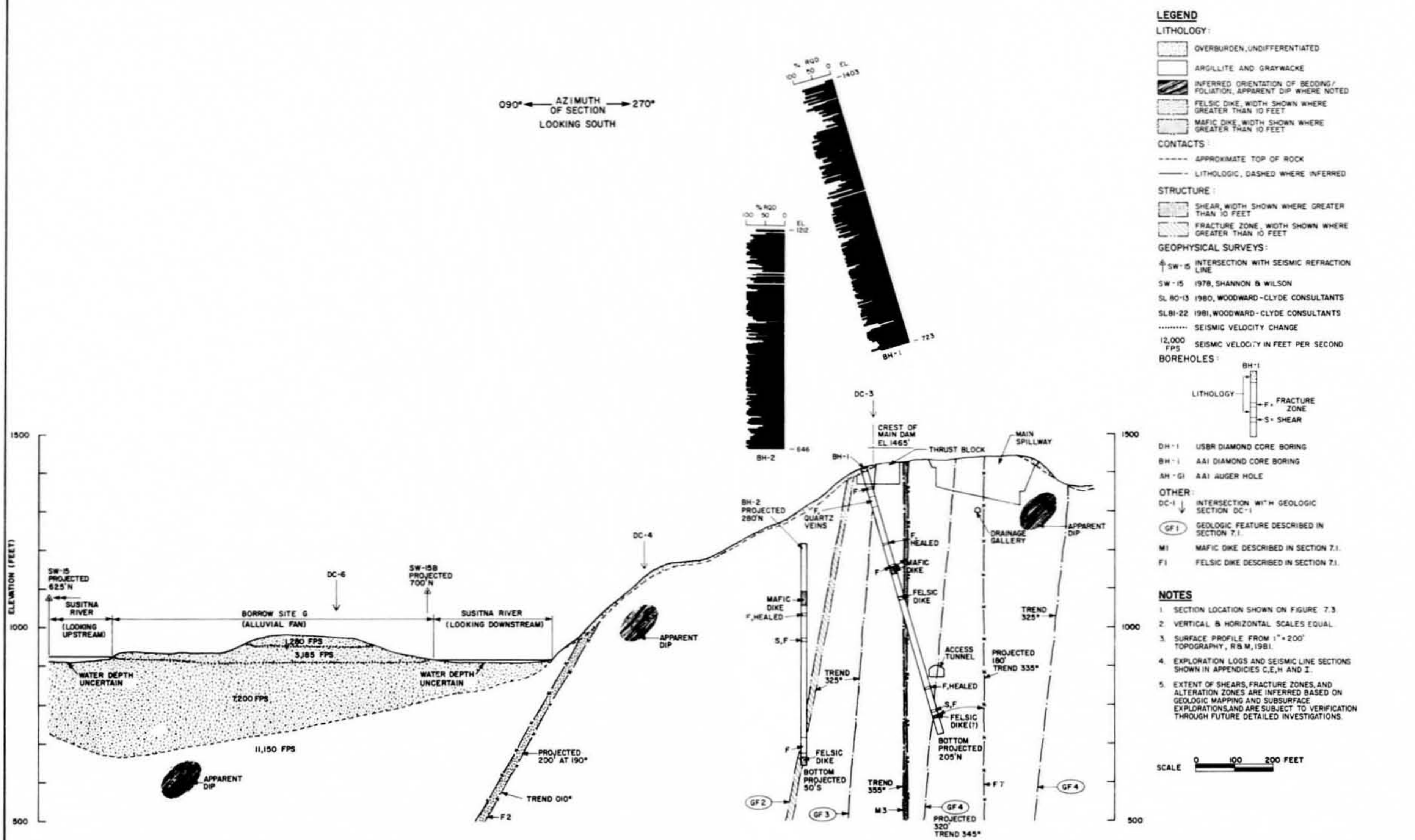
1. SECTION LOCATION SHOWN ON FIGURE 7.3.
2. VERTICAL & HORIZONTAL SCALES EQUAL.
3. SURFACE PROFILE FROM 1" = 200' TOPOGRAPHY, R&M, 1981.
4. EXPLORATION LOGS AND SEISMIC LINE SECTIONS SHOWN IN APPENDICES C,E,H AND I.
5. EXTENT OF SHEARS, FRACTURE ZONES, AND ALTERATION ZONES ARE INFERRED BASED ON GEOLOGIC MAPPING AND SUBSURFACE EXPLORATIONS, AND ARE SUBJECT TO VERIFICATION THROUGH FUTURE DETAILED INVESTIGATIONS.

SCALE 0 100 200 FEET

DEVIL CANYON
GEOLOGIC SECTION DC-1
SHEET 2 OF 2

ACRES

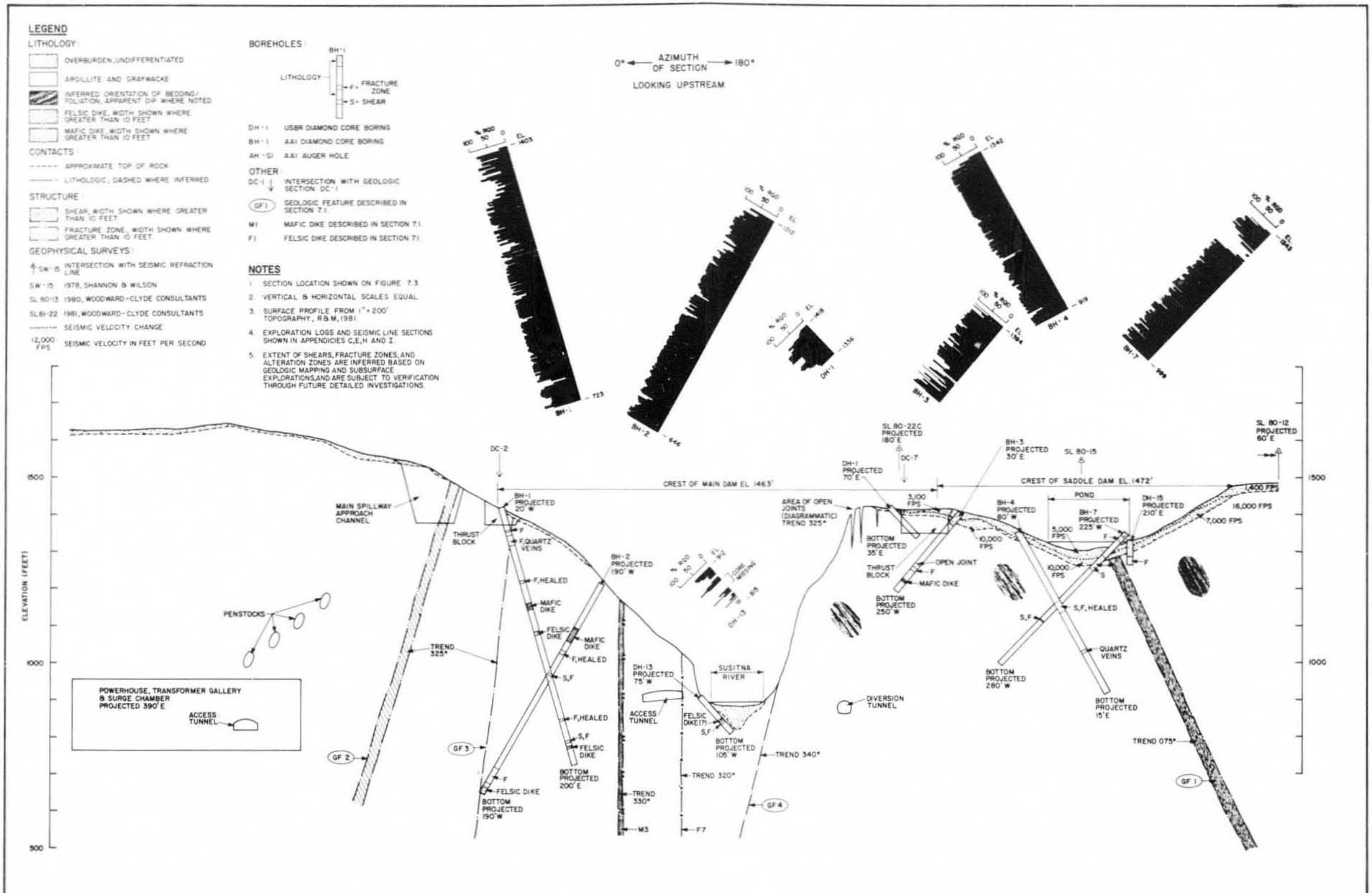
FIGURE 7.4



DEVIL CANYON
GEOLOGIC SECTION DC-2

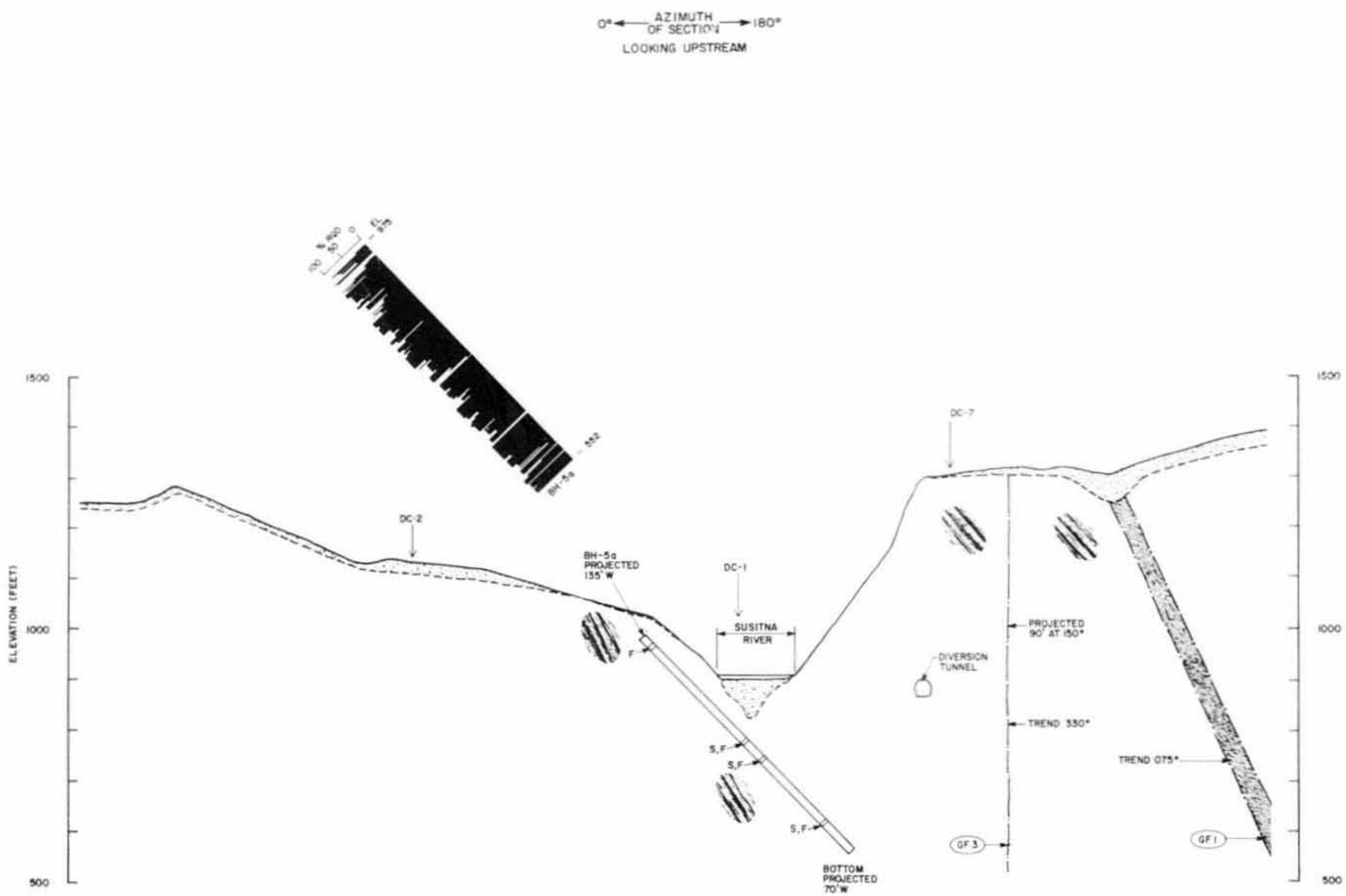
ACRES

FIGURE 7.5



DEVIL CANYON
GEOLOGIC SECTION DC-3

FIGURE 7.6



LEGEND

LITHOLOGY:

- OVERBURDEN, UNDIFFERENTIATED
- ARGILLITE AND GRAYWACKE
- INFERRED ORIENTATION OF BEDDING/ FOLIATION, APPARENT DIP WHERE NOTED
- FELSIC DIKE, WIDTH SHOWN WHERE GREATER THAN 10 FEET
- MAFIC DIKE, WIDTH SHOWN WHERE GREATER THAN 10 FEET

CONTACTS:

- ----- APPROXIMATE TOP OF ROCK
- ——— LITHOLOGIC, DASHED WHERE INFERRED

STRUCTURE:

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

GEOPHYSICAL SURVEYS:

- SW-15 INTERSECTION WITH SEISMIC REFRACTION LINE
- SW-15 1978, SHANNON & WILSON
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- SL81-22 1981, WOODWARD-CLYDE CONSULTANTS
- .... SEISMIC VELOCITY CHANGE
- 12,000 FPS SEISMIC VELOCITY IN FEET PER SECOND

BOREHOLES:

BH-1
LITHOLOGY
F = FRACTURE ZONE
S = SHEAR

- DH-1 USBR DIAMOND CORE BORING
- BH-1 AAI DIAMOND CORE BORING
- AH-G1 AAI AUGER HOLE

OTHER:

- DC-1 INTERSECTION WITH GEOLOGIC SECTION DC-1
- GF1 GEOLOGIC FEATURE DESCRIBED IN SECTION 7.1.
- M1 MAFIC DIKE DESCRIBED IN SECTION 7.1.
- F1 FELSIC DIKE DESCRIBED IN SECTION 7.1.

NOTES

1. SECTION LOCATION SHOWN ON FIGURE 7.3.
2. VERTICAL & HORIZONTAL SCALES EQUAL.
3. SURFACE PROFILE FROM 1" = 200' TOPOGRAPHY, R&M, 1981.
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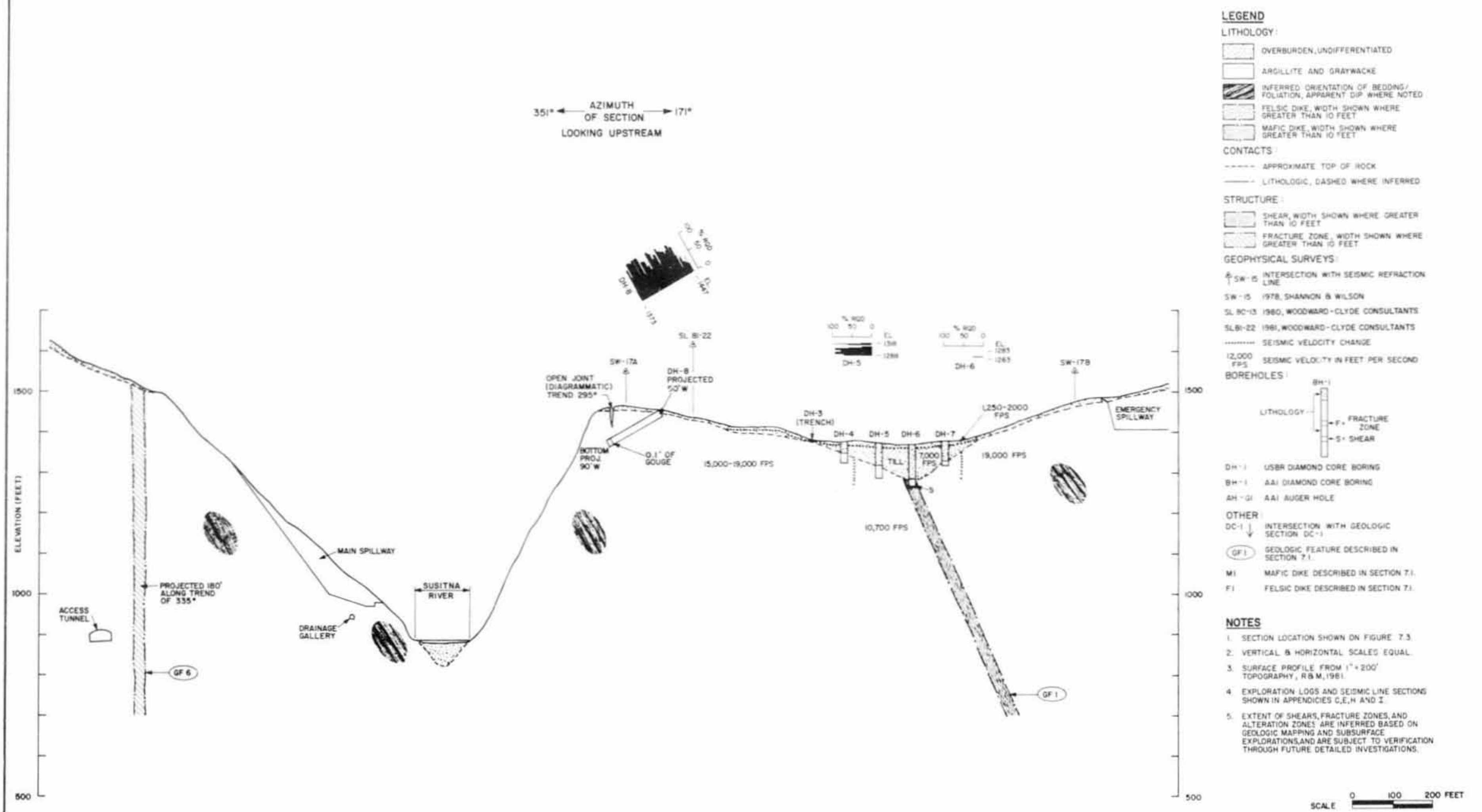
SCALE 0 100 200 FEET

DEVIL CANYON
GEOLOGIC SECTION DC-4

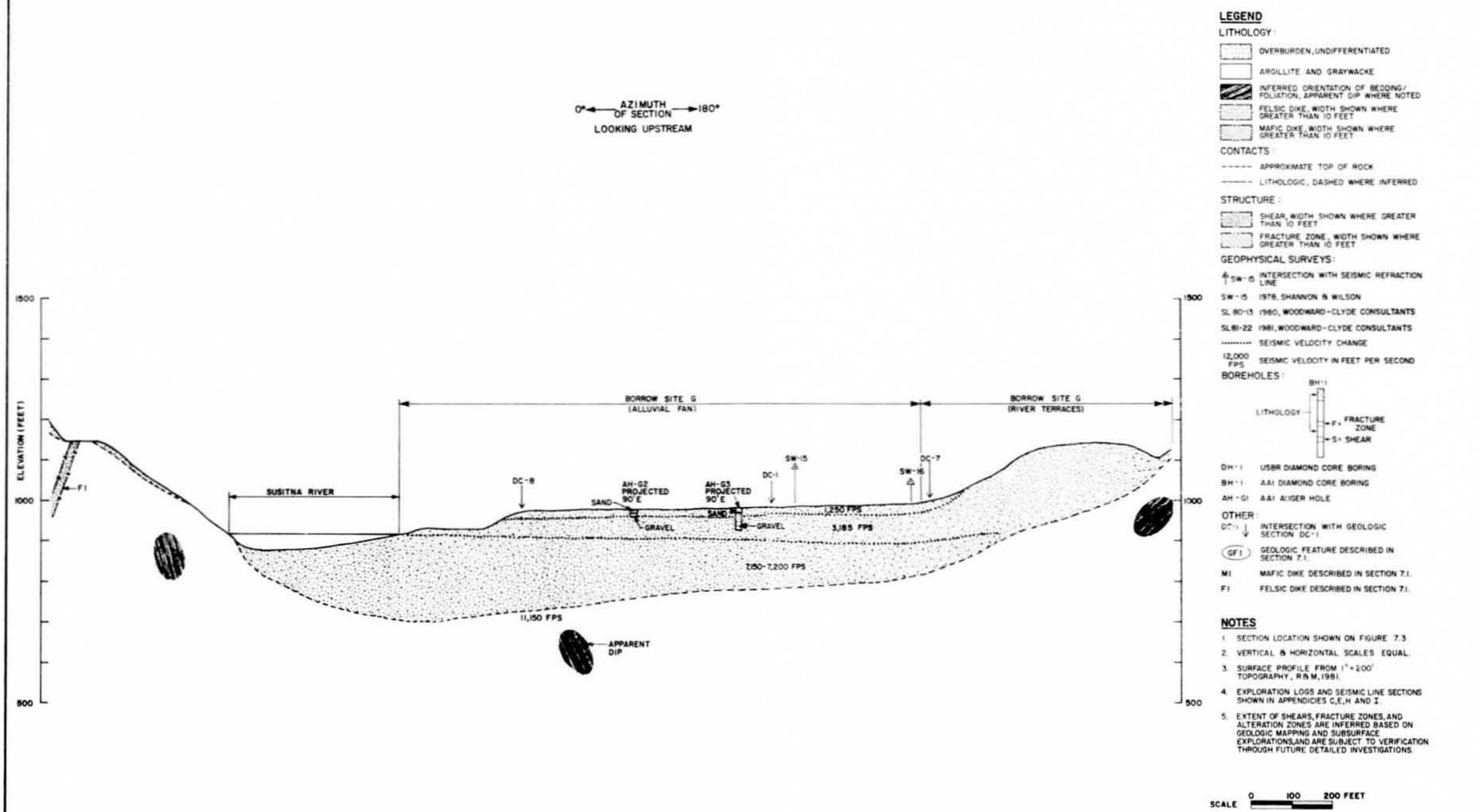
FIGURE 7.7

ACRES



DEVIL CANYON
GEOLOGIC SECTION DC-5

FIGURE 7.8



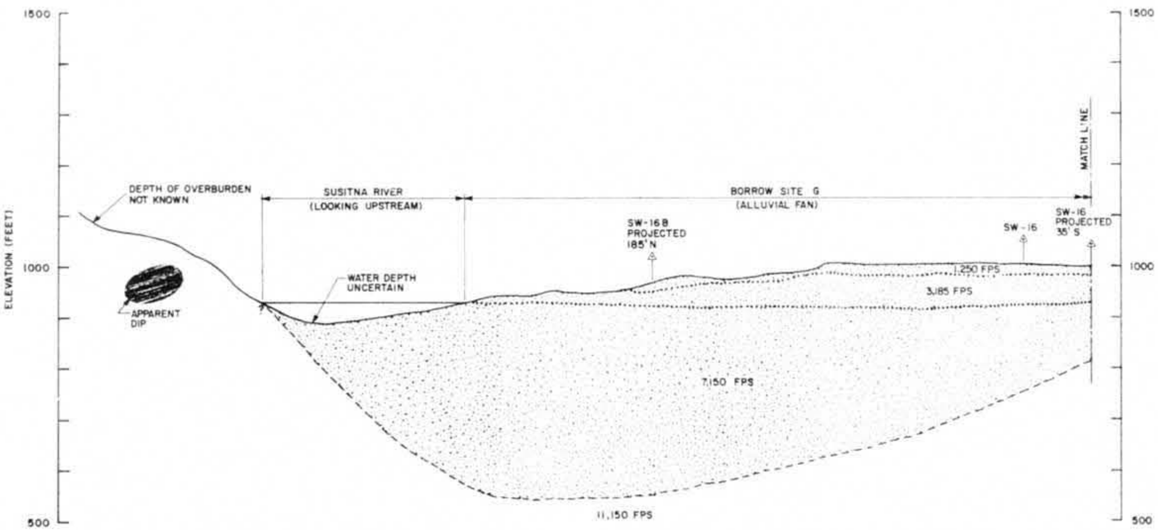
DEVIL CANYON
GEOLOGIC SECTION DC-6

ACRES

FIGURE 7.9

088° ← AZIMUTH OF SECTION → 268°

LOOKING SOUTH



LEGEND

LITHOLOGY:

- OVERBURDEN, UNDIFFERENTIATED
- ARGILLITE AND GRAYWACKE
- INFERRED ORIENTATION OF BEDDING/ FOLIATION, APPARENT DIP WHERE NOTED
- FELSIC DIKE, WIDTH SHOWN WHERE GREATER THAN 10 FEET
- MAFIC DIKE, WIDTH SHOWN WHERE GREATER THAN 10 FEET

CONTACTS:

- APPROXIMATE TOP OF ROCK
- LITHOLOGIC, DASHED WHERE INFERRED

STRUCTURE:

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

GEOPHYSICAL SURVEYS:

SW-15 INTERSECTION WITH SEISMIC REFRACTION LINE

SW-15 1978, SHANNON & WILSON

SL 80-13 1980, WOODWARD-CLYDE CONSULTANTS

SL81-22 1981, WOODWARD-CLYDE CONSULTANTS

SEISMIC VELOCITY CHANGE

12,000 FPS SEISMIC VELOCITY IN FEET PER SECOND

BOREHOLES:

BH-1

LITHOLOGY

F= FRACTURE ZONE

S= SHEAR

DH-1 USBR DIAMOND CORE BORING

BH-1 AAI DIAMOND CORE BORING

AH-G1 AAI AUGER HOLE

OTHER:

DC-1 INTERSECTION WITH GEOLOGIC SECTION DC-1

GF1 GEOLOGIC FEATURE DESCRIBED IN SECTION 7.1

M1 MAFIC DIKE DESCRIBED IN SECTION 7.1

F1 FELSIC DIKE DESCRIBED IN SECTION 7.1

NOTES

1. SECTION LOCATION SHOWN ON FIGURE 7.3
2. VERTICAL & HORIZONTAL SCALES EQUAL
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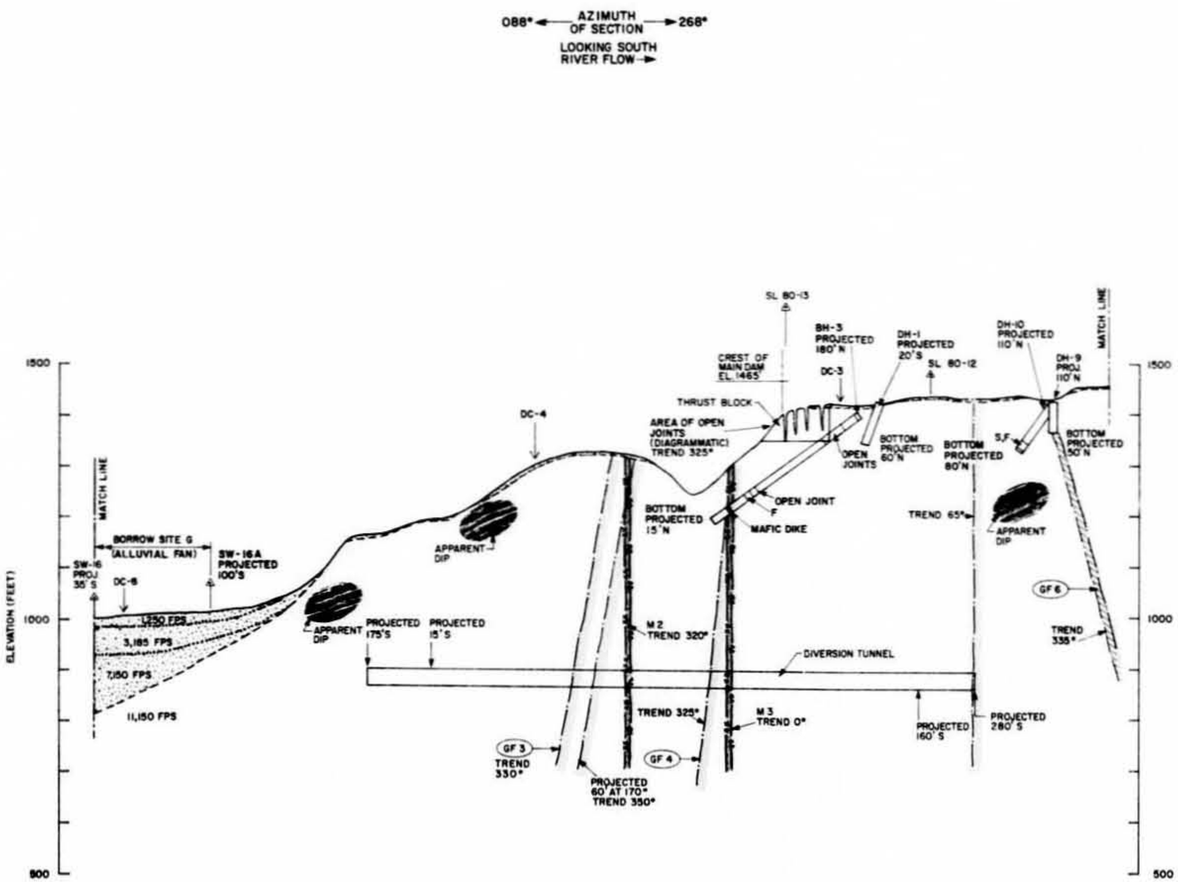
SCALE 0 100 200 FEET

DEVIL CANYON
GEOLOGIC SECTION DC-7
SHEET 1 OF 3

FIGURE 7.10

ACRES



LEGEND

LITHOLOGY:

- OVERBURDEN, UNDIFFERENTIATED
- ARGILLITE AND GRAYWACKE
- INFERRED ORIENTATION OF BEDDING/FOLIATION, APPARENT DIP WHERE NOTED
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- MAFIC DIKE, WIDTH SHOWN WHERE GREATER THAN 10 FEET

CONTACTS:

- APPROXIMATE TOP OF ROCK
- LITHOLOGIC, DASHED WHERE INFERRED

STRUCTURE:

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

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- SL81-22 1981, WOODWARD-CLYDE CONSULTANTS
- SEISMIC VELOCITY CHANGE
- 12,000 FPS SEISMIC VELOCITY IN FEET PER SECOND

BOREHOLES:

BH-1
LITHOLOGY
F = FRACTURE ZONE
S = SHEAR

- DH-1 USBR DIAMOND CORE BORING
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- AH-G1 AAI AUGER HOLE

OTHER:

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- GF1 GEOLOGIC FEATURE DESCRIBED IN SECTION 7.1.
- M1 MAFIC DIKE DESCRIBED IN SECTION 7.1.
- F1 FELSIC DIKE DESCRIBED IN SECTION 7.1.

NOTES

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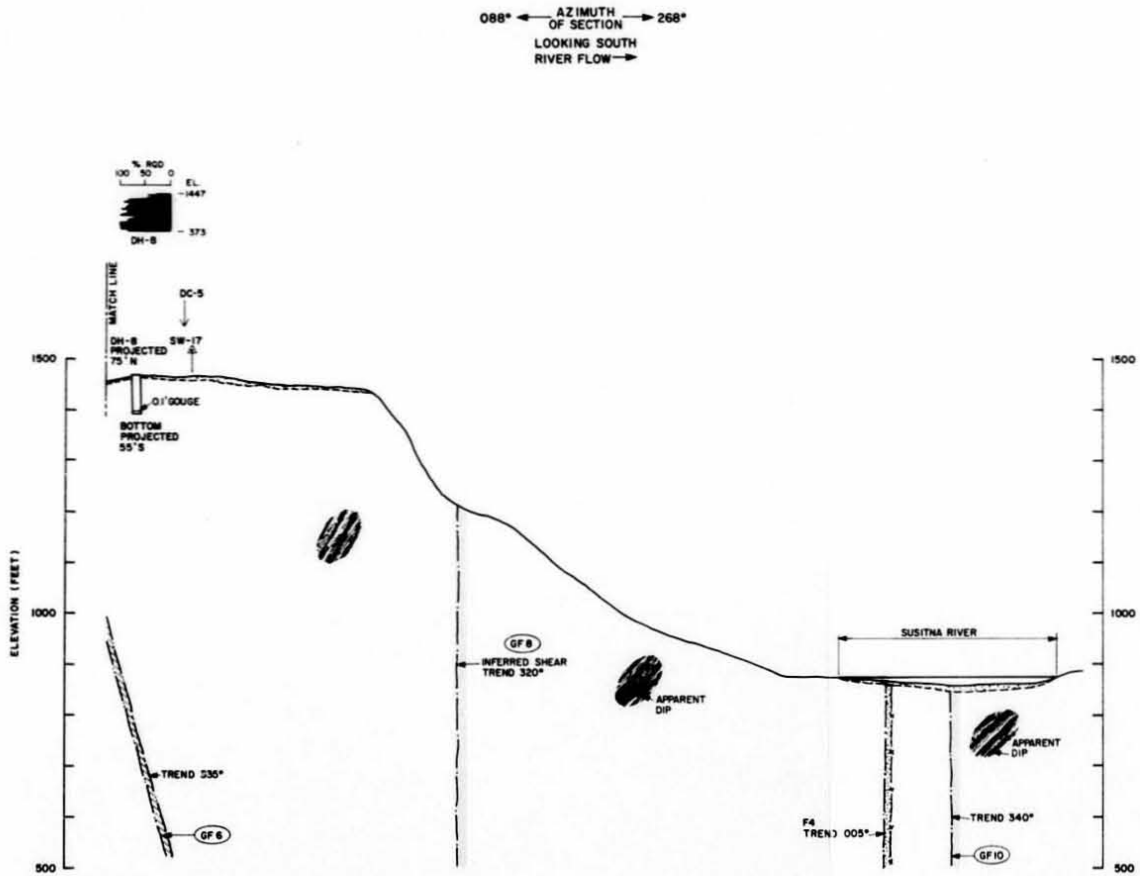
SCALE 0 100 200 FEET

DEVIL CANYON
GEOLOGIC SECTION DC-7
SHEET 2 OF 3

ACRES

FIGURE 7.10



LEGEND

LITHOLOGY:

- OVERBURDEN, UNDIFFERENTIATED
- ARGILLITE AND GRAYWACKE
- INFERRED ORIENTATION OF BEDDING/FOLIATION, APPARENT DIP WHERE NOTED
- FELSIC DIKE, WIDTH SHOWN WHERE GREATER THAN 10 FEET
- MAFIC DIKE, WIDTH SHOWN WHERE GREATER THAN 10 FEET

CONTACTS:

- ----- APPROXIMATE TOP OF ROCK
- —— LITHOLOGIC, DASHED WHERE INFERRED

STRUCTURE:

- SHEAR, WIDTH SHOWN WHERE GREATER THAN 10 FEET
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GEOPHYSICAL SURVEYS:

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- SL81-22 1981, WOODWARD-CLYDE CONSULTANTS
- .... SEISMIC VELOCITY CHANGE
- 12,000 FPS SEISMIC VELOCITY IN FEET PER SECOND

BOREHOLES:

BH-1
LITHOLOGY
F+ FRACTURE ZONE
S+ SHEAR

- DH-1 USBR DIAMOND CORE BORING
- BH-1 AAI DIAMOND CORE BORING
- AH-G1 AAI AUGER HOLE

OTHER:

- DC-1 INTERSECTION WITH GEOLOGIC SECTION DC-1
- GF1 GEOLOGIC FEATURE DESCRIBED IN SECTION 7.1.
- M1 MAFIC DIKE DESCRIBED IN SECTION 7.1.
- F1 FELSIC DIKE DESCRIBED IN SECTION 7.1.

NOTES

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SCALE 0 100 200 FEET

DEVIL CANYON
GEOLOGIC SECTION DC-7
SHEET 3 OF 3

FIGURE 7.10

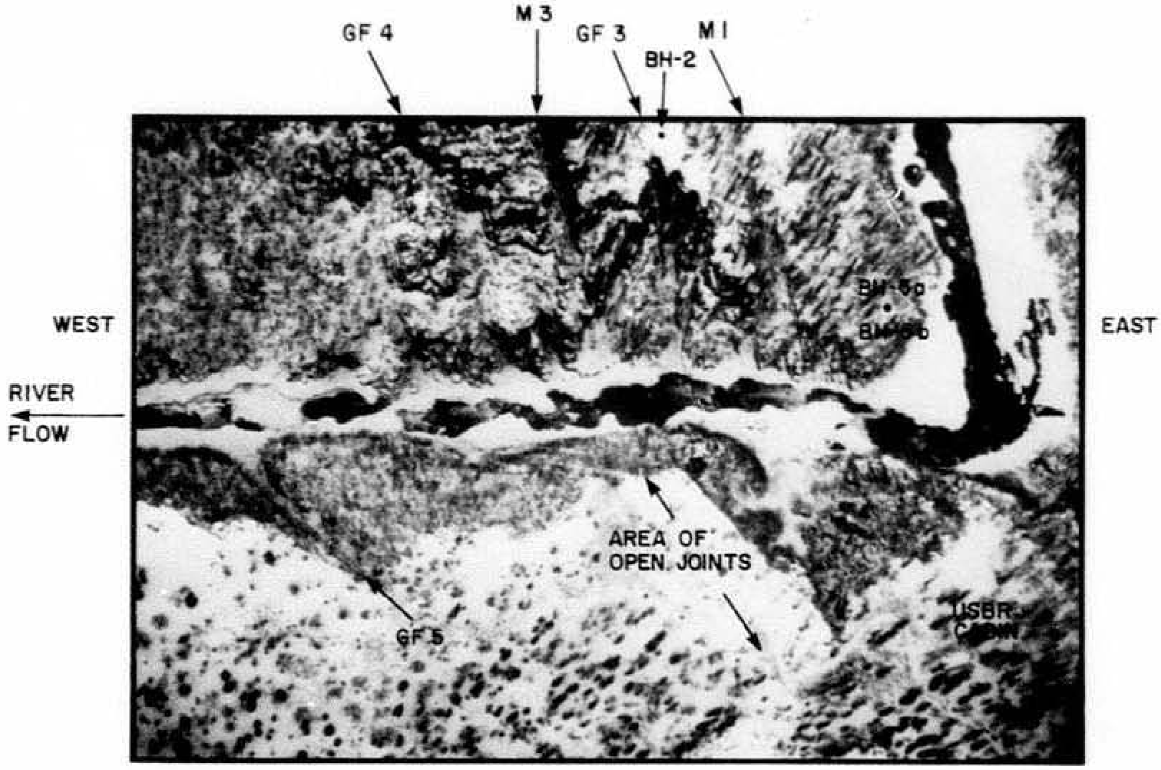
ACRES

ACROSS RIVER FROM CHEECHAKO CREEK
RIVER LEVEL-NORTH BANK

NOTES:
1. GRADED BEDS OF ARGILLITE/GRAYWACKE.
2. STRATIGRAPHIC TOP TO LOWER LEFT.

DEVIL CANYON
TYPICAL ARGILLITE/GRAYWACKE

FIGURE 7.11



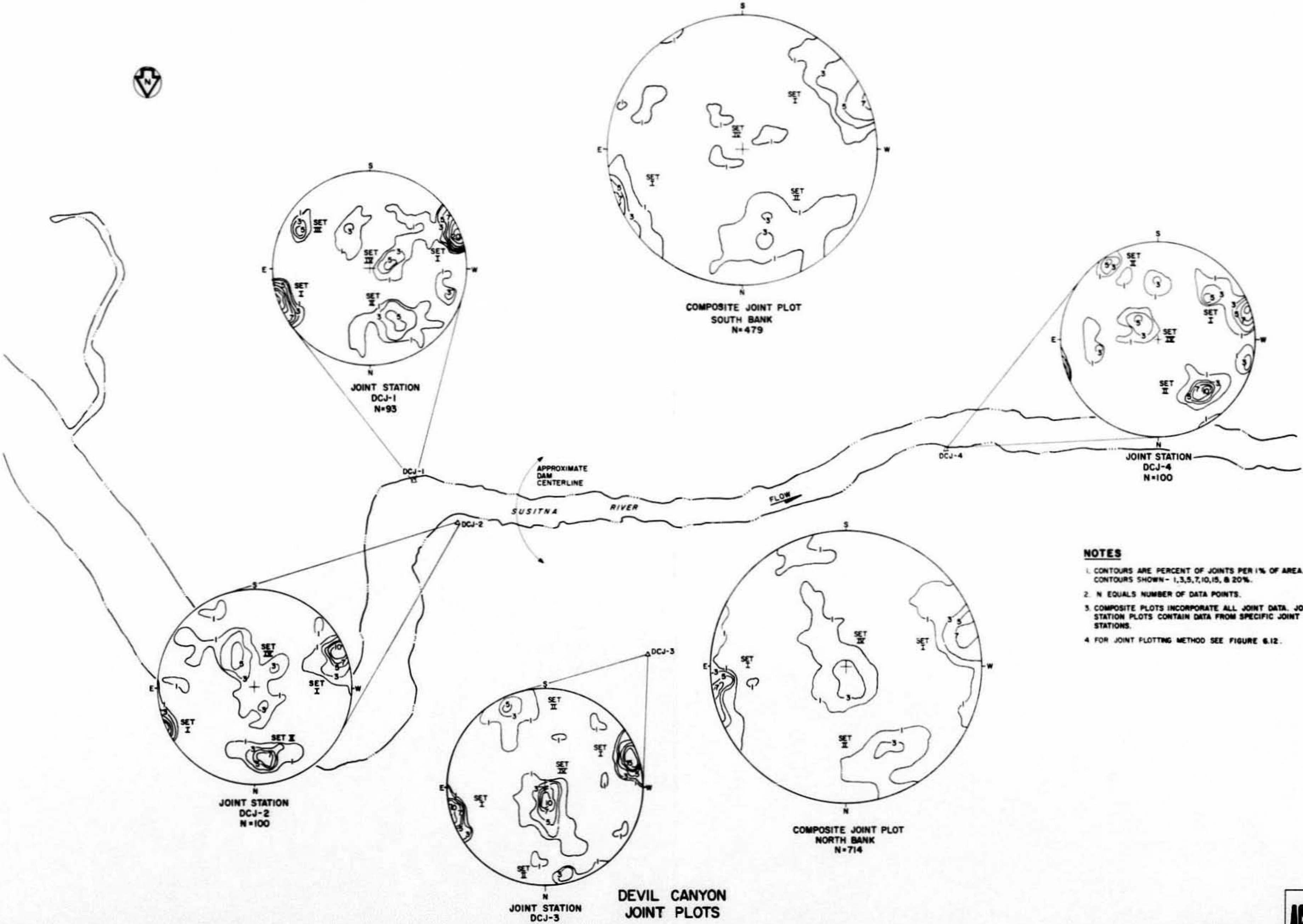
NOTES:

1. DIKES M I AND M 3 DESCRIBED IN SECTION 7.1.
2. GEOLOGIC FEATURES GF 3, GF 4, AND GF 5 DESCRIBED IN SECTION 7.1.

DEVIL CANYON
AERIAL VIEW OF SITE

ACRES

FIGURE 7.12

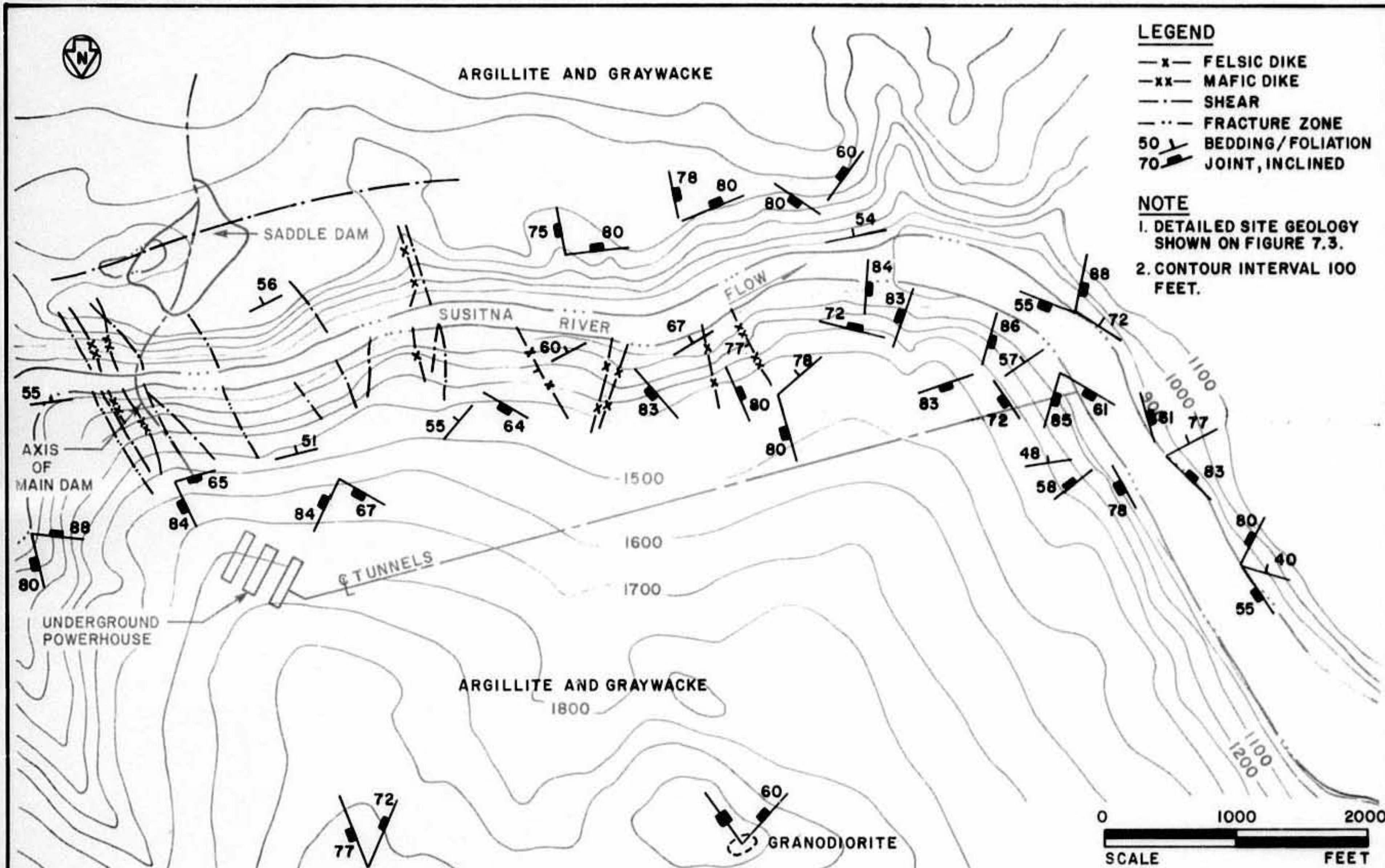


NOTES

1. CONTOURS ARE PERCENT OF JOINTS PER 1% OF AREA. CONTOURS SHOWN - 1,3,5,7,10,15, & 20%.
2. N EQUALS NUMBER OF DATA POINTS.
3. COMPOSITE PLOTS INCORPORATE ALL JOINT DATA. JOINT STATION PLOTS CONTAIN DATA FROM SPECIFIC JOINT STATIONS.
4. FOR JOINT PLOTTING METHOD SEE FIGURE 6.12.

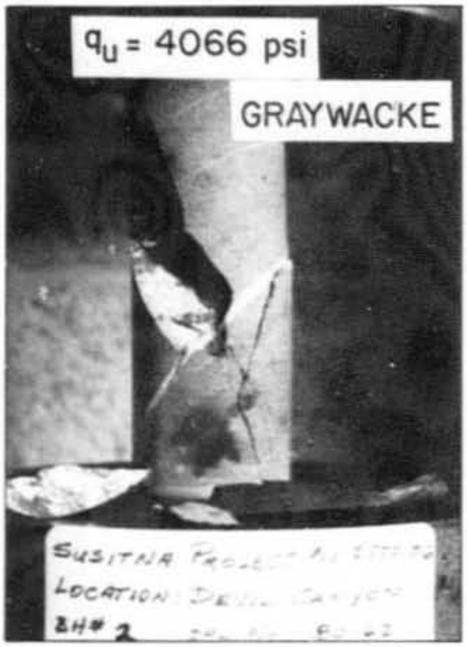
DEVIL CANYON
JOINT PLOTS

FIGURE 7.13

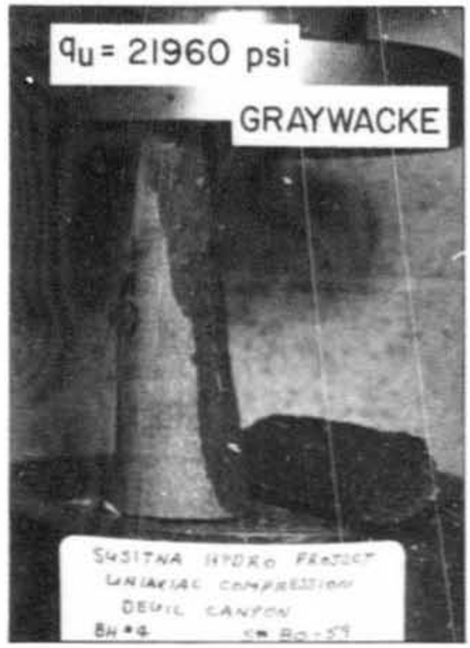


DEVIL CANYON
TAILRACE GEOLOGIC MAP

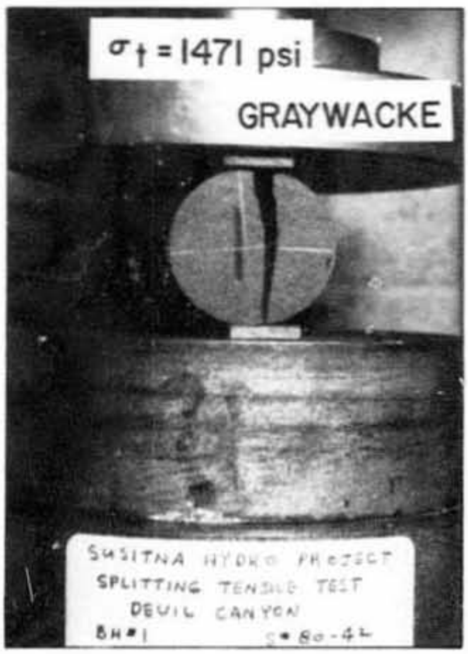
FIGURE 7.14



COMPRESSION TEST FAILURE
ALONG HEALED DISCONTINUITY



COMPRESSION TEST FAILURE
THROUGH INTACT ROCK



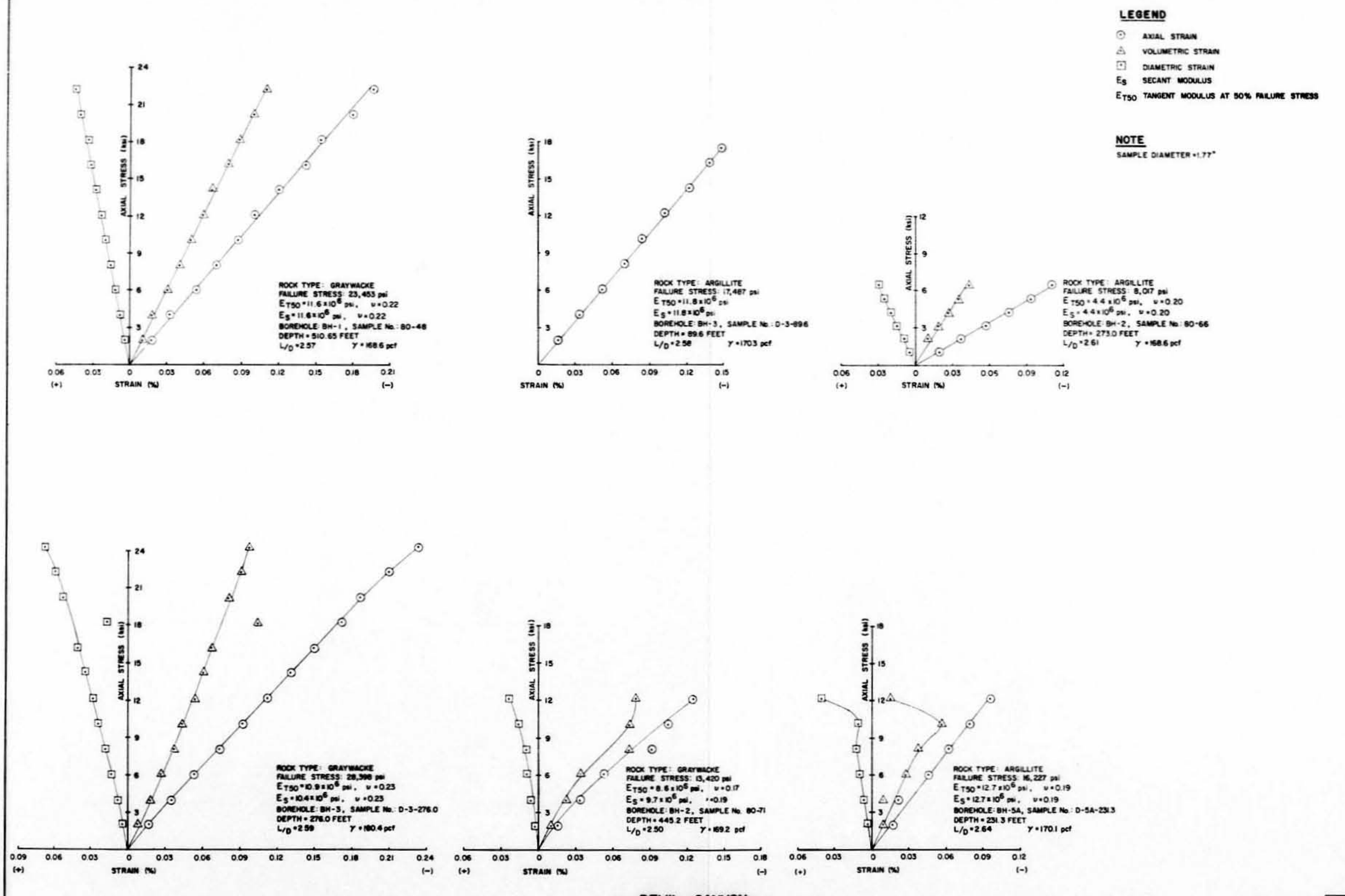
TYPICAL TENSILE STRENGTH TEST

TYPICAL COMPRESSION TEST
WITH STRESS-STRAIN READINGS

DEVIL CANYON
ROCK TESTS

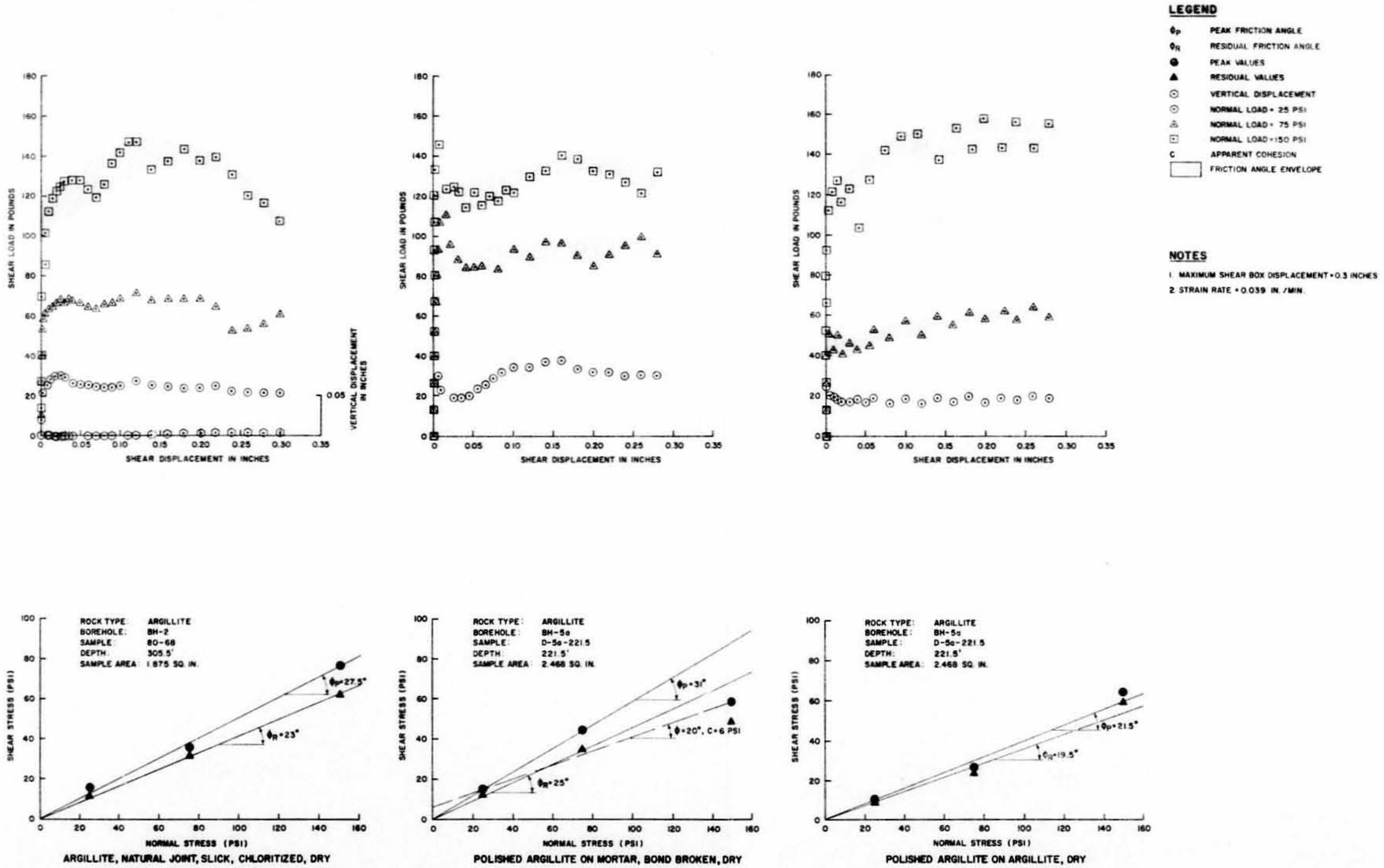
ACRES

FIGURE 7.15



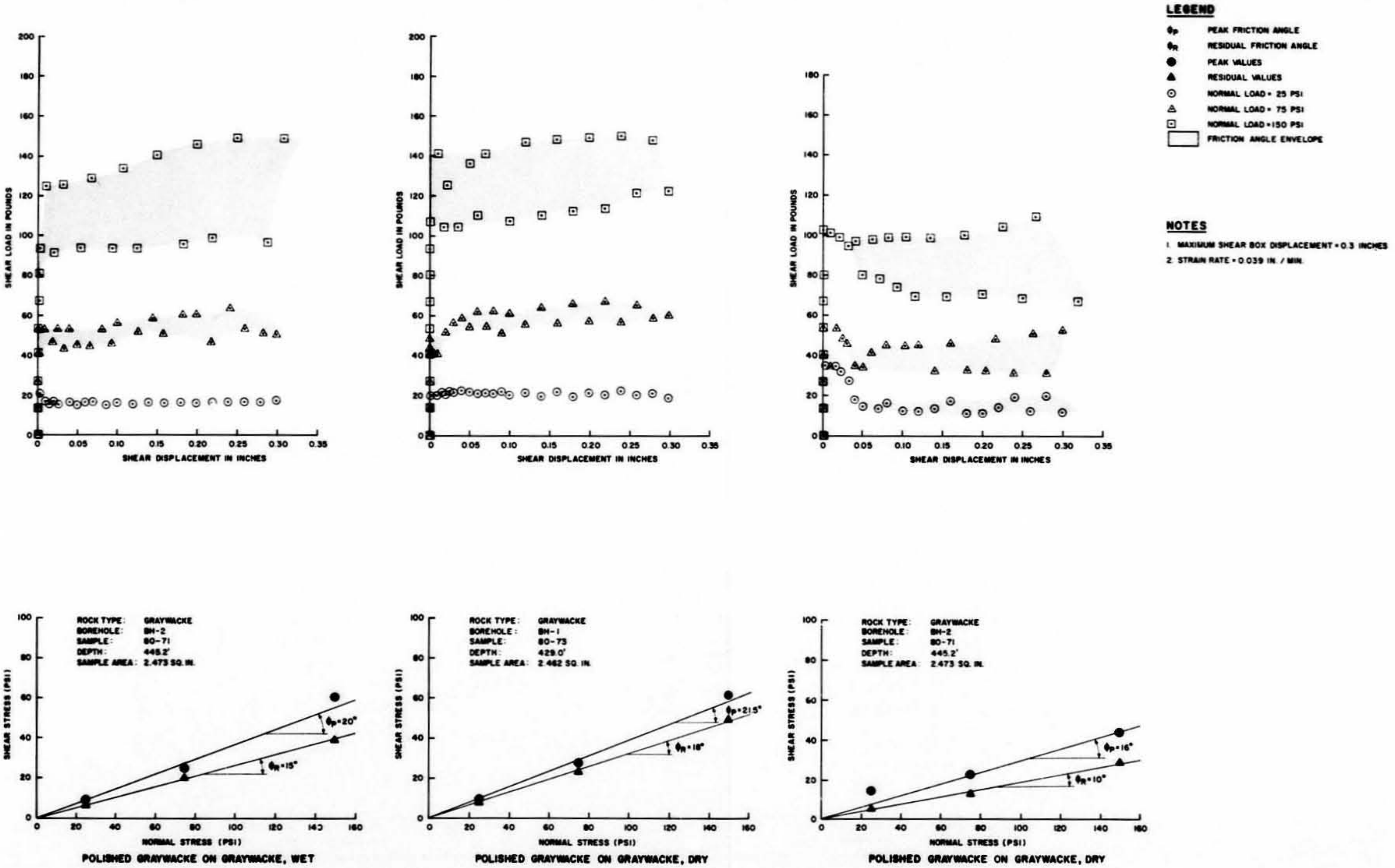
DEVIL CANYON
STATIC ELASTIC PROPERTIES
FOR ARGILLITE AND GRAYWACKE

FIGURE 7.16



DEVIL CANYON
DIRECT SHEAR TESTS
SHEET 1 OF 3

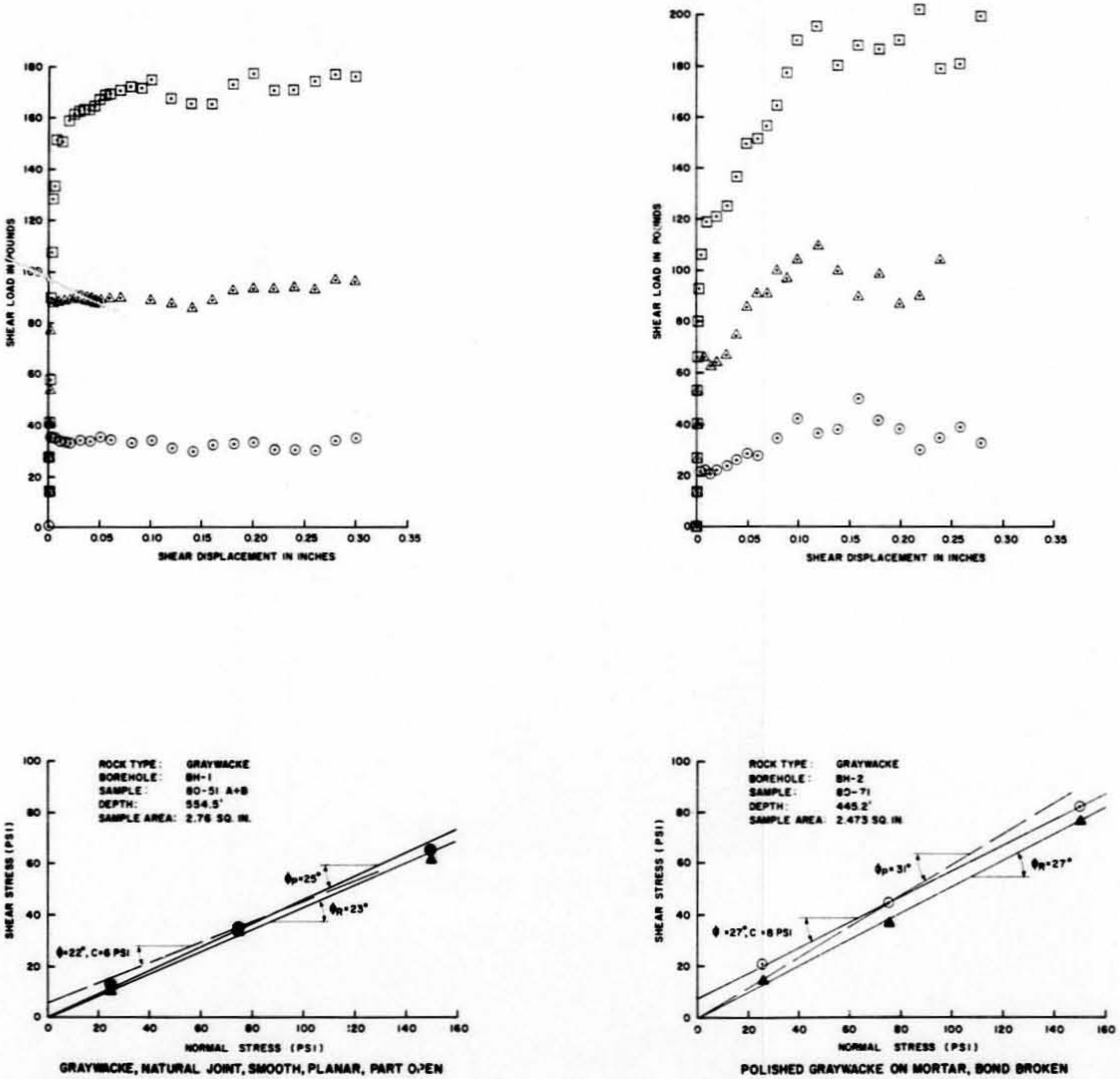
FIGURE 7.17



DEVIL CANYON
DIRECT SHEAR TESTS
SHEET 2 OF 3

ACRES

FIGURE 7.17



LEGEND

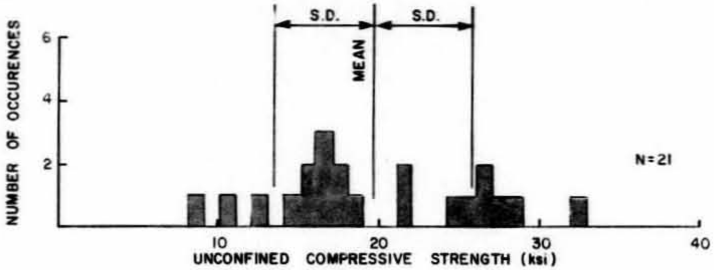
- ϕ_P PEAK FRICTION ANGLE
- ϕ_R RESIDUAL FRICTION ANGLE
- ● PEAK VALUES
- ▲ RESIDUAL VALUES
- ⊙ NORMAL LOAD = 25 PSI
- △ NORMAL LOAD = 75 PSI
- ⊡ NORMAL LOAD = 150 PSI
- C APPARENT COHESION

NOTES

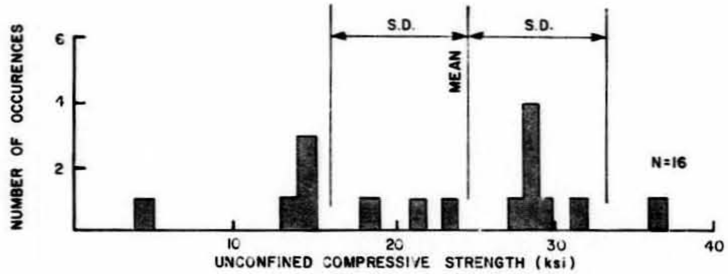
1. MAXIMUM SHEAR BOX DISPLACEMENT = 0.3 INCHES
2. STRAIN RATE = 0.039 IN. / MIN.

DEVIL CANYON
DIRECT SHEAR TESTS
SHEET 3 OF 3

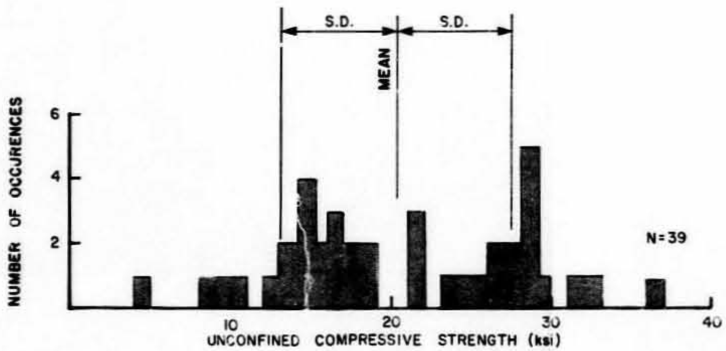
FIGURE 7.17



ARGILLITE (AAI, USBR)



GRAYWACKE (AAI, USBR)



ALL TESTS (AAI, USBR)

ROCK	N
ARGILLITE	21
GRAYWACKE	16
MAFIC DIKE	2
TOTAL = 39	

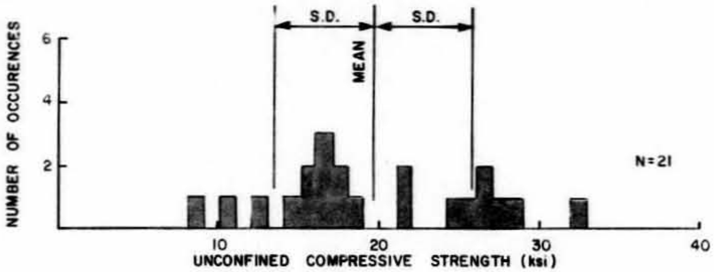
LEGEND

N - NUMBER OF TESTS
S.D. - STANDARD DEVIATION

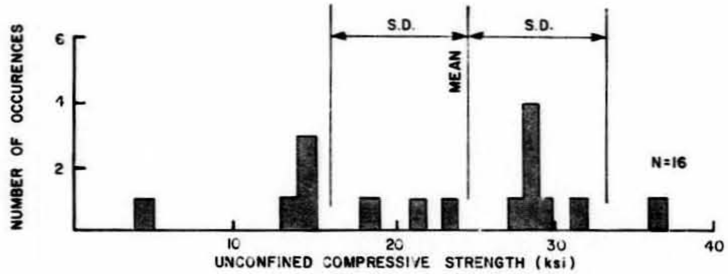
DEVIL CANYON
UNCONFINED COMPRESSIVE STRENGTH TEST RESULTS

RENCE: LAB REPORT C-933, USBR 1960

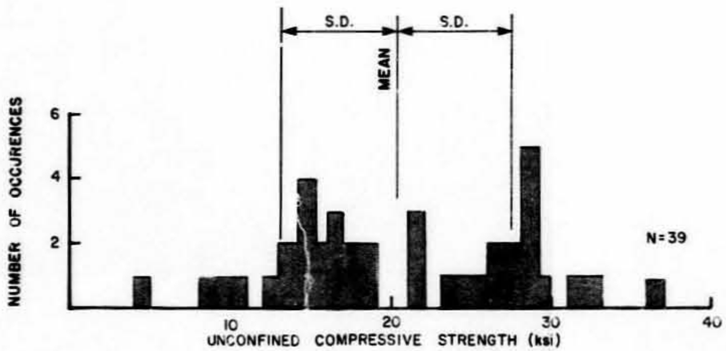
FIGURE 7.18



ARGILLITE (AAI, USBR)



GRAYWACKE (AAI, USBR)



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ROCK	N
ARGILLITE	21
GRAYWACKE	16
MAFIC DIKE	2
TOTAL = 39	

LEGEND

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DEVIL CANYON
UNCONFINED COMPRESSIVE STRENGTH TEST RESULTS

RENCE: LAB REPORT C-933, USBR 1960

FIGURE 7.18

LEGEND

N - NUMBER OF TESTS
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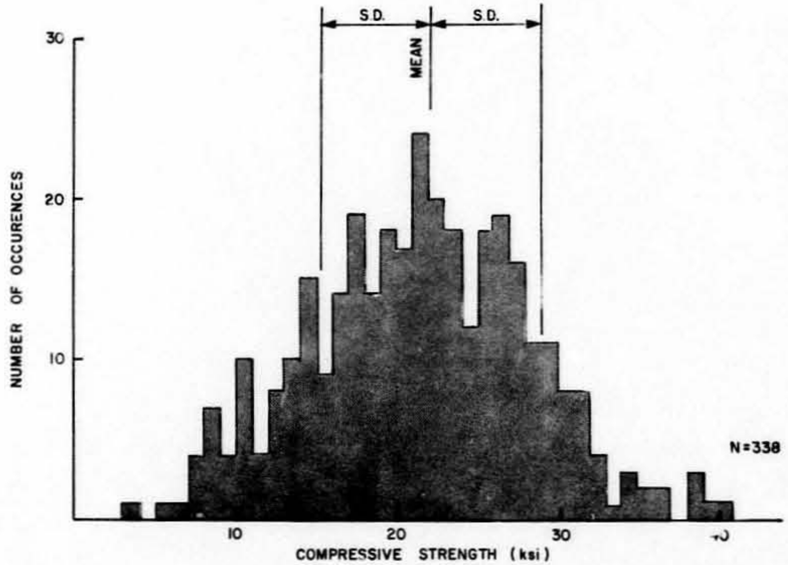
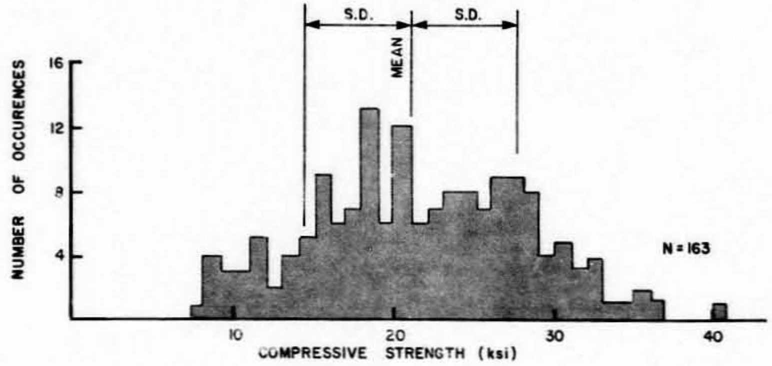
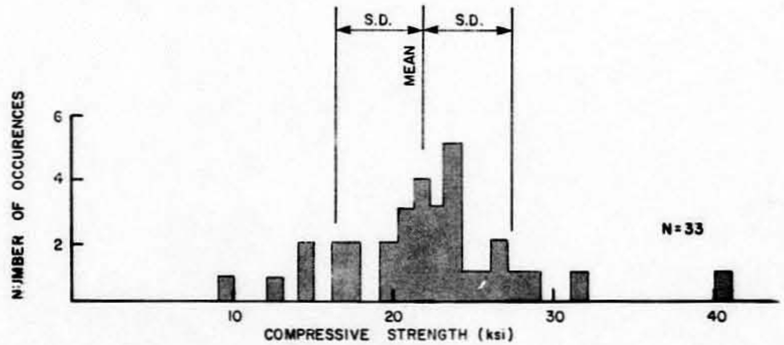


ALL DATA



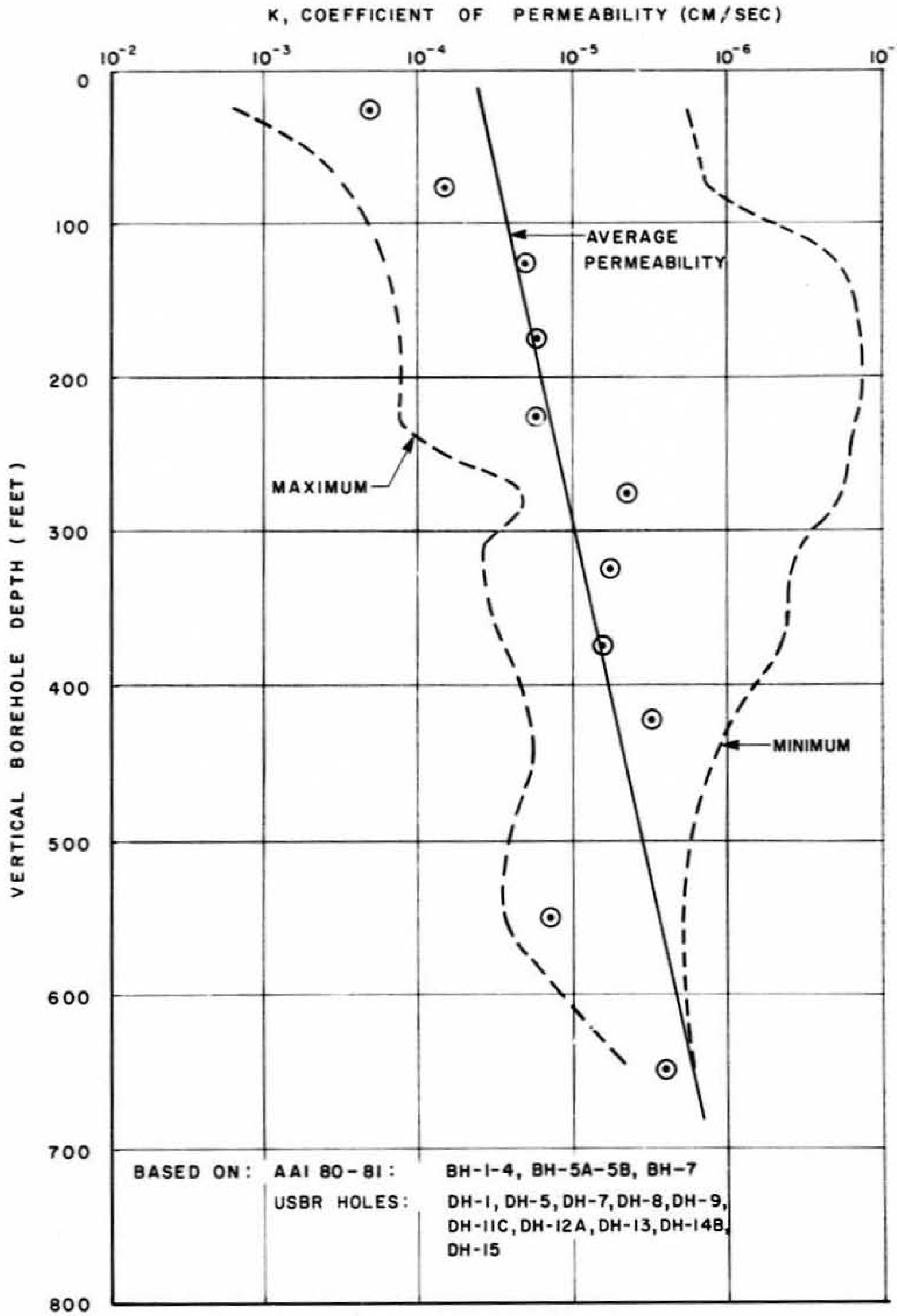
INTERBEDDED ARGILLITE AND GRAYWACKE



GRAYWACKE

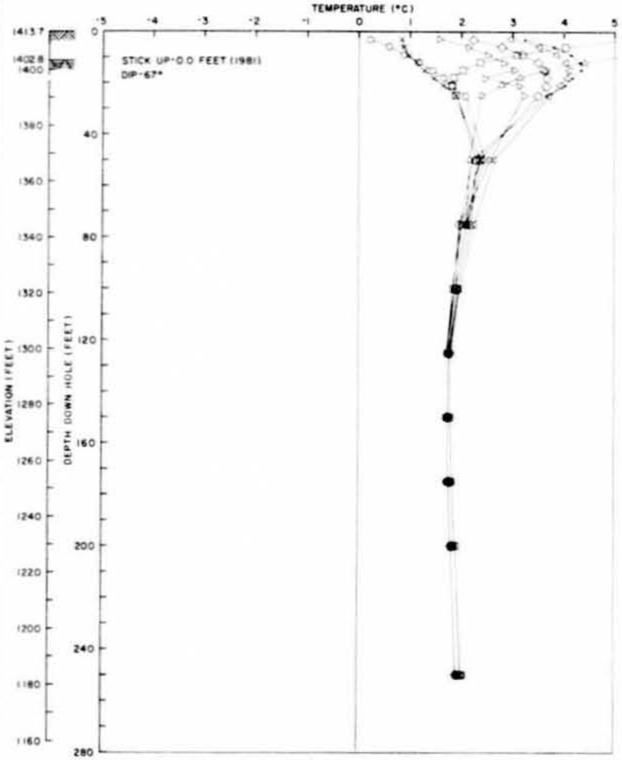
DEVIL CANYON
POINT LOAD TEST DATA

FIGURE 7.19

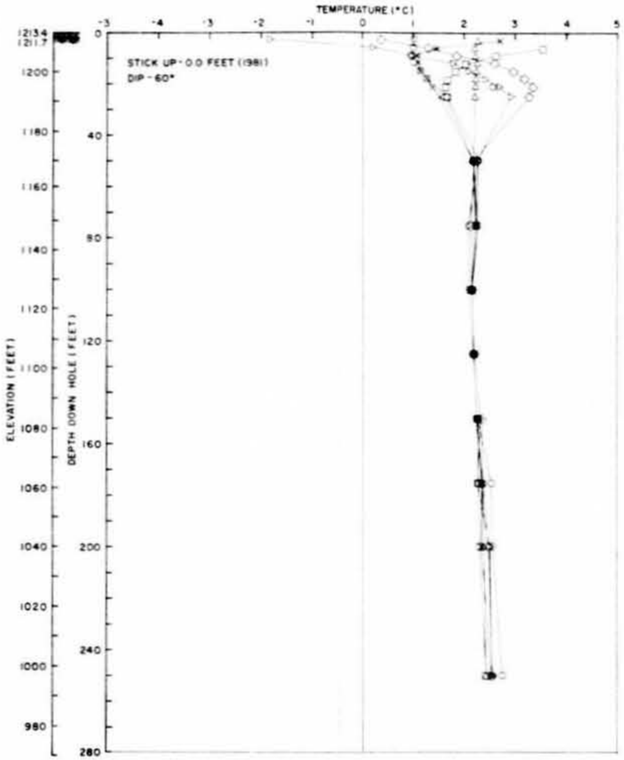


DEVIL CANYON ROCK PERMEABILITY

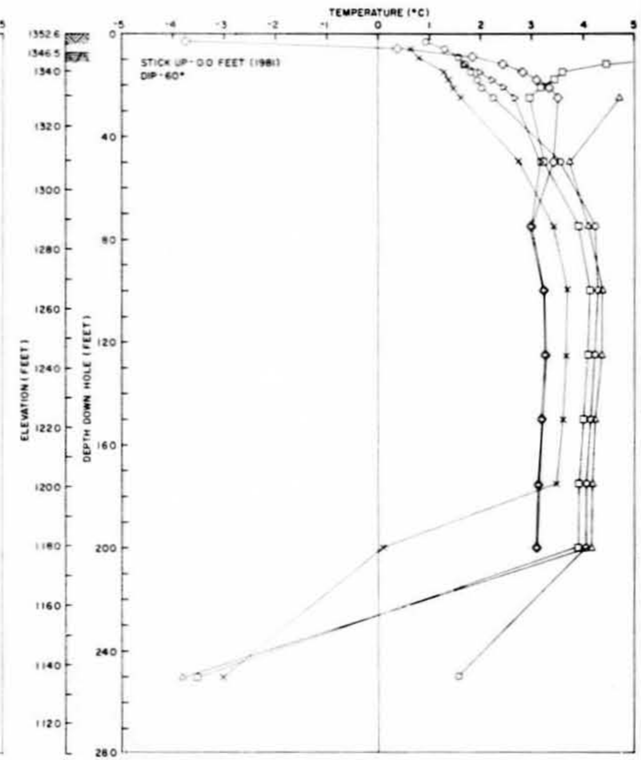
FIGURE 7.20



BH-1



BH-2



BH-4

NOTE: DUE TO PROBLEMS ENCOUNTERED IN FIELD MEASUREMENTS, THE FOLLOWING ADJUSTMENTS WERE PERFORMED TO CONFORM TO EXISTING RELIABLE DATA. THESE FIXED LATERAL SHIFTS MAY NOT CORRECT THE FULL MAGNITUDE OF THE DISCREPANCIES.

DATE OF READING	ADJUSTMENT SUBTRACTED FROM CALCULATED READING (°C)
4-26-81	13.28
5-24-81	14.00
6-24-81	16.00
8-3-81	14.65

NOTE: THERMISTOR DATA FOR 5-24-81 IS QUESTIONABLE AT 200 AND 250 FEET. SENSOR AT 250 FEET WAS ERRATIC FOR 1-7-82 READING.

SCALE

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

LEGEND

LITHOLOGY:

- GROUND SURFACE
- TOP OF ROCK

BOREHOLES:

- AH AUGER HOLE — ACRES AMERICAN INCORPORATED
- BH BORE HOLE — ACRES AMERICAN INCORPORATED

DATA SOURCES:

INDEX OF THERMISTOR READING DATES:

- ◁ NOVEMBER 21, 1980
- ○ APRIL 19, 1981
- × MAY 24, 1981
- □ JUNE 24, 1981
- △ AUGUST 3, 1981
- • NOVEMBER 13, 1981
- ◇ DECEMBER 9, 1981
- ▷ JANUARY 7, 1982

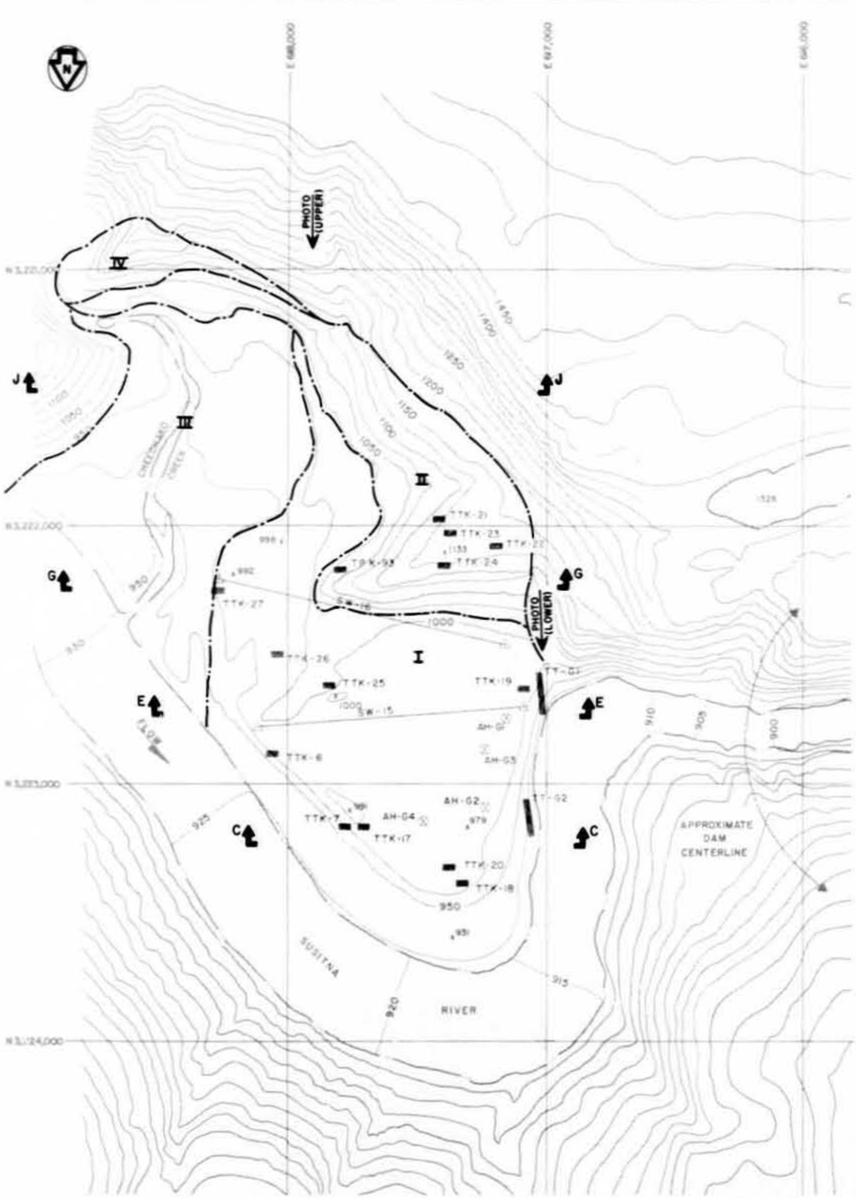
NOTES

1. LOCATION OF HOLES SHOWN ON FIGURE 5.2.
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 BOX-KEITHLEY 172 A, USED FOR 1980 THRU 1982 READINGS.
5. AUGER HOLES AH-G11 THRU AH-G14 CONTAIN THERMISTOR PROBES, BUT NO DATA WAS OBTAINED.
6. BORINGS ARE VERTICAL UNLESS A DIP IS INDICATED.

DEVIL CANYON
THERMISTOR DATA-DAMSITE

ACRES

FIGURE 7.21



LEGEND

CONTACTS:

MAPPED LIMIT OF BORROW SITE OR ZONE

BOREHOLES AND TEST PITS:

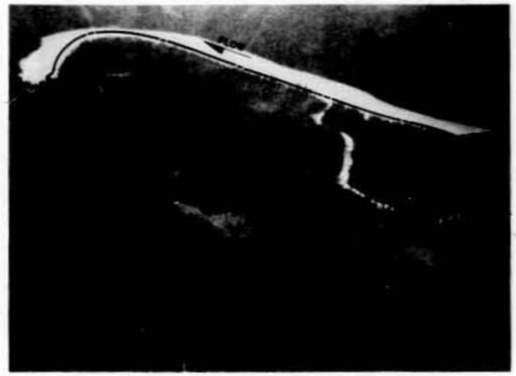
AH-G1	1980-81, AAI	AUGER BORING
TTK-17, TPK-93	1958, USBR	DOZER TRENCH
TT-G1	1981, AAI	DOZER TRENCH

GEOPHYSICAL SURVEYS:

SW-15 SEISMIC REFRACTION SURVEY END OR TURNING POINT – 1978, SHANNON & WILSON

OTHER:

E E CROSS SECTION LOCATION (SEE NOTE 2)



BORROW SITE G
(LOOKING NORTH)

NOTES

1. TYPICAL SECTIONS SHOWN ON FIGURE 7.23
2. FOR DETAILED GEOLOGY AND GEOLOGIC SECTIONS, SEE FIGURES 7.3 AND 7.4 THROUGH 7.10
3. SURFICIAL GEOLOGY SHOWN ON FIGURE 7.2.
4. 25 FOOT CONTOUR INTERVAL ADDED FROM SOURCE MAP (REFERENCED) IN BORROW SITE ONLY.
5. BORROW SITE LIMITS BASED ON FIELD AND AIR PHOTO INTERPRETATION OF BORROW MATERIAL. FINAL LIMITS, SUBJECT TO RESULTS OF DESIGN INVESTIGATIONS.
6. BORROW MATERIAL ZONES INDICATE MAPPED VARIATIONS IN MATERIAL TYPE.
   - ZONE I ALLUVIAL FAN / TERRACE DEPOSIT OF SAND AND GRAVELS.
   - ZONE II RIVER TERRACES, SIMILAR TO MATERIAL I.
   - ZONE III CHEECHAKO CREEK OUTWASH, BOULDERY GRAVELS.
   - ZONE IV ARGILLITE / GRAYWACKE TALUS DEPOSITS.
7. ENTIRE BORROW SITE LIES WITHIN PROPOSED DEVIL CANYON RESERVOIR LIMITS.
8. USBR, COE EXPLORATION LOGS AS REFERENCED.
9. AAI EXPLORATION LOGS SHOWN IN APPENDIX G.
10. PHOTOS TAKEN AUGUST, 1981.

TEST TRENCH TT-G1
(LOOKING NORTH)

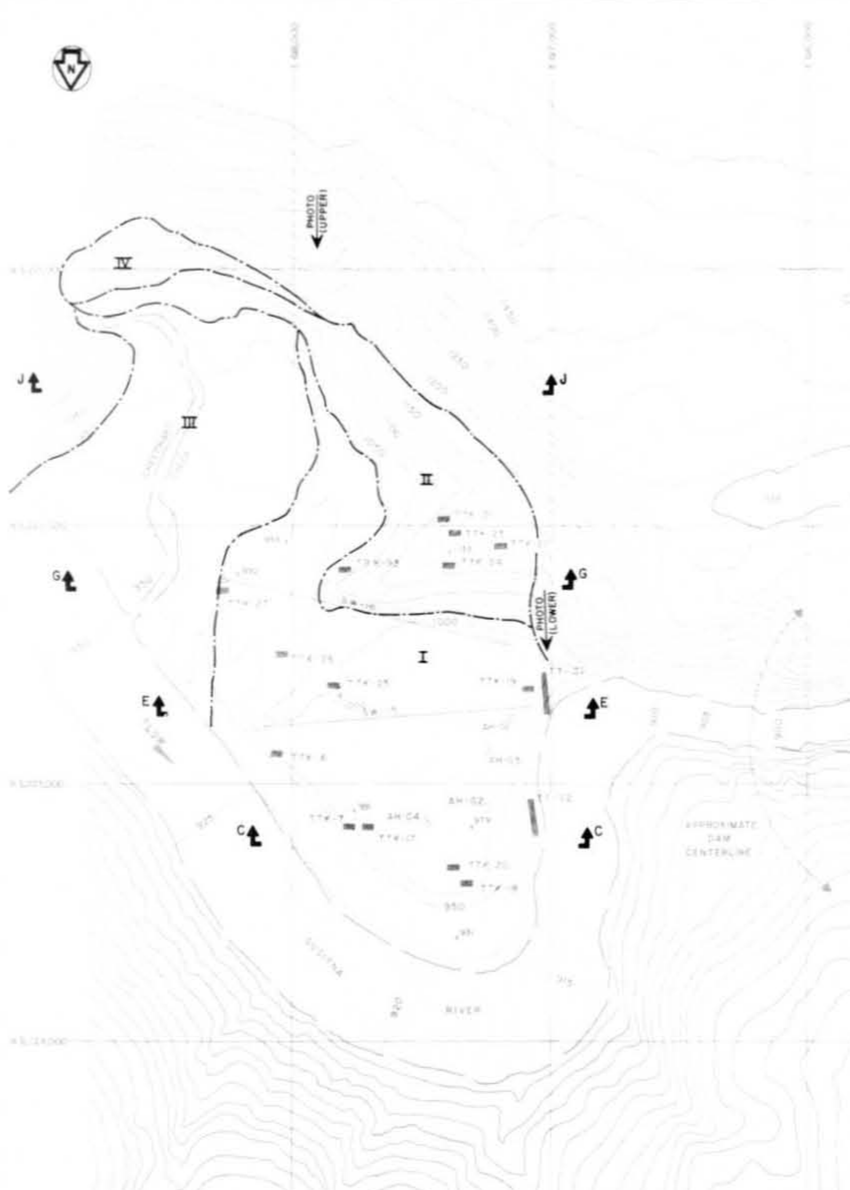
SCALE 0 200 400 FEET

REFERENCE: BASE MAP FROM R & M, 1981 – 1" = 200' DEVIL CANYON TOPOGRAPHY, RETRACED AT 25' CONTOURS
USBR, 1960
COE, 1978
WCC, 1978

DEVIL CANYON
BORROW SITE G PLAN

ACRES

FIGURE 7.22



BORROW SITE G
(LOOKING NORTH)

TEST TRENCH TT-G1
(LOOKING NORTH)

LEGEND

CONTACTS:

MAPPED LIMIT OF BORROW SITE OR ZONE

BOREHOLES AND TEST PITS:

AH	1980-81, AAI	AUGER BORING
TTK	1958, USBR	DOZER TRENCH
TT	1981, AAI	DOZER TRENCH

GEOPHYSICAL SURVEYS:

SEISMIC REFRACTION SURVEY END OR TURNING POINT – 1978, SHANNON & WILSON

OTHER:

E E CROSS SECTION LOCATION (SEE NOTE 2)

NOTES

1. TYPICAL SECTIONS SHOWN ON FIGURE 7.23
2. FOR DETAILED GEOLOGY AND GEOLOGIC SECTIONS, SEE FIGURES 7.3 AND 7.4 THROUGH 7.10
3. SURFICIAL GEOLOGY SHOWN ON FIGURE 7.2.
4. 25 FOOT CONTOUR INTERVAL ADDED FROM SOURCE MAP (REFERENCED) IN BORROW SITE ONLY.
5. BORROW SITE LIMITS BASED ON FIELD AND AIR PHOTO INTERPRETATION OF BORROW MATERIAL. FINAL LIMITS, SUBJECT TO RESULTS OF DESIGN INVESTIGATIONS.
6. BORROW MATERIAL ZONES INDICATE MAPPED VARIATIONS IN MATERIAL TYPE
   - ZONE I ALLUVIAL FAN / TERRACE DEPOSIT OF SAND AND GRAVELS.
   - ZONE II RIVER TERRACES, SIMILAR TO MATERIAL I
   - ZONE III CHEECHAKO CREEK OUTWASH, BOULDERY GRAVELS
   - ZONE IV ARGILLITE / GRAYWACKE TALUS DEPOSITS.
7. ENTIRE BORROW SITE LIES WITHIN PROPOSED DEVIL CANYON RESERVOIR LIMITS.
8. USBR, COE EXPLORATION LOGS AS REFERENCED.
9. AAI EXPLORATION LOGS SHOWN IN APPENDIX G.
10. PHOTOS TAKEN AUGUST, 1981.

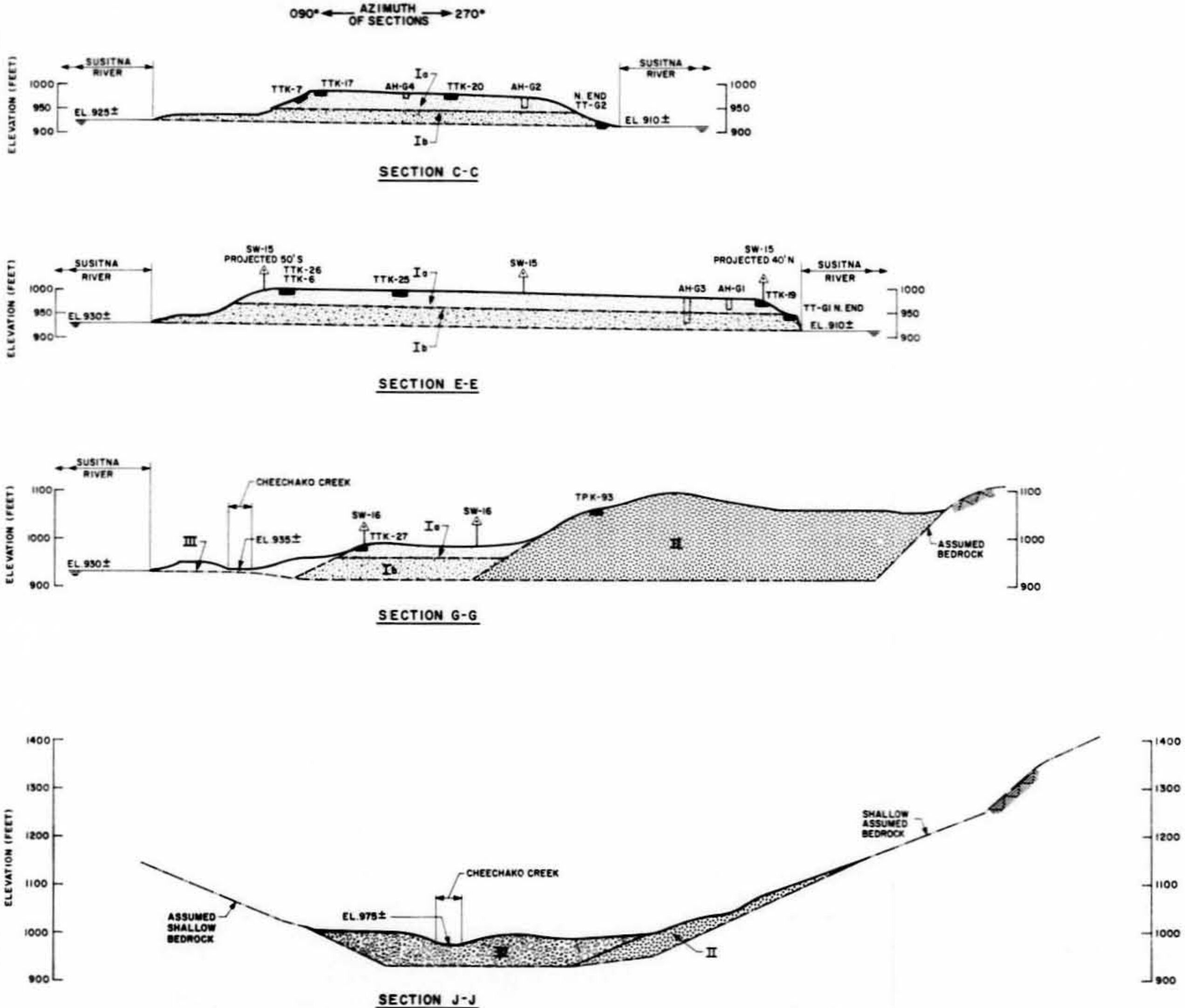
SCALE 0 200 400 FEET

REFERENCE: BASE MAP FROM R&M, 1981 – 1" = 200' DEVIL CANYON TOPOGRAPHY, RETRACED AT 25' CONTOURS
USBR, 1960
COE, 1978
WCC, 1978

DEVIL CANYON
BORROW SITE G PLAN

ACRES

FIGURE 7.22



LEGEND

CONTACTS:

MATERIAL LIMITS

ASSUMED TOP OF ROCK

LITHOLOGY:

ARGILLITE & GRAYWACKE OUTCROPS

BOREHOLES & TEST PITS:

AH-G1 1980-81, AAI AUGER BORING

TTK-17 1958, USBR DOZER TRENCH

TPK-93 1958, USBR HAND DUG TEST PIT

TT-G1 1981, AAI DOZER TRENCH

GEOPHYSICAL SURVEYS:

SW-15 SEISMIC REFRACTION SURVEY END OR TURNING POINT - 1978, SHANNON & WILSON

NOTES

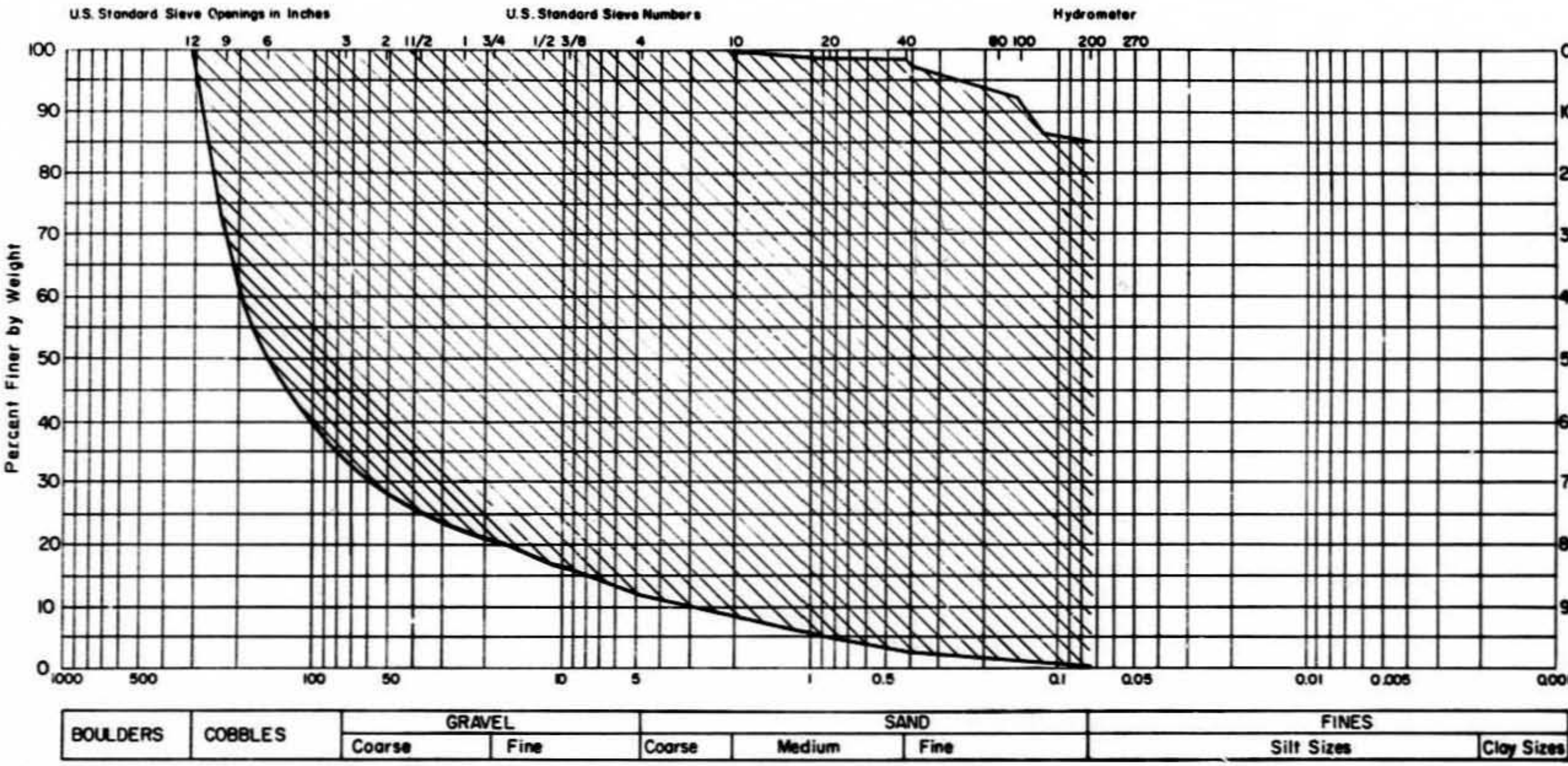
1. SECTION LOCATIONS AND BORROW SITE PHOTO SHOWN ON FIGURE 7.22.
2. FOR DETAILED GEOLOGY AND GEOLOGIC SECTIONS, SEE FIGURE 7.3 AND 7.4 THROUGH 7.10.
3. SURFICIAL GEOLOGY SHOWN ON FIGURE 7.2.
4. VERTICAL AND HORIZONTAL SCALE 1:1.
5. SECTION ELEVATIONS FROM REFERENCED BASE MAP.
6. BORROW SITE LIMITS BASED ON FIELD AND AIR PHOTO INTERPRETATION. FINAL MAPPED LIMITS OF BORROW MATERIALS, SUBJECT TO RESULTS OF DESIGN INVESTIGATIONS.
7. BORROW MATERIAL ZONES INDICATE MAPPED VARIATIONS IN MATERIAL TYPE.
   ZONE I ALLUVIAL FAN / TERRACE DEPOSIT OF SAND (Ia) AND GRAVEL, COARSER AT DEPTH (Ib)
   ZONE II RIVER TERRACES, SIMILAR TO MATERIAL I
   ZONE III CHEECHAKO CREEK OUTWASH, BOULDERY GRAVELS
   ZONE IV ARGILLITE / GRAYWACKE TALUS DEPOSITS
8. USBR, COE EXPLORATION LOGS AS REFERENCED.
9. AAI EXPLORATION LOGS SHOWN IN APPENDIX F.
10. EXPLORATIONS PROJECTED UP TO 150' ONTO SECTIONS.
11. SECTIONS STOPPED AT SUSITNA RIVER LEVEL.

SCALE 0 100 200 FEET

DEVIL CANYON
BORROW SITE G SECTIONS

FIGURE 7.23

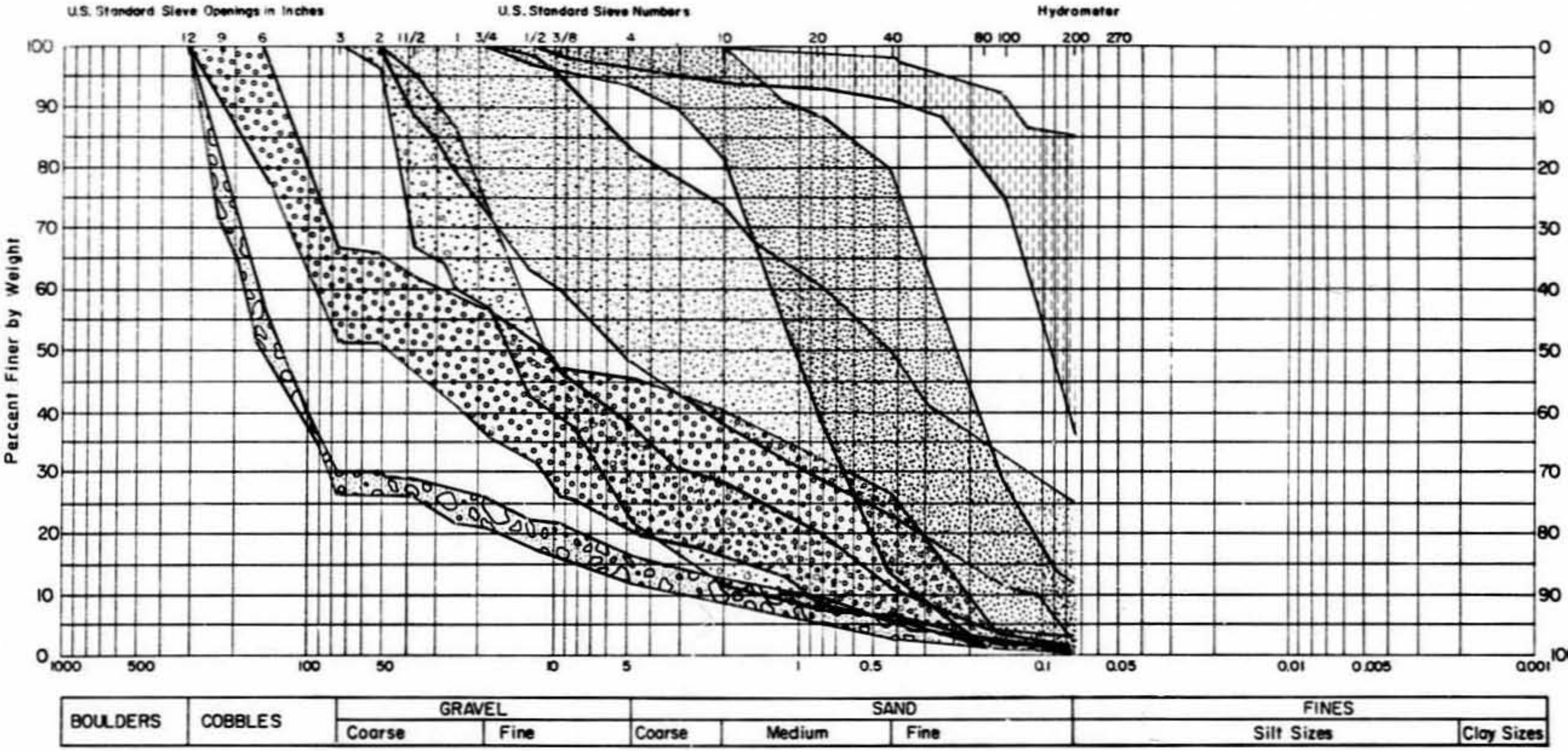
ACRES



TOTAL NUMBER OF SAMPLES: 47

DEVIL CANYON
BORROW SITE G
RANGE OF GRADATIONS

FIGURE 7.24

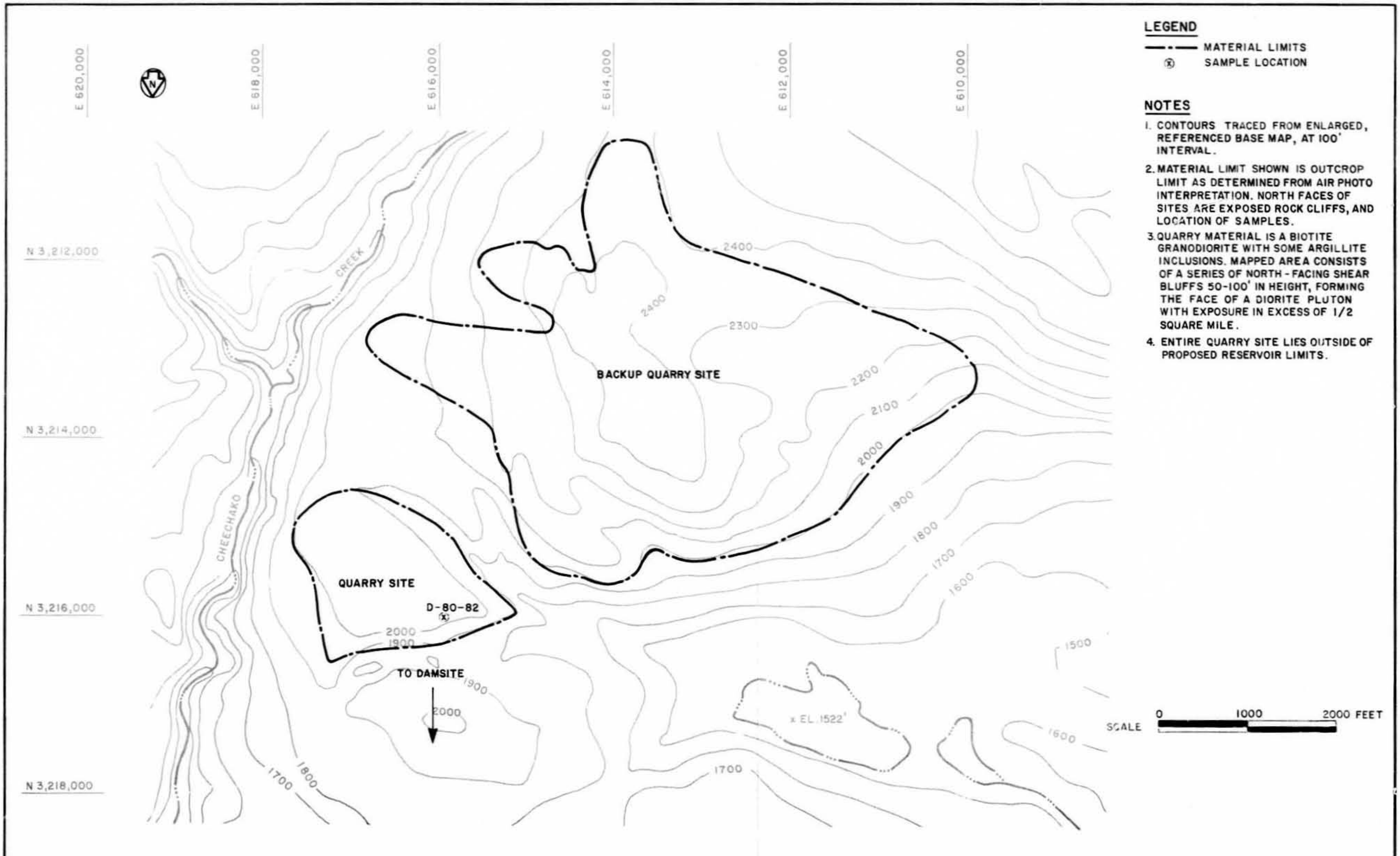


UNIT*	MATERIAL	NO. OF SAMPLES
C	SILT WITH SAND, GRAVEL	4
D	SAND WITH TRACE SILT	9
N	SANDY GRAVEL	3
O	SANDY GRAVEL	4
P	GRAVELLY SAND, SANDY GRAVEL	3
Z	SANDY GRAVEL WITH SILT, COBBLES	24

* SEE EXPLORATORY TRENCH GEOLOGIC SECTIONS, APPENDIX G

DEVIL CANYON
BORROW SITE G
STRATIGRAPHIC UNIT GRADATIONS

FIGURE 7.25



REFERENCE: BASE MAP FROM USGS 1:63,360 ALASKA QUADRANGLE TALKEETNA MOUNTAINS (D-5). COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4)

DEVIL CANYON
QUARRY SITE K

ACRES

FIGURE 7.26

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GLOSSARY*

Active Layer or Active Zone - The surficial layer of ground above the permafrost table that thaws each summer and refreezes each fall, and therefore represents the fluctuating freezing front of the permafrost table.

Alluvial - Pertaining to or composed of alluvium or deposited by a stream or running water.

Alluvial Fan - A low, outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, deposited by a stream at the place where it issues from a narrow mountain valley upon a plain or broad valley, or where a tributary stream is near or at its junction with the main stream or whenever a constriction in a valley abruptly ceases or the gradient of the stream suddenly decreases.

Alluvium - A general term for clay, silt, sand, gravel or similar unconsolidated detrital material deposited during comparatively recent geologic time by a stream or other body of running water as a sorted or semisorted sediment in the bed of the stream or on its flood plain or delta.

Alpine Glacier - Any glacier in a mountain range except an ice cap or ice sheet.

Alteration - Any change in the mineralogic composition brought about by physical or chemical means, especially by the action of hydrothermal solutions.

Andesite - A dark colored, fine grained extrusive rock that when prophyritic contains phenocrysts composed primarily of plagioclase and one or more of the mafic minerals (biotite, hornblende, pyroxene) and a groundmass composed generally of the same minerals as the phenocrysts. The extrusive equivalent of a diorite.

Annual Frost or Seasonal Frost - Frost which formed in the immediately previous freezing season and will thaw during the summer thaw season. By definition, all frost and frozen ground in the active layer.

Aquiclude - A body of relatively impermeable material that is capable of absorbing water slowly but functions as an upper or lower boundary of an aquifer and does not transmit ground water rapidly enough to supply a well or spring.

*Definitions modified from References 2, 13, 24, and 56.

Aquifer - A body of rock that contains sufficient saturated permeable material to conduct groundwater and to yield significantly greater quantities of groundwater than the adjacent units.

Argillaceous - Pertaining to, largely composed of, or containing clay-size particles or clay minerals.

Argillite - A compact rock, derived either from mudstone or shale that has undergone a somewhat higher degree of induration than is present in mudstone or shale but that is less clearly laminated than and without the fissility of shale, or that lacks the cleavage distinctive of slate.

Basalt - A dark to medium dark colored, extrusive and intrusive (as dikes) mafic igneous rock composed chiefly of calcic plagioclase and pyroxene in a glassy or fine-grained groundmass.

Batholith - A large, generally discordant, plutonic mass that has more than 40 square miles in surface exposure and is composed predominantly of medium to coarse grained rocks.

Bedrock - A general term for the rock, usually solid that underlies soil or other unconsolidated, surficial material.

Bimodal Flow/Slide - A slide that consists of a steep headwall, containing ice or ice-rich sediment, which retreats in a retrogressive fashion through melting, forming a debris flow, which slides down the face of the headwall to its base.

Block Slide/Glide - A translational landslide in which the slide mass remains essentially intact, moving outward and downward as a unit, most often along a pre-existing plane of weakness, such as bedding, joints and faults.

Break in Slope - A marked or abrupt change or inflection in a slope or profile, commonly meant to indicate the transition from steep valley or gorge walls to more rounded, flatter crest or plateau levels.

Breccia - Fragmented rock whose components are angular; used here to refer to crushed rock related to shearing.

Carbonate - A mineral compound characterized by a fundamental anionic structure of CO_3+, generally refers to calcite.

Cataclastic Rock - A rock containing angular fragments that have been produced by the crushing and fracturing of pre-existing rock as a result of mechanical forces in the crust.

Chlorite - A group of greenish, platy minerals, which are associated with and resemble the micas. Chlorite is widely distributed especially in low-grade metamorphic rocks, or as alteration products of ferromagnesium minerals in igneous rocks.

Colluvium Deposits - A general term applied to any loose, heterogeneous, and incoherent mass of soil material or rock fragments deposited chiefly by masswasting, usually at the base of a steep slope or cliff.

Compressive Strength - The maximum uniaxial compressive stress that can be applied to a material, under given conditions, before failure occurs.

Country Rock - The rock intruded by and surrounding an igneous intrusion.

Crystalline - Said of a rock consisting wholly of crystals or fragments of mineral crystals; especially so in an igneous rock developed through cooling from a molten state and containing no glass.

Dacite - A fine-grained extrusive rock with the same general composition as a quartz diorite or granodiorite.

Degrading Permafrost Zone - A decrease in thickness and/or aerial extent of permafrost because of natural or artificial causes as a result of climatic warming and/or change of terrain conditions such as disturbance or removal of an insulating vegetation layer by fire or human means.

Depth of Zero Annual Amplitude - The depth at which the annual effect of surface temperatures is not detectable. Below the depth of zero annual amplitude, the ground temperature changes only as a result of sustained thermal influences on the average ground or surface temperature, which will elevate or deepen the depth of zero annual amplitude.

Diabase - An intrusive rock whose main components are calcic plagioclase (labradorite) feldspar and pyroxene, which is characterized by lath shaped feldspar crystals.

Dike - A tabular igneous intrusion that cuts across the planar structures of the surrounding rock.

Diorite - A group of plutonic rocks intermediate in composition between acidic and basic rocks, characteristically composed of dark colored amphibole (especially hornblende), plagioclase feldspar, pyroxene and sometimes a small amount of quartz.

Dip - The angle that a structural surface, for example, a bedding plane or joint, makes with the horizontal, measured perpendicular to the strike of the structure.

Direct Shear Test - Test measuring the sliding resistance along discontinuities. Usually has two components, friction and cohesion, though cohesion may or may not be present. A peak angle implying maximum resistance, and a residual angle depicting the shear strength after larger shear displacements, are determined.

Drunken Forest - A group of trees leaning in a random orientation; usually associated with thermokarst topography, reflecting local slope instability.

Dynamic Elastic Properties - Young's Modulus and Poisson's Ratio determined using acoustic shear and compressional wave velocities of the material (ASTM 2845-69 (1976)).

Episode - A term used informally and without time implications for a distinctive and significant event or series of events in the glacial history of a region, each episode representing a different erosional or depositional environment.

Esker - A long, low, narrow, sinuous, steep-sided ridge or mound composed of irregularly stratified sand and gravel that was deposited by a subglacial or englacial stream flowing between ice walls or in an ice tunnel of a continuous glacier and was left behind when the ice melted.

Facies Change - A lateral or vertical variation in the lithologic or paleontologic characteristics of contemporaneous sedimentary deposits. It is caused by, or reflects, a change in the depositional environment.

Fault - (see Shear).

Felsic - A general term applied to an igneous rock having light-colored minerals in its mode. The opposite of mafic.

Flow Structure - The texture of an igneous rock, characterized by a wavy or swirling pattern in which platy or prismatic minerals are oriented along planes of lamellar flowage in fine grained and glassy igneous rocks.

Flows - A broad type of movement that exhibits the characteristics of a viscous fluid in its downslope motion.

Foliation - A general term for a planar arrangement of textural or structural features in any type of rock.

Fracture - A general term for any break due to mechanical failure by stress in a rock. Fracture includes cracks, joints and faults.

Fracture Zone - An area characterized by very close to closely spaced joints where no measurable relative movement has occurred.

Geothermal Gradient - The increase of temperature in the earth with depth. The rate commonly varies from 1°F/40 feet to 1°F/300 feet (1°C/22 meters to 1°C/160 meters).

Glaciofluvial - Pertaining to the meltwater streams flowing from glacier ice and especially to the deposits and landforms produced by such streams such as kame terraces and outwash plains.

Gouge - Rock material that has been ground to a uniformly fine particle size of clay or fine silt sizes.

Grain Size - The general dimensions (average diameter) of the particles in a sediment or rock or of the grains of a particular mineral that make up a sediment or rock:

Fine - less than 1 mm
Medium - 1mm to 5 mm
Coarse - Greater than 5 mm

Granodiorite - A group of coarse grained plutonic rock intermediate in composition between quartz diorite and quartz monzonite.

Graywacke - An old rock name that has been variously defined but is now generally applied to a gray or greenish gray, very hard, tough and firmly indurated, coarse grained sandstone that has a subconchoidal fracture and consists of poorly sorted and extremely angular to subangular grains of quartz and feldspar with an abundant variety of small, dark rock and mineral fragments embedded in a compacted, partly metamorphosed clayey matrix containing fine-grained micaceous and chloritic minerals.

Groundmass - The interstitial material of a porphyritic igneous rock; it is relatively more fine grained than the phenocrysts and may be glassy or microcrystalline.

Ground Temperature Envelope - An inverted cone-shaped zone including the maximum and minimum temperature as a function of depth on a ground temperature regime plot. Ranges from annual minimum air temperature at zero depth, showing maximum variation in temperature, to zero annual variation at the Depth of Zero Annual Amplitude.

Hematite - (see Iron Oxide)

Hydraulic Head - The height of the free surface of a body of water above a given subsurface point.

Hydrothermal - Of or pertaining to heated water, to the action of heated water or to the products of the action of heated water used in relation to hydrothermal alteration of minerals.

Ice, Massive - A comprehensive term used to describe large (with dimensions at least 2 to 25 inches) masses of underground ice, including ice wedges, pingo ice and ice lenses.

Ice, Segregated - Ice formed by the migration of pore water to the freezing plane where it forms into discrete lenses, layers or seams ranging in thickness from hairline to greater than 30 feet.

Ice Lens - 1. A dominantly horizontal lens-shaped body of ice of any dimension. 2. Commonly used for layers of segregated ice that are parallel to the ground surface. The lenses may range in thickness from hairline to as much as 30 feet.

Igneous - Rock or mineral that solidified from molten or partly molten material, that is, from a magma.

Inclusions - A fragment of older rock in an igneous rock to which it is not genetically related.

Intermontane - Situated between or surrounded by mountains, mountain ranges, or mountainous regions.

Iron Oxide - A general field term for a group of orange to brown amorphous naturally occurring hydrous ferric oxides whose actual mineralogy was not identified in this study. It is a common secondary material formed by weathering of iron or iron-bearing minerals.

Isotherm - A line connecting points of equal temperature.

Joint - A surface of actual or potential fracture or parting in a rock without measureable displacement.

Joint Set - A regional pattern or group of parallel joints.

Joint Spacing - The interval between joints of a particular joint set, measured on a line perpendicular to the joint planes:

Joint Spacing	Interval
Very close	< than 2 in.
Close	2 in. to 1 ft.
Moderately close	1 ft. to 3 ft.
Wide	3 ft. to 10 ft.
Very Wide	Greater than 10 ft.

Kame - A long, low, steep-sided hill, mound, knob, hummock or short irregular ridge, composed chiefly of poorly sorted and stratified sand and gravel deposited by a subglacial stream as an alluvial fan or delta against or upon the terminal margin of a melting glacier, and generally aligned parallel to the ice front.

Lacustrine Deposits - Pertaining to, produced by, or formed in a lake or lakes.

Latite - A porphyritic extrusive rock of intermediate composition.

Lithic - A descriptive term applied to rock fragments occurring in a later formed rock.

Limonite - (See Iron Oxide)

Mafic - Said of an igneous rock having dark-colored minerals in its mode - opposite of felsic.

Metamorphism - The mineralogical and structural adjustments of solid rock to physical and chemical conditions which have been imposed at depth below the surface zones of weathering and cementation, and which differ from the conditions under which the rocks in question originated, resulting in visible modifications of the rock properties.

Moraine - A mound, ridge or other distinct accumulation of unsorted, unstratified glacial drift, predominantly till, deposited chiefly by direct action of glacial ice in a variety of topographic land forms that are independent of control by the surface on which the drift lies.

Multiple Regressive Flow - Forms a series of arcuate concave downslope ridges as it retains some portion of the prefailure relief.

Multiple Retrogressive Flow/Slide - Series of arcuate blocks concave towards the toe, that step backwards higher and higher towards the headwall.

Normal Fault - A fault in which the overlying side appears to have moved downward relative to the underlying side.

Orogeny - The process of forming mountains, particularly by folding and thrusting.

Outwash - Stratified detritus, chiefly sand and gravel, removed or "washed out" from a glacier by meltwater streams and deposited in front of or beyond the terminal moraine or the margin of an active glacier. The coarser material is deposited closer to the ice.

Overburden - The soil, silt, sand, gravel, or other material overlying bedrock, either transported or formed in place.

Palsa - A round or elongated hillock or mound, maximum height about 30 feet, composed of a peat layer overlying mineral soil. It has a perenially frozen core that extends from within the covering peat layer downward into or toward the underlying mineral soil.

Patterned Ground - A general term for any ground surface of surficial soil materials exhibiting a discernible, more or less ordered and symmetrical, microphysiographic pattern. Used in this report as descriptive of frost wedge patterning.

Perched Ground Water - Unconfined ground water separate from an underlying main body of groundwater by an unsaturated zone with very low permeability.

Perched Water Table - The water surface of a body of perched ground water.

Permafrost - The thermal condition in soil or rock of temperatures below 32°F (0°C) persisting over at least two consecutive winters and the intervening summer; moisture in the form of water and ground ice may or may not be present. Earth materials in this thermal condition may be described as perenially frozen irrespective of their water and ice content.

Permafrost, Continuous - Permafrost occurring everywhere beneath the exposed land surface throughout a geographic regional zone, with the exception of widely scattered sites (such as newly deposited unconsolidated sediments) where the climate has just begun to impose its influence on the ground thermal regime and will cause the formation of continuous permafrost.

Permafrost, Discontinuous - Permafrost occurring in some areas beneath the ground surface throughout a geographic regional zone where other areas are free of permafrost.

Permeability - The property or capacity of a porous rock, sediment, or soil for transmitting a fluid without impairment of the structure of the medium.

Phenocrysts - The relatively large crystals which are found set in a finer-grained groundmass.

Phyllite - An argillaceous rock commonly formed by regional metamorphism and intermediate in metamorphic grade between slate and mica schist. Minute crystals of mica and chlorite impart a silky sheen to the surfaces of cleavage.

Piedmont Glacier - A thick continuous sheet of ice at the base of a mountain range, resting on land, formed by the spreading out and coalescing of valley glaciers from the higher elevations of the mountains.

Pluton - An igneous intrusion.

Plutonic Rock - An igneous rock formed at considerable depth by crystallization of magma or by chemical alteration.

Point Load Test - A test indirectly measuring compressive strength by loading samples diametrically, measuring the splitting load and converting that to compressive strength.

Polygonal Ground - A type of patterned ground consisting of a closed roughly equidimensional figure bounded by several sides, commonly more or less straight but some or all of which may be irregularly curved. A polygon may be either "low center" or "high center" depending on whether its center is lower or higher than its margins.

Porphyry - An igneous rock of any composition that contains conspicuous phenocrysts in a fine-grained groundmass.

Porphyroblast - The larger more or less euhedral crystals formed in metamorphic rocks which have grown during the process of metamorphism.

Proglacial - Immediately in front of or just beyond the outer limits of a glacier or ice sheet, generally at or near its lower end; said of lakes, streams, deposits and other features produced by or derived from the glacier ice.

Relict - Said of a topographic feature that remains after other parts of the feature have been removed or have disappeared.

Reverse Fault - A fault in which the overlying side appears to have moved upward relative to the underlying side.

Rhyolite - A group of extrusive igneous rocks generally porphyritic and exhibiting flow texture; the extrusive equivalent of a granite.

RQD (Rock Quality Designation) - A modified form of recording rock core recovery. The RQD is the ratio of the total length of core pieces, 4 inches and larger, to the length of the coring run actually drilled. RQD is expressed in percent.

Rotational Slide - A landslide in which shearing takes place on a well defined, curved shear surface, concave upward in cross-section, producing a backward rotation head of the in the displaced mass.

Seismic Refraction - A type of seismic exploration based on the measurement of seismic energy as a function of time after the shot, or initial energy impulse, and of the distance from the shot, by determining the arrival time of seismic waves which have traveled through overburden and/or bedrock in order to map layers in the overburden and the top of the bedrock surface.

Seismic Velocity - The rate of propogation of an elastic wave, measured in feet per second. The wave velocity depends upon the type of wave, as well as the elastic properties and density of the earth material through which it travels.

Shear - A surface or zone of rock fracture along which there has been measurable displacement.

Shear Strength - A material's resistance to shear failure. Intact materials possess both cohesive and frictional resistance. Discontinuities have frictional resistance but may or may not have cohesive resistance. Frictional resistance of discontinuities may have two components, one depicting planar surface sliding resistance and the other depicting surface roughness.

Skin Flow - The detachment of a thin veneer of vegetation and mineral soil with subsequent movement over a planar inclined surface, usually indicative of thawing, fine-grained overburden over permafrost.

Slickenside - A polished and smoothly striated surface that results from friction along a fault/shear plane.

Slides - Landslides exhibiting a more coherent displacement; a greater appearance of rigid body motion.

Solifluction Flow - Ground movements restricted to the active layer and generally requires fine-grained soils caused by melting of saturated soils.

Static Elastic Properties - Young's Modulus and Poisson's Ratio measured during unconfined compression tests (ASTM D 3148-80).

Strata - Plural of stratum.

Stratigraphic Column - A composite diagram that shows in a single column the subdivisions of part or all of the sequence of stratigraphic units of a given locality or region so arranged as to indicate their relations to the subdivisions of geologic time and their relative positions to each other.

Stratigraphy - The arrangement of strata, especially as to geographic position and chronologic order of sequence.

Stratum - A tabular or sheet-like mass or a single and distinct layer, of homogeneous or gradational sedimentary material (consolidated rock or unconsolidated earth) of any thickness, visually separable from other layers above and below by a discrete change in the character of the material deposited or by a sharp physical break in deposition, or by both.

Strike - The direction or trend that a structural surface, for example, a bedding or fault plane, describes as it intersects the horizontal.

Strike Slip Fault - A fault, the actual movement of which is parallel to the strike of the fault.

Talus - Rock fragments of any size or shape (usually coarse and angular) derived from and lying at the base of a cliff or very steep, rocky slope.

Tensile Strength - The maximum applied tensile stress that a body can withstand before failure occurs.

Terrace - Any long, narrow, relatively level or gently inclined surface, generally less broad than a plain, bounded along one edge by a steeper descending slope and along the other by a steeper ascending slope.

Terrace Deposits - A general term used to describe alluvial benches along the side of a stream or river valley, which are no longer within the normal floodplain of the body of water. Used in contrast to active river alluvium, within the present channel, and flood plain deposits which lie within the current hydrologic regime, but outside of annual flood limits.

Thalweg - The line connecting the lowest or deepest points along a stream bed or valley, whether under water or not. Applied in this report to include the lowest point of flow in a potential aquifer.

Thermistor - A thermally sensitive resistor employing a semiconductor with a large negative resistance-temperature coefficient, used as an electrical thermometer.

Thrust Fault - A reverse fault with a dip of 45° or less. Horizontal compression rather than vertical displacement is its characteristic feature.

Till - Unsorted and unstratified drift, generally unconsolidated, deposited directly by and underneath a glacier without subsequent reworking by water from the glacier and consisting of a heterogeneous mixture of clay, sand, gravel and boulders varying widely in size and shape.

Tundra - A treeless, generally level to undulating region of lichens, mosses, sedges, grasses and some low shrubs, including dwarf willows and birches, which is characteristic of both the Arctic and higher alpine regions outside of the Arctic.

Unit Weight - A term applied, especially in soil mechanics, to the weight per unit volume.

Varve - A sedimentary bed or lamina or sequence of laminae deposited in a body of still water within one year's time; specifically a thin pair of graded glaciolacustrine layers seasonally deposited (usually by meltwater streams) in a glacial lake or other body of still water in front of a glacier.

Volcanic Rock - A generally finely crystalline or glassy igneous rock resulting from volcanic action at or near the earth's surface, either ejected explosively or extruded as lava. The term includes near-surface intrusions that form a part of the volcanic structure.

Weathering - The destructive process or group of processes constituting that point of erosion whereby earthy and rocky materials on exposure to atmospheric agents at or near the earth's surface are changed in character (color, texture, composition, firmness or form), with little or no transport of the loosened or changed material.