ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT

INFORMATION PACKAGE
FOR
FIRST SPECIALIST CONSULTANTS PANEL MEETING

OCTOBER, 1980

ACRES

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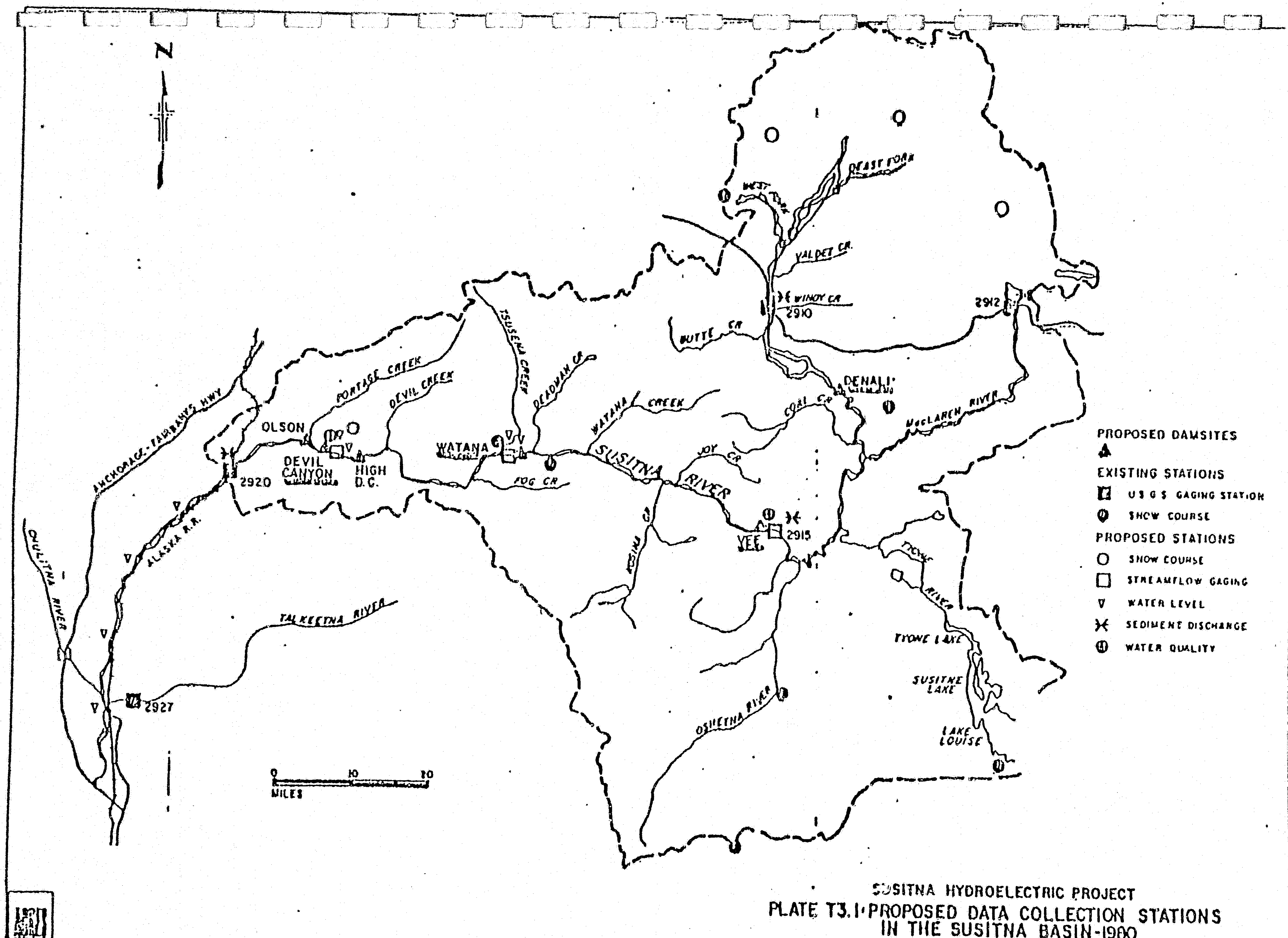

SUSITNA HYDROELECTRIC PROJECT
PLATE T3.1 PROPOSED DATA COLLECTION STATIONS IN THE SUSITNA BASIN-1980

5-75/5-76

1 - EXCERPTS FROM ACRES PLAN OF STUDY (PROPOSAL)

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Open Letter to the Public
Acknowledgement

EXECUTIVE SUMMARY

1 - INTRODUCTION

This Plan of Study (POS) has been prepared by Acres American Incorporated in response to the request of the Alaska Power Authority to provide a program leading to a license application to the Federal Energy Regulatory Commission for construction of the Susitna Hydroelectric Project. Major contributors to the plan and proposed participants in its implementation include R & M Consultants Incorporated (R & M), Terrestrial Environmental Specialists Incorporated (TES), Frank Moolin Associates (FMA), Woodward-Clyde Consultants (WCC), Salomon Brothers, and Cook Inlet Region Incorporated/ Holmes and Narver (CIRI/H & N).

The complete plan is made up of three major parts in addition to this executive summary. Part A sets forth the study plan itself and includes the establishment of program objectives, an overview of the study approach, a budget summary, a logistical plan, detailed activity descriptions, a proposed project schedule, and a summary assessment of work which must be continued beyond the point of license application. Part B is devoted to implementation of the plan. Key personnel assignments, an organizational structure, and coordination procedures are contained therein. Supplemental information in Part C provides supporting materials such as evidence of the qualifications of proposed corporate team members, detailed resumes for key project personnel, and similar items.

2 - BACKGROUND

A series of studies conducted initially by the Bureau of Reclamation and subsequently by the Corps of Engineers led to the recommendation that a two dam system should be constructed on the Susitna River. The upper dam at Watana would be an 810-foot-high earthfill structure and the lower a 635-foot-high concrete thin arch dam at Devil Canyon. Transmission lines would extend north and south to Fairbanks and Anchorage respectively, for a total of 365 miles. The total project was selected by the Corps as the best of several alternatives to contribute to satisfaction of a projected energy demand of 15 billion kilowatt hours by the year 2000.

The Corps' recommendation resulted in Congressional authorization to proceed with detailed feasibility studies in a cooperative effort with the State of Alaska under provisions of Section 203(e) of the Water Resources Development Act of 1976. Should feasibility be demonstrated, study costs would be reimbursed by the State. Amendments are currently being sought to facilitate the funding process and expedite study initiation.

It is the intent of the State of Alaska, through the Alaska Power Authority, to undertake the detailed studies required before a definite construction decision can be made. An alternative to consummating the cooperative agreement with the Corps of Engineers is to finance the study entirely with State resources, contracting with a private engineering firm to do those studies necessary to prepare and file a license application. Acres American Incorporated was selected as one of three private engineering firms to prepare plans of study.

3 - PROJECT OBJECTIVES

The primary objectives of the proposed study are threefold: (1) Establish technical, economic and financial feasibility; (2) Evaluate the environmental consequences of designing and constructing the Susitna Project; and (3) File a complete license application with the FERC.

Included within these overall objectives are certain specific items which must be satisfied. This latter group includes assessment of alternatives, preparation of an optimal development plan, cost estimates, risk analysis, environmental and social factor evaluations, annual system power cost estimates, preparation of the application itself, a public participation program, preparation of a plan for financing, minimization of study costs consistent with the satisfaction of other objectives, and maximization of employment opportunities in Alaska--including affirmative actions for native hire.

4 - PROPOSED APPROACH

Acres proposes to accomplish the essential objectives of the POS within a period of two and one half years. January 1, 1980 is the projected start date. In order to satisfy all of the objectives within this time frame, Acres has assembled a team which brings to the Susitna project a unique combination of capability and expertise, largely Alaska based. The group provides:

(i) A powerful design/project/construction management team experienced in studies, economic evaluation, risk analysis, alternatives assessments, licensing, design, financing and construction of large hydroelectric projects.

(ii) Strong northern and subarctic experience.

(iii) A skilled and readily available field exploration team with facilities, personnel and equipment experienced in all aspects of hydrologic and geotechnical design and exploration, particularly in the vicinity of the Susitna site.

(iv) An exceptional team of environmental specialists with first-hand knowledge and experience of the project area and ready to work closely with state environmental agencies in effectively meeting the requirements of the plan of study.

(v) A capability for detailed seismic studies by renowned experts as well as a comprehensive external review.

(vi) A logistic support capability which draws heavily upon the skills of Alaskan Natives whose land selections are in the project area.

(vii) Financial advice from an investment banking firm skilled in handling tax-exempt bond issues.

The combined knowledge, experience, and equipment of the Acres team will be brought to bear upon the project objectives through the accomplishment of thirteen specific tasks, each one of which is subdivided into a number of subtasks. In every case, task and subtask objectives are explicitly defined, as are proposed approaches, levels of effort, and schedules. The thirteen major tasks are:

Task 1 - Power Studies
Task 2 - Surveys and Site Facilities
Task 3 - Hydrology
Task 4 - Seismic Studies
Task 5 - Geotechnical Exploration
Task 6 - Design Development
Task 7 - Environmental Studies
Task 8 - Transmission
Task 9 - Cost Estimates and Schedules
Task 10 - Licensing
Task 11 - Marketing and Finance
Task 12 - Public Participation
Task 13 - Administration

Summary descriptions of the work to be undertaken in each of these Tasks are presented in Section 8 of this Executive Summary.

5 - COSTS AND SCHEDULES

The Budget Summary is shown in Table A.3.1. The entire POS calls for the expenditure of $19.7 million in 1979 dollars over a period of two and one half years from study initiation to filing the license application for these minimum efforts necessary to establish feasibility from a technical, economic, and environmental standpoint.

An additional amount of $3.4 million is required to conduct effective public participation, financing and local project management programs and to satisfy certain non-discretionary funding requirements.

Subsequent costs during the estimated 30-month period through award of the FERC license are estimated as $ 26.2 million, including provision of an estimated $8 million for the construction of a pioneer access road. The proposed project schedule is shown in Plate A2.1. Initial site facilities will be operational by March 1980 to support field investigations which will commence at that time. By the end of the first year of study, sufficient data will have been accumulated to make definitive recommendations as to continuation of the study program. The second year will involve continuation of field investigation efforts and development of conceptual designs along with initial mitigating measures. Field investigations continue in the third year and beyond, but sufficient information will have been accrued to permit the preparation of drafts for all required licensing exhibits by the end of the 29th month. Review will have been conducted throughout, both internally by panels of in-house experts and externally by independent review boards recommended to and selected by APA. Finalization of the license application including all exhibits will occur in the 30th month and a final review will be conducted at that time.

6 - ANTICIPATED DIFFICULTIES

Throughout the development of the POS, a number of potential problems have been identified and the difficulties associated with managing their resolution have been noted. Certain areas in particular have been long standing concerns of many interested parties in Alaska:

(1) The matter of generating a concept for optimal development calls for careful study of projected demand and alternative means of satisfying it. Without such a foundation, it is simply impossible to assure the Power Authority that the proper project will be planned in the right place and constructed in time to meet the energy needs of the Railbelt.

(2) Data acquisition will present difficulties, for seasonal and weather constraints as well as certain land use restrictions will lead to peak loading of site support facilities and the necessity for use of special equipment not normally readily available in Alaska because of conflicting demands from other projects.

(3) The financial risks of such a large project must be reduced insofar as possible, for investor confidence is a prerequisite to successful financing. It follows that a set of detailed risk analyses must be conducted concurrently with the development of designs.

(4) Particularly important design problems to be resolved involve earthquake hazards, ice occurrence, slope stability in long narrow reservoirs, and the long term effects of silt deposition in the upper reservoir.

(5) Careful and complete environmental studies will be required, yet the proposed study period is shorter than the time for some full cycle studies of certain species. A great deal of expertise is to be found in and should be sought from the Alaska Department of Fish and Game, yet the objectivity of that agency insofar as reviews and approvals are concerned, must be retained. In addition, compliance with all applicable State and Federal environmental laws will require strong coordination efforts.

(6) Preparation of the license application itself must be accomplished at the very time new FERC regulations will be promulgated.

(7) Informing and involving the public is necessary and important, but conflicting desires will be expressed and determination of how the public interest can best be served will be difficult.

(8) Control and coordination of the efforts of all parties involved in implementing this plan demands effective management.

7 - METHODS FOR RESOLVING DIFFICULTIES

Certain unique features and approaches are woven into the fabric of the POS as the basis for resolving the various problem areas noted above. Even so, the requirement to maintain a high degree of flexibility in adapting to new problems is clear, for there is simply no way to anticipate every difficulty which may be encountered. The plan provides a large measure of flexibility and a well defined chain of command as well as positive steps for addressing the noted problem areas:

(1) Careful studies of projected loads and possible alternatives for satisfying them will rely heavily upon use of models developed in Alaska for this purpose. Sophisticated computer programs which have been used by Acres with great success in the past in the analysis of major hydroelectric projects will also be employed. Power marketing studies and a careful analysis of non-hydroelectric alternatives will be undertaken by the Alaskan office of WCC, where intimate knowledge of the local scene is available. Insofar as hydroelectric alternatives are concerned, Acres will contribute its own extensive experience in planning, designing, and managing hydroelectric projects ranging in size from 500 kilowatts to thousands of megawatts. Optimal development of the Susitna River itself will flow naturally from these preliminary studies if the proposed project is shown to be the best alternative by the end of the first year of study.

(2) Data acquisition will be accelerated because site facilities will be furnished on time and of sufficient capacity by CIRI/H & N, whose earlier experiences on the Trans-Alaska Pipeline and whose intimate knowledge of project lands selected by Native Corporations will be important factors. The question of equipment availability and its operation in a sub-arctic environment has been accounted for through selection of R & M to undertake major geotechnical investigations and surveys. R & M is the only firm in Alaska which is self-contained and fully equipped for the purpose.

(3) Financial planning efforts by the prominent investment banking firm of Salomon Brothers will be complemented on the Acres team by the work of Mr. J. G. Warnock who successfully led the bond offering support documentation effort on the 5225 MW Churchill Falls project in Canada. The risk analyses will be undertaken by Dr. C. B. Chapman whose past experiences in this special area have supported certain large power projects in North America and abroad.

(4) Of the many potential design problems, none is of more serious concern than seismicity. WCC (California) will conduct exhaustive studies in this area and their work will be subjected to close scrutiny and confirmatory studies to be managed by an external board at a level of effort of $1 million. Ice studies, slope stability studies, permafrost studies and sedimentation studies are included in the plan. Much of the field work will be undertaken by R & M and the primary design efforts by Acres.

(5) The environmental effort will be conducted by TES whose core staff will be augmented by principal investigators from the faculty of the University of Alaska and other consultants with extensive Alaskan experience. ADF & G will be asked to conduct certain studies, but their objectivity will be preserved because they will be funded by and will report directly to APA in all such cases. Reviews, approvals, and coordination with ADF & G and with other State and Federal agencies will be sought throughout to minimize late stage non-concurrences. FERC has confirmed that all studies need not have been completed at the time of filing, provided that a plan for completing them is included in the application.

(6) A separate small team has been set up to ensure close monitoring of the preparation of numerous exhibits as well as to evaluate new regulations as they are published. Acres will lead this effort and will seek advice from time to time from legal consultants.

(7) A strong public participation program will include three major public meeting events and eight workshop sessions as well as a positive control on response to every public concern.

(8) The management expertise gained in Alaska on large projects by FMA will be heavily relied upon in the establishment of cost and schedule controls as well as in the preparation of realistic construction cost estimates, schedules and projected cash flows.

8 - ACTIVITY DESCRIPTIONS

As stated in Section 4, the Acres approach to the Susitna POS will be in terms of a series of 13 tasks, each with its specific objectives. Summary descriptions of these tasks follow.

8.1 - TASK 1: POWER STUDIES

(i) Task Objectives

To determine the need for power in the Alaska Railbelt Region, to develop forecasts for electric load growth in the area, to consider viable alternatives for meeting such load growth, to develop and rank a series of feasible, optimum expansion scenarios and finally to determine the environmental impacts of the selected optimum scenarios.

(ii) Task Output

The primary output of Task 1 will be a report dealing with the selection and ranking of optimum system expansion scenarios for the Alaska Railbelt Region. The final version of this report will be submitted for review and approval by Alaska Power Authority on or about Week 48 of the Study. Preliminary findings of the study will be discussed with Alaska Power Authority on or about Week 30 of the Study. Such a discussion will center on whether or not work on the Susitna Development should continue or whether another, possibly more viable alternative should be examined. Design Transmittals outlining intermediate stages of the power studies will also be issued.

(iii) List of Subtasks

Subtask 1.01 - Load Forecasting Methodology
Subtask 1.02 - Development of Load Growth Scenarios
Subtask 1.03 - Selection of Alternatives
Subtask 1.04 - Selection of Viable Expansion Sequences
Subtask 1.05 - Expansion Sequence Impact Assessments
Subtask 1.06 - Power Alternatives Study Report

8.2 - TASK 2: SURVEYS AND SITE FACILITIES

(i) Task Objectives

To provide for safe, cost effective, and environmentally acceptable logistical support of all project field activities; to conduct those surveys necessary to furnish data for use in other subtasks which must be performed prior to licensing; to resolve real estate issues associated with the proposed project in sufficient detail to permit preparation of Exhibit F of the FERC license application; and to undertake initial studies of proposed reservoir areas and access roads.

(ii) Task Output

The primary outputs of this task will be major portions of certain exhibits required for FERC license application and data which will be necessary inputs for many of the remaining exhibits. Specifically, this task will contribute to Exhibit D (demonstrating evidence of compliance with State water and land use laws), Exhibit E (providing water rights data and plans for perfecting rights to use water for project operation), Exhibit F (statement of land ownership). In addition, surveys and mapping will be essential portions of Exhibit J (general project map) and Exhibit K (detailed project map showing boundaries, survey data, land ownership, and feature locations). In addition to the data collection and exhibit preparation, a number of tangible products will be acquired or constructed and will generally be suitable for use during the post- application phase and beyond. In this latter category are included camp facilities, airfield, and similar semi-permanent items.

(iii) List of Subtasks

Subtask 2.01 - Provision for Land Use Payments and Directed Inspection Services
Subtask 2.02 - Provision of Field Camps and Associated Logistic Support
Subtask 2.03 - Design and Construction of Airstrip
Subtask 2.04 - Land Status Research
Subtask 2.05 - Land Acquisition Analysis
Subtask 2.06 - Right-of-Entry

Subtask 2.07 - Site Specific Surveys
Subtask 2.08 - Aerial Photography and Photogrammetric Mapping
Subtask 2.09 - Control Network Surveys
Subtask 2.10 - Access Roads
Subtask 2.11 - Map and Photo Search
Subtask 2.12 - Field Reconnaissance of Reservoir Areas
Subtask 2.13 - Marketability and Disposal Study for Reservoir Area
Subtask 2.14 - Cost Estimates for Reservoir Clearing
Subtask 2.15 - Slope Stability and Erosion Studies
Subtask 2.16 - Hydrographic Surveys

8.3 - TASK 3: HYDROLOGY

(i) Task Objectives

The basic objectives of this task are to undertake and report on all hydrologic, hydraulic, ice, and climatic studies necessary to complete the feasibility design of the project and to provide sufficient material for the FERC license application.

(ii) Task Output

- Data Index System

A data index system listing all the available hydrologic and climatologic data will be compiled and circulated. Hard copies of the more relevant data items will be stored in the project office in Anchorage and copies made available to those requesting it.

All the additional hydrologic and climatologic field data collected as part of this study will be documented on either computer printout sheets or typewritten tables.

- Written Sections and Drawings for Inclusion in the FERC License Application

Exhibit H - proposed reservoir operating rules, predicted reservoir behavior, and downstream water quality and flow conditions.

Exhibit I - dependable power flow, critical design low flow period, flow duration curves and tailwater rating curves.

Exhibit K - reservoir shorelines for maximum and minimum reservoir water levels and reservoir water level area and capacity curves.

Exhibit L - spillway design flood and capacity and freeboard allowance.

- Hydrologic Appendix to Engineering Report

The detailed technical appendix will contain sections on the following type of studies: hydrology (resource and floods), reservoir operation, hydraulic, sediment yield, river morphology, ice engineering, and climatic studies for transmission line design and hydrologic and hydraulic studies for the access road.

- A Series of Design Transmittals

These will summarize the pertinent design parameters obtained from the studies outlined above.

(iii) List of Subtasks

3.01 - Review of Available Material
3.02 - Field Data Index and Distribution System
3.03 - Field Data Collection and Processing
3.04 - Water Resources Studies
3.05 - Flood Studies
3.06 - Hydraulic and Ice Studies
3.07 - Sediment Yield and River Morphology Studies
3.08 - Climatic Studies for Transmission Line
3.09 - Access Road Studies

8.4 - TASK 4: SEISMIC STUDIES

(i) Task Objectives

To determine the earthquake ground motions which will provide the seismic design criteria for the major structures associated with the Susitna Hydroelectric Project, to undertake preliminary evaluations of the seismic stability of proposed earth-rockfill and concrete dams, to assess the potential for reservoir induced seismicity and landslides, and to identify soils which are susceptible to seismically-induced failure along the proposed transmission line and access road routes.

(ii) Task Output

The data collection programs and studies outlined in this task will be sufficiently comprehensive for FERC license applications.

Thorough presentations of conclusions, evaluations and data are also desirable for projects that are being carefully reviewed by permitting agencies. Woodward-Clyde Consultants has completed previous similar projects in Alaska and other states where permitting agencies, or other interested groups or agencies, are closely scrutinizing a project. Based upon our past experience, we believe that the Susitna Hydropower Project will undergo close scrutiny, and that the reports of the project should be complete and thorough. We propose to complete the reporting of the seismic geology and siesmology investigations with this philosophy as a guide.

The primary products of this task will include:

- Technical reports containing thorough documentation of all work done during the first year.
- Final technical reports containing thorough documentation for all studies during the first two years.
- Monthly management reports during the course of the investigation.

The technical reports will be accompanied by geologic maps showing locations of all controlling features, fault lines, etc.

Management reports will deal with technical and financial progress with respect to plan.

(iii) List of Subtasks

Subtask 4.01 - Review of Available Data
Subtask 4.02 - Short-term Seismologic Monitoring Program
Subtask 4.03 - Preliminary Reservoir Induced Seismicity
Subtask 4.04 - Remote Sensing Image Analysis
Subtask 4.05 - Seismic Geology Reconnaissance
Subtask 4.06 - Evaluation and Reporting
Subtask 4.07 - Preliminary Ground Motion Studies
Subtask 4.08 - Preliminary Analysis of Dam Stability
Subtask 4.09 - Long-term Seismologic Monitoring Program
Subtask 4.10 - Reservoir Induced Seismicity
Subtask 4.11 - Seismic Geology Field Studies
Subtask 4.12 - Evaluation and Reporting
Subtask 4.13 - Ground Motion Studies
Subtask 4.14 - Dam Stability Consulting Services
Subtask 4.15 - Soil Susceptibility to Seismically-Induced Failure

8.5 - TASK 5: GEOTECHNICAL EXPLORATION

(i) Task Objectives

To determine the surface and subsurface geology and geotechnical conditions for the feasibility studies of the proposed Susitna Hydroelectric Project, including the access roads and the transmission lines.

(ii) Task Output

The primary outputs of Task 5 will consist of comprehensive documentation of geotechnical exploration undertaken at the Devil Canyon and Watana sites, reservoirs, and access roads and transmission line routes. This documentation will include the following:

- geologic maps
- geologic sections
- descriptive and graphic borehole logs
- descriptive test trench logse

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- field inspection borehole and test trench logs
- photogeologic maps
- borehole rock core photographs
- low level air photointerpretation
- seismic and resistivity bedrock profiles
- radar imagery interpretation maps
- geotechnical exploration program summaries (1980, 1981, 1982)
- data summaries for
  -- in-hole seismic testing
  -- borehole camera studies
  -- laboratory testing.
- geotechnical exploration summary reports (1980, 1981)

(iii) List of Subtasks

Subtask 5.01 - Data Collection and Review
Subtask 5.02 - Photointerpretation
Subtask 5.03 - Exploratory Program Design (1980)
Subtask 5.04 - Exploratory Program (1980)
Subtask 5.05 - Exploratory Program Design (1981)
Subtask 5.06 - Exploratory Program (1981)
Subtask 5.07 - Exploratory Program Design (1982)
Subtask 5.08 - Data Compilation

8.6 - TASK 6: DESIGN DEVELOPMENT

(i) Task Objectives

To undertake planning studies, to evaluate, analyze and review all previous engineering studies related to hydroelectric development of the Upper Susitna River Basin and to develop preliminary engineering design and cost information for Watana and Devil Canyon Dam sites with all associated intake, outlet works, spillways and power facilities to allow preparation of a project feasibility report.

(ii) Task Output

The primary output of Task 6 will be a logical and systematic development of the requisite project features. Alternative sites for dams and power developments will be evaluated. Alternative arrangements at each site will also be considered. One such alternative will involve a 30 mile long tunnel from Watana to Devil Canyon to eliminate the high dam at that site. A Development Selection Report will be issued on or about Week 65 of the Study for review and approval by Alaska Power Authority. Preliminary findings of the study will be discussed on or about Week 50, in order to establish whether or not work on two dam sites should continue or whether more viable alternatives exist and should be examined. Design transmittals will be issued at appropriate points in the study. All necessary input from parallel tasks including hydrology, geotechnical, economic, seismic survey and environmental studies will be factored into the planning studies and the development of the various features of the project. Engineering evaluation criteria and project definition will be developed. If sites are found to be technically viable, economically feasible and environmentally acceptable, additional studies and investigations will be conducted to establish the feasibility of the project and the optimum scale and sequence of development.

(iii) List of Subtasks

Subtask 6.01 - Review of Previous Studies
Subtask 6.02 - Investigate Tunnel Alternative
Subtask 6.03 - Evaluate Alternative Susitna Developments
Subtask 6.04 - Evaluation of Arch Dam at Devil Canyon Site
Subtask 6.05 - Development Selection Report
Subtask 6.06 - Watana/Devil Canyon Staged Development Alternatives
Subtask 6.07 - Preliminary Watana Dam Alternatives
Subtask 6.08 - Preliminary Devil Canyon Dam Alternatives
Subtask 6.09 - Establish Watana Design Criteria
Subtask 6.10 - Establish Devil Canyon Design Criteria
Subtask 6.11 - Preliminary Design Watana Dam
Subtask 6.12 - Preliminary Design Devil Canyon Dam
Subtask 6.13 - Dam Selection Report
Subtask 6.14 - Spillway Design Criteria
Subtask 6.15 - Watana Spillway Alternatives
Subtask 6.16 - Devil Canyon Spillway Alternatives
Subtask 6.17 - Preliminary Design Watana Spillway
Subtask 6.18 - Preliminary Design Devil Canyon Spillway
Subtask 6.19 - Spillway Selection Report
Subtask 6.20 - Access and Camp Facilities
Subtask 6.21 - Watana Diversion Scheme
Subtask 6.22 - Devil Canyon Diversion Scheme
Subtask 6.23 - Optimize Watana Power Development
Subtask 6.24 - Optimize Devil Canyon Power Development
Subtask 6.25 - Optimize Dam Heights
Subtask 6.26 - Preliminary Design Watana Power Development
Subtask 6.27 - Preliminary Design Devil Canyon Power Development
Subtask 6.28 - Power Development Report
Subtask 6.29 - Watana General Arrangement
Subtask 6.30 - Devil Canyon General Arrangement
Subtask 6.31 - Feasibility Report

8.7 - Task 7 - Environmental Studies

(i) Task Objectives

The environmental program is designed to evaluate primarily the Susitna Hydroelectric Project and associated facilities, with respect to environmental impacts. To accomplish this, a comprehensive program of studies has been developed in the following disciplines: socioeconomics, archaeological and historical resources, geology, land use and recreation, water resources, fish ecology, wildlife ecology and plant ecology. Access roads, site facilities and transmission corridors will also be studied for environmental compatibility.

The overall objectives of the environmental studies are to describe the existing environmental conditions, evaluate alternatives in light of the existing conditions and, for the selected alternatives, predict future conditions with and without the proposed project so that changes (impacts) caused by the project may be assessed. To

Subtask 2.15 - Slope Stability and Erosion Studies

(a) Objectives

Estimate the extent to which cleared slopes will maintain stability; estimate the risk that continued reservoir operation will cause one or more slopes to fail; and estimate costs of minimizing slope failure risks.

(b) Approach

Field data collected during the reconnaissance under Subtask 2.12 will be used as the basis for analyzing the potential for slope stability problems. To the extent that such problems appear to exist, alternative means of slope protection will be considered. It will be assumed that slope protection will be required if there is a danger of failure during continued operation.

(c) Discussion

Risk estimates developed during this study will be used ultimately in the risk analysis to ensure that all potential difficulties have been accounted for. The costs of providing appropriate slope protection necessarily become a part of the total project cost estimate to be considered ultimately in determining project financibility and viability.

Subsequent to submission of the license application, much more detailed and vigorous erosion control studies will be required to minimize damage caused by a concentrated flow of water over newly constructed slopes or in areas where the natural vegetative cover has been removed. The objective of this post-application task will be to issue recommendations and delineate problem areas where an added degree of caution should be exercised. A two part study is contemplated to fulfill these needs. This task will be limited to the general site earthwork and is not intended to address erosion of the downstream channel of the dam site.

Input from the first phase of the detailed erosion study will come from an evaluation of soil types obtained from project test borings and laboratory test data. Air photo studies will also be used. It is presently anticipated that a sufficient number of test borings will have been drilled in other project tasks to accomplish this study without additional test borings. Nevertheless, samples of surficial soil may be collected for identification and classification purposes, and laboratory tests may be performed.

A report describing areas of varying degrees of erosion susceptibility will be prepared. Some of the factors that will be considered in this evaluation will be the soil type and its consistency. Included in this report will be a discussion of erosion control for general site grading.

(d) Schedule

Weeks 47 to 54

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(d) Schedule

Weeks 47 to 54

A.5.5 - TASK 4: SEISMIC STUDIES

(i) Task Objectives

To determine the earthquake ground motions which will provide the seismic design criteria for the major structures associated with the Susitna Hydroelectric Project, to undertake preliminary evaluations of the seismic stability of proposed earth-rockfill and concrete dams, to assess the potential for reservoir induced seismicity and landslides, and to identify soils which are susceptible to seismically-induced failure along the proposed transmission line and access road routes.

(ii) Task Output

The data collection programs and studies outlined in this task will be sufficiently comprehensive for FERC license applications.

Thorough presentations of conclusions, evaluations and data are also desirable for projects that are being carefully reviewed by permitting agencies. Complete reporting of the seismic geology and seismology investigations will be made with this philosophy as a guide. This task will be conducted primarily by Woodward-Clyde Consultants with review by Acres and field support by R&M Consultants. The ground motion study data will be utilized in Task 6 for design studies. Identification of seisimically susceptible soils for the road and transmission routes will be inputs to Task 2 and 8 studies. Field activities will be coordinated with the Task 5 activities.

The primary products of this task will include:

- Technical reports containing thorough documentation of all work done during the first year.

- Final technical reports containing thorough documentation for all studies during the first two years.

- Monthly management reports during the course of the investigation.

The technical reports will be accompanied by geologic maps showing locations of all controlling features, fault lines, etc.

Management reports will deal with technical and financial progress with respect to plan.

Subtask 4.01 - Review of Available Data

(a) Objective

To acquire, compile and review existing data and identify the earthquake setting of the Susitna River basin area.

(b) Approach

Data obtained under this subtask will be used to plan the details of the seismologic investigations (Subtasks 4.02, 4.03, 4.09 and 4.10) and the seismic geology field reconnaissance (Subtask 4.05). Available geological, seismological, and geophysical data for the region will be gathered from sources such as Woodward-Clyde files, the Department of Geologic and the Geophysical Institute of the University of Alaska, the Alaska Geological Survey, the U.S. Geological Survey and the major colleges and universities involved in research pertinent to the project. In addition, researchers with on-going programs of study will be contacted and the current status of their research will be obtained by discussions and written correspondence.

The acquisition of geological data will be concentrated on structural features of the earth that may represent major active faults. The geomorphic expressions of these features will also be identified from the available data.

Geophysical data regarding the structure of the earth will be acquired and reviewed. Regional gravity and magnetic data are particularly useful in identifying major discontinuities in the crust of the earth. These discontinuities may be along faults that could produce large earthquakes and surface fault ruptures. If available, other types of geophysical data such as seismic refraction, seismic reflection and electrical resistivity may also be of use in identifying major active faults.

Seismological data will be acquired for the project area. This data includes historical information on past earthquakes, instrumental data from the Geophysical Institute of the University of Alaska, and regional instrumental data from the U.S. Geological Survey.

The geological, seismological and geophysical data will be compiled in order to obtain a thorough current knowledge of the tectonics of the Susitna River area. The end product will consist of maps that identify faults, lineaments, and epicenter clusters or alignments identified by others. These maps will provide a basis for the proposed geological and seismological studies.

In addition to the data acquired for the project area, data relating to reservoir-induced seismicity will also be compiled. The world-wide data on reservoir-induced seismicity will provide a partial basis for evaluating whether or not induced earthquakes may be generated in the Susitna River area. Woodward-Clyde Consultants has an extensive file on world-wide data on reservoir-induced earthquakes, and is currently being retained for further research in reservoir-induced seismicity by the U.S. Geological Survey.

The specific products of this subtask include:

- Historical earthquake map and catalog

  A catalog of reported earthquakes with magnitude 4.0 and larger from 1899 to the present will be prepared for the region within 200 miles of the site. For the larger earthquakes in the period, the geologic and engineering effects will be discussed. Data quality as a function of time will be evaluated to estimate the completeness level of the catalog with respect to magnitude, focal depth and spatial location.

- Summary of recent regional monitoring

  Microearthquake monitoring by the University of Alaska Geophysical Institute and the U.S. Geological Survey will be reviewed and summary plots of seismicity data will be prepared. Results and interpretations based on these data will be reviewed with appropriate personnel in governmental and academic organizations. Of particular importance is evaluation of the accuracy of focal depth determinations based on these network studies.

- Tectonic model

  Based on available seismologic and geologic data, a preliminary kinematic tectonic model will be developed for the region within approximately 200 miles of the site. This model will be modified as needed by studies in later subtasks and will provide the basis for understanding the interrelated geologic source areas for future earthquake activity in the Alaskan interior. Applications and implications of seismic gap theory will be considered.

(c) Discussion

The seismicity and seismic sources of the Alaskan interior have only recently begun to be studied in significant detail. Interest in the seismicity of continental Alaska was stimulated by the major 1964 earthquake and involved the initiation of regional microearthquake monitoring and the augmentation of geological investigations to improve understanding of the tectonics of Alaska.

The seismological environment of the Susitna Project is characterized by two major earthquake sources:

- shallow earthquake activity occurring along crustal faults such as the Denali fault, with depth of focus less than approximately 12 miles; and

- earthquake activity in a Benioff zone which has a depth range of 30 to 90 miles and is associated with the subduction of the Pacific plate beneath Alaska.

Geological studies are used, along with seismological data, to investigate the shallow earthquake sources. The deeper-focus earthquake sources are not directly expressed at the earth's surface and must be investigated using seismological data combined with a kinematic understanding of the present-day tectonic activity of the Alaskan interior. The occurrence of past large earthquakes within the region, such as the 1904 and 1912 magnitude 7 to 8 earthquakes, indicates that both the shallow and deeper seismic zones may have the potential for generating earthquakes with ground motions significant to the project.

The Susitna River area is within a zone of active seismicity that extends from the Aleutian trough on the south into central and northern interior Alaska. Woodward-Clyde Consultants has previously conducted regional studies of seismic geology and seismicity over broad regions of Alaska. The past regional evaluations have been for the Trans-Alaska Pipeline System, the proposed Offshore Continental Shelf regions surrounding Alaska, and for the proposed Alcan Gas Pipeline. These past regional studies provide data regarding the earthquake sources in Alaska, and they also provide up-to-date knowledge of the current status of research in the area.

(d) Schedule

Weeks 0 through 22

Subtask 4.02 - Short-term Seismologic Monitoring Program

(a) Objective

Establish initial monitoring system, obtain and analyze basic seismologic data on potential earthquake sources within the Susitna River area and supply information required to implement a more thorough long-term monitoring program (Subtask 4.09).

(b) Approach

This subtask involves two major packages of work:

(1) Analysis of Existing Data

Further limited analysis of existing regional earthquake data will be undertaken to enable sufficiently accurate and appropriate selection of maximum earthquake sources and associated attenuation relationships. Source studies will be carried out on several of the largest historical earthquakes, including the 1904 and 1912 events, in order to constrain their location, & focal depth and causative geological structure. The maximum earthquake potential of the subduction zone beneath the Susitna site is poorly understood, and it will be of significant value to use the historical data to properly characterize this source. These studies will also be directed to the evaluation of the seismic attenuation characteristics of deeper earthquakes to enable the proper utilization of the results of the Alaskan OASES study by Woodward-Clyde Consultants (1978) and other studies in selecting appropriate attenuation relationships required for Subtask 4.07 and 4.13.

(2) Establishment of a Monitoring Network

Since the study area is in a remote but seismically active area additional detailed earthquake source data will be collected by installing and operating a localized microearthquake recording network.

The network will be established and operated during the summer of 1980. The area covered will include the region within approximately 30 miles of the dam sites. Eight to ten recorders with station spacing of 5 to 10 miles will be installed to record microearthquake activity down to magnitude of 1.0 or less. Low-power radio telemetery will be used to make the field operation as efficient as possible. Helicopter support will be used for installation and maintenance.

Initial station deployment will be guided by the information obtained during the data review (Subtask 4.01). It will be required to monitor known significant geologic features, such as the Susitna fault.

During the course of the study, some of the stations may be moved to study specific areas of activity. Data analysis will be carried out to locate active seismic sources and evaluate their spatial extent and focal depth. These analyses will also be used to establish causative stress orientations based on focal mechanism studies, to evaluate seismic attenuation, and to evaluate the statistical features of the microearthquake activity.

Specific results to be obtained relative to source and wave propagation assessment include the association of larger earthquakes (such as the 1904 and 1912 events) with probable source structures, depth determination of the Benioff Zone of deeper seismic activity and attenuation characteristics of subduction zone earthquakes. Seismic source location in terms of maximum earthquake potential in the Benioff Zone will be performed. Comparisons will be made with seismic activity in other comparable tectonic areas to assess attenuation and maximum earthquake potential. The scope of these studies will be modified as necessary on the basis of the results obtained as the work progresses.

Liaison will be maintained with data collection by the University of Alaska Geophysical Institute and the U.S. Geological Survey. The recording period is initially planned as three months; however, if this should need to be modified, appropriate recommendations will be made during the course of the study.

(c) Discussion

The present location and focal mechanism level using the Geophysical Institute network is approximately magnitude 2-1/2 or larger. The data obtained from the proposed monitoring program will supplement the existing regional network operations and will provide needed accuracy and detection threshold. In addition, the results obtained will provide the information needed to accurately site the long-term network stations (Subtask 4.09) and to select appropriate instrumentation. They will also aid in planning the seismic geology reconnaissance (Subtask 4.05).

(d) Schedule

Weeks 21 through 52

Subtask 4.03 - Preliminary Reservoir Induced Seismicity

(a) Objective

Evaluate the potential for the possible future occurrence of reservoir-induced seismicity (RIS) in the Susitna Project area.

(b) Approach

The results of this evaluation will be used to establish scenarios of possible outcomes of the occurrence of reservoir induced seismicity. Woodward-Clyde Consultants has recently completed a major analysis of geologic, seismologic and hydrologic factors associated with past cases of reservoir-induced seismicity. The results of this study also will be applied to the known factors for the Susitna project in order to statistically relate the Susitna Project to the potential for RIS. The resulting potential will be evaluated in terms of possible scenarios for the occurrence of induced activity, and the possible outcome of such occurrences will be discussed.

This analysis will result in a quantitative assessment of the potential for the occurrence of reservoir-induced seismicity as a result of the damming of the Susitna River. A comparison will be made of depth, volume, regional stress, geologic setting and faulting at the Susitna dam sites with the same parameters as the world's deep and/or very large reservoirs. Based on this comparison, the probability of reservoir-induced seismicity at the Susitna dam sites will be assessed.

A description of known cases of RIS emphasizing the relationship between filling of the reservoir and the length of time to the first and largest earthquakes and the relevance of these data to the Susitna dam sites will be discussed.

Scenarios will be presented that discuss possible courses of action that can be taken if RIS is anticipated or detected during filling of the reservoir.

(c) Discussion

The activities associated with this task will be closely coordinated with the hydraulic studies aimed at assessing the potential impact on the reservoir water level of a reservoir-induced slide. (See Subtask 3.06).

(d) Schedule

Weeks 23 through 50

Subtask 4.04 - Remote Sensing Image Analysis

(a) Objective

Select and interpret available remote sensing imagery to identify topographic features that may be associated with active faulting.

(b) Approach

Data obtained under this subtask will be used during the Seismic Geology Reconnaissance (Subtask 4.05) and the Seismic Geology Field Studies (Subtask 4.11) to identify youthful faults that may produce future earthquakes and future surface fault ruptures. Remote sensing imagery and aerial photography relevant to approximately 100 km radius about the dam site will be selected for a lineament analysis. This remote sensing data includes available Landsat, SLAR (side-landing airborne radar), Skylab photography; high altitude U-2, or RB-57 color infrared photographs, and black-and-white aerial photographs. The remote sensing and high altitude imagery and aerial photographs will be interpreted in terms of the geology, geomorphology and structure of the study region.

Interpretation will help to identify lineaments and other features that may be related to active faults. Seismicity clusters and alignments identified during the seismicity evaluation in Subtask 4.02 will be compared with the lineaments identified by the imagery interpretation and the known faults on existing maps to assess the possible relationship of the epicentral locations, surficial lineaments and mapped faults. The imagery interpretation will be conducted by geologists experienced in lineament evaluation and in the recognition of features associated with active faults. It will be important to distinguish these lineaments from similar features that result from non-tectonic geologic processes.

(c) Discussion

The activities in this task (100) will be closely coordinated with the photo interpretation studies being conducted for the dam site, reservoir and constructed material areas (Subtask 5.02) to ensure that information requests and analyses are not duplicated. Following an initial aerial and ground reconnaissance it may be decided that low-sun-angle aerial photography should be acquired for specific geomorphic features that may be fault-related. For this purpose, low-sun-angle color infrared and black-and-white photography at a scale of approximately 1:24,000 is proposed. This has proven exceedingly valuable in delineating subtle topographic features that may be fault-related. The long shadows cast by the low-sun-angle highlight subtle topographic features related to faults, such as scarps or offsets, that would be undetectable with conventional vertical aerial photographs.

Color infrared photography has also proven extremely useful in delineating subtle features in the terrain such as a contrast in vegetation or in surface moisture. Such features are often associated with faults where ground water is either closest along the fault zone or on only one side of the fault.

A map of lineaments within 100 km of the project area will be produced as a guide for Subtasks 4.05 and 4.11. The lineament map will be supplemented by mapped faults from Subtask 4.01, in order to compare known faults with lineaments of various origins.

(d) Schedule

Aerial photographs will be ordered during the first month. The analysis will be performed during weeks 10 through 26.

Subtask 4.05 - Seismic Geology Reconnaissance

(a) Objective

Perform a reconnaissance investigation of known faults in the Susitna River area, and of lineaments that may be faults, identify active faults and establish priorities for more detailed field investigations.

(b) Approach

This task will utilize the data obtained from Subtask 4.01 and the aerial photographic interpretations outlined in Subtask 4.04 as a basis for planning aerial and ground reconnaissance.

The aerial reconnaissance will systematically cover all lineaments and faults identified in previous subtasks. A field analysis will be made in order to identify whether or not each feature may be an active fault capable of impacting the project area due to its being associated with a large earthquake or capable of producing a future surface fault rupture. Features within 60 miles of the project area will be studied during the reconnaissance, with each lineament and fault being identified by number. In addition, regional reconnaissance of major features such as the Denali fault and the Castle Mountain fault which may extend as far as 200 miles from the project area will be investigated. Interpretations regarding the origin of each feature will be made by expert seismic geologists with past experience on similar projects. Those features that are interpreted to originate from youthful faulting, or features of unknown origin that may be due to youthful faulting, will be studied further in the field and subjected to reconnaissance-level geologic mapping.

The reconnaissance-level geologic mapping will be oriented toward identifying whether or not the bedrock units near the feature suggest the presence or absence of a fault. In addition, the Quaternary geomorphic surfaces and stratigraphic units in proximity to each feature will be studied to aid in identifying whether or not faulting has occurred in young units. The reconnaissance-level mapping, at a scale of 1:63,360, will aid in identifying those features that will require detailed study during the field season of 1981.

These activities will be coordinated with the geologic mapping tasks associated in Subtask 5.04.

(c) Discussion

The Susitna River area is in a complex tectonic area that is poorly known geologically. Previous work by Kachadoorian and Moore emphasized the structural complexity of this area, and the large number of linear features at the surface that may be due to faulting or to other origins. These surface features require field investigation to identify their origins. In order to identify the origins of some features, it may require detailed mapping, trending, borings, or geophysical data. Despite thorough investigations, however, it may not be possible to obtain definitive information regarding the origins of all the lineaments.

Woodward-Clyde Consultants has conducted seismic geology reconnaissance investigations over large regions of Alaska and in many other seismically active areas of the world. Based upon that experience, we estimate that reconnaissance-level investigations as proposed in this subtask will define the origins of about 90 percent of the lineaments identified on remote sensing images. If these features are considered to be controlling faults for the design of dams and other important facilities, further detailed investigations will be undertaken in the Seismic Geology Field Studies, Subtask 4.11.

The products of this subtask will consist of a map that identifies recently active faults and features of unknown origins that may be faults significant to one or more dam sites and other critical facilities. In addition, all field observations will be tabulated for each lineament studied, and preliminary estimates of the maximum credible earthquake and faulting, along with the recurrences of faulting, will be made for each active fault and other features that may be faults.

(d) <u>Schedule</u>

Weeks 24 through 39

This task can begin after Subtask 4.04 is complete. Subtask 4.02 should either proceed concurrently with this subtask or it should precede this subtask.

Subtask 4.06 - Evaluation and Reporting

(a) Objectives

Complete a preliminary evaluation of the seismic environment of the project, define the earthquake source parameters required for earthquake engineering input in design and document the studies in reports suitable for use in design studies (Task 6).

(b) Approach

The approach of this subtask will be to provide a probabilistic analysis of earthquakes concerning control of active faulting, and to estimate maximum credible earthquakes for each active fault. These analyses will be completed by an interdisciplinary team utilizing the reconnaissance-level information obtained from Subtask 4.01 to 4.05. Reporting will be in a format suitable for use in selecting the design basis earthquakes, and will include thorough documentation that will be suitable for FERC and peer group review.

(c) Discussion

A panel of leading experts in seismology investigation and seismic design of major structures will be convened during this activity to review and comment on all study work undertaken and the findings thereof.

Overall management and coordination of Subtasks 4.01 to 4.05 is also incorporated in this subtask.

(d) Schedule

Weeks 18 through 52

Subtask 4.07 - Preliminary Ground Motion Studies

(a) Objective

Undertake a preliminary estimate of the ground motions (ground shaking) to which proposed project facilities may be subjected during earthquakes.

(b) Approach

The ground motion characteristics to be estimated include peak parameters (peak accelerations, velocities, and displacements), response spectra (describing the frequency content of ground shaking) and significant duration (describing the time duration of strong ground shaking). This initial assessment of ground motions will be made using information from the seismic geology (Subtask 4.05) and seismology (Subtask 4.02) studies. The ground motion estimates will be refined if necessary on the basis of additional information gathered during the second year. (See Subtask 4.13).

In consideration of ground motions, the terms "seismic exposure" and "seismic risk" are sometimes used interchangeably. However, for the purposes of this proposal they have two distinctly different meanings:

- "Seismic Exposure" is used to define the nature of the earthquake-induced ground motion characteristics at a specific site;
- "Seismic Risk" is used to define the risk as the probability of structural damage or destruction by an earthquake at the project site. It reflects the degree to which the structure has been designed to cope with earthquakes.

Ground motions will be estimated using a probabilistic approach, usually called a seismic exposure analysis. In this approach, the probability of exceeding various amplitudes of ground motion is estimated, taking into account the frequency of occurrence of earthquakes from all significant seismic sources and the attenuation of ground motion from each source to the locations of project facilities. Earthquakes of various magnitudes, up to the magnitudes of maximum credible events, will be considered. Attenuation relationships will be derived from examination and analyses of earthquake recordings made in similar tectonic environments and in similar subsurface geologic conditions, including available recordings from Alaska. WCC has recently conducted a comprehensive state-of-the-art analysis of seismic exposure in Alaskan offshore areas (OASES, 1978). The results and data of this previous study, which included assessment of activity for major onshore faults (e.g., Denali Fault, Castle Mountain fault) as well as offshore faults (e.g., Benioff zone), will be extremely valuable to the progress study.

Available from OASES

The end products of this subtask will consist of estimates of the probability of exceedence during selected time periods (e.g., 100 years) of various levels of ground motions at the locations of each proposed major dam and other major facilities. For the long transmission lines and major access roads, the probability estimates will be given for appropriate segments of the systems. Probability levels and corresponding amplitudes of ground motions that may be considered in selecting project seismic design criteria will be discussed. For the dams, ground motion criteria will be consistent with ground motions associated with maximum credible earthquakes. For less critical project components, ground motion characteristics having a higher probability of exceedence would be used as design criteria.

(c) Discussion

It is widely recognized that neither the occurrence of future earthquakes nor the resulting ground motions at a site can be predicted with great accuracy even when the best available data and technology are employed. The fact is recognized in the above approach and considerable attention will be devoted to determining the reliability of the estimated design criteria.

The key interrelationships of this subtask and others are the following:

Projections of earthquake recurrence and identification of maximum credible earthquakes is an essential input to this subtask and will be accomplished in Subtask 4.06. The results of this subtask constitute essential input to Subtask 4.08 (Preliminary Analysis of Dam Stability) and Subtask 4.15 (Identification of Soils Susceptible to Seismically Induced Failure Along the Transmission Line and Access Road Routes).

The products of this task include the following:

- Estimates of the probability of exceedence during selected time periods (e.g., 100 years) of various degrees of ground motion at the location of each proposed major dam and other major project components.

- A discussion of and recommendations for project ground motion design criteria.

(d) Schedule

Weeks 24 through 52

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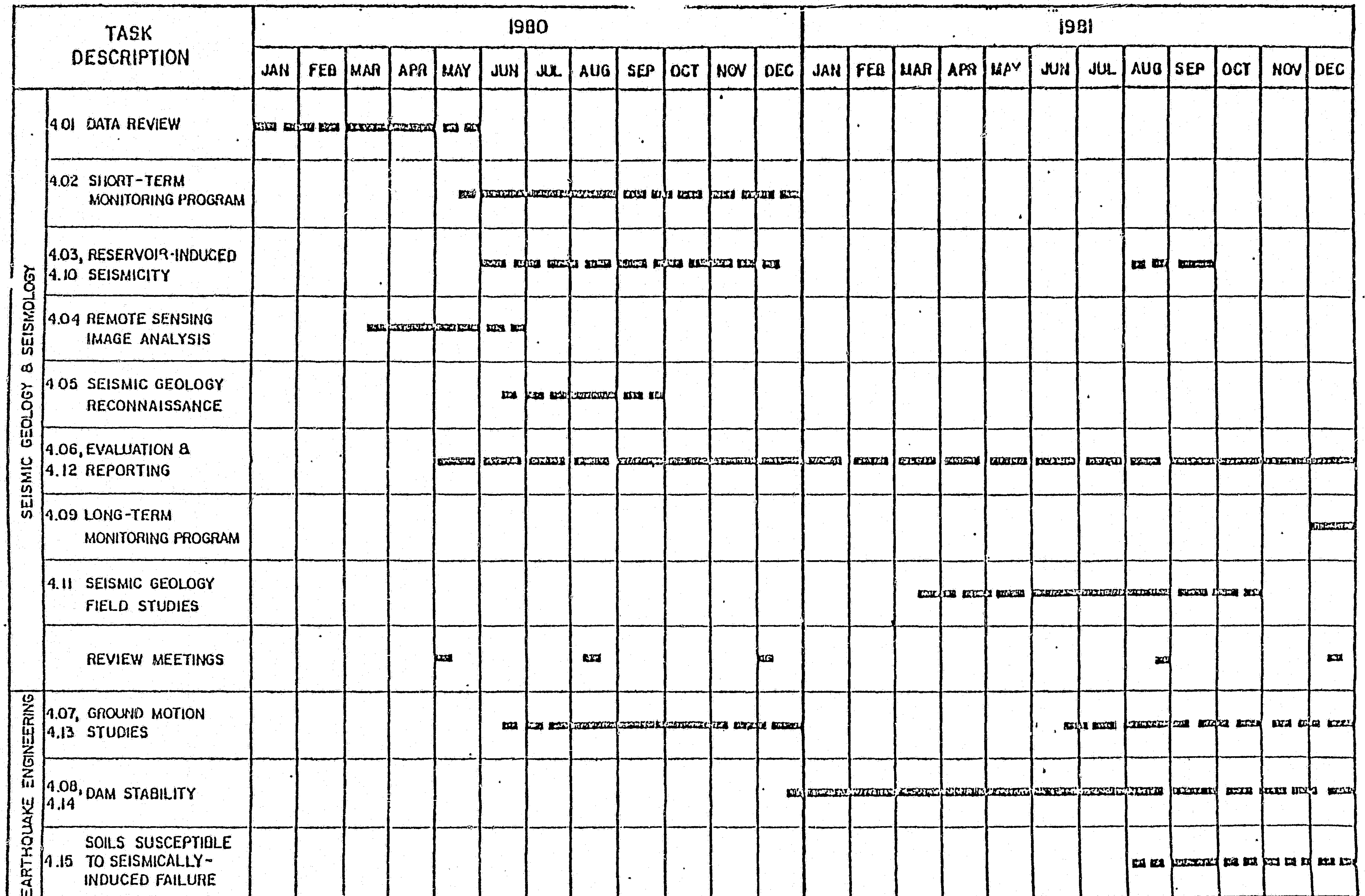


SUSITNA HYDROELECTRIC PROJECT

PLAN OF STUDY

PLATE T4.1: TASK 4 SCHEDULE

A.5.6 - TASK 5: GEOTECHNICAL EXPLORATION

(i) Task Objectives

To determine the surface and subsurface geology and geotechnical conditions for the feasibility studies of the proposed Susitna Hydroelectric Project, including the access roads and the transmission lines.

(ii) Task Output

The Task 5 studies will be designed to provide input to the Task 6 design studies and will provide support to the Task 4 studies.

The primary outputs of Task 5 will consist of comprehensive documentation of geotechnical exploration undertaken at the Devil Canyon and Watana sites, reservoirs, and access roads and transmission line routes. This documentation will include the following:

- geologic maps
- geologic sections
- descriptive and graphic borehole logs
- descriptive test trench logs
- field inspection borehole and test trench logs
- photogeologic maps
- borehole rock core photographs
- low level air photointerpretation
- seismic and resistivity bedrock profiles
- radar imagery interpretation maps
- geotechnical exploration program summaries (1980, 1981, 1982)
- data summaries for
  -- in-hole seismic testing
  -- borehole camera studies
  -- laboratory testing.
- geotechnical exploration summary reports (1980, 1981)

(iii) List of Subtasks

Subtask 5.01 - Data Collection and Review
Subtask 5.02 - Photointerpretation
Subtask 5.03 - Exploratory Program Design (1980)
Subtask 5.04 - Exploratory Program (1980)
Subtask 5.05 - Exploratory Program Design (1981)
Subtask 5.06 - Exploratory Program (1981)
Subtask 5.07 - Exploratory Program Design (1982)
Subtask 5.08 - Data Compilation

(iv) Subtask Scope Statements

For the purposes of this Plan of Study, the geotechnical exploratory programs are essentially divided into first-, second- and third-year stages (1980, 1981 and 1982). Exploratory work to be undertaken in 1982 and beyond is not included in Task 5 activities. Preparation of the program for 1982 is nevertheless included on the understanding that the 1982 program will be initiated prior to submission of the FERC license application, but is not an essential prerequisite to that submission. The 1980 geotechnical exploration program will be designed to identify and investigate in limited detail those geological and geotechnical conditions which will significantly affect the feasibility of the proposed dam projects. Limited preplanning opportunities and climatic constraints are such that investigations in 1980 will be somewhat limited in scope, and the data limited in detail. Emphasis will therefore be placed on identifying and investigating to the maximum extent the most adverse geotechnical conditions encountered.

The objectives of the 1981 geotechncial exploration program will be to investigate in more detail those geological and geotechnical conditions, both general and adverse, which will significantly affect the design and construction of the proposed dam projects. Exploration along the routes selected for the access roads and transmission lines will also be undertaken in 1981. Although the scope of the exploratory work and the data produced in 1981 will still be somewhat limited, the exploratory program will be designed to establish with reasonable confidence the feasibility and total cost of the project, access roads and transmission lines. The exploratory program in 1982 will be yet more detailed. This and subsequent programs will be aimed at providing greater certainty in the design of major dams and structures with a view towards further ensuring the safety of structures while minimizing potential project cost overruns due to unforeseen geotechnical design conditions. The geotechncal exploration programs will be specifically designed to be complementary to the work already completed.

The geotechnical exploration programs in the field will also be severely constrained by difficulties of access and maneuverability of equipment imposed by weather conditions and the requirements for environmental preservation. Full account has been taken of these constraints in developing this Plan of Study.

A detailed discussion of the individual subtasks follows. It should be stressed that the exploration program design is based on the assumption that Watana and Devil Canyon are the selected sites.

Subtask 5.01 - Data Collection and Review

(a) Objective

Collect and review all existing geological and geotechnical data pertaining to the Susitna Project area, including the access road and transmission line corridors and the Susitna River basin.

(b) Approach

Data to be collected at this stage include, but are not limited to the following:

- previous regional and site geological mapping and studies
- published or unpublished geological and geotechnical data and reports from federal, state, academic or private sources
- air photos and high level ERTS photos of the project area, including the proposed access road and transmission line
- geophysical survey, remote sensing and seismicity studies and data pertaining or relevant to the project

A short field visit will be made to the proposed damsites for preliminary geologic interpretation. This will assist in making the preliminary damsite and dam alignment selections in Task 6. This in turn will determine the design of the exploratory investigation program. The data and results of review will be assembled into a brief report with appropriate appendices. These documents will be made available for subsequent use by all project design and study groups.

Borehole rock cores from previous investigations will also be examined in Anchorage. Contacts will be made with the University of Alaska to gather geologic and geotechnical data. A check will be made for mining interests in the project areas. Data pertaining to geological and geotechnical problems associated with the construction of large embankments, access roads and transmission lines will be collected. Discussions will be held with the U.S Corps of Engineers concerning details of the past field studies.

This task will be undertaken by Acres' Anchorage staff with appropriate support from R&M Consultants.

(c) Schedule

Week 0 through 9

Subtask 5.02 - Photointerpretation

(a) Objective

Perform air photointerpretation and terrain analysis of the Watana and Devil Canyon damsite areas, reservoir areas, construction material borrow areas and access road and transmission line corridors, and identify adverse geological features and geotechnical conditions that would signficantly affect the design and construction of the project features.

(b) Approach

Photointerpretation will be based on available air photography obtained under Subtask 5.01, and new aerial photos of a larger scale obtained under Task 2 for the damsites, reservoirs, and construction materials borrow areas, access road and transmission line corridors.

The initial photoanalysis will utilize existing air photos obtained either from private or government sources. These photos are believed to be high level and consequently small scale. They will, however, serve to establish preliminary surface geology, including geomorphology, geologic history, glacial geology, lithology and stratigraphy, structural geology, permafrost characteristics and geohydrology and engineering geology. Land forms will be identified. Alluvial or glaciofluvial deposits of previous sand and gravel, glacial deposits of impervious till and floodplain deposits of poorly drained, compressible silty materials will be located. The distribution, quality and stratigraphic relationships of rock types will be identified.

Photo analysis will also be used to generally delineate or infer permafrost areas and buried channels. Groundwater regimes will also be studied and unstable and/or erodible slopes identified.

A short field study will be required to verify the photo-interpretation analysis. This will be performed early in the first field season (1980).

(c) Discussion

New air photos produced under Task 2 will be available at the end of the first field season. These low level, high resolution, large scale photos will have two purposes:

- preparation of second year exploratory investigation program
- production of accurate topographic maps on which to base subsequent geological mapping and design studies.

Photointerpretation under this subtask will be undertaken by Acres' Anchorage staff and closely coordinated with the photointerpretation work done by WCC (Subtask 4.05) in order to eliminate unnecessary duplication of work.

The results of photointerpretation will be documented in the form of brief summary reports and appended photographs and maps to highlight the principal findings.

(d) Schedule

Weeks 5 through 41

Subtask 5.03 - Exploratory Program Design (1980)

(a) Objective

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.

(b) Approach

The design of the various exploratory investigations will be based on the results of the data collection and review study (Subtask 5.01) and the air-photo interpretation study (Subtask 5.02). Input from the preliminary access road studies under Task 2 will also be required.

Generally, these exploratory investigations will consist of geologic mapping, auger drilling and sampling, test trenching, seismic and resistivity studies, airborne radar imagery techniques and laboratory testing. In cases where environmental damage is a problem or accessibility is poor, test trenches will be replaced by shallow auger drilling by helicopter. The design will specify the following details:

- area to be geologically mapped
- position and extent of seismic and resistivity lines
- areas to be investigated by airborne radar imagery techniques
- types and numbers of laboratory tests.

Investigations for access roads will be confined to geologic mapping and radar imagery. Table A5.4 and A5.5 detail the type and extent of investigations and laboratory testing that are currently proposed elsewhere. The design of the exploratory investigations will be flexible enough to permit changes during the execution of the work. These changes will become evident as the field studies proceed.

(c) Discussion

Work under this subtask will be performed by Acres' Anchorage staff with support in logistical planning provided by R&M and close liaison with WCC.

In the design of the exploratory investigations, full advantage will be taken of the extensive investigations previously undertaken. These include drilling, test pitting, geologic mapping and seismic surveys by the US Corps of Engineers at Watana damsite, and the drilling investigations and seismic studies at Devil Canyon by the US Corps of Engineers and the US Bureau of Reclamation.

- Watana Site

At the Watana damsite area, 17 boreholes have been drilled for a total of 3,340 feet and 11 boreholes have been drilled, totalling 1,815 feet in the right bank spillway and buried channel area. Reconnaissance reservoir mapping and fault mapping has been performed by Kachadoorian. A total of 19 auger and diamond drill

TABLE A5.4

PROPOSED GEOTECHNICAL EXPLORATORY PROGRAM - 1980

Area	Exploration	PROJECT STRUCTURES/FACILITIES: Devil Canyon Dam & Reservoir	PROJECT STRUCTURES/FACILITIES: Watana Dam & Reservoir
Damsite	Geologic Mapping	yes	yes
	Geophysical (seismic and resistivity)	3 - 900 ft. lines at buried channel site 3 - Oblique 450 ft. lines across river channel 2 - 1,000 ft. lines on right abutment	1 - 5,000 ft. line at proposed spillway site 2 - Oblique 1,500 ft. lines across river within upstream portion of dam
	Diamond Drilling	1000 ft.	600 ft.
	Airborne radar imagery	$\pm$ 3,500 ft. at right and left abutment and saddle dam site	$\pm$ 4,000 ft. at right and left abutments
Dam Construction Materials		One established and two new borrow areas	Four established and two new borrow areas
	Geologic Mapping	yes	yes
	Portable Auger Drilling	20 - 10 ft. deep holes in the two proposed borrow areas	20 - 10 ft. deep holes in the two proposed borrow areas
	Geophysical (seismic and resistivity)	2 - 1,000 ft. lines in the two proposed borrow areas	2 - 1,000 ft. lines in the two proposed borrow areas
	Test Trenches	30 trenches in the three borrow areas	30 trenches in threen of borrow areas
	Airborne Radar Imagery	6 - 1,000 ft. lines in the three borrow areas	8 - 1,000 ft. lines in four of the borrow areas
Reservoir Basin	Geologic Mapping	yes	yes
	Portable Auger Drilling	10 - 10 ft. deep holes	10 - 10 ft. deep holes
	Geophysical (seismic)	2,000 ft.	6,000 ft. at site of right bank relict channel
	Diamond Drilling	100 ft.	100 ft.
	Airborne Radar Imagery	10,000 ft.	20,000 ft.

TABLE A5.5

PROPOSED GEOTECHNICAL EXPLORATORY PROGRAM - 1981

Area	Type of Exploration	POWER STRUCTURES/FACILITIES		
		Devil Canyon Dam & Reservoir	Watana Dam & Reservoir	Other
Damsite	Geologic Mapping	yes	yes	
	Diamond Drilling	4 holes in right abutment (powerhouse and dam) 4 holes in left abutment (saddle dam and diversion tunnel) 3 holes in riverbed*	2 holes in relict channel, right abutment 2 holes in right abutment spillway and dam) 2 holes in left abutment (powerhouse and dam)**	
	In-hole Seismic	1500 ft.	1000 ft.	
	Borehole Camera	1500 ft.	1200 ft.	
	Test Trenching	15 trenches	15 trenches	
Dam Construction Materials		Three borrow areas from 1980 program plus two new areas	Six borrow areas from 1980 program plus two new areas	
	Auger Drilling	10 - 30 ft. deep holes	12 - 30 ft. deep holes	
	Diamond Drilling	10 - 50 ft. deep holes in five borrow areas	12 - 50 ft. deep holes in six borrow areas	
	Test Trenching	30 trenches in two new areas	30 trenches in two new areas	
Reservoir Basin	Geologic Mapping	yes	yes	
	Portable Auger Drilling	10 - 10 ft. deep holes	10 - 10 ft. deep holes	
	Diamond Drilling	3 - 100 ft. deep holes, 1 - 200 ft.	3 - 100 ft. deep holes, 1 - 200 ft.	
	Geophysical/Seismic	1000 ft.	1000 ft.	
	Reservoir Slope Monitoring	1 - 200 ft. slope indicators	1 - 200 ft. slope indicator	
Access Road Route (Approx. 50 miles)				ACCESS ROAD
	Geologic Mapping			yes
	Airborne Radar Imagery			10 miles (20% of total length)
	Portable Auger Drilling			25 - 10 ft. deep holes
	Hollow Stem Auger Diamond Drilling			15 - 50 ft. deep holes

holes and 26 test pits have been made in the construction material areas. A total of 69,600 feet of seismic surveys has also been completed.

These investigations have tentatively shown the Watana site to be suitable for an earth and rock-fill dam. The dam foundation contains small shear zones but no major shear zones have been found. Construction materials appear to be available and suitable. Although the important Susitna fault traverses the reservoir, no active faults have as yet been proven in the reservoir. There has been a suggestion that the Tsusena Creek alignment downstream of the dam may represent discontinuity of some kind. Discontinuous permafrost exists locally. Overburden depth in the riverbed at the site appears to be less than 80 feet. A deep buried and potentially leaky channel exists in the right abutment.

Further studies at Watana are required to prove the absence of major faults in the riverbed and in the abutments, to delineate permafrost zones and identify its characteristics, prove the availability and suitability of the construction materials, confirm good quality rock in the spillway and powerhouse area and define the buried channel and identify its geohydrologic properties.

- Devil Canyon Site

At the Devil Canyon damsite, 13 boreholes totalling 1,350 feet have been drilled in the dam area and another eight boreholes totalling 735 feet have been drilled in the left abutment buried channel area. Nineteen test trenches have been excavated in potential borrow areas. A total of 3,300 feet of seismic surveys have been performed. Although there has been little geologic mapping of the abutments at Devil Canyon, the investigations have shown this site to be suitable for a concrete gravity structure.

Major shear zones have not been found in the dam foundation area but minor shear zones are present. Although no active faults have been found in the reservoir, a deep buried channel exists in the left abutment. Some potential construction material areas have been identified.

Further studies at Devil Canyon are required to prove the absence of major faulting in the riverbed and abutments or active faults in the reservoir. Studies are also needed to determine the site geology in more detail, to delineate and evaluate the left abutment buried channel and to prove the availability and suitability of construction materials.

(d) Schedule

Weeks 12 through 20

Subtask 5.04 - Exploratory Program (1980)

(a) Objective

Perform initial surface and subsurface investigations at Watana and Devil Canyon sites and reservoir areas and access road routes to establish general and specific geological and foundation conditions.

(b) Approach

The program will essentially be designed to

- obtain more details on the surface and subsurface geology and foundation conditions at the Watana and Devil Canyon damsites.

- complete the preliminary evaluation of the availability and suitability of the various construction materials required, i.e. fine and coarse aggregate, fine and coarse rockfill, impervious earth fill, pervious and semipervious granular fill and riprap.

- determine the surface geology and geotechnical conditions in limited detail to the Watana and Devil Canyon reservoir areas.

- provide preliminary geologic assessments of the proposed access road routes.

Field work programs will generally be designed by Acres' Anchorage office personnel with input from the Buffalo design group as needed. Seismologic input will be provided by WCC and logistical support by R&M. All field operations will be performed by R&M with appropriate technical inspection and supervision by Acres and to a lesser extent the WCC staff.

(c) Damsites

The proposed exploratory investigations will supplement previous work in establishing general and specific surface and subsurface geologic and foundation conditions at the Devil Canyon and Watana damsite areas.

The investigations will comprise geologic mapping, diamond drilling, geophysical, seismic and resistivity studies and airborne radar imagery, to substantiate and augment the available information on

- depth, distribution, type, stratigraphy and properties of overburden

- distribution, type, quality, degree of weathering and permeability of bedrock

- location, orientation, width, continuity, filling characteristics and capability of major discontinuities in bedrock such as faults

- orientation, frequency, opening, continuity and filling of joints in bedrock

- permafrost characteristics including location, temperature profile and soil type

- groundwater regime

Emphasis will be placed on locating and studying adverse geological features. Such features will include faults, excessive depths of overburden in riverbeds and buried channels which will signficantly effect the design and cost of a dam project at a given site.

The geologic mapping at Watana and Devil Canyon damsites will be undertaken to supplement and verify the previous geological mapping carried out by the U.S. Corps of Engineers and the U.S. Geological Survey (Kachadoorian).

The photointerpretation (Subtask 5.02) will be checked in the field, and adverse geologic features and conditions suggested in the photointerpretation will be investigated on the ground. The geologic mapping will utilize the most recent topographic maps. Aerial photos and survey lines normal to the river will be used as reference in the field. The geologic mapping will be performed primarily by Acres' Anchorage office personnel with assistance from R&M.

Geophysical seismic refraction and resistivity studies will be carried out primarily to determine bedrock depth in deep overburden areas such as buried relict channels and the riverbed area. This work will be done at both damsites. Seismic work can be misleading in permafrost regimes and resistivity provides a reasonable alternative.

Bedrock depth profiles will be prepared from these studies. Airborne radar imagery will be used to delineate the areas of permafrost. The geophysical work, including the interpretation, will be undertaken by R&M, with review and liaison by Acres' Anchorage office personnel.

(d) Construction Materials

The exploratory investigations for construction materials will comprise geological mapping, portable auger drilling, geophysical seismic and resistivity studies, test trenching and laboratory testing.

The geologic mapping, drilling, trenching and geophysical work will generally be used to establish the limits, depth, stratigraphy, type and properties of the borrow materials. The limits, type and properties of potential quarry rock will be similarly determined. The explorations will also serve to verify the photointerpretation and previous studies by the Corps of Engineers. Groundwater and permafrost conditions will be investigated and extensive soil sampling undertaken. Rock outcrops will be mapped and test trenches excavated by small track-mounted backhoes to a depth of about 13 feet.

Geophysical techniques such as seismic refraction and resistivity will be used to prove the depth of the potential borrow materials and the groundwater depth. Airborne radar imagery or low sun angle air photos will be used to assist in identifying the permafrost areas.

A moderate amount of laboratory testing of the borrow material will be conducted at this stage. The testing will comprise routine soil identification tests including unit weight, moisture content, consistency, Atterberg limits and gradation.

Standard Proctor compaction tests will also be performed on pervious and impervious material and permeability of compacted impervious materials assessed. Some dynamic shear strength tests under high confining pressures will also be performed on impervious and pervious materials. Potential concrete aggregate samples will be tested for sodium sulfate soundness, acidity and Los Angeles abrasion characteristics.

All field exploration work under this subtask will be undertaken by R&M. Laboratory testing on borrow material will be performed by R&M with some assistance from WCC .

Design liaison, supervision and review will be provided by Acres' Anchorage office personnel.

(e) Reservoir Areas

The exploratory investigations to be carried out for the reservoir areas will include geologic mapping, portable auger drilling and geophysical seismic refraction surveys.

The primary aim will be to map those geological features and geotechnical conditions in the reservoir area which may seriously affect the reservoir performance. Such features may include previous buried channels or faults in the reservoir rim which may jeopardize the reservoir watertightness, faults which may be activated under reservoir impounding and natural slopes which may become unstable or erodible with reservoir impounding or reservoir drawdown.

The geologic mapping will be on a reconnaissance scale. The air-photo interpretation (Subtask 5.02) will be checked on the ground and specific adverse features suggested in the photointerpretation will be investigated. The distribution, type and properties of overburden and bedrock materials will be checked against the photointerpretation. Portable auger drills will be used to drill shallow holes to assist in establishing the subsurface geology and geologic history. Low sun angle air photos or airborne radar imagery techniques will be utilized to help delineate general permafrost areas which may cause unstable slopes once the reservoir is impounded. Specific test areas will be identified in which auger borings utilizing a modified CRREL core barrel will be used to sample permafrost. Thermal probes will be installed in the holes to determine temperature profiles.

No buried channels have been found to date in the reservoir rim. If such channels are suggested in the photointerpretation, geophysical seismic studies will be initiated to determine the depth and nature of the overburden and channel widths.

A relatively minor amount of laboratory testing will also be undertaken in this phase. This will comprise routine soils identification tests on those samples taken in the reservoir studies.

All field and laboratory work undertaken under this subtask will be performed by R&M. Design liaison, supervision and review will be provided by Acres' Anchorage office personnel.

(f). Schedule

Weeks 20 through 40

No buried channels have been found to date in the reservoir rim. If such channels are suggested in the photointerpretation, geophysical seismic studies will be initiated to determine the depth and nature of the overburden and channel widths.

A relatively minor amount of laboratory testing will also be undertaken in this phase. This will comprise routine soils identification tests on those samples taken in the reservoir studies.

All field and laboratory work undertaken under this subtask will be performed by R&M. Design liaison, supervision and review will be provided by Acres' Anchorage office personnel.

(f). Schedule

Weeks 20 through 40

A.5.7 - TASK 6: DESIGN DEVELOPMENT

(i) Task Objectives

To undertake planning studies, to evaluate, analyze and review all previous engineering studies related to hydroelectric development of the Upper Susitna River Basin and to develop preliminary engineering design and cost information for Watana and Devil Canyon Dam sites with all associated intake, outlet works, spillways and power facilities to allow preparation of a project feasibility report.

(ii) Task Output

The primary output of Task 6 will be a logical and systematic development of the requisite project features. Alternative sites for dams and power developments will be evaluated. Alternative arrangements at each site will also be considered. One such alternative will involve a 30-mile long power tunnel from Watana to Devil Canyon to eliminate the high dam at that site. A Development Selection Report will be issued on or about Week 65 of the Study for review and approval by Alaska Power Authority. Preliminary findings of the study will be discussed on or about Week 50, in order to establish whether or not work on two dam sites should continue or whether more viable alternatives exist and should be examined. Design transmittals will be at appropriate points in the study. All necessary input from parallel tasks including hydrology, geotechnical, economic, seismic, survey, and environmental studies will be factored into the planning studies and the development of the various features of the project. Engineering evaluation criteria and project definition will be developed. If sites are found to be technically viable, economically feasible and environmentally acceptable, additional studies and investigations will be conducted to establish the feasibility of the project and the optimum scale and sequence of development.

(iii) List of Subtasks

Subtask 6.01 - Review of Previous Studies
Subtask 6.02 - Investigate Tunnel Alternative
Subtask 6.03 - Evaluate Alternative Susitna Developments
Subtask 6.04 - Evaluation of Arch Dam at Devil Canyon Site
Subtask 6.05 - Development Selection Report
Subtask 6.06 - Watana/Devil Canyon Staged Development Alternatives
Subtask 6.07 - Preliminary Watana Dam Alternatives
Subtask 6.08 - Preliminary Devil Canyon Dam Alternatives
Subtask 6.09 - Establish Watana Design Criteria
Subtask 6.10 - Establish Devil Canyon Design Criteria
Subtask 6.11 - Preliminary Design Watana Dam
Subtask 6.12 - Preliminary Design Devil Canyon Dam
Subtask 6.13 - Dam Selection Report
Subtask 6.14 - Spillway Design Criteria
Subtask 6.15 - Watana Spillway Alternatives
Subtask 6.16 - Devil Canyon Spillway Alternatives
Subtask 6.17 - Preliminary Design Watana Spillway
Subtask 6.18 - Preliminary Design Devil Canyon Spillway

Subtask 6.19 - Spillway Selection Report
Subtask 6.20 - Access and Camp Facilities
Subtask 6.21 - Watana Diversion Scheme
Subtask 6.22 - Devil Canyon Diversion Scheme
Subtask 6.23 - Optimize Watana Power Development
Subtask 6.24 - Optimize Devil Canyon Power Development
Subtask 6.25 - Optimize Dam Heights
Subtask 6.26 - Preliminary Design Watana Power Development
Subtask 6.27 - Preliminary Design Devil Canyon Power Development
Subtask 6.28 - Power Development Report
Subtask 6.29 - Watana General Arrangement
Subtask 6.30 - Devil Canyon General Arrangement
Subtask 6.31 - Feasibility Report

(iv) Subtask Scope Statements

Plate T6.1 illustrates the interrelationship of various subtask studies and the logical input of various other tasks. The subtasks have been specifically arranged to make maximum use of input from various other tasks including Tasks 1 through 5 and 7 through 9. A detailed discussion of the objectives, the methodologies and associated costs and scheduling for each subtask follows. Note that for the purpose of this plan of study, it has been assumed that only Watana and Devil Canyon sites will be considered for additional field exploration and analysis. However, in the initial subtasks, all possible sites and modes of development on the Susitna will be examined to confirm that the Watana/Devil Canyon arrangement is the most appropriate.

Subtask 6.01 - Review of Previous Studies and Reports

(a) Objective

Assemble and review all available engineering data, siting and economic studies relating both to the Susitna hydropower development and to alternative potential sites.

(b) Approach

Reports and also field reconnaissance studies generated by various agencies including USBR, the Corps of Engineers, Kaiser and others will be reviewed to assess the design assumptions for the sites. Information obtained from these reports, including reservoir storage and power head, site evaluation, geologic and seismic conditions, topographic features and other special physical and environmental constraints, will be tabulated. Total potential for power development at each site and the associated costs will be assembled in tabular form; costs will be updated to current levels for comparison. Sites studied will include all those identified in the previous reports.

Layouts for all sites and special constraints for each site will be identified. All conceptual design parameters will be developed to update the cost of each site to a uniform level in order to rank the sites. The task will include the indexing of all basic information that could be used in analysis under Subtask 6.03. Indexing will include all basic information on nature, type and extent of geotechnical investigations previously completed, maximum level of development considered for each site, type and size of dam selected, type and size of spillway considered for each site studied, and on-line dates considered in the previous reports. Other data to be indexed will include reservoir storage, average, maximum and minimum flow, regulated flow, power capacity and energy development at each site, equivalent construction costs and other factors, such as special environmental and seismic impact on each site.

(c) Discussion

The level of study previously undertaken for each site varies considerably, not only with respect to geotechnical investigations and preliminary planning, but also in relation to hydrologic and economic assessment. Project ranking techniques and cost updating criteria will necessarily have to include additional cost parameters and analysis. These data will be used at the specified level of development as an input to Task 6.03.

In order to meet the overall objectives of the subtask, a critical review and assessment will be made of all technical information on power capacities; and other constraints for the development of each site will be identified. Previous work has identified six dam sites for which ranges of heights and power installation have been considered. These sites will be analyzed in order to select the projects which are both technically feasible and economically attractive for initial construction and are compatible with the plan for hydropower development of the entire basin. It is likely that some of the sites will be rejected in initial screening because of poor foundations or because of very high cost of development. Previous studies have demonstrated that the Watana and Devil Canyon sites are probably the most favored; but if the studies under this task indicate otherwise discussions with the Alaska Power Authority will be scheduled immediately.

All cost data from the previous reports will be updated to 1980 cost levels. As project costs are highly dependent not only upon site foundation conditions, size of spillway and outlet works, but also upon whether a low level outlet is provided, costs will be adjusted to a common design.

(d) Schedule

Weeks 25 through 40

Subtask 6.02 - Investigate Tunnel Alternatives

(a) Objective

To investigate the feasibility of a scheme for development of the Susitna River eliminating the Devil Canyon project by the substitution of a tunnel-supplied power plant fed from the Watana dam site.

(b) Approach

A preliminary review of the proposed Watana/Devil Canyon development of the Susitna River suggests that a feasible alternative, which would allow the elimination of the major reservoir formed by the Devil Canyon dam, would comprise the construction of a power tunnel starting at, or near, the currently proposed Watana site and terminating at a power plant near the proposed Devil Canyon site as illustrated in Plate T6.2.

In addition to the reduced environmental impact brought about by the elimination of the Devil Canyon dam and lake, the tunnel alternative would eliminate a major dam, reduce the size of one power plant, and allow a much larger proportion of the construction work to be located underground, shielded from severe Alaskan winters.

Potential disadvantages of the tunnel alternative include loss of power output due both to head losses in the tunnel and to the necessity to maintain flow in the river between Watana and the lower power plant tailrace. The considerable length of the tunnel would require the provision of several construction adits with corresponding environmental impacts during construction.

In order to make an initial assessment as to whether this alternative should be carried forward into more detailed evaluation, the following activities are proposed:

(1) On the basis of the material assembled in Subtask 6.01, a number of tunnel alternative arrangements will be identified. Some preliminary concepts are shown in Plate T6.2. Several others incorporating different tunnel alignments and intake/power plant locations will be identified.

(2) These initial alternatives will be subjected to a gross screening to eliminate those least likely to meet economic, technical or environmental requirements. Preliminary layouts will be developed for those remaining and major dimensional and design characteristics will be established.

(3) Preliminary quantity and cost estimates will be prepared for the selected tunnel alternatives, together with corresponding cash flows.

(4) Estimates of capacity and energy for each of the alternatives will be developed.

(5) The most attractive of the tunnel alternatives will be compared from the technical, economic, and environmental standpoints with other options for the river development identified in Subtask 6.03.

(c) Discussion

The tunnel alternative to the Devil Canyon project would appear, from initial review, to have some rather attractive features which may warrant careful evaluation. From the environmental standpoint, the elimination of the large Devil Canyon reservoir must be a significant step. This may, of course, be offset to some extent by the increased live storage to be provided at Watana and by the possible wider spread of construction activity during tunnel construction. Initial "order of magnitude" cost estimates seem to indicate at least a trade-off level of cost for the tunnel alternative, without assessing the impact on the schedule and power generation capabilities of the long power tunnel.

(d) Schedule

Weeks 30 through 50

Subtask 6.03 - Evaluate Alternative Susitna Developments

(a) Objective

To identify the most appropriate scheme for development of the Susitna River on the initial basis of technical feasibility and cost.

(b) Approach

Primary input for this subtask from the cost and technical standpoints will be derived from the review of previous studies (Subtask 6.01) and from the investigation of the "tunnel alternatives" (Subtask 6.02). Further input will be provided from the hydrological studies undertaken in Task 3 and from the public participation program carried out under Task 12. This subtask will involve the development, comparison and subsequent ranking of all reasonably feasible combinations of sites and power facilities identified either in the previous studies or in the course of Acres studies to this time. Economic parameters for a range of dam heights and power installations will be developed for each site and for the complete river development; these will be analyzed by computer to identify the most promising scheme.

Specific activities will include:

- Evaluation of six previously identified sites including Susitna I and II, Denali, Vee, Watana and Devil Canyon and other sites, for which data will be obtained from the review of literature (Subtask 6.01).

- Data on rated head, regulated flow, yield and power available from previous reports for these sites will be developed and the value and cost of power for each site will be compared. Only previous layouts and engineering information generated will be evaluated.

- Data on foundation conditions, availability of construction materials, limits of development of each site, access conditions, seismic and environmental conditions for each site will be reviewed in site-ranking studies.

- Sites with extremely poor foundation conditions and other serious constraints related to seismic or environmental impact will be rejected.

- A summary report on this ranking study will be prepared.

(c) Discussion

By this stage of the study, costs of alternative power and energy will be available for economic comparison and development of cost-benefit ratios of each individual site, and by combination for each set of developments discussed above. It would appear from previous studies that the combination of Watana and Devil Canyon sites is the most promising development, and it is expected that the results of this work will verify this. However, if the results of the study indicate otherwise, the layout, costs and details of the alternative arrangement will be brought to the same level as the studies for the 1979 report by the Corps of Engineers for the Watana and Devil Canyon sites. The evaluation will rank the sites or the combination of various sites with power capability at each, and establish associated costs and cost-benefit ratios for each combination studied. Alternatives will include combinations of Watana dam sites and power tunnels. The results of these studies will be documented in the form of a memorandum which will form a basis for further studies. The report will explain the mechanics of the evaluation process and the rationale of specific site and combinations of sites, foundation suitability and availability of construction materials. Economic comparisons from cost/benefit analysis will indicate the environmental impact on each such site. The selected alternative will be that which proves to be the most favorable for development of the Upper Susitna Basin.

(d) Schedule

Weeks 40 through 60

Subtask 6.04 - Evaluation of Arch Dam at Devil Canyon Site

(a) Objective

To make a preliminary assessment of the feasibility of an arch dam at the Devil Canyon site.

(b) Approach

The original development at the Devil Canyon site recommended by the Corps of Engineers incorporated a 635 foot high double curvature thin arch dam with a crest length of 1,370 feet. Following critical comment by the OMB, the Corps, in their Supplemental Feasibility Report (1979), proposed an alternative which would replace the arch dam with a more costly gravity dam. The primary rationale was the reduced sensitivity of the gravity dam to foundation and abutment conditions.

We will critically review the feasibility of an arch dam at the Devil Canyon site from both economic and technical aspects, as well as the overall safety aspect.

The review and evaluation will comprise the following:

- Assembly and review of all available material relating to the arch dam design recommended in the Corps' report and earlier in Bureau of Reclamation reports.
- A critical examination of all geotechnical data relating to the foundation and abutment conditions at the proposed dam site. These data may well include further information obtained in the course of the ongoing field investigations.
- A critical review of the seismic conditions at the site, particularly in the light of material developed in the course of Task 4 Seismicity Studies.
- A review of current design practice in relation to high arch dam design in seismically sensitive areas.
- The development of the draft design of an arch dam appropriate to the conditions at Devil Canyon. Design will be accompanied by associated schedule and cost estimate, including impact on associated structures.
- Review of proposed design by Special Consultants and modifications as required.
- Final evaluation of feasibility of the arch dam from the technical, economic and safety standpoints and development of a recommendation as to whether an arch dam or another design of dam should be carried through to the licensing documentation.

(c) Discussion

The arch dam design at Devil Canyon was supplemented with an alternative conventional gravity design by the Corps in the 1979 Supplemental Report. Economic feasibility of the project using more conservative design approaches was demonstrated. An underlying concern regarding the safety of arch dams in high zones is evinced by the recent decision regarding the Auburn dam.

However, it is of interest to note that as reported in a recent issue of Water Power and Dam Construction, April 1979, not one failure of a concrete dam directly caused by earthquakes has ever been recorded. Linear analytical techniques for evaluation of the response of concrete structures to seismic forces have evolved, the most widely used being the finite element technique. Acres recently utilized this technique to evaluate the Karun high arch dam proposed in Iran with a height of 325 meters. In general, concrete dams perform very well when subjected to earthquakes. Of the types available, arch dams generally have proven to perform the best and buttress dams have been subject to the severest damage because of abrupt change in section and the resultant stress concentrators.

The V-shape canyon with a ratio of 2.15 (width at crest level--1,370 feet to depth--635 feet) is favorable for a double curvature arch dam. As an example, the experience of dam building in Japan can be cited. The average seismic intensity experienced at various types of Japanese dams (in 12 point scale) is:

- gravity dams 9.8
- arch and arch gravity 10
- rockfill dams 8.5

Such high arch dams as Kurobe (186 m), Nagovado (155 m), Iagisawa (131 m), Takane (130 m), Kawamata (120 m) and others were built in areas with earthquake intensity 10 to 11 points.

There are a number of approaches which can be used to condition the abutments of arch dams to weaknesses of the rock. Stresses in the foundation may be reduced, not only by increasing the abutment thickness of the arch, but also by using abutment pads. In addition to being a very satisfactory means of spreading arch thrusts, abutment pads provide an efficient means of bridging faults and other weaknesses in the foundation. Abutment pads are applied on the world's highest arch dams at Ingury (U.S.S.R. 271 m) and were proposed for the Auburn dam (U.S.A. 209 m).

Severe weather conditions will cause serious problems for both dam types. Besides the necessity to prevent freezing and cracking of concrete during construction, a serious consideration will be consolidation of the dam body and rock base.

In Russian dams built in Siberia, grouting joints between monoliths were replaced by slots 1.2 m wide backfilled with concrete after cooling the monolith below the average annual temperature (the average annual temperature in the core of the dam is 2°C to 3°C higher than the average annual temperature of the area). If the area average temperature is below zero, the concrete should be cooled to a temperature of not more than +1 to +2°C. Such a procedure involves a long time and high cost. The Russian Mamakan and Zeya dams are hammerhead type (buttress type). This type of dam provides easy access to the slots from the hollow spaces. Concreting of the slots is performed after warming up the surfaces of slots by means of electric heaters. After filling the reservoir, the temperature of the dam body will rise and the concrete plugs will be compressed.

Another problem is prevention of the negative effect on the stress state of the dam caused by freezing of the downstream part of the dam. Static analysis and model tests performed for gravity dams located in Siberia (annual average temperature -2°C to -4°C) showed that for the winter, the frost can penetrate to the center of the dam, causing opening of the horizontal joints and, as a consequence, tensile stresses on the upper face of the dam (reductions in the compressive stresses of up to 30 percent were demonstrated). For this reason, hammerhead or massive buttress dams with heating inside the hollows were built in Russia (Mamakan, Zeya, Bratsk, Buchtarma) instead of massive gravity dams. At the Mamakan dam, the electric heating system is in operation for one to one and a half months a year, and the capacity of the heaters is 80 kW. Another method of preventing freezing is to insulate the downstream face of the dam.

Consolidation of an arch dam is much easier because arch dams do not have longitudinal construction joints. Concreting of the slots after cooling the monolith below the average temperature will produce an effect similar to heating gravity monoliths. In general, arch dams, since they are more flexible and smaller volume working structures, can cope more easily with severe temperature conditions than gravity dams.

Nonetheless, some improvements of the presently proposed arch dam are likely to be necessary.

(1) An abutment pad should be used. It functions as a transition structure between arch and rock, and as such, may be thickened, widened and reinforced as necessary. In addition, the abutment pad may be used to improve symmetry of the canyon profile.

(2) A two-centered dam layout with two separate pairs of lines of centers, one for each side of the dam, should be used to cope with the unsymmetrical shape of the canyon.

(3) The slenderness of the dam is $\frac{85.6}{635} = 0.135$ (base thickness to height), and it requires reevaluation in light of seismic and temperature conditions.

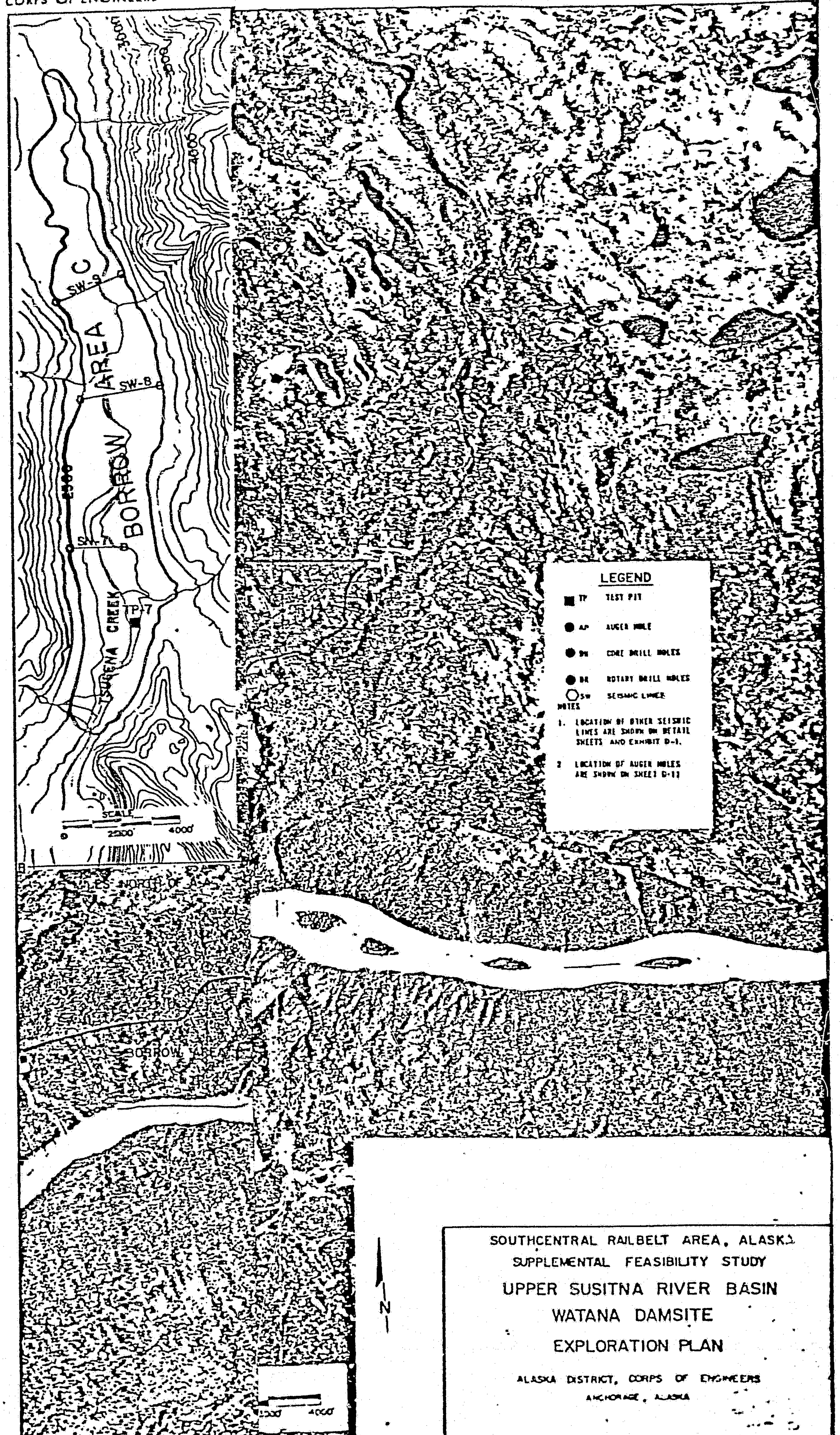
The slenderness coefficient should probably be increased to 0.16 and the base thickness to 0.16 x 635 = 101.6 feet (31 m).

Note, however, that even if it is considered that an earthfill, rockfill dam or concrete-gravity dam should be considered for FERC licensing application, some background information should be developed for an arch dam. Later studies may possibly indicate technical feasibility or economic and environmental desirability, and the option to revert to the arch design should be maintained open for as long as possible.

(d) Schedule

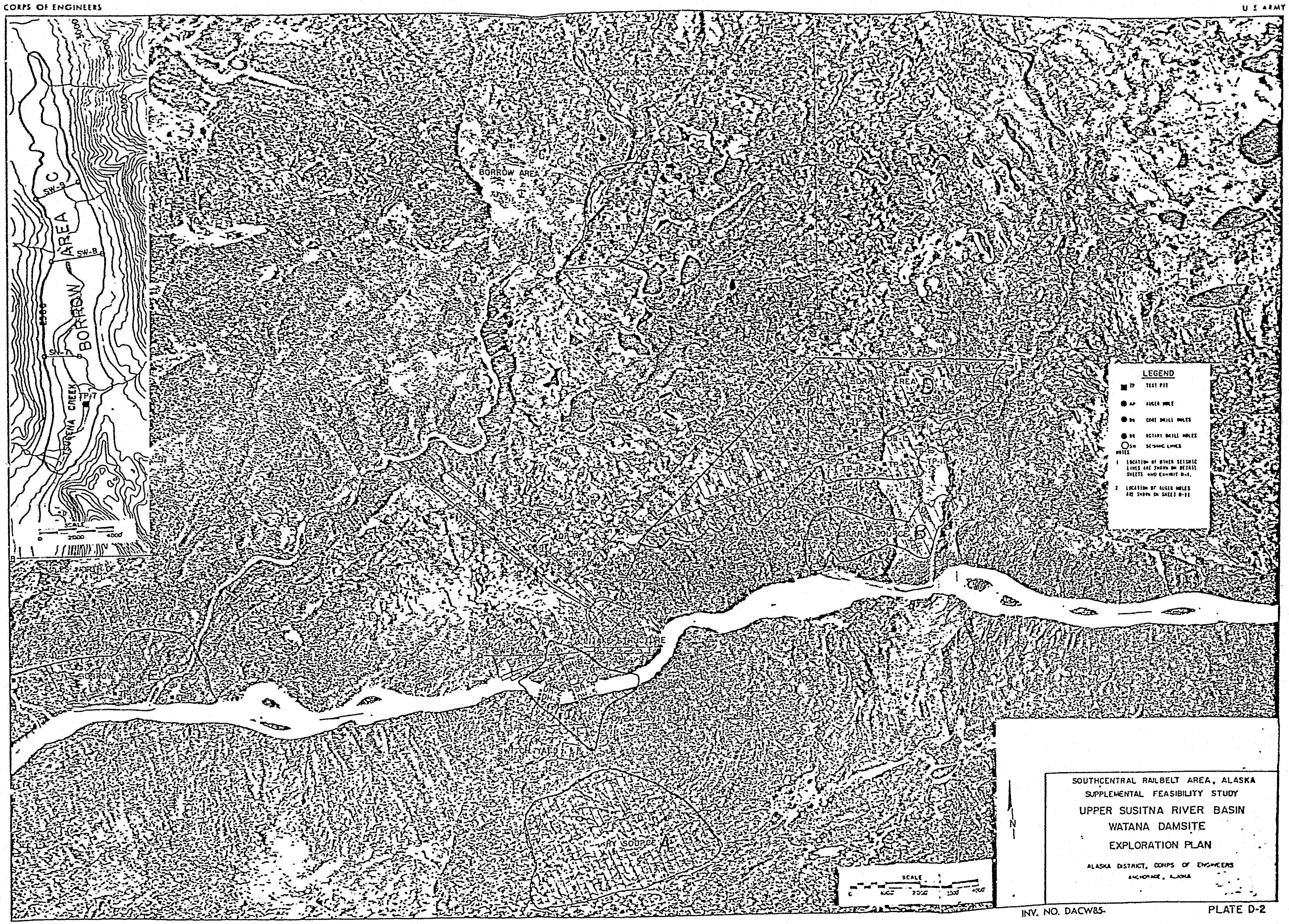
Weeks 45 through 65

2 - PROJECT MAPS, EXPLORATION



SOUTHCENTRAL RAILBELT AREA, ALASKA
SUPPLEMENTAL FEASIBILITY STUDY
UPPER SUSITNA RIVER BASIN
WATANA DAMSITE
EXPLORATION PLAN

ALASKA DISTRICT, CORPS OF ENGINEERS
ANCHORAGE, ALASKA



SOUTHCENTRAL RAILBELT AREA, ALASKA
SUPPLEMENTAL FEASIBILITY STUDY
UPPER SUSITNA RIVER BASIN
WATANA DAMSITE
EXPLORATION PLAN

ALASKA DISTRICT, CORPS OF ENGINEERS
ANCHORAGE, ALASKA

INV. NO. DACW85-

PLATE D-2

NOTES
1. TOPOGRAPHIC CONTOURS ARE BASED ON AERIAL PHOTOGRAPHY DATED 10 JUNE 1978 VERTICAL DATUM IS MEAN SEA LEVEL (MSL)

1980 Winter Seismic lines

SL-80-4

SL-80-5

● BH-1 BOREHOLE LOCATION

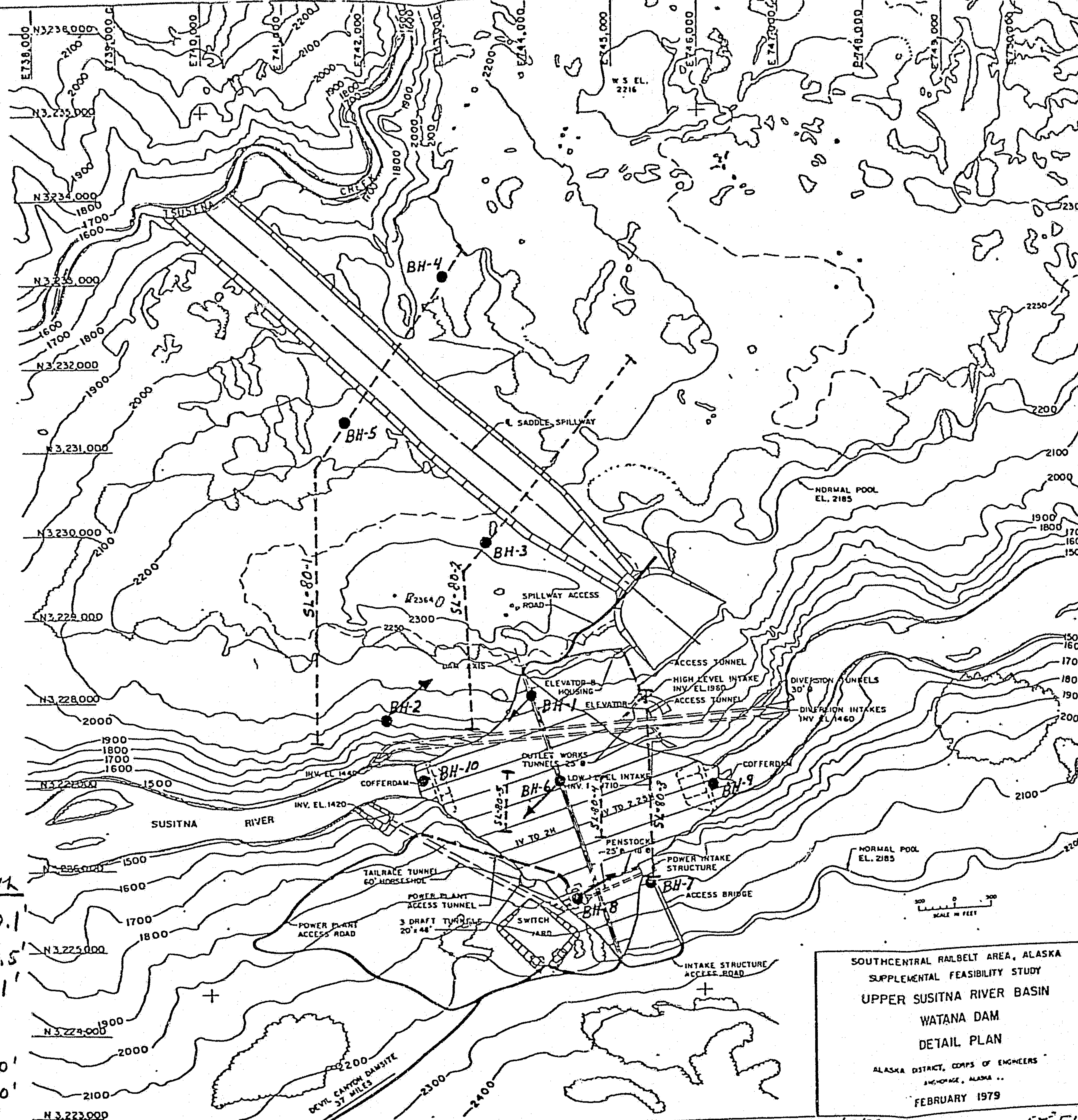
SL-3 SEISMIC LINE

1980 Summer Program

Boring	Surf. El.	Angle from Vert.	Azimuth	Depth
BH-6	1550'	60°	225°	740.1'
BH-8	2000'	60°	60°	750.5'
BH-2	1900'	55°	45°	401'

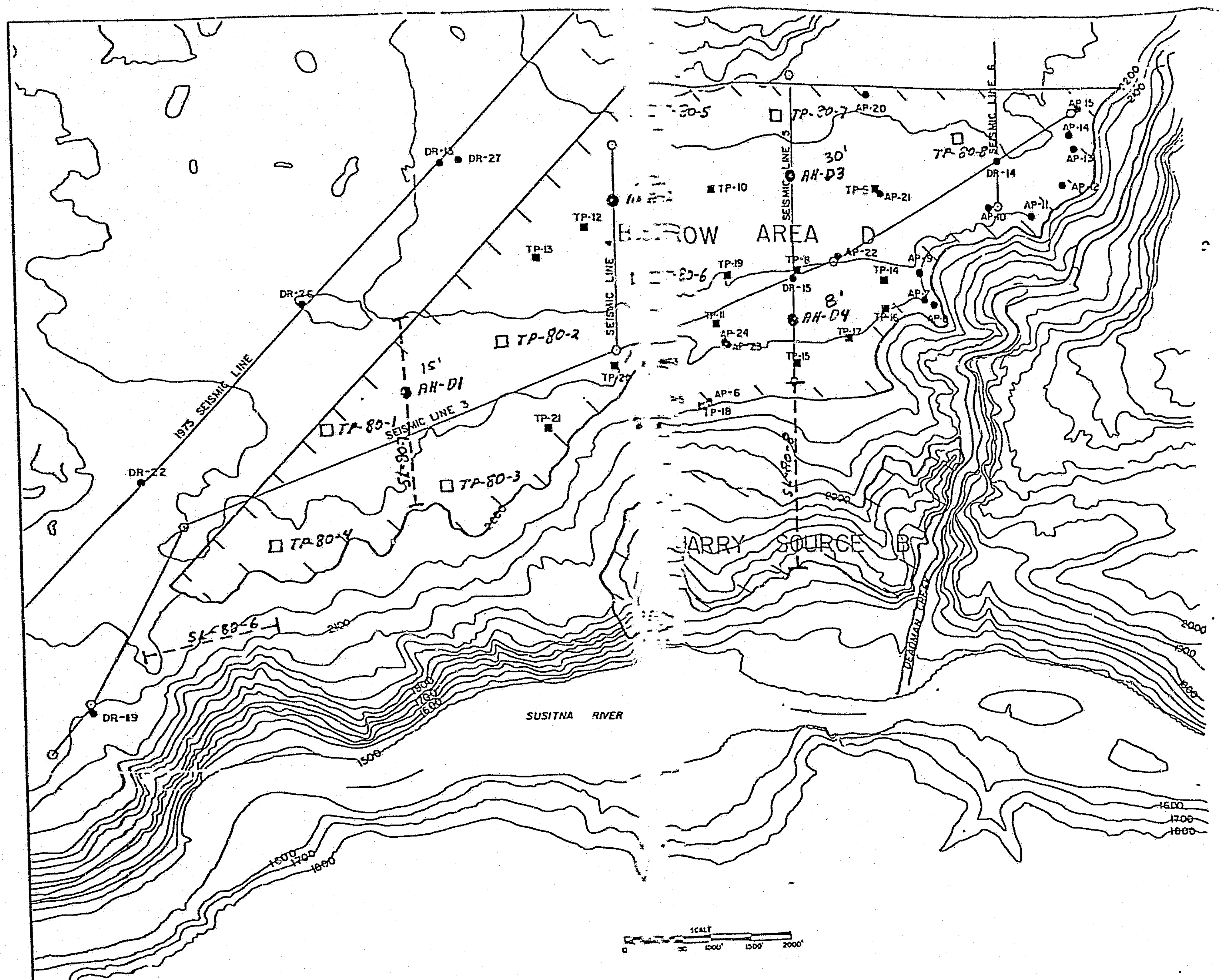
Proposed 1980 Winter Program

BH-9		Vert		150'
BH 10		Vert		150'



REVISION 1 8/13/80
RENUMBER SEISMIC LINES

FIGURE 1



□ TP-4 TEST PIT
● AH-1 AUGER HOLE
SL-6 SEISMIC LINE

LEGEND

■ TP TEST PITS
● DR DRILL HOLE
● AP AUGER HOLE
○ SW SEISMIC LINE

NOTES

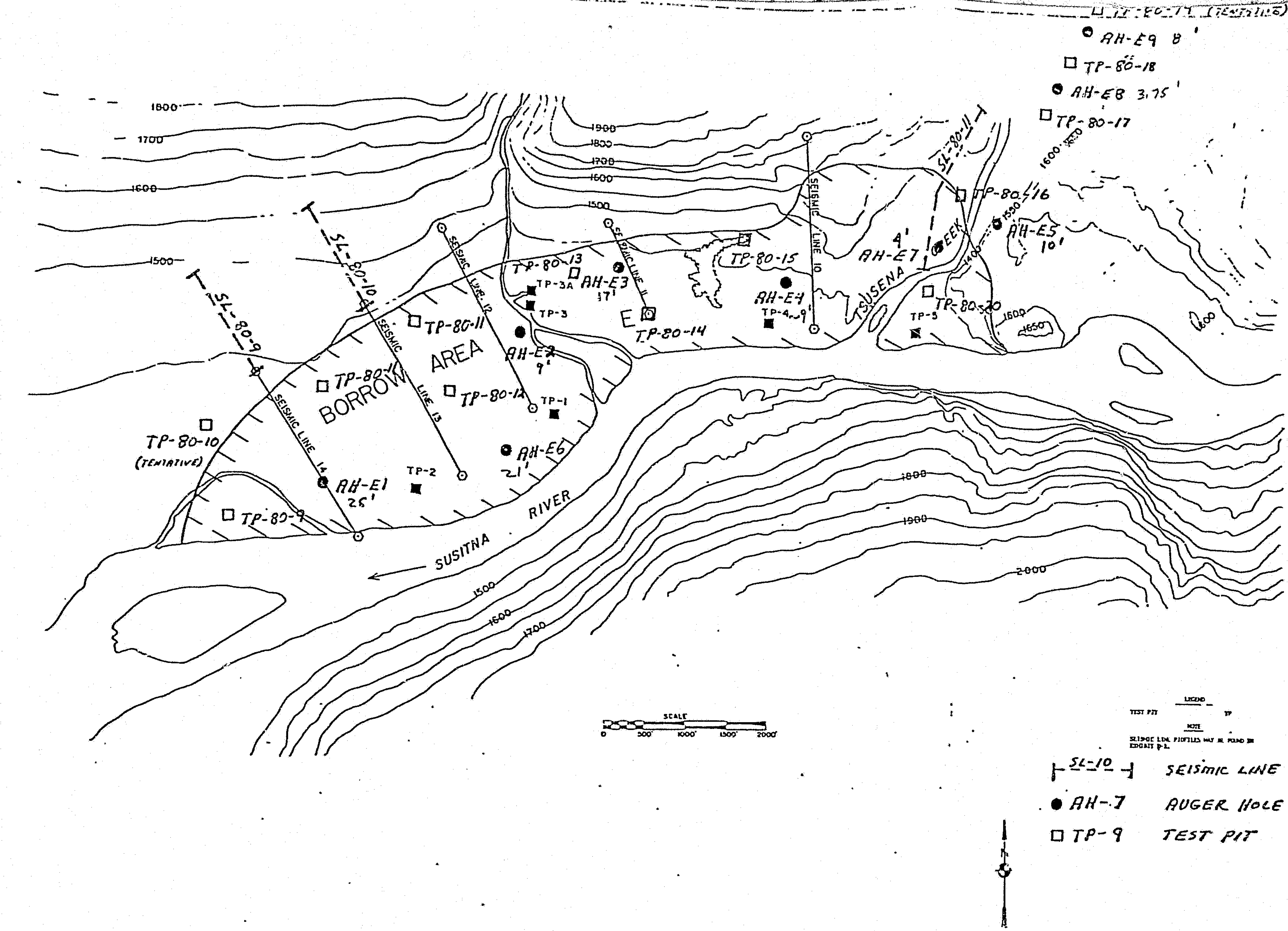
1. SEISMIC LINE PROFILES MAY BE FOUND IN EXHIBIT B-1.
2. AUGER HOLES 16-19 LIE NORTH OF BORROW AREA D, ZERO TO ½ MILE NORTH OF AND BETWEEN AP-15 AND AP-20. SEE PLATE D-2.
3. AP-1 AND AP-2 ARE NEAR DR-20 IN SPILLWAY AREA. SEE PLATE B-2.
4. FOR LOCATION OF TP 6-7 AND TP 22-26, SEE PLATE D-2.

SOUTHCENTRAL RAILBELT AREA, ALASKA
SUPPLEMENTAL FEASIBILITY STUDY
UPPER SUSITNA RIVER BASIN
WATANA DAMSITE
QUARRY SOURCE B & BORROW AREA D

ALASKA DISTRICT, CORPS OF ENGINEERS
ANCHORAGE, ALASKA

REVISION 1 8/13/80
RENUMBER BOREHOLES & TEST PITS

FIGURE 3

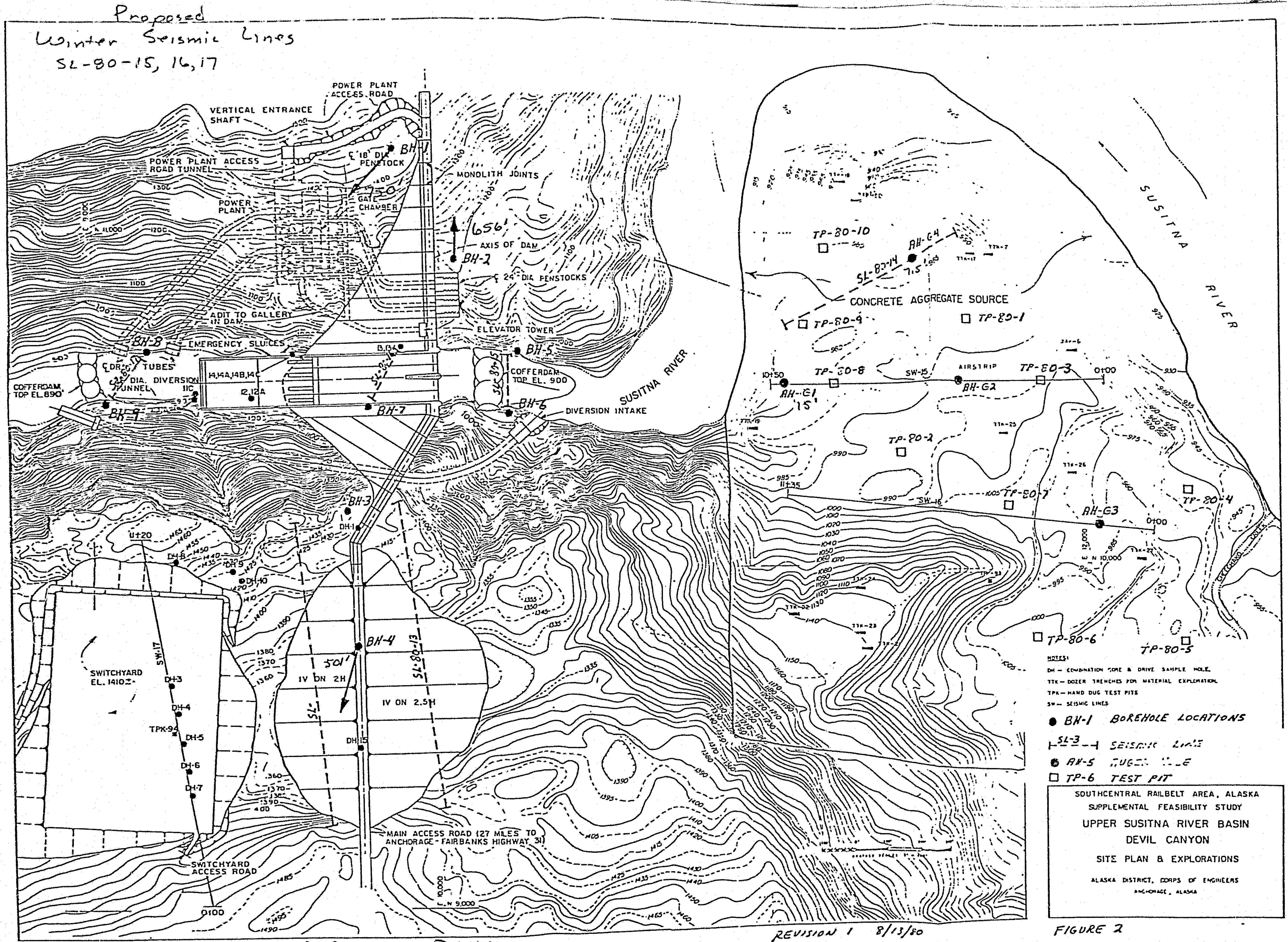


SOUTHCENTRAL RAILBELT AREA, ALASKA
SUPPLEMENTAL FEASIBILITY STUDY
UPPER SUSITNA RIVER BASIN
WATANA DAMSITE
BORROW AREA E

ALASKA DISTRICT, CORPS OF ENGINEERS
ANCHORAGE, ALASKA

Revision 2 8/13/80
Renumber holes, seismic lines and test pits
Relocate test pits

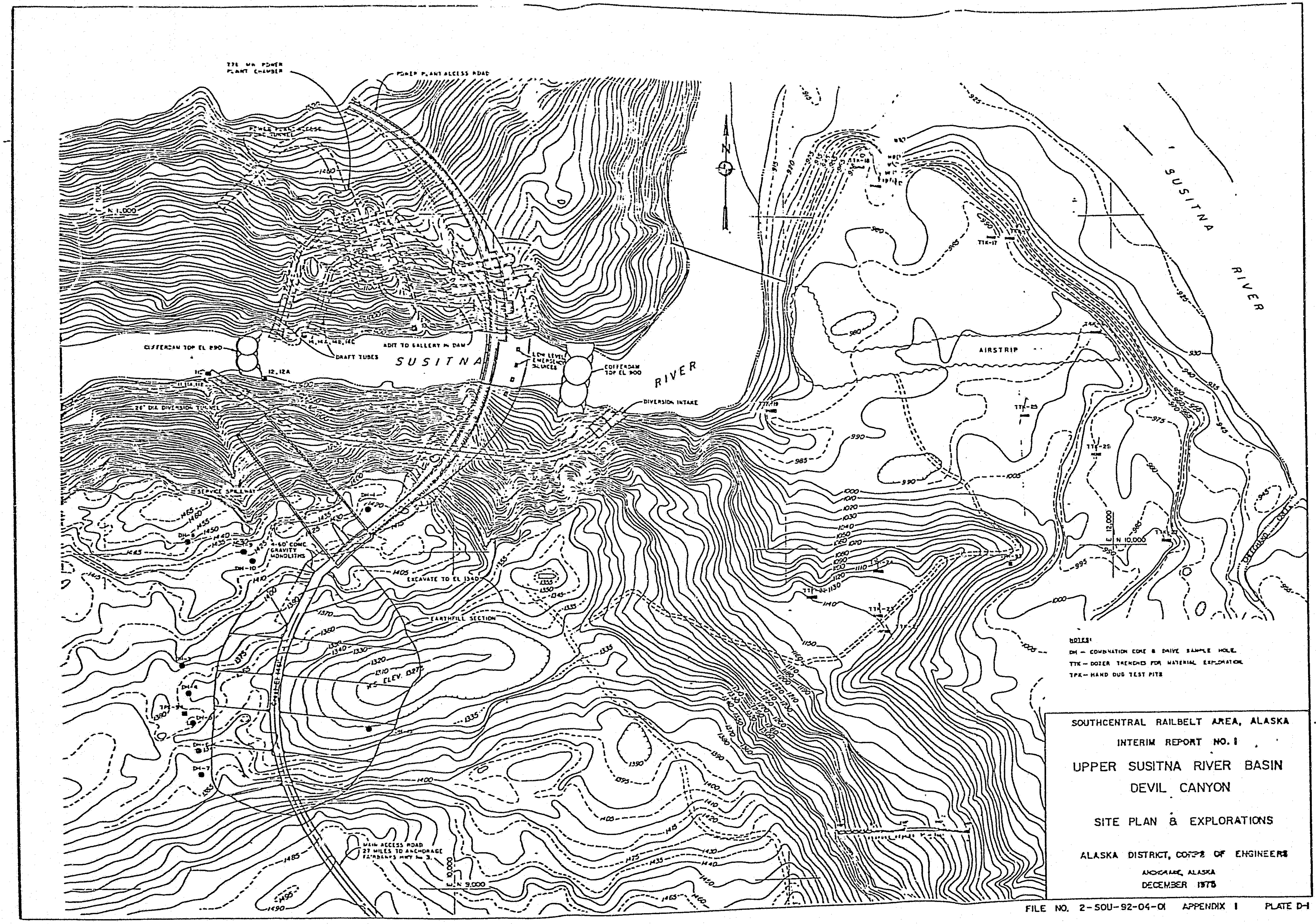
FIGURE 4



1980 Summer Drilling
BH-1, 2, 4

REVISION 1 8/13/80
RENUMBER BOREHOLES ; TEST PITS
; SEISMIC LINES

FIGURE 2



SOUTHCENTRAL RAILBELT AREA, ALASKA

INTERIM REPORT NO. 1

UPPER SUSITNA RIVER BASIN

DEVIL CANYON

SITE PLAN & EXPLORATIONS

ALASKA DISTRICT, CORPS OF ENGINEERS

ANCHORAGE, ALASKA

DECEMBER 1975

FILE NO. 2-SOU-92-04-01 APPENDIX 1 PLATE D-1

SUSITNA HYDROELECTRIC PROJECT

INTERNAL REVIEW BOARD MEETING #1

GEOTECHNICAL AND SEISMIC ASPECTS

JULY 23, 1980

NOTES ON MEETING

TABLE OF CONTENTS

YIDC

SUSITNA HYDROELECTRIC PROJECT

AGENDA OF IST INTERNAL

BOARD REVIEW MEETING - GEOTECHNICAL

AND SEISMIC ASPECTS

Time & Location: Wednesday, July 23, 1980, 8:30 a.m. (all day)
Board Room, Niagara Falls Office
Ontario, Canada

In Attendance:

Project Team	Review Board
J. Lawrence	D. MacDonald
C. Debelius	J. MacPherson
J. Gill	L. Wolofski
I. Hutchison	D. Hepburn
V. Singh	H. Eichenbaum
S. Thompson	
J. W. Haughton	

Purpose: To review work plan for 1980 Task 4 (Seismic Studies) and Task 5 (Geotechnical Investigations) and preparation for External Review Board Meeting (tentatively scheduled for late August).

Moderator: John D. Lawrence

Agenda:

Time	Topic	Speaker
8:30 AM	Introduction	J. D. Lawrence / J. W. Haughton
9:00 AM	Existing geologic, geotechnical & seismic data	S. Thompson & V. Singh
10:00 AM	Break	
10:15 AM	1980 Geotechnical Field Program	J. Gill
11:15 AM	Discussion	
12:00	Lunch	
1:00 PM	1980 Seismic Studies	V. Singh
2:00 PM	Discussion	
2:30 PM	Wrap-up & Summary of Board Views	
3:15 PM	Break	
3:30 PM	Scope and schedule of External Review Panel Meeting	

NOTE: Speakers are requested to hand out detailed agendas of their presentations during the meeting.

SUSITNA HYDROELECTRIC PROJECT

INTERNAL REVIEW BOARD MEETING #1, JULY 23, 1980

PRIMARY OBJECTIVES

1. Familiarization

2. Review of:

   - proposed dam locations and types (preliminary concepts only)

   - geotechnical exploration program scope and schedule

   - proposed seismic and reservoir induced seismicity programs

   - potential tunneling problems (preliminary concepts only)

3. Recommendations for scope of first external review panel meeting (late August)

SUSITNA HYDROELECTRIC PROJECT
INTERNAL REVIEW BOARD MEETING #1,
July 23, 1980
ACRES CONSULTING SERVICES OFFICE, CANADA
SUMMARY

August 4, 1980
P5700.13.10

In Attendance:

Project Team	Review Board
J. Lawrence	D. MacDonald
C. Debelius	J. MacPherson
J. Gill	L. Wolofsky
R. Henschel	
I. Hutchison	
V. Singh	
S. Thompson	
J. Hayden	

Introduction

John Lawrence began the meeting with introductions of all participants, followed by a brief summary of the agenda and speakers. A series of slides and talk was used to give general background on the Susitna Study Project, the various subcontractors forming the study team, and their role in overall project. This portion was concluded with slides taken along the Susitna River Valley, starting in glacial headwaters and progressing into the lower river basin. John Hayden gave a brief summary of the current status on all the various subtasks, with the exception of Tasks 4 and 5 which were discussed later in detail.

Existing Geologic, Geotechnical and Seismic Data

Virendra Singh summarized the geotechnical data currently available for the four sites of interest; i.e., Denali, Vee, Devil Canyon and Watana. This data includes a summary of investigation completed by others at each site, significant features identified and conclusions about each site. (see attached copies of view graphs.) Some additional data had only recently been received and review and compilation (subtask 5.01) had been consequently delayed.

Stewart Thompson gave a brief review of the regional and site specific geology for both proposed damsites. The geologic history is very complex and not well understood. Information at both sites is somewhat limited due to poor rock exposures. Field mapping program of damsites and reservoirs is currently planned but access is very difficult. A series of slides were presented showing general conditions and geology. At Devil Canyon there is believed to be a relict channel and possible shear zone on the left abutment which needs further investigation as it may have serious impact on site suitability or type of dam. Also, possible stress relief features (open fractures) exist in the left abutment which need to be drilled and verified. It was recommended that in order to prove the abutment suitable for an arch dam it may be necessary to excavate adits in due course. Slope stability in the reservoir also needs to be investigated. Permafrost conditions, thick overburden and steep slopes combined with thawing and wave action produced by reservoir can potentially result in localized beaching, slides and slope failures. There is a need to identify potential problem areas and evaluate effects of such failures. It was suggested that such slides will most probably occur and the effort in the study should be directed towards a means of handling the problem. The large waves created by earthquakes or landslides was discussed. Adequate freeboard would have to be maintained in the reservoir to handle such cases.

1980 Geotechnical Field Program

Jim Gill reviewed the geotechnical program as originally developed for the Plan of Study and the permitting requirements for the program. BLM is lead agency, however, most activities are located on native lands. There is presently a problem with the Chickaloon Village lawsuit over disputed land claims which is interfering with field programs. We are not allowed to work on disputed lands until the matter is settled. The major area affected is borrow area G at Devil Canyon (see map). Based on a review of existing data, budget and logistics, the original program as developed in the Plan of Study was revised for 1980 with the intention of providing an increased amount of diamond drilling this year with sufficient work in borrow areas to confirm materials and overlap next years program. The revised program as shown in Figs. 1 thru 5, and detailed in Tables 1 thru 4 was discussed.

Following the recent site visit by S. Thompson, L. Wolofsky and P. Morris, the program was reviewed and revised somewhat further. Based on their recommendations the total number of diamond drill holes to be completed this year was revised to 3 at each site. (Watana BH-6, 2 & 8; Devil Canyon-BH 1, 2, & 4.) The philosophy behind this change was to reduce the expenditures during 1980 while still maximizing the data obtained, and leaving enough flexibility to allow for changes in layout which may result from Task 6 studies and which would then be investigated in 1981. Presently BH-6 at Watana is complete and BH-2 is underway. The auger drilling program is complete, but had some difficulties as the materials generally contained boulders, particularly in borrow area E, and it was not possible to get holes as deep as originally planned. This results in need for deep test pits (probably in fall/winter) to obtain samples for lab testing.

Other areas which require some further discussion and development include:

- application of SLAR and low sun angle photos for identification of permafrost
- high moisture contents (>7%) from thawing frozen materials in borrow areas will make handling and suitability of materials very questionable.

- intrumentation consisting of thermal probe and piezometers has to be evaluated further and the type and means of installation resolved.
- existing piezometers installed by the Corps of Engineers should be reinstated and read if possible. Interpretation of readings is currently difficult as riser pipes are filled with diesel fuel.
- possibility of using technical climbers at Devil Canyon for mapping.

Discussion: A general discussion of the morning's topics raised the following points:

- at Devil Canyon there is a need to look at earth/rockfill dam alternatives and possible borrow sources for construction materials.
- all available geotechnical data pertaining to Devil Canyon is to be reviewed in Buffalo and commented on by the end of September.
- methods of sampling permafrost in rock and the significance to design need to be reviewed. Past projects have used "chiller" set-up with good results.

  There is a question of what temperature to use for solution to prevent formation of ice during drilling.
- spillway designs and locations need to be determined at both sites.
- it is desirable to minimize 1980 program and keep enough money and flexibility to allow for layout changes in structures. Emphasize features this year which will have a major impact on site suitability.
- there is a need to advance layout studies to late 1980 to allow sufficient time for design of 1981 investigation program.
- tunnel alternative layouts are underway. Any investigation (for tunnel) will be done in 1981, but will be a major change to the original Plan of Study.
- there is a need to resolve which load growth forecast the dam designs

are to be based on. It is possible to have range of schemes for various forecasts.

- the earthquake factor to be used in design has to be established so preliminary work can start. A figure of 0.68 mentioned in previous Corps reports is a peak acceleration for 1 cycle and not for periods of strong ground motion which is likely to be 1/2 to 2/3 of this. An acceleration of 0.5 g is considered adequate for preliminary design. The impact of such a factor on dam design should be evaluated as soon as possible.

1980 Sesmic Studies;

Virendra Singh summarized the seismological studies presently being performed by Woodward-Clyde Consultants, which include installation of a micro seismic monitoring network and identification and evaluation of potential activity of faults within the project area. The primary objective of these studies is to define the maximum probable earthquake distance from sites and attenuation at the sites such that an appropriate earthquake factor and gound motion can be selected for design. WCC is also supposed to evaluate potential for reservoir induced seismicity. It is expected that a site meeting in late August will be held by WCC with a preliminary report in October and a final report in November (see viewgraphs).

Discussion

There was some discussion about reservoir induced seismicity (RIS). WCC Preliminary evaluation of historical data indicates about a 90% probability of reservoir induced seismicity for Watana and a 50% probability for Devil Canyon. General consensus was that (RIS) would occur, but that magnitude of resultant earthquake would be less than the maximum probable design earthquake and should therefore not have any significant affect on design.

WCC studies are geared toward developing the maximum probable earthquake in project area and attenuation curves to each site. Acres is to select design earthquake. It is considered that three months of monitoring of the micro-seismic network would be sufficient this season, and that it is not necessary to monitor all winter. Reservoir induced seismicity is a potential psychological problem to people rather than a design problem. There is some concern over the Susitna fault as to whether or not it really is a fault, and if so, whether it is active. The location is within about 2-3 miles of Watana damsite.

There was considerable discussion over what earthquake factor to use in preliminary design. Previous reports give values up to 0.68g, which is greater than any known values used for existing dam designs. It was felt that this value is the maximum peak acceleration for one cycle and not the value for the period of strong ground motions of significant duration which would be used for design. Normally the value for design would be 2/3 to 1/2 of the peak. It was suggested that value for preliminary design should be 0.5g and it would be worthwhile to examine literature on existing dams in high seismic areas to get a feel for what effect it will have on the design of Watana or Devil Canyon. After reviewing the problem in-house the next step would be to consult outside expertise via the proposed review panel. A recent ICOLD report has case histories of large dam failures in China due to earthquake. It includes very detailed analysis of failure mechanisms which might prove useful.

There is a need to develop approximate layouts of both developments by early '81 so that investigation programs can be developed. It was generally considered better to spend extra time in the office now (earlier than originally scheduled) developing layouts based on assumptions rather than having to potentially waste time in the field on exploration of non-feasible schemes.

Conclusions

Wrap-Up - Some of the key points which came out of the meeting were:

1) The schedule for layout studies must be re-examined and accelerated, such that preliminary layouts are available in early '81. This will allow for flexibility in the design of the '81 drilling program.

2) The type, layout and discharge channels for spillways must be examined.

3) Earthquake factor to be used in preliminary design must be deter mined.

   Very little precedence exists for such high seismic regions. It was suggested that we assume 0.5g until more data from WCC becomes available in the near future. Acres should review current designs for dams in highly seismic areas with the possibility of requesting outside opinions/expertise.

4) Devil Canyon will require adits to verify abutments for an arch dam prior to design. In the original POS it had not been planned to use adits until Phase II work. It will be possible to use borehole data and down-hole camera, geophysical logging and instrumentation both to verify that the site appears suitable and that adits should subsequently be used to confirm this.

5) To apply for the FERC license there has to be sufficient data for a specific dam layout at a specific site to prove feasibility. Some flexibility may be allowed for relatively minor changes after licens ing, but a major change such as type of dam, or location may not be acceptable to FERC. It presently appears that it is not possible to

prove suitability of Devil Canyon site for arch dam by mid 1982 in view of the need for adits not currently scheduled. Therefore it will probably be necessary to submit a license application for both dams with a type of dam other than an arch at Devil Canyon, or submit separate applications as data becomes available. It remains to be determined if there is any way to delay submission of Devil Canyon section of license application to allow sufficient time to satisfactorily prove the suitability of the Devil Canyon site for an arch dam or other dam type. There is also a problem with licensing if investigations prove that one of the sites is not suitable, and a new site has to be investigated. Data must be reviewed as it becomes available and discussions held with FERC people has been very cooperative in this respect thus far.

6) The question of reservoir slope stability and how we are going to handle it needs to be addressed further. From preliminary site reconnaissance it is obvious that beaching, thawing and slope instability will occur with reservoir filling. There is a need to identify those area which are likely to present problems, and to determine what effects they will have on the reservoir and what measures, if any, have to be taken. This problem will be aggravated by the proposed 100-150 foot annual fluctuation in reservoir levels at Watana. Aesthetically it could be a problem but should not have serious engineering impacts on operation of the reservoirs. It was proposed that an in-house review be made of reports for similar projects to determine what alternatives have been used.

External Review Panel

At present the status of the External Review Panel, originally scheduled for late August, is unclear. A five member review panel was recommended to APA by Acres. These recommendations are currently being reviewed by the APA Board of Directors. The last word was that APA may appoint another firm to interface with the panel. It is likely that this firm would then have Acres make a presentation to the panel and then make its own recommendations to APA based on finds by the review panel. Scheduling of all this is still undecided as the other firm has not been selected yet. It was suggested that earliest possible meeting might be in late September. In light of this situation it was suggested that we (Acres) should recommend to APA a separate meeting of a smaller panel of outside consultants (possibly members scheduled for the APA review panel) in the near future to review our programs, since the external APA review panel may be too late to accomplish anything useful. This matter was to be looked into further by John Lawrence.

Closing

Another meeting of the Internal Review Panel and Project Team was tentatively scheduled for later this year to review the completed field data and earthquake data from Woodward-Clyde.

If possible, site visits for review panel member will be arranged at convenient times in the summer program, with possible on-site meetings.

Reported by Robert Henschel

Robert Henschel

ATTACHMENT

A

EXISTING GEOTECHNICAL & SEISMIC DATA

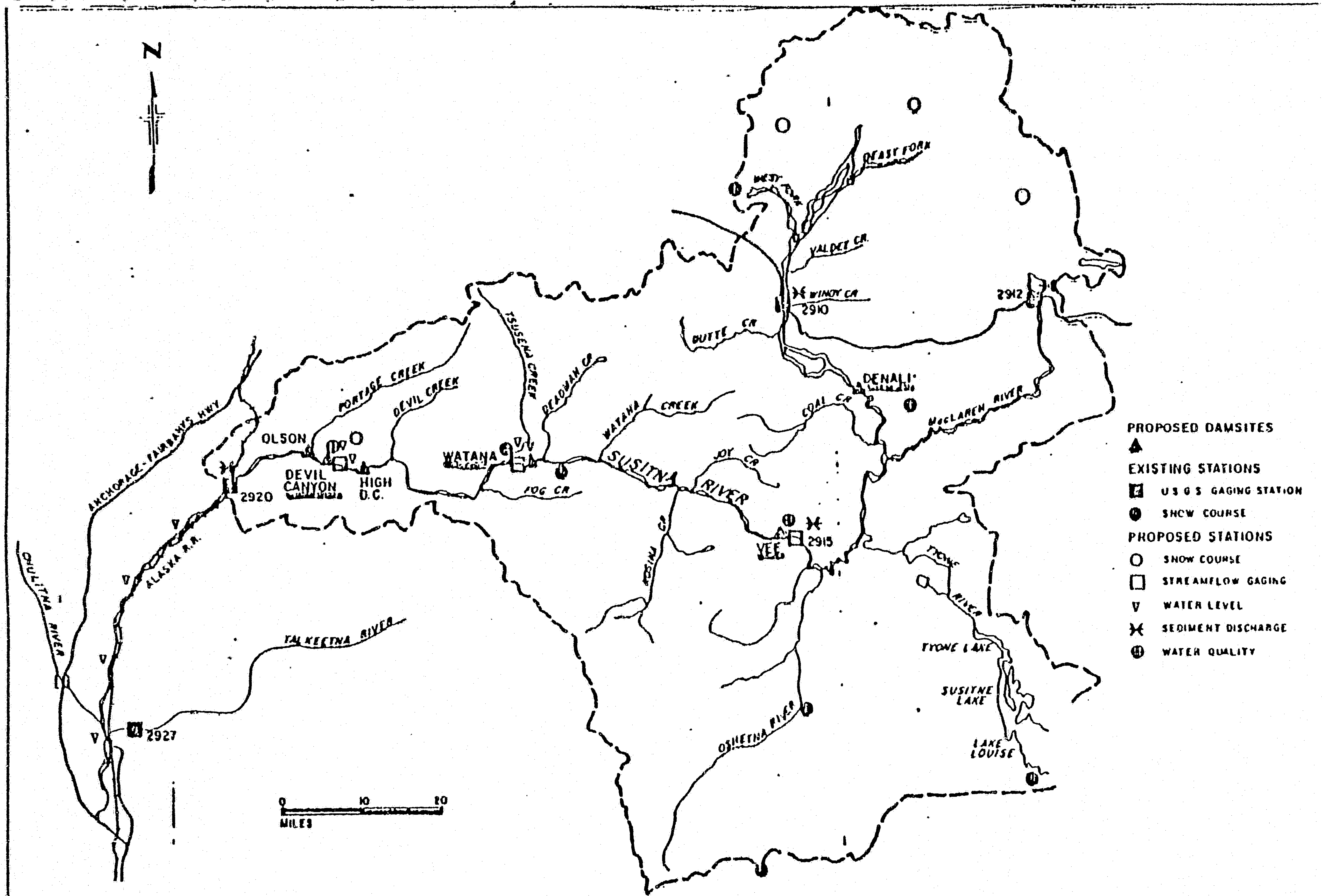
I. GENERAL

  A. Geology and Seismic Reports
  B. Site Specific Data

II. SITE SPECIFIC DATA - GEOTECHNICAL

  A. Denali Site
  B. Vee Canyon
  C. Devil Canyon
    - Investigations
    - Significant Features
    - Summary and Conclusions
  D. Watana
    - Investigations
    - Significant Features
    - Summary and Conclusions

III. DISCUSSIONS



SUSITNA HYDROELECTRIC PROJECT

PLATE T3.1·PROPOSED DATA COLLECTION STATIONS IN THE SUSITNA BASIN-1980

DENALI

STRUCTURE: 235' HIGH EARTH DAM

INVESTIGATION:

1958-'59 USBR

5 BOREHOLES ~ 200' DEEP

14 TEST PITS

LAB TESTS

CONSOLIDATION
GRADATION
INDEX TESTS
PETROGRAPHIC

SIGNIFICANT FEATURES:

RELATIVELY LOOSE SANDS AND GRAVELS OF UNKNOWN THICKNESS

PERVIOUS STRATA - RIGHT ABUTMENT

100'± PERMAFROST - BOTH ABUTS.

COMPRESSIBLE STRATA - BOTH ABUTS.

MAXIMUM EARTHQUAKE MAGNITUDE 8.5 AT 40 MILES

DENALI

STRUCTURE: 235' HIGH EARTH DAM

INVESTIGATION:

1958-'59 USBR

5 BOREHOLES ~ 200' DEEP

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100' ± PERMAFROST - BOTH ABUTS.

COMPRESSIBLE STRATA - BOTH ABUTS.

MAXIMUM EARTHQUAKE MAGNITUDE

8.5 AT 40 MILES

DSA

MATERIAL SOURCES:

PERVIOUS - ADEQUATE SUPPLY,
0.5 TO 5 MILE HAUL

IMPERVIOUS - PROCESS FROM TILL

PROBLEMS:

DEEP PERMAFROST

COMPRESSIBLE FOUNDATION MTLS.

EXCESSIVE FOUNDATION TREATMENT

PERVIOUS STRATA - RIGHT ABUT.

DEEP CUTOFF

LIQUIFACTION

SUMMARY:

MOVE SITE 8000' D/S

EXTENSIVE FIELD INVESTIGATIONS
REQUIRED

VEE

VEE CANYON

STRUCTURE: 470' HIGH EARTH DAM

INVESTIGATION:

1960-'62 USBR

13 BOREHOLES, 1646LF, 180' MAX.

16 DOZER TRENCHES

SIGNIFICANT FEATURES:

VERY STEEP CANYON (800')

125' OVERBURDEN

POOR QUALITY ROCK

SADDLE DAM

400' OVERBURDEN

PERMAFROST TO >60'

ROCKLINE BELOW EXISTING RIVER El.

MATERIAL SOURCES:

NOT DELINEATED

GLACIO-FLUVIAL FOR EMBANKMENT

RIVER CHANNEL FOR AGG.

DEVIL

DEVIL CANY

MMARY:

EXTENSIVE GROUTING

DETAILED FOUNDATION AND ABUTMEN
EXPLORATION REQUIRED

PILOT TUNNELS RECOMMENDED

AMPLE AGGREGATE AVAILABLE,
PROCESSING REQ'D.

STRUCTURE: 810' HIGH EARTH DAM

INVESTIGATION:

1950-'53, USBR, RECONNAISSANCE
1975, COE, "
D+M, 22500 LF SEISMIC
1978 COE 28 BOREHOLES
30' TO 600' DEEP
27 TEST PITS
18 AUGER HOLES
S+W 47665 LF SEISMIC

INSTRUMENTATION
10 PIEZOMETERS
13 TEMP. PROBES

SIGNIFICANT FEATURES

300'-600' WIDE VALLEY, 30°-60° SLOPES
40'-80' OVERBURDEN
5'-40' WEATHERED ROCK
ALLUVIUM - FROZEN TO SOFT.
RELICT CHANNEL UP TO 454' DEEP;
FILLED WITH GLACIAL AND
ALLUVIAL MTLS.
NEAR VERTICAL SHEAR ZONES
THE "FINNS" AND "FINGERBUSTER"

UNDERGROUND STRUCTURES

ROCK CONDITIONS - FAVORABLE
SOME SUPPORTS REQUIRED

SUMMARY

ADDITIONAL EXPLORATION

GENERAL - ROCK STRUCTURE
- RIVER CHANNEL
- FOG LAKE FAULTING, LEAKAGE

RIGHT ABUT. - SLIDE BLOCK (?)
- OVERBURDEN THICKNESS

LEFT ABUT. - PERMAFROST

BORROW AREAS - LAKE DEPOSITS

SPILLWAY - BURIED STREAM CHANNEL

DOWNSTREAM - SUSITNA FAULT?

ATTACHMENT

B

SUSITNA HYDROELECTRIC PROJECT

TASK 4 & 5

INTERNAL REVIEW MEETING

JULY 23, 1980

1980 GEOTECHNICAL PROGRAM

1. Scope of Geotechnical Work Contained in the Acres Plan of Study.

2. Scope of 1980 Geotechnical Investigations Under Bureau of Land Management Permit No. AK-017-0096.

3. Spring 1980 Revised Program.

4. Current 1980 Geotechnical Program.

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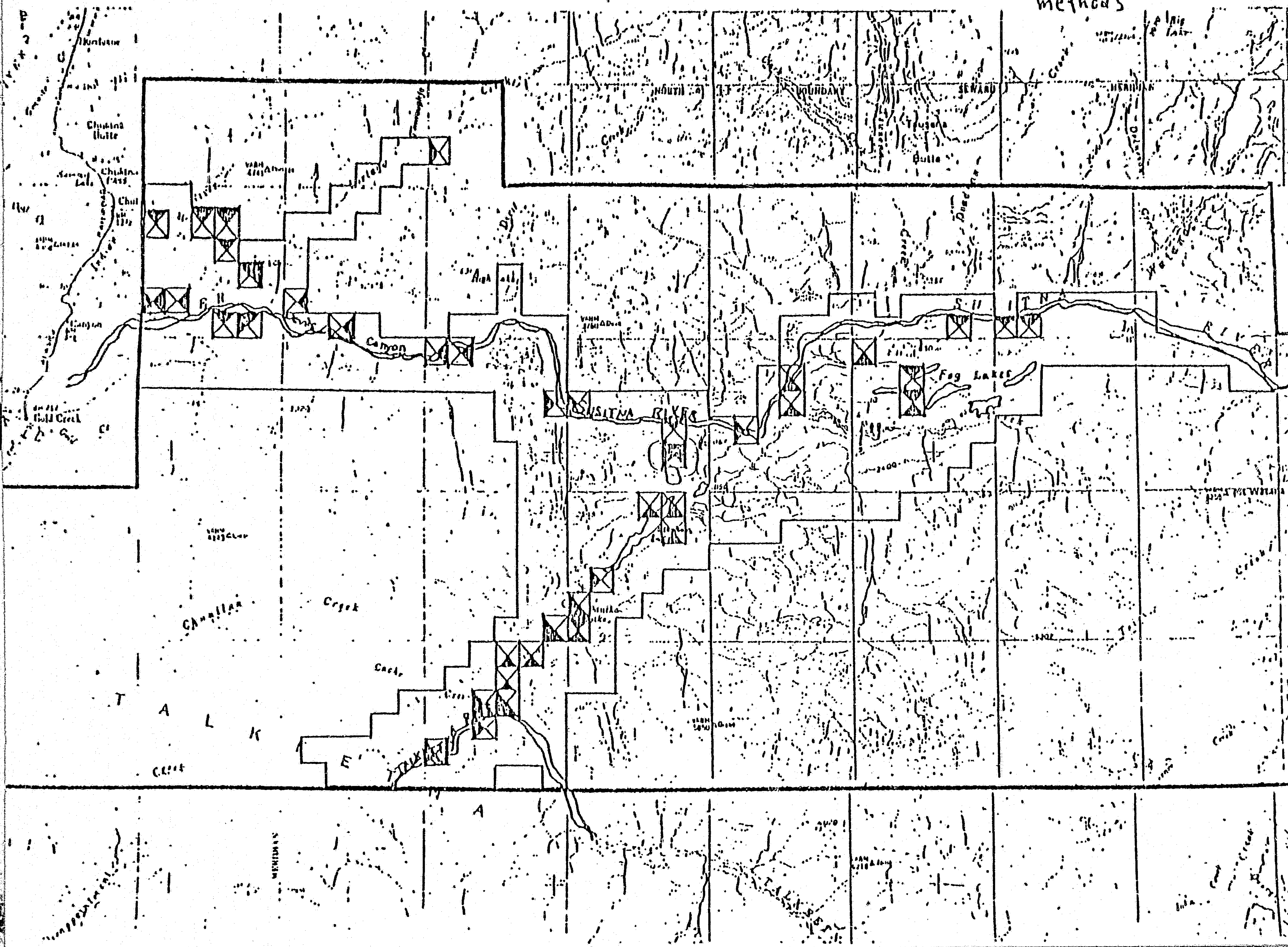


WATANA DAMSITE

PROPOSED DRILLING PROGRAM

HOLE NO.	LOCATION	APPROX. ELEV.	AZIMUTH	INCL.	HOLE LENGTH	PRIMARY OBJECTIVES	SPECIAL TESTING
BH-1	RT. ABUT.		225°	60°	250-300'	GEOLOGIC STRUCTURE, VELOCITY DISCONTINUITY	PERMEABILITY
BH-2	RT. ABUT.		45°	55°	200-500'	GEOLOGIC STRUCTURE, GRADATIONAL CONTACT, VELOCITY DISCONTINUITY, BURIED CHANNEL?	PERMEABILITY, CAMERA, IN-HOLE GEOPHYSICS
BH-3	RT. ABUT.		—	VERT.	50-100'	OVERBURDEN THICKNESS, CORRELATE W/ SEISMIC	
BH-4	RT. ABUT.		—	VERT.	200-300'	OVERBURDEN THICKNESS, CORRELATE W/SEISMIC	
BH-5	RT. ABUT.		—	VERT	100-200'	OVERBURDEN THICKNESS, CORRELATE W/SEISMIC	
BH-6	RT. ABUT.		225°	60°	740'	GEOLOGIC STRUCTURE (FAULT IN RIVER CHANNEL?)	PERM, CAMERA, GEOPHYS THERMISTOR / PIEZOMETER
BH-7	LT. ABUT		—	VERT	100-150'	OVERBURDEN THICKNESS, GEOLOGY AND STRUCTURE	PERM, THERMISTOR, SLOPE INDICATOR
BH-8	LT ABUT		60°	60°	600-750'	GEOLOGIC STRUCTURE (POWERHOUSE)	PERM, CAMERA, GEO-PHYSICS, THERMISTORS
BH-9	RIVER U/S		—	VERT	100-150'	OVERBURDEN THICKNESS, FOUNDATION AND PERM. FOR COFFERDAM	PERMEABILITY
BH-10	RIVER D/S		—	VERT	100-150'	OVERBURDEN THICKNESS, FOUNDATION AND PERM. FOR COFFERDAM	PERMEABILITY

i..3L.. 2

WATANA DAM SITE

SEISMIC REFRACTION SURVEY

SEISMIC LINE	LOCATION	APPROX. LENGTH	PRIMARY OBJECTIVES	REMARKS
SL-1	RT. ABUT.	6600'	INVESTIGATE BURIED CHANNEL, OVERBURDEN THICKNESS, VELOCITY ANOMALY, ALT. SPILLWAY RTE	
SL-2	RT ABUT.	4400'	INVESTIGATE BURIED CHANNEL, OVERBURDEN THICKNESS, VELOCITY ANOMALY, ALT. SPILLWAY RTE.	
SL-3	RIVER	2200'	INVESTIGATE OVERBURDEN THICKNESS, ROCK QUALITY (INTAKE, ACCES/DIVERSION TUNNELS, RIVER CHANNEL	
SL-4	RIVER	1100'	OVERBURDEN THICKNESS (CORE ZONE) CHANNEL SHAPE	SHOOT IN WINTER OFF RIVER IC.
SL-5	RIVER	1100'	OVERBURDEN THICKNESS, CHANNEL SHAPE	SHOOT IN WINTER OFF RIVER IC.

DEVIL CANYON DAMSITE

PROPOSED DRILLING PROGRAM

HOLE NO.	LOCATION	APPROX. ELEV.	AZIMUTH	INCL.	HOLE LENGTH	PRIMARY OBJECTIVES	SPECIAL TESTING
DH-1	RT. ABUT.		225°	60°	500-600'	GEOLOGIC STRUCTURE, ROCK QUALITY (POWERHOUSE)	PERM, CAMERA, GEO-PHYSICS, THERMISTORS
DH-2	RT. ABUT.		240°	65-75°	350-450'	GEOLOGIC STRUCTURE, ROCK QUALITY (DAM FOUNDATION)	PERM, CAMERA, GEO-PHYSICS, THERMISTOR, NET
DH-3	LT. ABUT.		45°	70°	500-600'	GEOLOGIC STRUCTURE, ROCK QUALITY (DAM FOUNDATION, DIVERSION TUNNEL	PERM, CAMERA
DH-4	LT. ABUT.		150°	60°	400-600'	GEOLOGIC STRUCTURE (SHEAR ZONE/OLD CHANNEL) CORRELATE W/SEISMIC	PERM, CAMERA, GEO-PHYSICS
DH-5	RIVER - RT.		225°	70°	400-500'	OVERBURDEN THICKNESS, POSSIBLE FAULTING IN RIVER CHANNEL	PERM, CAMERA
DH-6	RIVER - LT.		—	VERT	100-150'	OVERBURDEN THICKNESS, FOUNDATION AND PERMEABILITY FOR COFFERDAM	PERMEABILITY
DH-7	RIVER - LT.		—	VERT	100-150'	OVERBURDEN THICKNESS, GEOLOGIC STRUCTURE (MAY BE INCLINED IF NECESSARY)	PERM, CAMERA
DH-8	RIVER - RT.		45°	60°	100-150'	OVERBURDEN THICKNESS, GEOLOGIC STRUCTURE, ROCK QUALITY (DRAFT TUBES)	PERM, CAMERA
DH-9	RIVER - LT.		—	VERT	100-150'	OVERBURDEN THICKNESS, FOUNDATION AND PERMEABILITY FOR COFFERDAM	PERMEABILITY

TABLE 7

DEVIL CANYON DAMSITE

SEISMIC REFRACTION SURVEY

SEISMIC LINE	LOCATION	APPROX. LENGTH	PRIMARY OBJECTIVES	REMARKS
SL-1	LT. ABUT.	900'	INVESTIGATE OVERBURDEN THICKNESS, RELICT CHANNEL, POSSIBLE SHEAR ZONE (SADDLE DAM)	
SL-2	LT. ABUT.	900'	INVESTIGATE OVERBURDEN THICKNESS, RELICT CHANNEL, POSSIBLE SHEAR ZONE (SADDLE DAM)	
SL-3	RIVER	300'	INVESTIGATE OVERBURDEN THICKNESS, CHANNEL SHAPE (COFFERDAM)	SHOOT IN WINTER OFF RIVER ICE
SL-4	RIVER	300'	INVESTIGATE OVERBURDEN THICKNESS, CHANNEL SHAPE (DAM FOUNDATION)	SHOOT IN WINTER OFF RIVER ICE
SL-5	RIVER	300'	INVESTIGATE OVERBURDEN THICKNESS, CHANNEL SHAPE (COFFERDAM)	SHOOT IN WINTER OFF RIVER ICE

00235

NOTES

1. TOPOGRAPHIC CONTOURS ARE BASED ON AERIAL PHOTOGRAPHY DATED 10 JUNE, 1978 VERTICAL DATUM IS MEAN SEA LEVEL (M.S.L.)

● BH-1 BOREHOLE LOCATION

SL-3 SEISMIC LINE

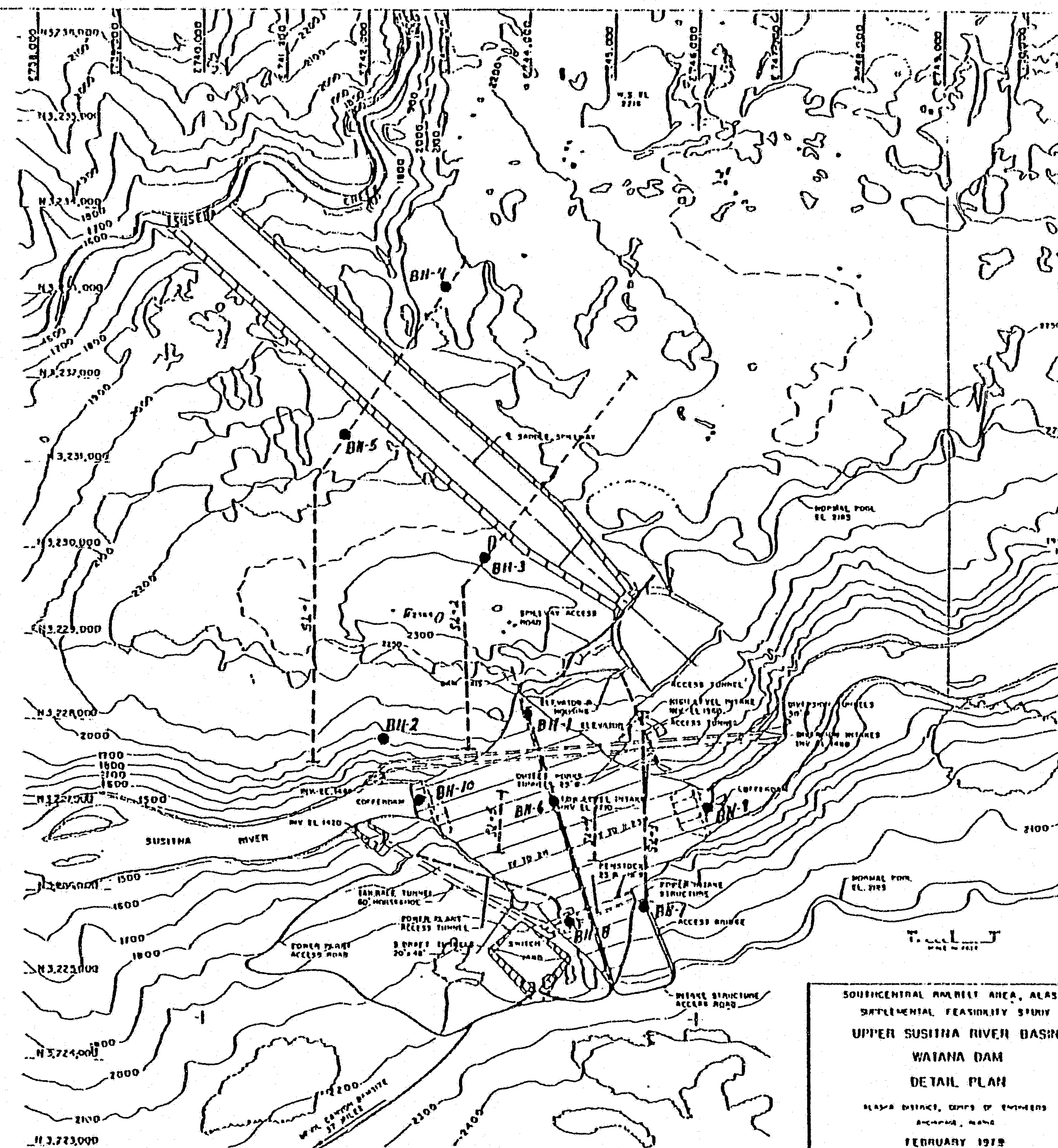
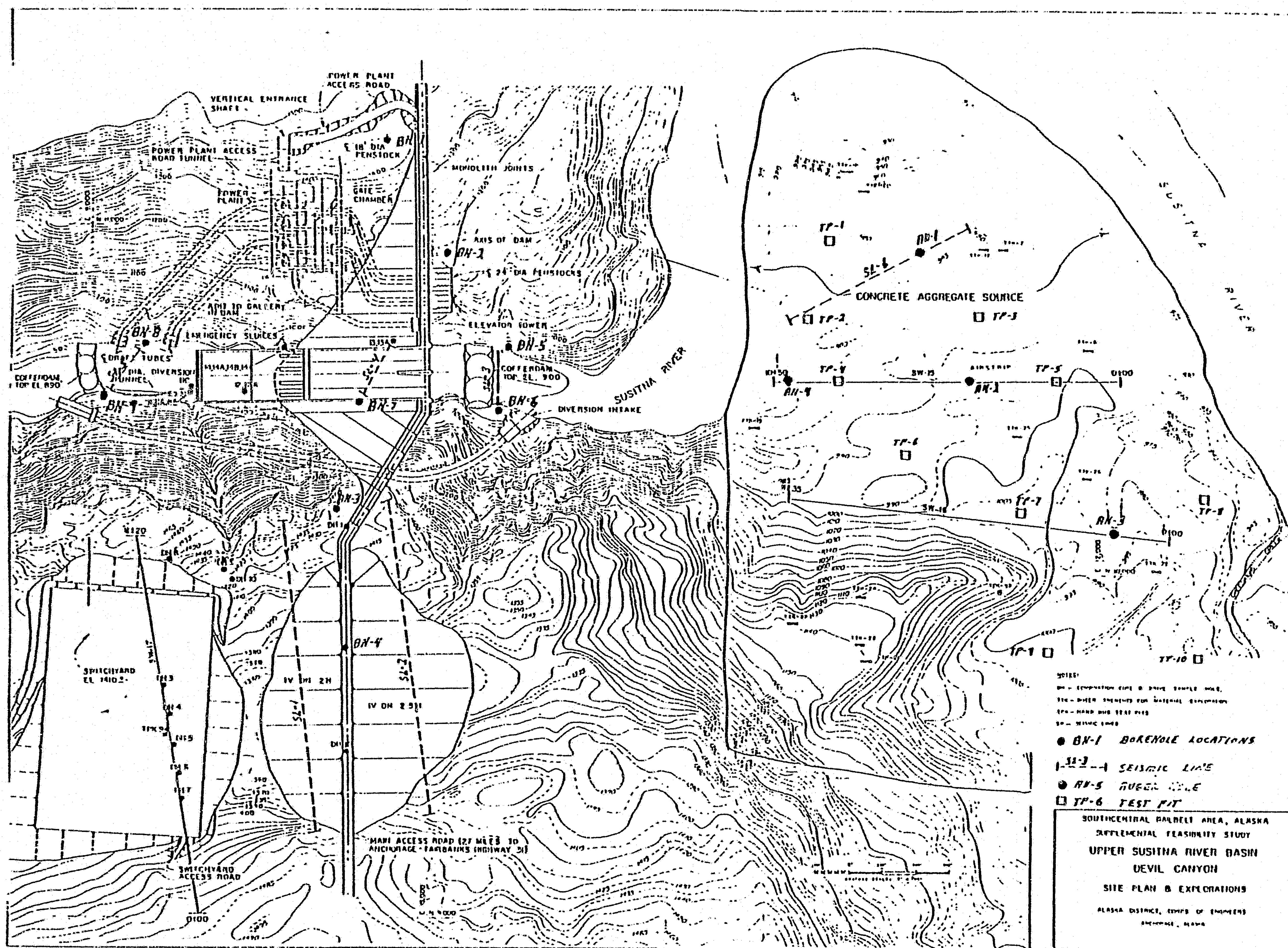
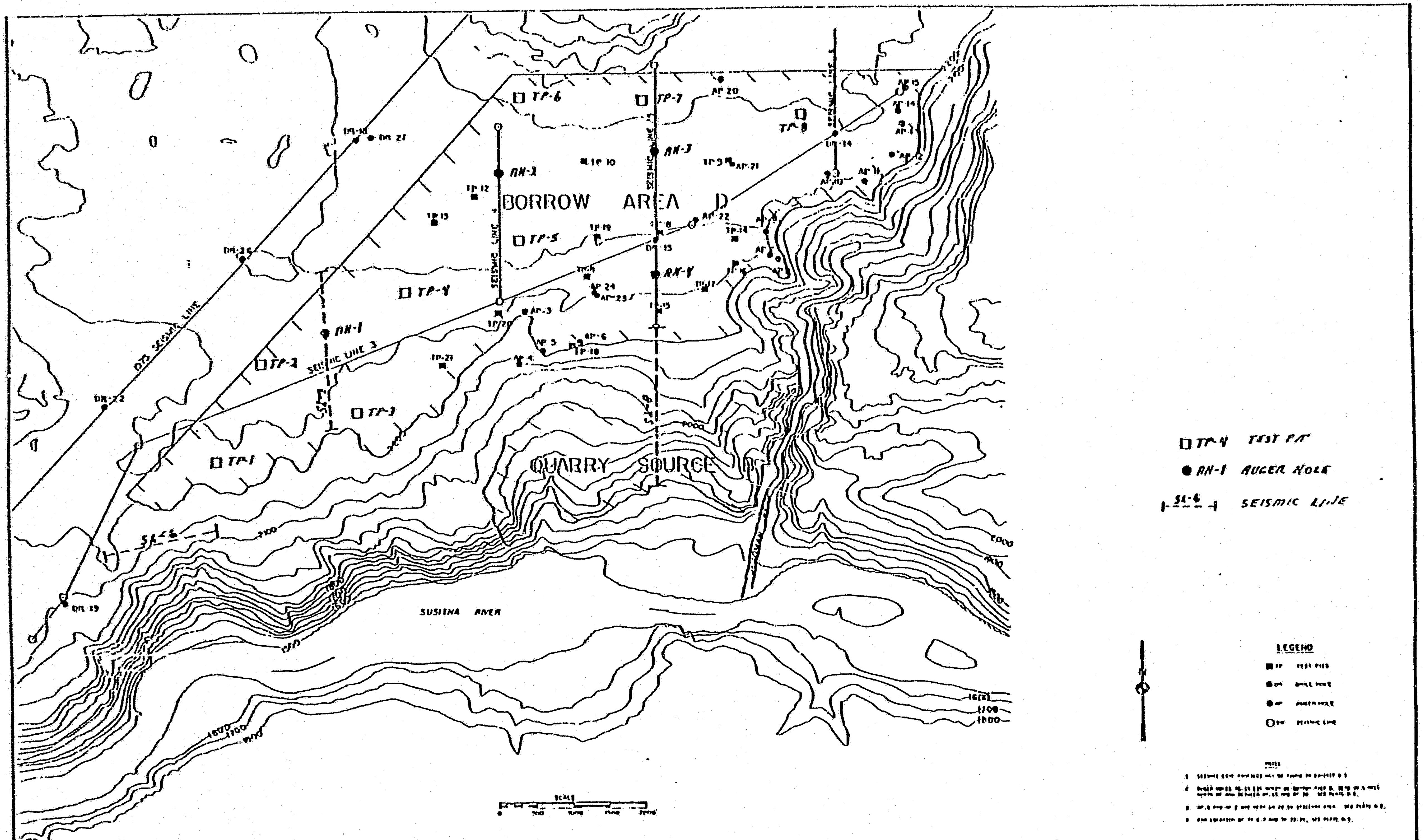


FIGURE 1



POWER PLANT ACCESS ROAD
VERTICAL ENTRANCE SHAFT
POWER PLANT ACCESS ROAD TUNNEL
18' DIA PENSTOCK
POWER PLANT
GATE CHAMBER
MONOLITH JOINTS
AXIS OF DAM
BH-2
24' DIA PENSTOCKS
ADIT TO GALLERY
EMERGENCY SLUICES
ELEVATOR TOWER
BH-8
BH-5
DRAFT TUBES
COFFERDAM TOP EL 890
COFFERDAM TOP EL. 900
BH-7
BH-6
DIVERSION INTAKE
SUSITNA RIVER
BH-3
BH-4
SWITCHYARD EL 1410±
SWITCHYARD ACCESS ROAD
MAIN ACCESS ROAD (27 MILES) TO ANCHORAGE - FAIRBANKS HIGHWAY 3)
SL-1
SL-2
CONCRETE AGGREGATE SOURCE
TP-1
TP-2
TP-3
TP-4
TP-5
TP-6
TP-7
TP-8
TP-9
TP-10
AH-1
AH-2
AH-3
AH-4
SUSITNA RIVER
● BH-1 BOREHOLE LOCATIONS
SEISMIC LINE
AH-5 AUGER HOLE
TP-6 TEST PIT
SOUTHCENTRAL RAILBELT AREA, ALASKA
SUPPLEMENTAL FEASIBILITY STUDY
UPPER SUSITNA RIVER BASIN
DEVIL CANYON
SITE PLAN & EXPLORATIONS
ALASKA DISTRICT, CORPS OF ENGINEERS

FIGURE 2

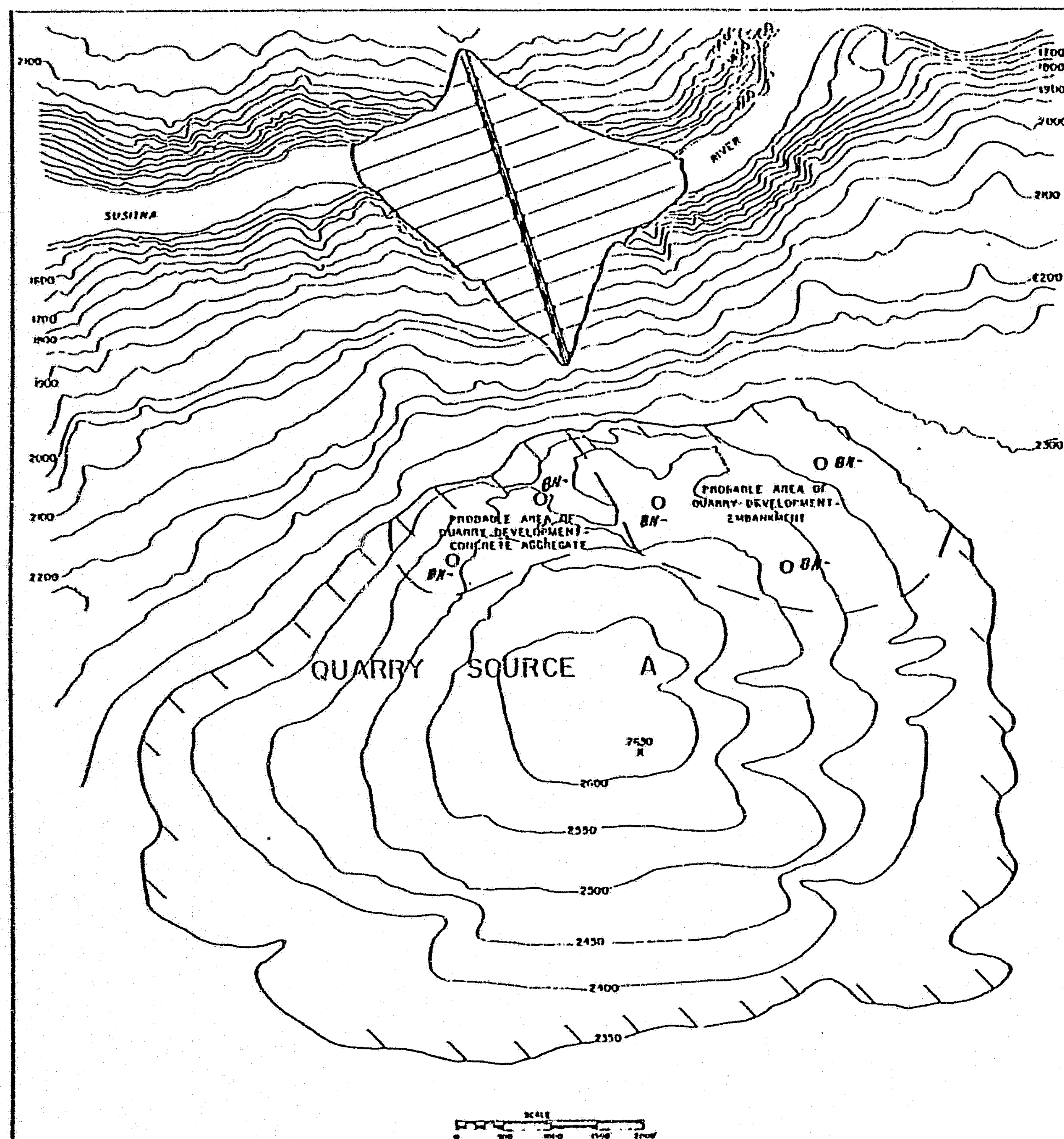


SOUTHCENTRAL RAILBELT AREA, ALASKA
SUPPLEMENTAL FEASIBILITY STUDY

UPPER SUSITNA RIVER BASIN
WATANA DAMSITE
QUARRY SOURCE B & BORROW AREA D

ALASKA DISTRICT, CORPS OF ENGINEERS
ANCHORAGE, ALASKA

FIGURE 3



O BH- TENTATIVE BOREHOLE LOCATION

SOUTHCENTRAL RAILBELT AREA, ALASKA
SUPPLEMENTAL FEASIBILITY STUDY
UPPER SUSITNA RIVER BASIN
WATANA DAMSITE
QUARRY SOURCE A
ALASKA DISTRICT, CORPS OF ENGINEERS
ANCHORAGE, ALASKA

FIGURE 5

ATTACHMENT

C

1980 SEISMIC STUDIES

I. GENERAL

- WCC Project Team
- Status of 1980 Activities
- Monitoring of Program

II. SUSITNA VALLEY SEISMIC SETTING

- Seismotectonic Setting
- Available Historical & Instrumented Records
- Limitations of the Record Data

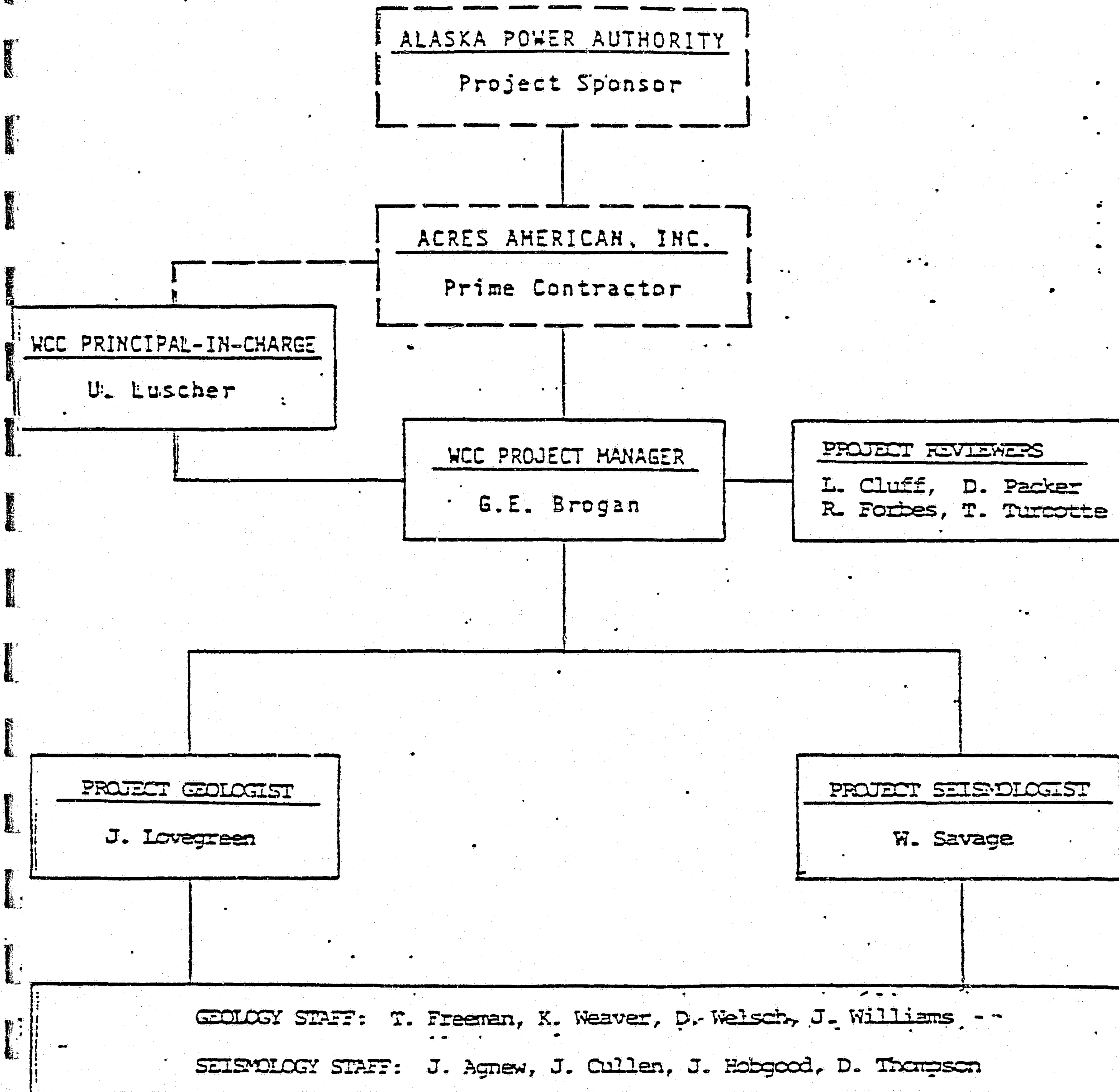
III. PURPOSE OF THE PROGRAM

- Definition of Seismic Event
- Source of Seismic Event
- Surface Rupture Potential

IV. STATUS OF PROGRAM

- Office Studies
- Field Studies
- Microseismic Network

V. DISCUSSIONS



WOODWARD-CLYDE CONSULTANTS PROJECT ORGANIZATION

STATUS OF 1980 ACTIVITIES

4.01 REVIEW OF AVAILABLE DATA — C

4.02 SHORT TERM SEISMOLOGIC MONITORING — U

4.03 PRELIMINARY R. I. S. — C

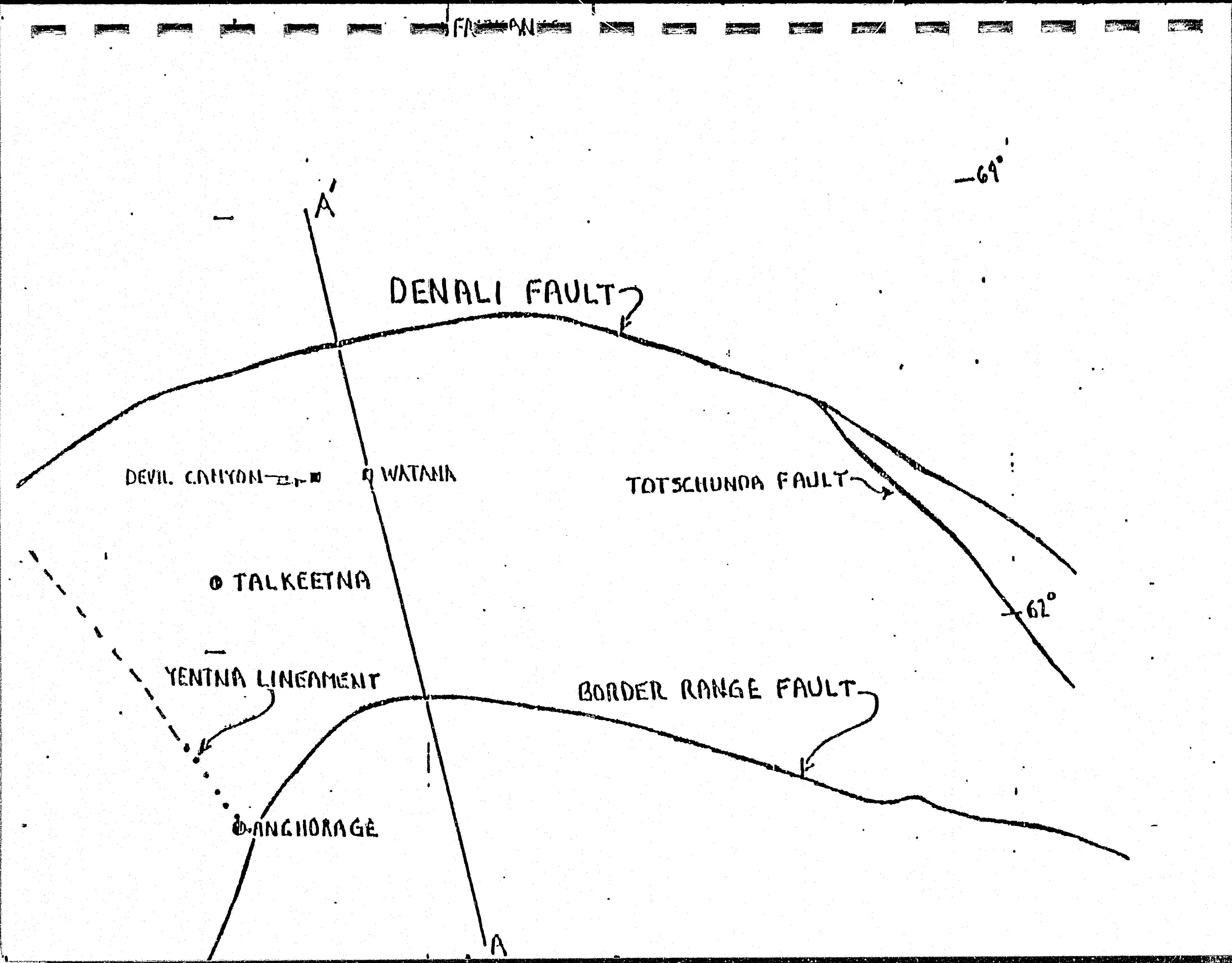
4.04 REMOTE SENSING IMAGE ANALYSIS — P.

4.05 SEISMIC GEOLOGY RECONNAISSANCE — U

4.07 PREM. GROUND MOTION STUDIES

MONITORING - FIELD
ACTIVITIES
~~ANCHORAGE~~

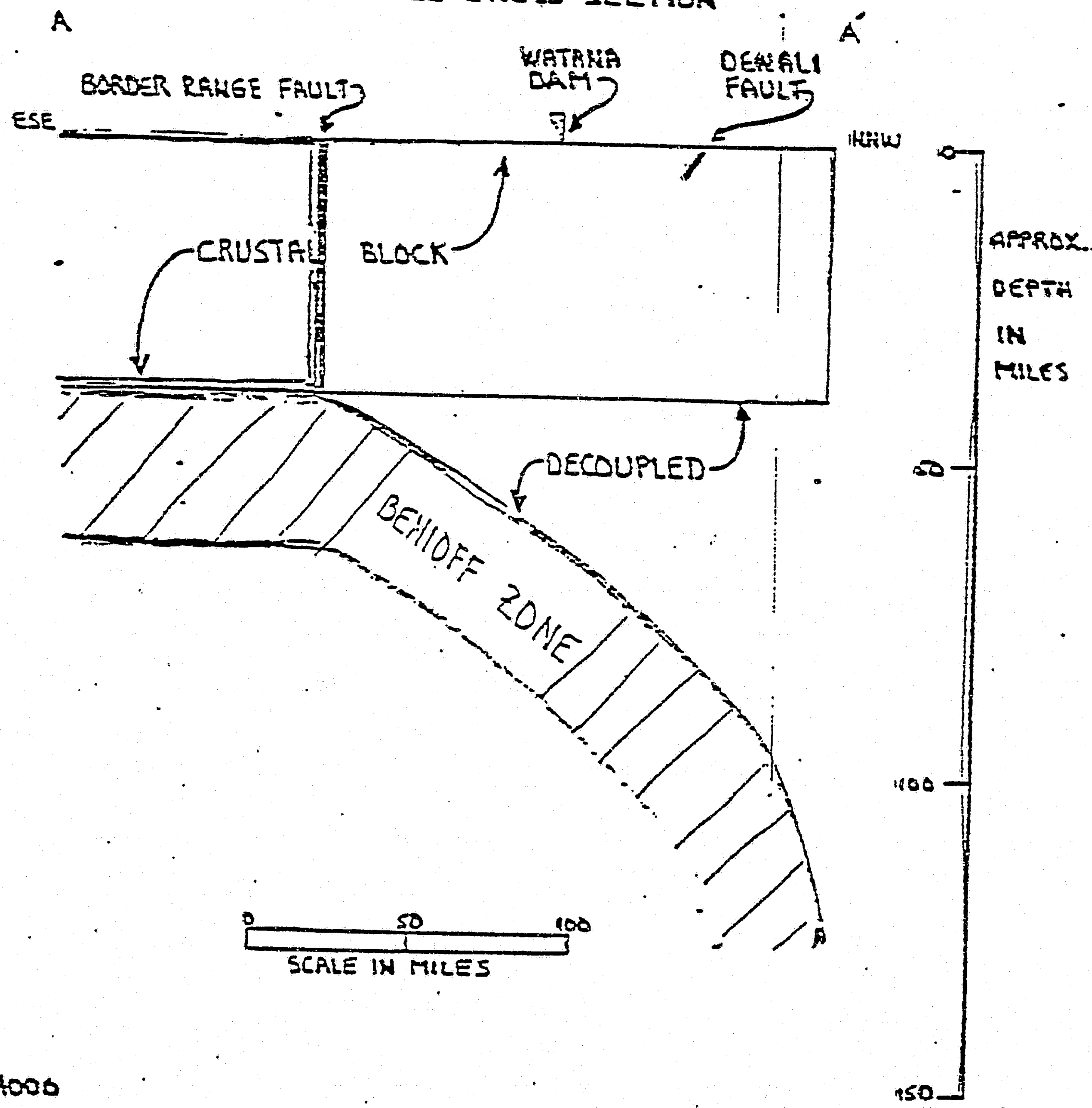
- TECHNICAL PART
incl PLAN OF
STUDY
BUFFALO


A'
64°
DENALI FAULT
DEVIL CANYON
WATANA
TOTSCHUNDA FAULT
TALKEETNA
62°
YENTNA LINEAMENT
BORDER RANGE FAULT
ANCHORAGE
A

3 - TYPES OF EARTHQUAKES

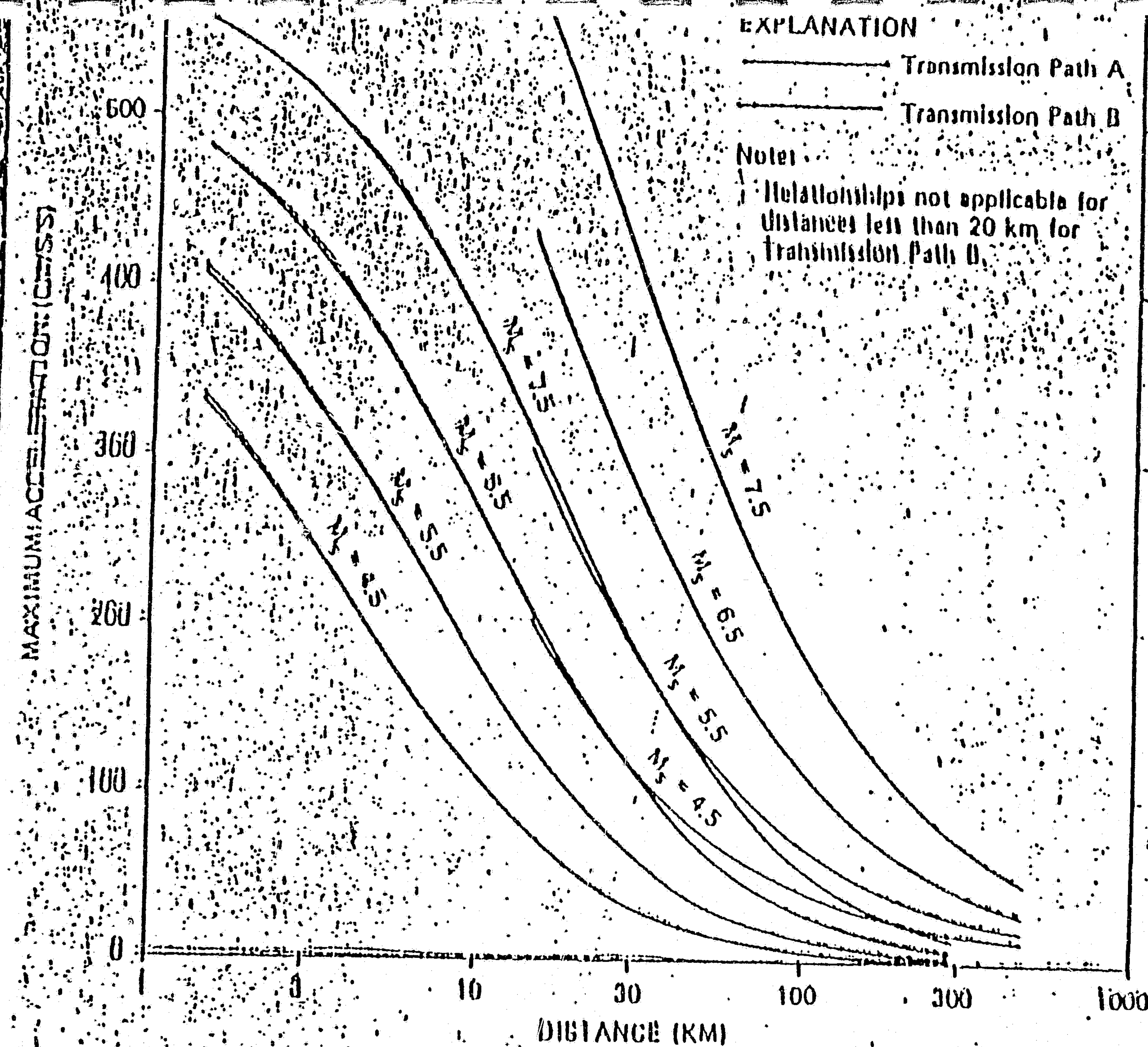
- SHALLOW EARTHQUAKE
  N.A. | PACIFIC PLATE CONTACT
- SHALLOW WITHIN N.A. PLATE CRUST
- DEEP - ORIGINATING IN BENIOFF ZONE

TECTONIC MODEL CROSS SECTION



14658A-4006

10 JUNE 80



a) Maximum Acceleration

$a = b_1 e^{b_2 M} (R+C)^{b_3}$

AVAILABLE HISTORIC &
INSTRUMENTED DATA IS
- LIMITED

Recorded History is about
less than 100 YRS

DATA DOES NOT CLEARLY
INDICATE DECOUPLIN

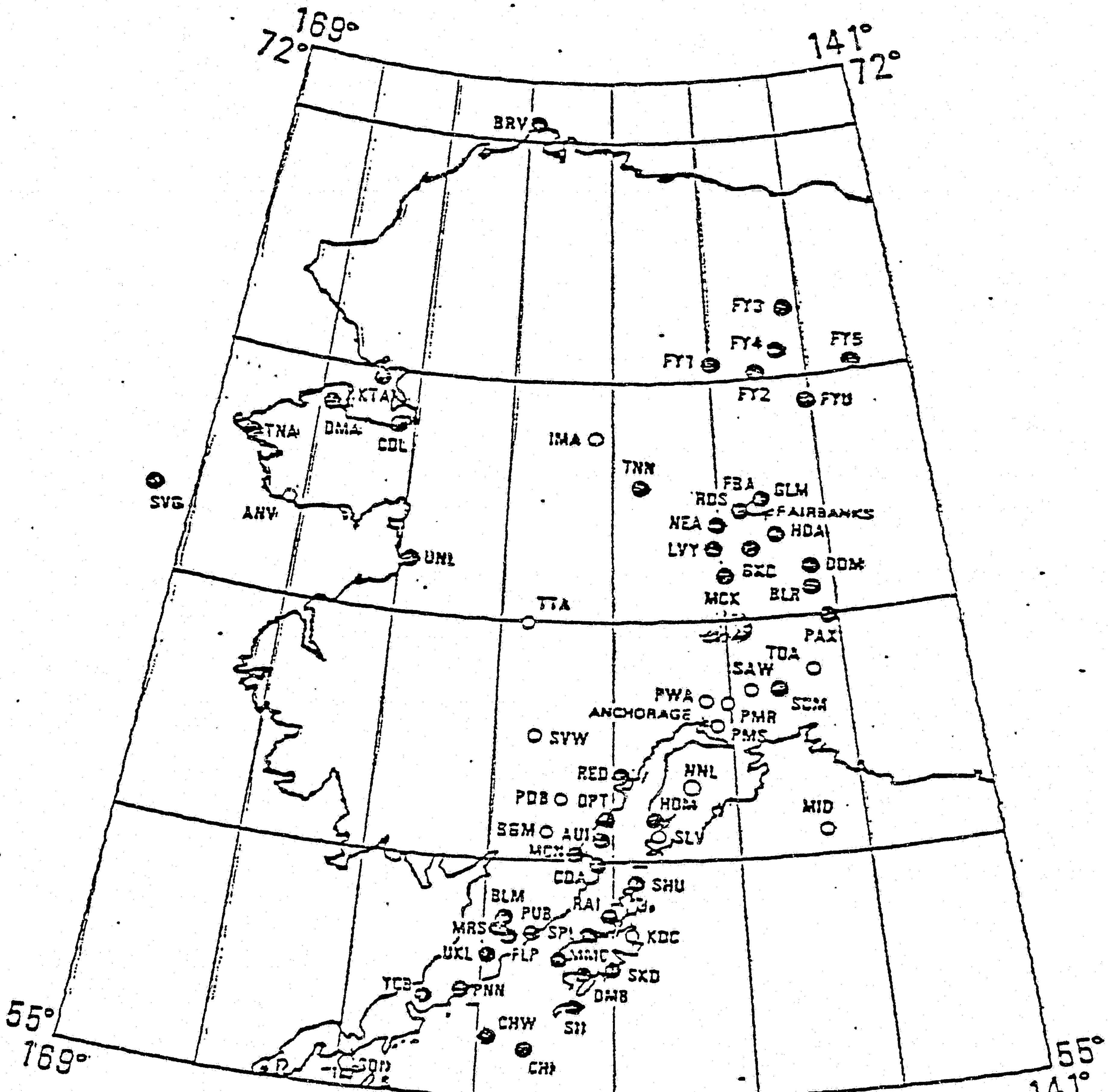
PURPOSE →

EVALUATION OF EARTHQUAKE SOURCES

- HISTORICAL SEISMICITY.
- REGIONAL TECTONICS.
- SEISMIC GEOLOGY—ACTIVE FAULTING.
- MICROEARTHQUAKE STUDIES.

MICROEARTHQUAKE STUDY OBJECTIVES

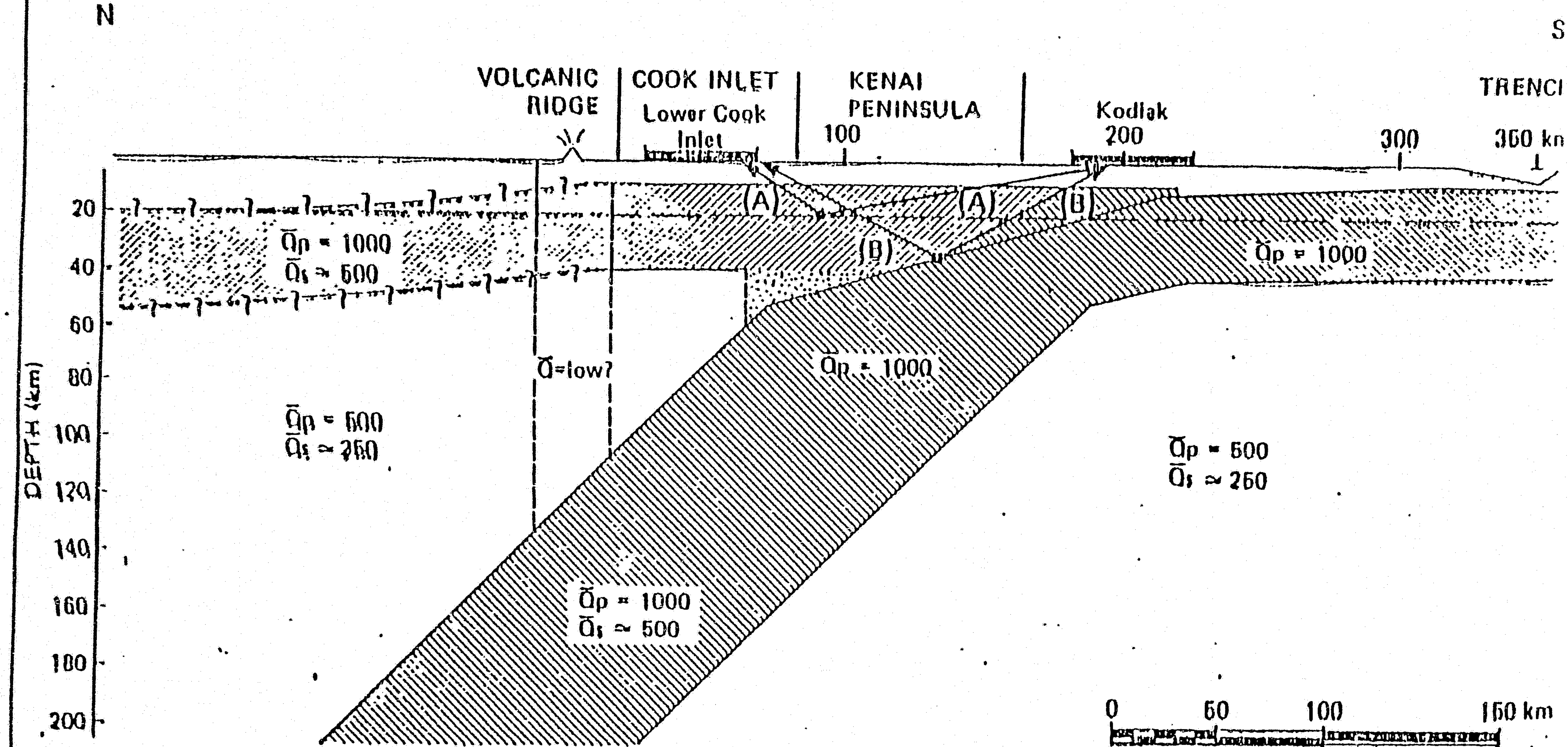
- LOCATIONS AND FOCAL DEPTHS OF MICROEARTHQUAKES.
- STYLE OF FAULTING.
- STRESS ORIENTATION.
- GEOLOGIC ASSOCIATIONS OF MICROEARTHQUAKES.
- SOURCE AND WAVE PROPAGATION CHARACTERISTICS.



GEOGRAPHIC LOCATIONS OF SEISMIC STATIONS

14658A-4000

10 JUNE 1980

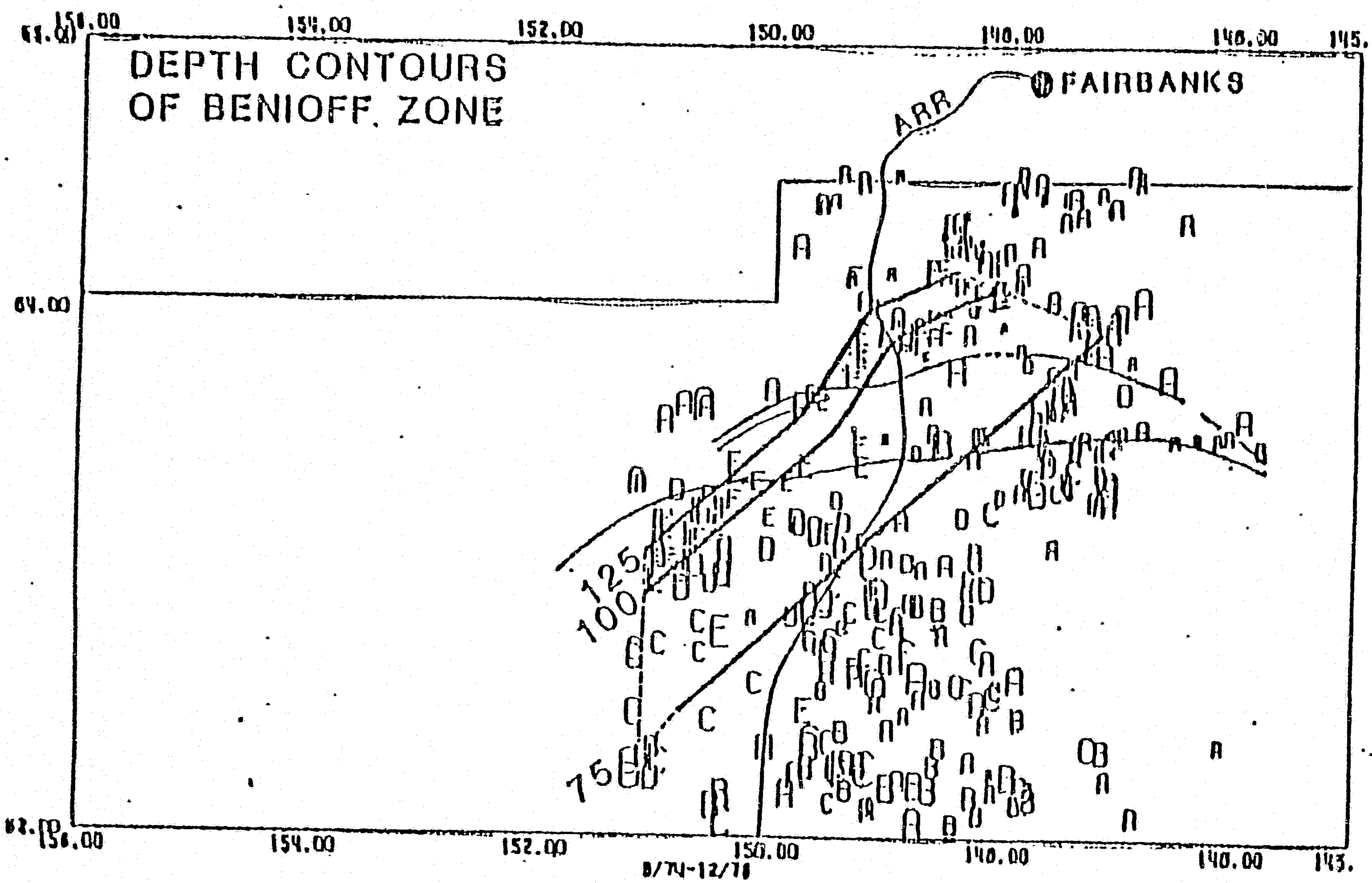


Notes:

I) $\bar{Q}p$ and $\bar{Q}s$ are inferred average values from p and s wave velocities.

II) Location and dips of subducting plates are schematic.

III) See volume II Section 2.



⊕ DAM SITES

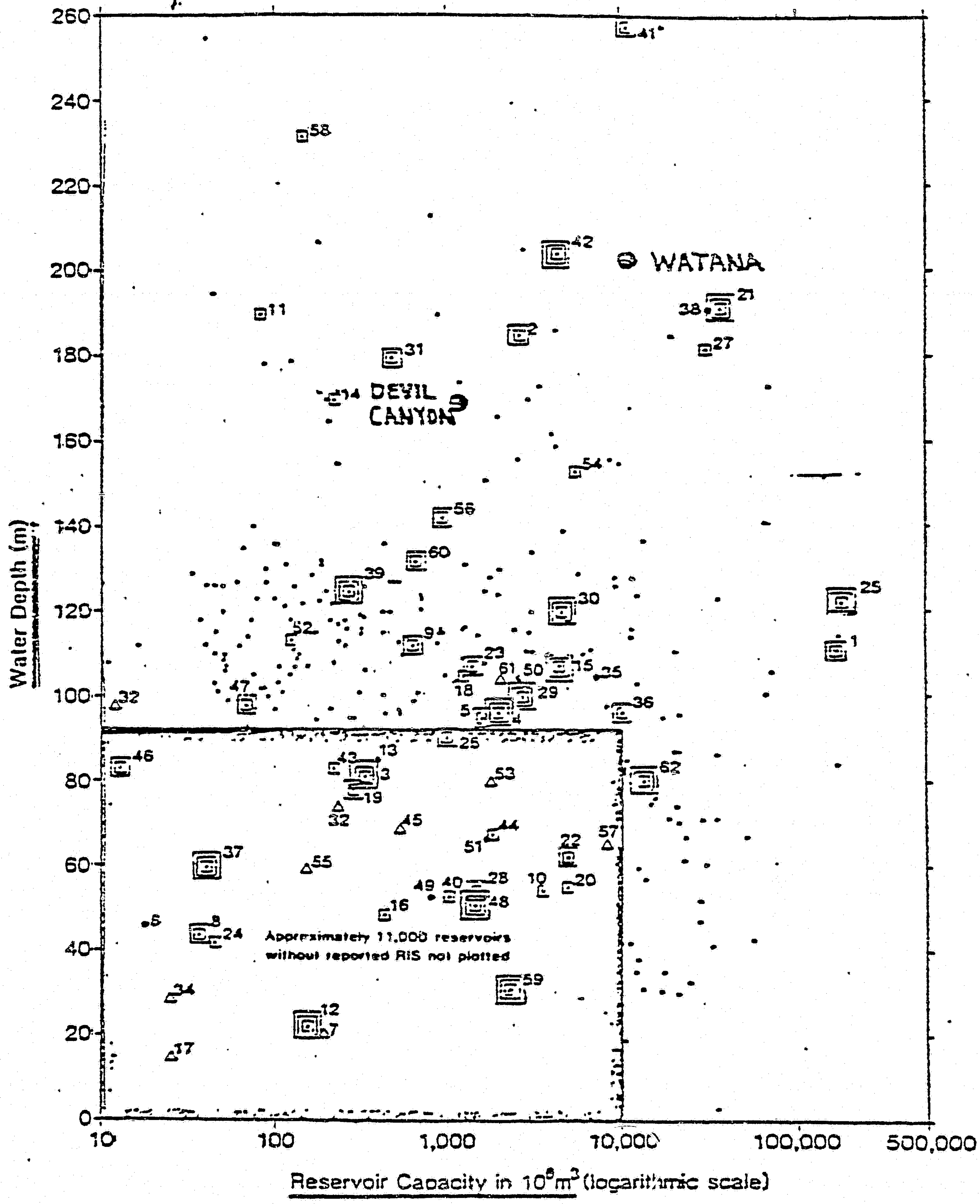
14658A-4000

10 JUNE 1980

RESERVOIR INDUCED SEISMICITY

REVIEW OF 1980 FIELD PROGRAM RESULTS

RIS, WATER DEPTH & WATER VOLUME



Note: The following reservoirs were not plotted because of insufficient data: Kinersani, Sharavathi.

*41 - Nurek (USSR) depth is in excess of 285 m.

EXPLANATION:

- • Deep and/or very large reservoir
- Accepted case of RIS, maximum magnitude ≥ 5
- Accepted case of RIS, maximum magnitude 3-5.
- Accepted case of RIS, maximum magnitude ≤ 3
- △ Questionable case of RIS
- • I Not RIS

4 - REPORTS BY OTHERS

SECTION D

FOUNDATION AND MATERIALS

TABLE OF CONTENTS

TABLE OF CONTENTS (cont)

LIST OF CHARTS

SUMMARY OF CHANGES

CHANGES TO THE 1976 INTERIM FEASIBILITY REPORT

In 1978, The Alaska District, Corps of Engineers, performed additional field explorations and geologic studies to verify the feasibility of the Watana damsite. As a result of these studies, considerably more information is now available concerning the site and the regional geology of the area. Therefore, the entire sections on Regional Geology, pages D-1 through D-9; Watana Site, pages D-10 through D-12; and the paragraph on Seismology at Devil Canyon, page D-7, of Appendix D, Foundations and Materials, of the 1976 Interim Feasibility Report are deleted and replaced by this supplemental report. No changes to the Vee Canyon and Denali sites have been made. Plate D-3, Watana - Site Plan and Centerline Profile is deleted and replaced with revised drawings. Several new plates showing geologic sections, borrow areas, and exploration logs have been added. These are listed in the index.

CHANGES IN DESIGN

As a result of the additional field exploration and geologic studies, a more knowledgeable assessment of the proposed project can now be made. A summary of the items which reflect changes to the 1976 Interim Feasibility Report, or reinforce the basic concepts of that report follows.

1. Nothing was found during this phase of the study to cast doubt on the feasibility of a dam at the Watana damsite. All exploration and geologic studies reinforced the concept that a large earth and rockfill or a concrete gravity dam could be built in this general vicinity.

2. Detailed surveys were performed at the Watana site. It was found that the topography used for the 1976 report was in error by approximately 15 feet. Therefore, the elevations shown on the plates or sections in this supplement are 15 feet lower than those shown in the 1976 report. The detailed survey showed the valley section to be a little wider than previously assumed and therefore, the crest length of the dam and the total quantities within the dam are somewhat larger.

3. The explorations at the damsite indicate that the rock is as good or better than previously assumed. Foundation rock is considered adequate to support either an earth-rockfill structure or a concrete gravity dam. To support this conclusion, the regional and site geology as well as the rock structure are discussed in much greater detail in this supplemental report.

4. The 1976 report recognized that the Watana damsite is an area of marginal permafrost and, therefore, permanently frozen ground could be expected in the vicinity. In the 1978 exploration program, specific locations of permafrost were identified and a number of temperature measuring devices were installed. The earlier assumption that permafrost does exist over much of this area was confirmed; however, it was determined that this is a very "warm" permafrost, ranging from 0° C to -1° C. Premafrost was encountered in bedrock in the left abutment of the dam and its effects on the grouting in this area are discussed in this supplemental report. Permafrost was also encountered in the impervious borrow area; however, because of its marginal temperature, it tends to be soft and can be easily excavated. A more detailed discussion is contained in the body of this report.

5. The 1976 report envisioned rather large amounts of gravel available for construction of the shells of the dam and limited amounts of impervious core material. The recent explorations indicate that this is not the case since gravels in large quantities were not verified but large quantities of impervious core material were discovered near the damsite. Because of the apparent shortage of gravel and an excess of impervious material, the dam section has been completely revised. The gravel shells have been changed to rock shells. This change to rockfill has allowed the use of a somewhat steeper slope on the upstream face of the dam. A large portion of the rock will come from required excavation of the spillway. The remainder will come from excavation of underground facilities and access roads and from a large borrow source on the left abutment.

6. The foundation excavation has been increased to require the entire foundation of the dam to be stripped to bedrock. The 1976 report envisioned excavation to bedrock under the core and filters only. However, because the evidence of the limited drilling performed is inconclusive, it was considered adviseable to require removal of in situ gravels beneath the entire embankment. If additional drilling supports a less conservative approach, the change can be made under subsequent feature design.

7. The core has been widened somewhat from that shown in the 1976 report and a zone of semipervious material, approximately of the same width as the core, has been added. This was done because large amounts of semipervious material are available and estimates show that it can be placed within the dam at a considerably lower cost than the rock shell material. The total thickness of these impervious and semipervious zones was determined by considering their effect on total stability of the dam and the difficulties of placing materials which require careful moisture control in the arctic environment. Laboratory tests performed on these materials indicate that optimum moisture will be a rather critical factor in their compaction. Therefore, the use of such materials has been held to within reasonable limits.

8. The 1976 report showed a vertical access shaft to the low-level drain system which passed through the embankment of the dam. This has now been changed to a tunnel through the right abutment, thereby eliminating any structures in the dam embankment.

9. A grout gallery has been added to the lower portions of the dam to facilitate grouting and to accommodate the process of thawing the permafrost. Use of the gallery will allow embankment placement and curtain grouting to proceed simultaneously, resulting in a shortened construction schedule. The gallery will also provide for "read-out" stations for instrumentation in the foundation and lower levels of the embankment and for general access.

10. The spillway location as shown in the 1976 report has been shifted southwest to a location which insures rock cut for its entire length. The rock and overburden material from this large excavation will be utilized in the dam embankment.

11. The 1976 report discusses a potential problem of seepage along a relict channel in the right abutment. The 1978 explorations verified the existence of this channel; however, studies indicate that it is not a problem and, therefore, no remedial action is required.

12. The diverison tunnel portals have been shifted to ensure their location in reasonably sound rock.

13. Professional services of Ellis Krinitzsky of the Waterways Experiment Station and Reuben Kachadoorian and Henry J. Moore from the U.S. Geological Survey were obtained by contract to perform seismic studies and evaluate the earthquake risk at these sites. Their work was divided into two phases. Kachadoorian and Moore of USGS performed the field reconnaissance to look for active faults and other geologic hazards. Krinitzsky's work was aimed at assessing the potential earthquakes which could be associated with such faulting. The USGS report recognized that this is a highly seismic region; however, the geologic reconnaissance of the proposed Devil Canyon and Watana damsites and reservoirs did not uncover evidence of recent or active faulting along any of the known or inferred faults. In their work they did not uncover evidence of the Susitna Fault, which was previously thought to exist a short distance west of the Watana damsite. Krinitzsky's work assessed the possible occurrance of earthquakes at the damsite and the motions that are likely to be associated with earthqauke activity. His findings indicate that the design of the proposed dams to withstand such activity is within the state of the art of seismic design.

14. In the fall of 1978, the consulting firm of Shannon & Wilson was engaged to perform refraction seismograph work at both the Watana and Devil Canyon damsites. This work supplemented the drilling information. The location maps and seismic velocity profiles from the Shannon & Wilson report are included as Exhibit D-1 to this appendix.

REGIONAL GEOLOGY

PHYSIOGRAPHY

The area of study is located within the Coastal Trough Province of southcentral Alaska. The Susitna River is a glacially fed stream which heads on the southern slopes of the Alaska Range, and flows by way of a continuously widening valley to the tidewaters of Cook Inlet. Within the upper 200 river miles, the Susitna passes through a variety of land forms related to the lithology and geology of the region. From its proglacial channel in the Alaska Range, it passes through a broad, glaciated, intermontane valley characterized by knob and kettle topography and by braided river channels. Turning westward along the northern edge of the Copper River lowlands, the river enters a deep, V-shaped valley and traverses the Talkeetna Mountains, emerging into an outwash plain and broad valley which it follows to the sea.

Three regional topographic lows, still identifiable today, are the Susitna River-Chulitna River area downstream of the Devil Canyon site, the middle reach of the Susitna River from Prairie Creek to Watana Creek, and the Oshetna River area at the Susitna Big Bend. These may represent drainage base levels that existed during the glacial periods. Whether they were interconnected at one time is not known since glaciation has modified the original drainages. One possible interpretation is that the ancestral Susitna River may have followed the course of the present Watana Creek and continued southwest along an ancestral valley through the area now occupied by Stephan Lake, Prairie Creek, and the Talkeetna River.

The Susitna River, presently incised 500 feet into that broad, ancestral, U-shaped valley, makes two sharp right-angle turns downstream of Watana Creek in the Fog Creek area and leaves the ancestral valley to flow westward into the steep, V-shaped Devil Canyon area. Glaciation probably blocked its former southwest course forcing the river to find a new outlet in Devil Canyon. Once established in a westward course, the Susitna River downcut its channel rapidly and became entrenched in Devil Canyon.

INFERRED GEOLOGIC HISTORY

The upper Susitna River basin is a complex geologic area with a variety of sedimentary, igneous, and metamorphic rock types. These range from Pennsylvanian to Pleistocene in age and have undergone at least three major periods of tectonic deformation.

The oldest outcrops in the area are Pennsylvanian and Permian aged metavolcanic flows and tuffs, locally containing limestone interbeds that have subsequently been altered to marble. This transitional shelf environment continued throughout the Triassic and into early Jurassic times, with alternate deposition of basalt and thin sedimentary interbeds. Metavolcaniclastics include altered marine sandstones and shales. This deposition was contemporaneous with a massive outpouring of lavas in the eastern Alaska Range, resulting in regional subsidence.

The first major tectonic upheaval in the Susitna area occurred in mid to late Jurassic time and consisted of large plutonic intrusions accompanied by uplift and intense metamorphism. Erosional remnants of these intrusives include amphibolites, greenschists, diorites, and acidic granitic types in the upper Watana reservoir areas. This uplift, and subsequent erosional period, was followed by marine deposition of argillite and graywacke in late Cretaceous. These rocks are exposed in the northwestern half of the upper Susitna basin and include the phyllites of the Devil Canyon site.

The second major tectonic event occurred in middle to late Cretaceous. Most of the structural features in the Talkeetna Mountains, including thrust faulting, complex folding, and uplift, occurred at that time. As a result of the thrust faulting, Pennsylvanian and Permian volcanic flows and tuffs were thrust over the much younger late Cretaceous argillite and graywacke.

In early Tertiary, approximately 65 million years ago, the northwestern portion of the upper Susitna basin was intruded by plutons of igneous rock. The diorite pluton that underlies the Watana site is one of these intrusives. Deposition of undifferentiated volcanic flows, pyroclastics, and associated near-surface intrusives occurred concurrent with and following the intrusion of the plutons.

The third major tectonic event was a period of extensive uplift and erosion in middle Tertiary to Quaternary. Uplift of 3,000 feet has been measured in the southern Talkeetna Mountains. The widespread erosion that occurred during this period removed thick rock sequences from the Susitna basin area.

Glaciation has been the prime erosion agent during the past several million years. At least two, and probably more, periods of glaciation occurred within the upper Susitna basin area. The central and eastern portions of the area may have been partially covered by glacial lakes during the latter glaciations. Renewed uplift in late Pleistocene rejuvenated the erosion cycle until the streams, with their increased gradients, became incised within glaciated valleys. The area currently is undergoing continued stream erosion, and is covered in many areas with a veneer of glacial and alluvial clay, silt, sand, and gravel deposits.

REGIONAL TECTONICS

The arcuate structure of southcentral Alaska reflect both the magnitude and direction of regional tectonic forces caused by the collision of the North American and Pacific Plates. The Talkeetna Mountains and adjacent Susitna River basin are believed to have been thrust northwestward onto the North American Plate from their parent continental blocks. It was this thrusting action which caused most of the structural features now seen in the upper Susitna basin.

Two major tectonic features bracket the basin area. The Denali Fault, about 43 miles north of the damsites and active during the Holocene, is one of the better known Alaskan faults. A second fracture, the Castle Mountain Fault, is 75 miles south of the river basin. The Susitna basin is roughly subdivided by the northeast-southwest trending Talkeetna Thrust, which roughly parallels the location of the Susitna Fault, as referred to in the 1976 Interim Feasibility Report. The Talkeetna River is a surface expression of the southern portion of both structures; however, Kachadoorian and Moore were unable to locate evidence of faulting in the Tsusena Creek area and, therefore, expressed doubt that the Susitna Fault exists. They found evidence of movement in the Talkeetna River and Watana Creek valleys and postulated that the Talkeetna Thrust could be a projection of this feature. Such a projection passes about 4 miles to the south of Watana damsite. The major alpine orogeny which formed many of the basins' present northeast-southwest trending compressional structures occurred in conjunction with the Talkeetna Thrust in late Cretaceous. Another contemporary zone of intense shearing, roughly parallel to the Talkeetna Thrust, is located about 15 miles east of the Talkeetna Thrust.

Two poorly exposed normal faults of probable Cenozoic age have been projected from gravimetric data as occurring in the Chulitna River valley about 15 miles northwest of the proposed Devil Canyon damsite. These faults have the northeast-southwest trend typical of the major structures within the area. No faults with recent movement have been observed within the upper Susitna River basin.

SEISMICITY

A seismological assessment of the basin area was prepared by Dr. E.L. Krinitzsky of the U.S. Army Engineer Waterways Experiment Station in the summer of 1978, under contract with the Alaska District, Corps of Engineers. Field reconnaissance to look for active faults and other geological hazards was conducted by U.S. Geological Survey under the direction of Reuben Kachadoorian and Henry J. Moore. These reports are included as Exhibits D-3 and D-2 in this appendix. They recognize that the Devil Canyon and Watana damsites are in a region of high seismicity and major faults. However, the geologic reconnaissance of the proposed Devil Canyon and Watana damsites and reservoir areas by the USGS experts did not uncover evidence of recent or active faulting along any of the known or inferred faults. The tectonic framework of the region is not well understood because of the lack of local seismic monitoring stations. Present knowledge indicates that historical earthquakes in the area often have hypocenter depths in excess of 50 km. Such events are associated with movement along the Benioff zone and often are not directly associated with local surface faulting. The Denali Fault in the Alaska Range, approximately 43 miles to the north, is the dominant surface feature in this area. The Susitna Fault, previously thought to exist west of the Watana damsite, was not confirmed in recent geologic mapping by the USGS team, nor did they find any evidence of faulting in the river channel at either of the damsites. The results of the core drilling and geologic reconnaissance at the damsite are strong evidence that no major faulting exists under the Watana damsite. The lack of significant shearing in DH-21, the 600-foot cross river hole, reinforces this conclusion.

Krinitzsky's work assessed the possible occurrence of earthquake activity based on the USGS field work. He assumes an earthquake of magnitude 8 along the Denali Fault, however, these motions are not critical when attenuated to the damsites. To account for the possibility that a major active fault could exist near the damsites, Krinitzsky has assigned a "floating" earthquake of magnitude 7 which could occur in the near vicinity of the dam. This generates the most severe design motions. The rational for the "floating" earthquake and a table of associated motions is included in his report (Exhibit D-3). This criteria is within the state of the art for earthquake design for large dams, and therefore, should not preclude proceeding with detailed design of the projects.

ROCK AND SOIL UNITS

The proposed Watana damsite and reservoir area is underlain by a complex series of metamorphic, igneous, and sedimentary rock. Specific formation names have not been applied to most of these units and they are instead assigned lithologic descriptions for correlation and mapping purposes. The distribution of various rock units that underlie the proposed reservoir are shown on Plate 5. Following is a brief description of the various rock units, beginning at the upper end of the reservoir and proceeding downstream to the damsite. Additional information and descriptive details concerning the rock units are included in the U.S. Geological Survey's Open File Report 78-558-A, Reconnaissance Geologic Map and Geochronology, Talkeetna Mountains Quadrangle, Corps of Engineers. Field reconnaissance to look for active faults and other geological hazards was conducted by U.S. Geological Survey under the direction of Reuben Kachadoorian and Henry J. Moore. These reports are included as Exhibits D-3 and D-2 in this appendix. They recognize that the Devil Canyon and Watana damsites are in a region of high seismicity and major faults. However, the geologic reconnaissance of the proposed Devil Canyon and Watana damsites and reservoir areas by the USGS experts did not uncover evidence of recent or active faulting along any of the known or inferred faults. The tectonic framework of the region is not well understood because of the lack of local seismic monitoring stations. Present knowledge indicates that historical earthquakes in the area often have hypocenter depths in excess of 50 km. Such events are associated with movement along the Benioff zone and often are not directly associated with local surface faulting. The Denali Fault in the Alaska Range, approximately 43 miles to the north, is the dominant surface feature in this area. The Susitna Fault, previously thought to exist west of the Watana damsite, was not confirmed in recent geologic mapping by the USGS team, nor did they find any evidence of faulting in the river channel at either of the damsites. The results of the core drilling and geologic reconnaissance at the damsite are strong evidence that no major faulting exists under the Watana damsite. The lack of significant shearing in DH-21, the 600-foot cross river hole, reinforces this conclusion.

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The proposed Watana damsite and reservoir area is underlain by a complex series of metamorphic, igneous, and sedimentary rock. Specific formation names have not been applied to most of these units and they are instead assigned lithologic descriptions for correlation and mapping purposes. The distribution of various rock units that underlie the proposed reservoir are shown on Plate 5. Following is a brief description of the various rock units, beginning at the upper end of the reservoir and proceeding downstream to the damsite. Additional information and descriptive details concerning the rock units are included in the U.S. Geological Survey's Open File Report 78-558-A, Reconnaissance Geologic Map and Geochronology, Talkeetna Mountains Quadrangle, Northern Part of Anchorage Quadrangle, and Southwest Corner of Healy Quadrangle, Alaska, by Csejtey, et. al., 1978. This report is included at the back of this appendix as Exhibit 5.

The upper reaches of the reservoir are underlain by an amphibolite unit. These are metamorphic rocks including greenschists, diorites, and local marble interbeds. Directly downstream of this unit is a zone of granitic types that are exposed north of the river at elevations above the proposed reservoir level.

The oldest rocks exposed within the area are farther downstream within the middle reservoir reaches and include both volcanics and limestone units. The volcanics consist mostly of metamorphosed basalt and andesite flows and tuffs that outcrop in the vicinity of Jay Creek and downstream from Kosina Creek. The limestone unit consists of marble interbeds that occur locally within the volcanics. The volcanics are overlain farther downstream by a volcanic unit of younger age consisting of a series of metamorphosed basaltic flows with interbeds of chert, argillite, and marble. This unit is exposed both near the mouth of Watana Creek and on the higher slopes west of Watana Creek. A much younger series of interbedded conglomerates, sandstones, and claystones is exposed along the lower reaches of Watana Creek directly upstream from its mouth.

The downstream reaches of the reservoir area are underlain by a sequence of argillites and graywackes. Exposed within the immediate damsite area is a granitic body intruded into these metasediments. It consists primarily of diorite with upstream and downstream margins that include associated schist, gneiss, and composite igneous and metamorphic rock types. Andesite flows and dikes are associated with this diorite pluton.

Other granitic intrusives occur east of the reservoir area. Locally, these intrusives are overlain by a series of younger igneous flows and tuffs and related shallow intrusives.

Overburden units in the proposed reservoir area include deposits of glacial till and drift with associated outwash and lake sediments, colluvium including slopewash and talus, alluvium and local slide debris.

ROCK STRUCTURE

Rocks within the reservoir area have undergone a complex deformation sequence, including uplift, intrusion, thrust faulting, folding, shearing, and associated metamorphism. The most significant structural feature within the reservoir area is the Talkeetna Thrust which strikes northeastward across the lower reservoir area and is roughly parallel to the lower reaches of Watana Creek. The Talkeetna Thrust, within the Watana reservoir area, has displaced the volcanic unit over the much younger metasediments.

A northeast striking shear zone that dips steeply southeasterly, and is roughly parallel to the Talkeetna Thrust, crosses the reservoir area about 15 miles east of the Talkeetna Thrust near Kosina Creek. Whether this shear zone represents a significant feature is not known.

The most significant rock structure in the immediate dam area is the intrusive diorite pluton of Tertiary age. It is observable for 4 miles parallel to the river and 2 miles north and south and is probably of great depth. Upstream and downstream border zones developed with several different metamorphic and igneous rock varieties. Two distinct northwest trending shear zones have been mapped in the vicinity of the damsite. One is 3,400 feet upstream and the other 2,500 feet downstream from the proposed dam axis. Attitudes vary with strikes ranging from N 40° W to 60° W and dips from 70° to 90° either SW or NE. The two shears can be seen in the right valley wall, but not on the left valley wall. The left wall is obscured by a slide block at the upstream shear, and the left wall at the downstream shear has a rock face that parallels the shear direction making observations difficult. The upstream shear zone has been named "The Fins," and has an observable width in excess of 400 feet. It includes seven near vertical rock fins averaging 5 to 25 feet in width bounded on both sides by altered and crushed rock. The downstream shear zone, named "Finger Buster", is somewhat less distinct and is partially covered by slope debris. It has an estimated width of 300 feet. Another northwest trending shear zone, similar to the two shears mentioned above, occurs downstream from the damsite in the vicinity of Tsusena Creek.

Fracture patterns including both joints and local shears have been mapped within accessible areas in the vicinity of the damsite. Details of this mapping are shown on Plates D-3 and D-4. Fractures include both cooling type jointing and structural deformation jointing resulting from the regional tectonic forces of uplift and thrust faulting. Shear, tension, and relief joints resulting from unloading by erosion of overlying sediments and/or melting of glacial ice are all present within the damsite area. A joint diagram plotted on an equal area stereographic projection is shown in Figure D-6. The dominant fracture orientation is to the northwest, but fractures strike in several directions. The major joint sets are N 50° W and the minor joint sets are N 30° E as observed within the area.

DEVIL CANYON

SEISMIC REFRACTION SURVEY

During September 1978, seismic refraction surveys were undertaken at Watana and Devil Canyon damsites by Shannon and Wilson, geotechnical consultants. At Devil Canyon, the seismic survey consisted of three lines, each approximately 1,100 feet long. One of these lines was located near the proposed alinement of the saddle dam on the left abutment and the remaining two lines were located near an abandoned airstrip on the alluvial fan at the confluence of Cheechako Creek and the Susitna River (see Plate D-1). The seismic line near the centerline of the left abutment saddle dam was alined to expand information derived from drilling accomplished on this site by the U.S. Bureau of Reclamation (USBR) in 1957. The refraction profile correlated well with the top of rock from the drilling data (see Sheet No. 10, Exhibit D-1). A lower velocity zone of rock sandwiched between competent phyllite indicates the possibility of a shear zone at the low point of the saddle. This correlates with hole DH-6 which indicated shearing in the 20 feet of bedrock penetrated by the boring.

The seismic lines on the Cheechako Creek aggregate deposit were alined to establish the depth to bedrock beneath these deposits and thereby confirm the quantity of material available for borrow. The velocities for the material in the alluvium indicate that the area is composed of a layer of sands and gravels or glacial materials several hundred feet thick overlying bedrock. This confirms the existence of material well in excess of the requirements for the project.

The location map and seismic velocity profiles from the Shannon & Wilson report and included in Exhibit D-1 to this appendix.

MATERIAL REQUIREMENTS

Concrete Requirements

Material requirements for Devil Canyon dam are based on a concrete gravity dam. Under this proposal approximately 2.6 million cubic yards of concrete will be required, most of which will be mass concrete. The remainder will be structural concrete for the appurtenant structures to the dam, including the powerplant. With stockpile losses, this amount of concrete will require approximately 3 million cubic yards of processed aggregate.

The USBR located an extensive deposit of material which will yield concrete aggregate of adequate quality in an alluvial fan approximately 1,000 feet upstream of the proposed dam axis. The fan was formed at the confluence of Cheechako Creek and the Susitna River.

Thirteen test pits and trenches were dug in the fan area by Bureau of Reclamation personnel in 1957. About 1,300 pounds of minus 3-inch material was tested by the USBR for basic aggregate suitability studies. An additional 200 pounds of material was collected by Corps of Engineers personnel in 1975 from the existing Bureau test pits and the riverbank. This material was tested by the North Pacific Division Materials Laboratory in 1978 .

If the excavation of materials is confined to that part of the alluvium located above river level (elevation 910 to 920 feet) with conservative back slopes through the ridges and benches, approximately 6,000,000 cubic yards of material is available in this location with all the resulting excavation in the reservoir area. Seismic refraction surveys indicate that usable gravel exists to approximately elevation 870 feet, so additional material could be retrieved if needed by bailing from below the water surface. Placement of the coffer dam, sizing of the diversion tunnel, and the ability to control the flow in the river at Watana dam will ultimately affect the method of exploitation of this source.

The locations of the test pits are shown on Plate D-1 and the detailed logs can be found in the U.S. Bureau of Reclamation's Alaska Geologic Report #7, Devil Canyon Project, dated March 1960. Laboratory investigations of the aggregate samples were reported in USBR Report #C-932 by their Concrete Laboratory Branch, dated 21 December 1959.

Petrographic analyses of the fine (sand sized) particles and coarse (gravel size) particles indicate that the sands and gravels in the fan are composed of quartz diorites, diorites, granites, andesites, dacites, metavolcanic rocks, aplites, breccias, schists, phyllites, argillites, and amphibolites. The gravel particles are stream worn and generally rounded in shape. The sand grains vary from nearly rounded to sharply angular in shape, averaging subangular. The specific gravity (BSSD) of the material ranges from 2.68 to 2.80.

Results from both labs indicate that the material in the Cheechako Creek fan is of adequate quality for use as concrete aggregate.

Embankment Material Requirements

The saddle dam on the left abutment, associated with the concrete gravity dam, will require approximately 835,000 cubic yards of material. These materials will be obtained from the same sources as discussed in the Interim Feasibility Report.

WATANA SITE

SCOPE OF INVESTIGATIONS

Field Reconnaissance

Geologic reconnaissance and mapping of the reservoir area and damsite were conducted concurrently with subsurface investigations throughout the spring and early summer of 1978. The work of the geologic teams was made easier in the early spring as rock outcrops were not obscured by the leaves on the trees and the dense ground foliage. Through the months of March and April, geologic mapping of the lower canyon was done from the frozen surface of the river, which allowed access to areas otherwise inaccessible after the ice had melted and high summer flows on the river had begun. Within the damsite area the primary purpose was to find, identify, and trace the surface expressions of discontinuities and shear zones as an aid in directing the drilling program and to provide preliminary geologic mapping of the site. Within the reservoir area, the primary thrust of the reconnaissance was toward identification of slopes, which by reason of shape, structure or overburden mantle could develop minor slumps and slides as a result of permafrost degradation or seismic action.

Borings and Test Pits

During 1978, explorations were conducted in the dam foundation and relict channel area. Core borings in the valley walls and floor were used to explore the quality and structure of the foundation rock and to obtain representative samples for testing. Borings in the relict channel area were used to define the depth of overburden, the extent of permafrost, the location of the water table and to examine, by drilling and sampling, the nature and condition of the materials.

Shallow auger holes were also used to determine the extent of deposits in the borrow areas and to verify the existence of quantities necessary for embankment construction.

Locations of explorations are shown on Plate D-2. Logs are shown on Plates D-19 through D-37; and core photos are shown on Plates D-38 through D-45.

Test pits were dug in potential borrow areas utilizing tractor-mounted backhoes. Bulk sack samples were retrieved from each test pit for testing later at the North Pacific Divison Materials Laboratory in Troutdale, Oregon.

A total of 27 test pits were dug in four areas as follows:

1. The mouth of Tsusena Creek (Borrow Area 'E') - 6 test pits.

2. The glacial till borrow area (Borrow Area 'D') - 14 test pits.

3. Upper Tsusena Creek, north of Tsusena Butte, (Borrow Area 'C') - 1 test pit.

4. Middle Tsusena Creek - 6 test pits.

The locations of Test Pits 1 through 5 and 8 through 21 are shown on Plates D-12 and D-11. The remainder of the test pits are located in areas which are not presently considered as borrow areas; however, they may be located on Plate D-2. The logs of all the test pits are shown on the appropriate borrow area Plates D-19 through D-22.

Seismic Refraction Surveys

A seismic refraction exploration program consisting of 22,500 lineal feet of seismic refraction lines was completed by Dames and Moore, Consultants, in 1975. Results of those investigations were presented as Exhibit D-1, Section D, Foundation and Materials, in the 1976 Interim Feasibility Report. In the fall of 1978, an additional seismic refraction survey was completed by Shannon and Wilson, Consultants, which includes 47,665 feet of seismic refraction lines. Locations of these additional seismic explorations are shown on Plate D-2, and the location map and seismic velocity profiles are presented as Exhibit D-1. The survey confirmed the findings of the Dames and Moore study. It confirmed the existence of a buried channel in the relict channel area and in general supported conclusions relating to shear zones in the abutments as interpreted from the recent core borings and geologic reconnaissance. The Shannon and Wilson survey also confirmed the existence of large quantities of borrow materials on Tsusena Creek in the proposed borrow area.

Instrumentation

Instrumentation conducted under this phase of the project consisted of the installation and data reading of ground water measurement devices, temperature logging devices, and the recording of the ambient temperature.

Ground Water: All piezometers installed were of the open well point type and were filled with diesel oil where they extend through permafrost zones to prevent freezing. A total of 10 piezometers were installed at the following locations.

TABLE D-1

Location	Surface Elevation	Tip Elevation	Date Set	Size
DR-14	2,340	2,271.0	26 Apr	4"
	2,340	2,295.2	19 Aug	1-1/2"
DR-20	2,207	2,123.8	30 May	1-1/2"
DR-18	2,172	2,107.0	21 Jun	1-1/2"
DR-17	2,167	2,136.3	8 Jun	1-1/2"
DR-16	2,099	2,053.8	5 Jun	1-1/2"
AP-1	2,202	2,188.6	20 Jun	1-1/2"
AP-2	2,200	2,189.0	20 Jun	1-1/2"
DR-19	2,151	2,109.0	3 Jul	1-1/2"
DR-22	2,229	2,005.5	3 Aug	1-1/2"
DR-26	2,295	2,229.5	11 Aug	1-1/2"

All locations are shown on Plate D-2 and Plate D-11. Plotted data is shown on Plates D-16 through D-18.

Subsurface Temperature: The principal temperature logging device consisted of a 3/4-inch galvanized pipe, with the lower end capped and sealed. The pipe was filled with a mixture of ethylene glycol and water (50/50) or arctic grade diesel fuel. Readings were taken using a digital volt-ohm meter and a single thermister which was lowered into the pipe.

At location DR-26 both a 3/4-inch galvanized and a 1-1/2-inch PVC pipe were installed to determine if readings could be duplicated in a pipe of larger diameter. A total of 14 devices were installed at the locations shown in Table D-2.

TABLE D-2

Location	Date Installed	Length	Stick Up	Buried Depth	Fluid
AP-8	23 Jun	64'	4.2'	58.9'	Diesel
AP-9	23 Jun	21'	3.2'	17.8'	Diesel
DH-12	3 Jul	129'	1.8'	127.2'	Diesel
DH-23	17 Jul	76'	0.5'	75.5'	Antifreeze
DH-24	1 Aug	86'	1.2'	84.8'	Antifreeze
DR-18	21 Jun	251'	3.4'	247.6'	Diesel
DR-19	3 Jul	83'	3.9'	79.1'	Diesel
DR-22	3 Aug	492'	2.0'	490.0'	Antifreeze
DH-28	30 Aug	124'	1.0'	123.0'	Antifreeze
DR-26 (3/4" pipe)	11 Aug	68'	3.8'	64.2'	Antifreeze
DR-26 (1-1/2" pipe)	11 Aug	99'	3.4'	95.6'	Antifreeze
DR-14	19 Aug	65'	2.8'	62.2'	Antifreeze
DH-21	23 Aug	160'	2.0'	158.0'	Antifreeze
DH-25	15 Aug	80'	4.0'	76.0'	Antifreeze

All locations are shown on Plate D-2 and Plate D-11. The plotted temperature data can be found on Plates D-13 through D-15.

A second type of temperature logging device, installed at DR-22, consisted of a multipoint thermistor string. The purpose of this installation was to act as a check against the 3/4-inch fluid filled devices described above.

Ambient Temperature: The ambient temperature was obtained using a standard high-low Mercury thermometer placed in the shade on the right abutment riverbank approximately 4 feet above the ground. Prior to this phase of the project, there was no ambient temperature data available for this section of Alaska. Data obtained is shown on Table D-3.

TABLE D-3

Date	High °F	Low °F	Date	High °F	Low °F
23 Mar 78	22	0	23 May 78	60	39
24 Mar 78	24	13	24 May 78	60	32
25 Mar 78	28	19	25 May 78	61	40
27 Mar 78	32	10	26 May 78	41	36
28 Mar 78	26	13	27 May 78	64	--
29 Mar 78	40	6	28 May 78	--	36
30 Mar 78	35	6	29 May 78	58	33
31 Mar 78	36	5	30 May 78	63	36
1 Apr 78	31	5	31 May 78	66	40
2 Apr 78	28	-4	1 Jun 78	54	36
3 Apr 78	28	3	2 Jun 78	58	38
4 Apr 78	36	4	3 Jun 78	68	41
5 Apr 78	36	20	4 Jun 78	68	38
6 Apr 78	33	11	5 Jun 78	57	39
7-8 Apr 78	40	28	6 Jun 78	66	44
9 Apr 78	41	10	11 Jun 78	72	44
10 Apr 78	43	13	12 Jun 78	62	39
11 Apr 78	38	20	14 Jun 78	57	40
12 Apr 78	38	15	16 Jun 78	58	34
13 Apr 78	40	30	19 Jun 78	52	33
14 Apr 78	44	32	20 Jun 78	61	33
15 Apr 78	40	38	21 Jun 78	63	--
16 Apr 78	39	29	22 Jun 78	--	46
17 Apr 78	38	21	27 Jun 78	55	38
18 Apr 78	43	21	28 Jun 78	59	37
19 Apr 78	44	20	30 Jun 78	62	43
20 Apr 78	48	24	1 Jul 78	57	41
21 Apr 78	44	25	2 Jul 78	62	43
22 Apr 78	45	30	4 Jul 78	70	47
23-24 Apr 78	47	32	7 Jul 78	62	40
25-26 Apr 78	50	26	8 Jul 78	73	43
30 Apr 78	59	32	9 Jul 78	70	49
1 May 78	60	34	10 Jul 78	66	42
9 May 78	64	30	11 Jul 78	71	--
10 May 78	72	33	12 Jul 78	--	50
11 May 78	70	33	14 Jul 78	59	50
12 May 78	65	40	16 Jul 78	58	47
13 May 78	72	30	26 Jul 78	66	45
14 May 78	72	31	27 Jul 78	78	40
15 May 78	66	36	28 Jul 78	74	55
16 May 78	55	32	29 Jul 78	78	39
17 May 78	60	30	30 Jul 78	82	46
18 May 78	64	37	31 Jul 78	84	52
19 May 78	60	37	1 Aug 78	80	58
20 May 78	75	24	9 Aug 78	71	46
21 May 78	70	43	10 Aug 78	68	54
22 May 78	--	36	11 Aug 78	66	49

Accuracy of Subsurface Temperature Data: Resistance measurements were obtained using a Keithley volt-ohm meter, which allowed readings to the nearest ohm. With a span of 225 ohms per degree centigrade, 1 ohm represents 0.005° C. The temperature data in this report has been reported to 0.01° C and is reliable to that degree of accuracy. To verify the accuracy of each thermister, its resistance was measured in an ice bath. It was found that the thermistors are very stable and do not tend to drift from their original resistance at 0.00° C.

General Comments

The drilling in the permafrost was performed with core drills and rotary drills, which introduce a large amount of heat into the ground. Where the permafrost temperature is only slightly below the freezing point, this tends to melt the permafrost and makes identification very difficult. Therefore, the drilling operation may or may not reflect the existence of permafrost, and it is necessary to rely heavily on the instrumentation for a true evaluation of the location and depth, at which permafrost exists. By December of 1978, the temperature logging devices may not have stabilized due primarily to the fact that the drilling method used was rotary with drilling "mud" as the circulation medium, which tends to thaw the permafrost. Upon inspection of the plotted data for the locations in this area it can be seen that the temperatures are gradually approaching the 0° C point. Through a continual program of monitoring these points, a great deal can be learned about "freeze back."

At location DR-26, 3/4 inch and 1-1/2 inch pipes were installed to determine if convection currents in the pipe would affect the accuracy of the near surface readings. It can be seen from the temperature plots, shown on Plates D-13 through D-15, that there is a degree of convection in the upper zones, while with depth the two readings are very similar. At location DR-22, the string had 14 thermistors in a 150 foot length. The data obtained from this string has not been included in this report since its reliability is in question. This is due to damage received during installation as well as the fact that the thermistors are of a lower quality and adequate calibration could not be obtained prior to installation. At location DH-12 the 3/4-inch pipe temperature logging device was lost when it was decided that the bore-hole camera should be run in this boring. At location DH-25 no data is available because the 3/4-inch pipe froze up during installation.

SITE GEOLOGY

Introduction

The river valley at the site has a V-shaped lower or bottom canyon deeply incised into an upper, much broader, U-shaped river valley of considerable extent and width.

The lower river valley floor ranges from 300 to 600 feet wide and has side slopes of 35 to 60 degrees with locally scattered rock outcrops that rise in near vertical cliffs. The incised portion of the canyon extends from subriver level upward about 500 feet to approximate elevation 2,000 feet, where it ranges in width from 1,500 to 3,000 feet. Above elevation 2,000 feet, there is a distinct flattening of the valley slopes and the area broadens out into a very wide former river valley. Width of this former valley base level is from 8 to 10 miles in the lower reservoir area, narrows to about 1 mile in the midreservoir area upstream of Jay Creek and widens to more than 20 miles in the upper reaches of the reservoir.

Foundation Conditions

The site was mapped and explored with 17 core holes, 12 of which are on the dam axis shown in this report. Six of the holes are angle holes, five were drilled normal to the dominant structural trend, and one drilled across the river valley. The exploration plan with hole locations is presented on Plate D-2.

The river valley is filled with alluvium consisting of gravels, cobbles, and boulders in a matrix of sand or silty sand. Overburden depths in the valley bottom range from 40 to 80 feet and may exceed 100 feet in places. Overburden depths on the valley slopes range up to 10 feet deep on the left abutment and up to 20 feet on the right abutment. However, overburden upstream of the left abutment is more than 56 feet deep.

Overburden on the valley slopes is mostly glacial debris and talus consisting of various gravel and sand mixtures and some silts, with cobbles and small boulders. The underlying rock is diorite, granodiorite, and quartz diorite with local andesite porphyry dikes and more widely scattered minor felsite dikes. Most of the rock, although fractured, is relatively fresh and hard to very hard within 5 to 40 feet of top of rock. Overburden and rock stripping depths along the dam axis are shown in cross section on Plate D-7.

Fractures are closely to moderately spaced at the bedrock surface, generally becoming more widely spaced with depth. Fracture zones found at all depths tend to be tight or recemented with calcite or silica. The northwest trending joints and high angle shears mapped in the rock outcrops are found at different depths within most drill holes and range from single fractures to broken zones more than 20 feet thick. Broken rock within the shear zones is locally decomposed but consists mainly of moderately hard to very hard fragments. Many fractures have thin clay gouge seams and slicken sides. Pyrite and chlorite mineralization is found as coatings on many fracture surfaces. Shears are

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Valley Conditions

The river valley bottom was explored with six core drill holes. Three holes are on the axis and three are about 1,000 feet downstream of centerline in the toe area. River alluvium varied in depth from 44 to 78 feet. This alluvium consists of gravels, cobbles, and boulders imbedded in sands with local gravelly or silty sand lenses. The gravels and larger sizes are mostly subrounded to rounded with occasional large boulders. Most large sizes are of dioritic composition, but metamorphic and other rock types were also noted. Most of the gravels are fresh, but a few are coated with plastic fines. Alluvial materials in some areas were frozen to depths in excess of 50 feet and possibly all the way to bedrock at the time of drilling.

The bedrock is a diorite that in most holes is very closely fractured in the upper 10 to 20 feet. Fractures become more widely spaced with depth; however, local zones of closely spaced fractures occur throughout. Joints are both open and rehealed or cemented with calcite and silica. The rock below river level is mostly fresh and hard to very hard. Shear zones occur in several of the holes and include some thin clay gouge coatings and slickensides. Soft chloritic materials were also encountered in one shear zone, and iron staining with pyrite mineralization is common. It should be noted that DH-21 was drilled essentially across the river from the left to the right abutment. No major fault or significant change in materials was seen although six minor shear zones were encountered in the hole. Most of these zones are less than 3 feet thick, whereas, some of the vertical holes penetrated sheared material for distances of more than 10 feet. This confirms the near vertical nature of most shearing. Geologic mapping in rock exposures along the riverbank also indicates the near vertical nature of shearing. An andesite porphyry dike was penetrated at depth by DH-21. This dike has an apparent thickness of about 13 feet, and the contacts with the diorite are tight and contain no notable planes of weakness.

The left abutment was explored with five drill holes, three on the dam axis and one each upstream and downstream of the embankment. Overburden depths in the downstream hole and the three axis holes are less than 10 feet. This overburden consists of small subangular to subrounded boulders in silt, sand, and gravel. Overburden in DH-28, located approximately 1,000 feet downstream of the axis at elevation 1,971 feet, consists of 6 feet of silty clay overlaying 2 feet of sand. DH-25, located about 750 feet upstream of the axis at elevation 2,045 feet, penetrated a vertical depth of 56 feet of glacial and alluvial deposits and had not yet encountered rock when it was abandoned. Overburden in DH-25 consists primarily of gravelly, silty sand with boulders to a depth of 15 feet, underlain by gravelly, clayey silt. Gravels are sub-rounded to rounded and the clayey silts are stiff and plastic.

Rock in the three axis holes is a hard quartz diorite, whereas in DH-28 downstream of the embankment, it is an andesite porphyry. The relationship between the quartz diorite as a plutontic rock and the andesite porphyry as a surface flow rock is not clearly understood. This contact area between the two type rocks is in the location of the underground powerhouse and will be closely explored during design investigations. It is assumed the underground powerhouse will be located in the dioritic rock. Weathering is primarily staining on fracture surfaces. Fracture spacings vary from very close to moderately spaced; spacing increases with depth.

Fractured zones, encountered in all holes, are from less than 1 to more than 20 feet thick and are separated by from 10 to more than 50 feet of relatively undisturbed rock. Many fractures include thin seams of clay gouge, slickensides, secondary pyrite, and breccia. DH-28, downstream of the embankment, appears to have been drilled in an andesite porphyry breccia contact zone adjacent to the diorite pluton. Much of the core is brecciated, moderately weathered to highly altered, and recovered in small fragments. Several zones of clay gouge were noted.

Right abutment conditions were explored with six core drill holes along the proposed dam axis. Three of these holes were angle holes drilled normal to the dominant structural trends. Overburden depths within the six holes range from 4 to 20 feet, with the greater depths in the holes farthest upslope. Overburden consists of gravelly sand with cobbles and small boulders.

Bedrock is moderately hard, but weathered, closely fractured and locally sheared in the upper 10 to 40 feet. The rock is diorite or quartz diorite with zones of quartz diorite breccia. The quartz diorite breccia is healed, probably formed during emplacement, and is not considered a zone of weakness.

Fractured zones encountered during drilling are similar to those noted on the left abutment. Shears range up to 22 feet thick and are separated from each other by about 10 to 100 feet of competent rock. Very thin films of clay gouge and slickensides occur on some fracture surfaces. Iron staining occurs on many fracture surfaces and fine disseminated pyrite mineralization occurs more widely.

Relict Channel Area

The relict channel is a suspected ancestoral Susitna River channel north of the right abutment under the broad terrace area between Deadman and Tsusena Creeks. Ground surfaces within the Relict Channel area are between elevation 2,100 and 2,300 feet along low elongated ridges and shallow depressions. This area was originally explored with two seismic lines and the results presented in the Feasibility Report, Appendix 1 as Exhibit D-1. Subsequent 1978 explorations include 1,814 linear feet of drilling, borrow explorations near Deadman Creek and 23,600 feet of seismic refraction lines. The 11 drill holes range from 21 to 494 feet in depth and were mostly noncore rotary holes supplemented with drive samples and some bedrock coring. The results of these 1978 explorations confirm the existence of the deeply buried bedrock surface depression discovered during the 1975 seismic investigations. The lowest bedrock elevation encountered in drilling was in DR-22 at 1,775 feet, MSL or 454 feet below ground surface.

Overburden consists of both glacial and alluvial materials occurring in varying sequences that are difficult to correlate with the limited drilling to date.

Outwash occurs over much of the area, consisting of gravelly, silty sands or silty, gravelly sands in varying proportions, with some local cobbles and boulders and more widely scattered clay lenses. These materials are mostly loose and the fines are predominantly non-plastic.

Glacial till is the most abundant overburden material found within the relict channel area. These tills occur in three separate sequences in the deepest drill holes, separated by lenses of alluvial materials. The near surface tills are normally consolidated while the tills from greater depths are highly over consolidated and dense. It is quite probable that this over consolidation was caused by glacial loading in the geologic past. All of the tills contain fines that are nonplastic or only moderately plastic. Smaller gravel sizes are rounded, while larger sizes are more subrounded to subangular. Materials are poorly sorted with little or no indication of bedding. The tills vary considerably in thickness from only a few feet to a maximum of 163 feet in DR-18.

Apparent river deposited alluvial lenses which represent inter-glacial periods, separate many of the till units. These deposits consist of sandy gravels with some silts. Sandy alluvial units have a tendency to cave during drilling and several appear to have relatively high permeabilities. Most of these river deposits were less than 50 feet in thickness but in DR-22, directly above bedrock, the alluvial unit was 159 feet thick.

At least two deposits of lake sediments were encountered during drilling. The larger of these was named "Lake Woller" and occurs in DR-13, DR-15, DR-26, and DR-27 in varying thicknesses. Maximum thickness is 60+ feet in DR-13. Lake Woller deposits appear to be confined between elevations 2,240 and 2,305 feet. Another apparent lake deposit was penetrated in DR-18 and DR-20. Maximum thickness of this deposit is 33 feet and appears to be confined between elevations 2,130 and 2,190 feet. Both lake deposits may represent either quiet lake deposition during an interglacial period, or possibly proglacial lakes formed during glacial retreats. The lake deposits consist primarily of highly to moderately plastic clays and silts with local gravel and sand lenses.

Spillway

The original location of the Saddle Spillway in the Interim Feasibility Report, Appendix I, Plate D-3, was found to lie directly upon two adverse structures. The overburden depths increased from 9 feet at DR-17 on the left side of the proposed alinement to 231 feet at DR-18 on the right or east side of the spillway. This depth of overburden prevailed throughout the length of the spillway, including the proposed gate structure area.

The glacial tills, clay, and intermittent sand lenses of the overburden would have required additional excavation and flatter sideslopes. Added expense would also have resulted from increased foundation requirements for the gate structure and from the full length lining which would have been required in the spillway channel. To avoid these disadvantages a change of the channel alinement was made.

The new proposed alinement lies approximately 800 feet laterally to the left (southwest) of the original design and will be in rock cut from inlet to final outlet at Tsusena Creek. This alinement will also avoid potential structural problems from the second adverse structure, the shear zone titled "The Fins" (Plate D-4) which will now parallel the spillway for its entire length. Rock quality is such that excavated rock will be used as dam shell rock.

As a result of the move, it is anticipated that sound bedrock will be encountered at a maximum depth of 25 feet at the gate structure and will continue down spillway for at least 2,500 feet. As the spillway dips down to Tsusena Creek, deeper glacial till is again encountered, so the final section of the outflow may not be totally founded on bedrock. The plunge pool at Tsusena Creek will be contained by existing rock cliffs.

Permafrost

The Watana damsite lies within the discontinuous permafrost zone of Alaska. For this reason it is to be expected that permafrost would be found during the exploratory effort, particularly on north facing slopes and areas where arctic vegetation has effectively insulated the ground surface. Depths of permafrost within the discontinuous zone are variable and often change drastically within short distances depending on exposure, ground cover, soil characteristics and other factors.

Permafrost conditions at Watana as indicated by the exploratory work done to date appear to be typical for the zone. The left abutment which faces north and is either continuously shaded or receives only low angle rays from the sun was explored with core drilling equipment. Five holes were drilled and pressure tested by pumping water into the drill holes at selected intervals using a double packer. Observation of drill water returns and pressure tests showed that permafrost exists for the entire depth of the holes. Holes drilled in the right abutment, where the sun's rays are most effective, did not indicate any permafrost. Within the relict channel areas, on the terrace north of the right abutment, indications of permafrost were observed as reflected by ground water conditions and water table measurements, drill action, and sampling. Drill hole DR-27 was sampled and ice lenses were retrieved from a depth of 30 through 36 feet. Permafrost was also encountered during test pit activities. However, in general, permafrost in the spillway and relict channel area, while encountered as near as 1 foot to the surface, is expected to be confined to a relatively shallow layer. This expectation has been reinforced by the fact that ground water has been encountered at various depths. In order to study the thermal regime of the permafrost and to more accurately define the lower limits of the frozen zone, temperature probes were installed at 13 locations. These locations are shown on Table 1 under the heading "Instrumentation" and the graphs of readings taken to date are shown on Plates D-13 through D-15. It is still too early to reach definite conclusions from the limited data obtained since installation due to the fact that heat was introduced into the regime by drilling and equilibrium may not yet be reestablished. However, it appears that the readings do support the conclusion that permafrost is not as widespread or as deep as was previous believed.

Of equal significance is the fact that the temperature probes indicate that the temperatures within the permafrost are generally within 1 degree of freezing. Construction in cold regious has shown that, within this range, materials can be excavated with considerably less dificulty than in areas where the permafrost temperatures are lower. Particularly in borrow areas, where a rather large area can be exposed, degradation is rapid and by alternating from side to side in the area, the material can be ripped, left exposed to the sun for a few hours and then handled in the normal fashion. The fragile nature of the permafrost regime as indicated by temperature studies will be of prime importance in the scheduling related to foundation grouting. Permafrost barely within the frozen range will be much easier to thaw and foundation grouting will be facilitated.

As explorations at the damsite continue, the installation of frost probes will be expanded to provide detailed knowledge of the extent of existing permaforst areas as well as their condition. A discussion of design type of probes installed and the degree of accuracy to be expected from data readings can be found under "Instrumentation."

Ground Water

Ground water conditions in the terrace area north of the spillway alinement were examined during exploratory drilling, but the use of drilling mud used for most of the rotary drilling made direct water table measurements difficult. Pervious zones were occasionally encountered where loss of drilling mud was noted. Examples are DR-22 where mud losses were experienced of approximately 50 gallons per foot of hole drilled between elevations 2,025 and 2,000 feet and losses of approximately 14 gallons per foot of hole drilled between elevation 1,940 and 1,855 feet. In a very few instances water tables could be measured at the time of drilling. A notable example of artesian head was measured while drilling DR-13 and DR-14. In both of these holes the ground water was under sufficient head to rise from elevation 2,240 and 2,270 feet, respectively, to elevation 2,300 ± feet when the overlying clay layer was penetrated by the drill.

A discussion of the overburden units encountered in the terrace area can be found under the heading "Relict Channel Area." It will be noted in that discussion that at least two deposits of lake sediments were encountered which appear to be rather extensive. As might be expected, perched water was encountered above the higher deposit, Lake Woller, in some holes because of the impermeability of the material. In the alluvial zones between the lake deposits water was usually encountered although, as previously noted, in only one instance was this water under artesian head. Below the lower lake deposit, approximate elevation 2,190 feet, the glacial tills were very compact and can be expected to be relatively impervious. The over consolidation of these materials as previously stated is probably due to being overloaded by the weight of ice in glacial times.

The significance of ground water conditions in this area lies in the fact that the deep deposits in the relict channel area will be under a head of approximately 400 feet from the proposed Watana reservoir. The decision as to whether or not an impervious cutoff across this channel is necessary depends on the pervious nature of the materials encountered. While a more detailed program of exploring, sampling, and testing will be undertaken to ensure that pervious layers will not present a seepage danger in this area, it is presently believed that no impervious barrier is required. A more detailed discussion of the rationale in support of this belief can be found under the heading "Seepage Control, Relict Channel."

Reservoir Geology

The Watana reservoir includes seven general zones of geology, as indicated by Plate D-5 (Watana Reservoir Surficial Geology). Glacial fill, outwash, and proglacial lake deposits predominate in the meandering reaches of the river upstream of the Oshetna River confluence. The next zone extends downstream along the incised channel to Jay Creek and Kosina Creek, and includes localized sedimentary and alluvial units with metamorphics such as the Vee Canyon schist. The predominating dioritic gneiss and amphibolite is laced with bands of mica schist, pyroxenite, and augen gneiss that are inferred to correspond with contact and shear zones trending northeast. The area around Jay and Kosina Creeks and downstream to Watana Creek includes two zones with outcrops of high grade schist and basalt flows at the river level. The surrounding hills are composed of volcanics with limestone interbeds on the south, and mixed volcanics and near surface intrusives to the north for a minimum of 10 miles. The Watana Creek area consists of basalt flows and semiconsolidated predominately clastic sediments overlain by thick glacial and outwash deposits. This area also contains the Talkeetna Thrust as identified by the U.S. Geological Survey. Downstream of Watana Creek lie the remaining two units, starting with moderately metamorphosed sediments (phyllite, argillite, graywacke) with two bands of schist. The final unit starts just upstream of Deadman Creek and includes all materials downstream to Fog Creek below the damsite. The predominate types are the diorites, granites, and migmatites of the damsite pluton.

The Watana reservoir includes many permafrost areas, especially on north facing slopes. Frozen overburden will tend to slough as the reservoir is filled and the permafrost degrades. Since most of the lower canyon elevations are covered with only shallow overburden deposits, sloughing will be minor and have minimal effects upon the reservoir. Deep overburden deposits, mostly of glacial origin, occur above approximate elevation 2,000 feet where the slopes flatten out into a broad river valley base level. Most of these glacial deposits will be stable due to the flat topography.

Some rock and overburden landslide deposits have occurred within the reservoir area. One such slide deposit, known as the "Slide Block," is located upstream of the axis on the south bank opposite "The Fins" shear. Several old and potential landslides are identified by Kachadoorian and Moore in their reconnaissance of the project area.

In general terms, the geology in the immediate damsite is controlled by the diorite intrusive believed to be the top of a stock which uplifted the surrounding sediments and volcanics and was later eroded by glaciers. Subsequent glacial and stream deposition has masked much of the flat upland areas and stream valleys.

DAM DESIGN

Dam Foundation Treatment

Main Dam: Foundation conditions are more than adequate for construction of an earth-rockfill dam. The underlying rock is a diorite or granodiorite which, in nonfractured fresh samples, had unconfined compressive strengths that ranged from 18,470 to 29,530 psi. Only the uppermost 20 to 40 feet of this rock is closely fractured and sufficiently weathered to require removal within the core area. Stripping depths along the centerline section are shown on Plate D-7. Stripping to sound foundation rock is required for the entire length and width of the impervious core. Foundation treatment within the rock excavation area will include removal of all loose and highly fractured rock and soft materials, cleanup, and dental treatment. If there are any zones where more than an 8 foot width of soft materials is removed, the dental concrete will be contact grouted to the adjoining rock. Stripping to rock will also be required under the remainder of the embankment area. However, in this area excavation will not include removal of the inplace rock. Only the loose and severly weathered surface rock will be removed. Steep or overhanging rock walls will be trimmed to a smooth shape for proper placement of embankment materials. Exploratory drilling in 1978 has shown the materials in the river channel to be a well graded mixture of gravels and cobbles as good, or better, than the materials that would be used to replace them. As the exploration program continues, these gravels will be more completely explored and it may be demonstrated at that time that there is no need for their removal beneath the shell zones. Should this prove to be the case, the change can be made during feature design.

Provision has been made for a 6- by 8-foot concrete grouting gallery with concrete lining to be constructed in foundation rock under the impervious core. This gallery will begin at elevation 1,900 feet on the left abutment and will terminate at elevation 1,800 feet on the right abutment. It will provide access for drilling and grouting which, in some areas may be delayed to allow thawing of permafrost. Access to the gallery will be provided from the powerhouse on the left abutment and, by adit, from the downstream toe of the right abutment. Grouting will be on a single line of holes utilizing split spacing, stage grouting techniques. Grout holes will be slanted upstream and may be included to intercept the dominant high angle northwest tending fracture system. Preliminary grout hole depths are estimated at two-thirds the height of the embankment to a maximum depth of 300 feet with primary spacing of 20 feet, secondary spacing of 10 feet, and tertiary spacing of 5 feet with additional holes as required.

Determination of final grout hole depths, spacing, inclination, grout mixtures, and grouting methods will be dependent on the results of future explorations, permeability studies, test grouting, and permafrost thawing investigations.

Rock permeability test results are shown on the drill logs presented on Plates D-28 through D-37. Coefficients of permeability (K) were computed in feet per minute times 10^{-4}. Permeability coefficients ranged from 0.0 to 23.1 and average 4.9 for those holes that were tested.

Drill holes in the left abutment area indicated very low permeability due to permafrost. River section hole DH-1 had variable permeability coefficients that range from 0.48 to 2.52 and averaged 1.98. Drill water returns in the river holes were quite variable throughout the entire hole depths and tended to drop off to low percentages at the greater depths in the axis area. Right abutment drill holes had permeability coefficients that ranged from 0.0 to 23.09 and averaged 5.47. DH-10 was the only hole tested that had relatively low permeability coefficients throughout. Drill water returns had similar patterns with variable percentage losses. DH-7 and DH-9 had 0 percent returns throughout and DH-8 and DH-11 maintained high percentages of drill water returns throughout.

The existence of permafrost in the left abutment and the possibility of minor amounts in the right abutment necessitates assessment of the problem of thawing a zone in the foundation bedrock sufficiently wide and deep to allow proper installation of the grout curtain. In anticipation of this need, the U.S. Army Cold Regions Research and Engineering Laboratory was asked to do a desk study on thawing the permanently frozen bedrock. The Technical Note which was submitted in response to the request is included as Exhibit D-4.

Embankment Design

Design of the dam embankment at Watana damsite has been based on the availability and proximity of construction materials in addition to their suitability as engineering materials. As a result of these considerations, the embankment contains a central section consisting of an impervious core buttressed on the downstream side by a semipervious zone.

This central section is supported, both upstream and downstream, by suitable fine and coarse filters and rockfill shells. A typical cross-section of the embankment is shown on Plate D-9.

The impervious core and semipervious zone will be constructed using the glacial till which is readily available in the area. The semi-pervious material will be obtained by selecting the coarser grained materials while the finer materials will be placed in the impervious zone. These materials, as discussed under "Embankment Materials," have been shown by exploration and test to be a well graded mixture, which, when compacted, has a very good shear strength and a high degree of impermeability. Tests have shown that this material is quite sensitive to moisture control; therefore, special attention must be paid to this aspect of the design and construction. The 14,000,000 cubic yards required are available within a very reasonable haul distance and will only require removal of oversize boulders prior to use.

The fine filter material can be obtained from the gravelly sand deposit at the mouth of Tsusena Creek. Chart D-3 shows an envelope of gradations from this source superimposed onto the envelope for the fine filter as established by engineering design criteria. This comparison indicates that the Tsusena Creek source can provide material within the ranges of sizes necessary to protect the core and semipervious zone against piping or migration of fines into the filter material.

Proven sources of gravel which can yield large quantities of material are scarce within short haul distances of the project. For this reason, the decision was made to use material from the rockfill source as a coarse filter. Chart D-5 is an envelope of the required gradation which will provide proper filtering action for the fine filter material. A curve has been superimposed on this envelope which represents the materials expected from the rockfill source. As indicated, the rockfill will provide the proper filter action. The maximum size material in the coarse filter and the lift thickness for placement will, of course, be limited to ensure design criteria are met.

The decision to utilize rockfill rather than gravel for the embankment shells was made when reconnaissance and exploration indicated that dependable deposits of gravels which would provide the necessary quantities could not be verified within reasonable haul distances of the damsite. On the other hand, rockfill can be readily obtained as discussed under "Embankment Materials." Riprap for wave protection can be obtained from the same source.

It is recognized that the 1 vertical on 2 to 2.25 horizontal side-slopes shown on the typical cross section for the dam are conservative for a rockfill dam, and, if rockfill is used, these slopes will be refined in accordance with sound engineering practice. Refraction seismic lines in the borrow areas show velocities which could represent large deposits of gravels or glacial materials but rather extensive explorations will be required to verify the true nature and quantity of the materials. Should these explorations reveal that suitable gravel deposits in the area are sufficiently extensive to provide the large quantities required for the dam shell sections, the gravel will be used in preference to borrowing quarried rock for rockfill.

Powerhouse and Underground Structures

An underground powerhouse is well suited to meet the restrictions of subarctic weather and other environmental factors. Topographically, the narrow Susitna Canyon is well situated for this type of underground construction. The diorite pluton that underlies the foundation area is expected to be competent for excavation and support of underground facilites, but the location and design of the various structures may have to be adjusted in some areas. "The Fins" and "Fingerbuster" Shear Zones shown on Plate D-3 and discussed in paragraph "Rock Structure" are the two most significant shears within the damsite area. Other northwest trending steep angled minor shears involving displacements of a fraction of an inch up to a few feet are common in the site area and were noted in many of the drill holes. These minor shears appear to represent mass adjustments to regional stress and compensation can be made for them in design and construction of the underground structures.

Prior to powerhouse excavation, exploratory adits located near the crown of the various chambers will be driven to confirm final design criteria. The chambers will be constructed with straight walls as required for maximum dimensions, and not notched or cut irregualarly for support of interior powerhouse facilities. Rock support will include pattern bolts consistent with wall and crown conditions. Use of steel channeling and remedial concrete is anticipated in local areas where fallout may occur or in fracture zones having a substantial width of crushed rock. Wire mesh will be utilized where necessary as a temporary facility prior to placing concrete. A thin layer of wire reinforced shotcrete may be placed on the main powerhouse chamber walls and crown as a protective measure against rock raveling. Additional shotcrete will be utilized, as required, to seal surfaces and retain rock strengths. Construction methods in the large chambers will include controlled blasting and rock removal in lifts from the top downward. Gutter and floor sloping for drainage will be provided in the interior structures between chambers.

Intake Structure

Consolidation grouting may be necessary for the intake structure foundation and the bridge pier footings. The higher bridge pier footings will also be recessed into sound rock. Tunnel portals will be designed so that there is a minimum of two tunnel diameters of sound rock above the heading where they go underground. Initial tunnel support will be by pattern bolts, with steel channeling and wire mesh where necessary in closely fractured areas. Major shear zones will require steel supports. Hydraulic and geologic considerations will necessitate final concrete linings for all but the access tunnels, and steel liners for the penstocks. Grout rings will be required in the penstock portal areas.

The two diversion tunnels are to be separated by a minimum of four tunnel diameters to provide greater structural stability. Downstream diversion tunnel portals will have to be located to avoid the "Finger Buster" shear zone to insure adequate portal construction conditions.

Spillway

The gated spillway has been relocated about 800 feet southeast of the alinement presented in the 1976 report so that it will be constructed in a through rock cut. The spillway will be unlined beyond the spillway gate structure and apron. The new spillway alinement extending from the Susitna north valley wall to Tsusena Creek and the spillway gradient are shown on Plates B-2 and B-5. It is anticipated that, with the exception of minor amounts of waste, all the excavated materials from the spillway will be used in the dam embankment. The major part of the excavation is in rock and this material will be used in the shell sections. The overburden materials are glacial till which, when separated from the boulders can be used in the impervious or semipervious zones.

Seepage Control - Relict Channel

The relict channel area is an overburden terrace underlain by a bedrock depression, and extends northward from the right abutment for about 6,000 feet. This terrace is composed of glacial till, some of which has been reworked by alluvial action. For this reason, consideration was given to the possibility of seepage through the area where rock contours are below the proposed reservoir elevation. However, preliminary seepage calculations indicate that even in the relict channel area, where the head differential approaches 350 feet, and using a very conservative 'k' value of 500 feet per day, the seepage would be less than 0.02 cubic feet per second per foot of width for a pervious layer assumed to be 80 feet thick. Assuming such a layer to be 200 feet wide, the seepage would be in the order of 4 cubic feet per second, which is a minor amount. The exit velocities associated with such seepage would be too low to cause serious piping or erosion. Investigations during the summer of 1978 support this conclusion. In holes DR-13 and DR-14, located in the vicinity of Borrow Area "D," ground water was encountered in alluvial layers between elevation 2,240 and 2,280 feet with an artesian head which exceeded the proposed reservoir level by 100 feet. In spite of this high head condition, no evidence was found indicating seepage out of this layer into either Deadman Creek or Tsusena Creek. Indeed, it is probable that the effect of this artesian water, which evidently has its access to the alluvial layer in the upper reaches of Tsusena or Deadman Creek, would be to resist flow from the reservoir into the aquifer. Because mud losses in DR-22, located at the center of the relict channel, indicated the possibility of permeable layers at approximate elevations 1,900 and 2,000 feet, a falling head permeability test was performed at this hole. The permeabilities calculated from this test are a further indication the seepage through the terrace would be minor or nonexistent. Consequently, it was unnecessary to include any cutoff through the saddle and relict channel area.

CONSTRUCTION MATERIALS

Material Requirements

Embankment: Approximately 57,792,000 cubic yards of embankment materials will be required to construct an earthfill dam at Watana site. The impervious core is estimated to require 7,373,000 cubic yards and the semipervious fill zone 6,077,000 cubic yards of material. The fine filters are estimated to require 5,621,000 cubic yards of material and the coarse filters 2,201,000 cubic yards. The pervious rock shells, which make up the largest portion of the dam, will require approximately 36,297,000 cubic yards. Slope protection on the upstream side of the dam is estimated to require 223,000 cubic yards of riprap.

Sources of Materials

General: Several sources of embankment materials were investigated in the damsite area. These sources included two quarry locations which could yield rock shell and coarse filter materials, a source of glacial till which could produce core material, and two areas containing relatively clean sands and gravels for the fine filter material. Additional embankment materials will be generated by required excavation for the dam foundation, underground facilities, and the spillway channel. All rock excavation from the spillway channel will be incorporated into the rock shell zone of the dam. The overburden encountered in the excavation for the spillway channel will be glacial till which can be processed by removal of oversize material for use as core material.

Rock Shell Materials: Rock shell materials may be obtained from two quarry locations shown on Plates D-10 and D-11.

Quarry sites were located on the left abutment of the dam (Quarry Source 'A') and in the northwest quadrant of the confluence of Deadman Creek and the Susitna River (Quarry Source'B'). The Quarry Source (A) on the left abutment is an outcrop of igneous rock ranging in elevation from approximately 2,300 to 2,630 feet. The total volume of the hill above the surrounding terrain is approximately 200 million cubic yards of rock. Development would consist of open faces on the north flank of the dome with the final quarry floor at an elevation of 2,300 feet. This type of development would maintain the visible profile of the hill essentially as it is now. The resulting quarry floor could provide an ideal site for parking areas, visitor facilities, and perhaps, the switchyard.

The material in the hill is a diorite on the western side and a rhyodacite porphory on the eastern half. The appearance of outcropings and exposed faces of each material indicates that the hill is composed of sound rock.

The product of this quarry will be used for the rockfill shell zones of the dam and in the coarse filter and riprap. This site (Quarry 'A') represents the nearest source of adequate quantities of rock materials for the dam. From the approximate center of the quarry to the approximate center of the dam is a distance of 4,000 feet and movement of material would be downhill. If properly developed, virtually all of the material removed from the quarry will be used in the dam and the oversize material, overburden and weathered waste material can be disposed of immediately adjacent to the quarry in the reservoir area upstream of the dam.

The quarry source at the confluence of Deadman Creek and the Susitna River (Source 'B') could be developed by excavating rock from the open faces visible on Deadman Creek and continuing the development of a face to the westward, maintaining the face between elevation 1,700 and 2,000 feet. Stripping and clearing would be minimized by developing a long, narrow quarry paralleling the river and using the quarry floor as a haul road for the length of development. If exploited in this way, the quarry could yield 17,000,000 cubic yards of material.

The rock exposed in this area is a moderately weathered diorite. The product of this quarry could be used on the rockfill shell sections of the dam. The distance from the center of the Quarry 'B' to the center of the dam is approximately 2 miles.

The only reason for utilizing this quarry source instead of the Quarry 'A' on the left abutment would be the lessened environmental impact since the quarry at Deadman Creek would be entirely in the reservoir area. However, since the haul distance is greater and the net environmental impact of the Quarry 'A' on the left abutment is small, this area is a less desirable source of embankment materials.

Core Material: Impervious and semipervious materials can be excavated from the glacial tills which are present at the damsite. The most logical source of glacial till appears to be in an area denoted as Borrow Area 'D' which lies between Deadman Creek and the saddle on the north side of the dam (see Plate D-11).

Exploration in this area was accomplished by drilling with a track-mounted, self-propelled auger and a Failing 1500 rotary drill, by test pitting with a backhoe, and by use of seismic refraction methods. Five holes were completed using the air rotary drill, 14 holes were completed using the auger, 14 pits were completed with the backhoe, and 4 seismic refraction lines were extended across the proposed limits of the borrow area. The material in the area is composed of a surface layer of natural ground cover of roots and moss, approximately 2 feet of boulders and organic silts underlain by the tills which are classified as gravelly silty sands. The tills range from 15 to 25 feet thick and usually overlie a clay, sandy gravelly clay and silty sandy gravel.

Sack samples from the test pits (in Borrow Area D) were tested at the North Pacific Division Materials Laboratory to determine gradations, compaction, consolidation characteristics, permeability, and triaxial shear strength.

Gradation tests were run on each sample from each test pit. An envelope of the gradation curves derived from the tests of samples from Test Pits 8 through 19 is shown on Chart D-2. Because the range of gradations of materials from the test pits centrally located in the area is limited, a composite sample was formed. Use of a composite sample was necessary to provide adequate material for a representative testing program since retrieval of large bulk samples from the site was not possible.

The coefficient of permeability (K_{20}) for the minus 1-inch fraction of the till material, compacted to 95 percent of maximum density with an optimum water content of 7.5 percent equals 10.90×10^{-6} cm/sec. This relatively low coefficient of permeability is coupled with an adequate shear strength at the optimum water content, acceptable consolidation values even when loaded to 32 tons/sq ft and a narrow band of gradation throughout the central portion of the outlined borrow area. The shape of the compaction curves indicates that moisture content is critical in obtaining maximum densities with a pronounced peak at the relatively low optimum moisture content of 7.5 percent. The results of the triaxial compression tests indicate that in the unsaturated and undrained condition the glacial tills will be sensitive to moisture contents higher than optimum but that if placed on the dry side of optimum they will maintain strength essentially equal to those obtained when placed at optimum.

The results of this testing program indicate that the glacial tills can be placed and compacted to provide a suitable material for both the impervious and semipervious zones. The specifications will need to provide for close controls of the moisture content and the quality assurance programs will have to be adequately staffed to provide for careful checks of moisture content in the pervious and semipervious fill. Detailed laboratory reports of the tests conducted are included as Charts D-6 through D-29.

The materials from Borrow Area D can be used with very little processing. The ground cover and organic silts and boulders will be stripped from the surface and disposed of as designated near the mouth of Deadman Creek in the reservoir area. The remainder of the material can be utilized in the core of the embankment if oversize (12 inch plus) material is removed by mechanically raking in the pit or on the embankment fill. Less than 10 percent of the material will be too large to use in the core. Since removal of only the silty, sandy gravel above the clays will result in the floor of Borrow Area 'D' being above reservoir elevation, it will be necessary to contour and seed the borrow area after the completion of removal of materials as a restoration measure. Approximately 630 acres will be restored.

Filter Material: The nearest source of clean sands and gravels for use in the fine filter of the embankment dam is an alluvial deposit formed by materials washed out of Tsusena Creek and deposited at the confluence of Tsusena Creek and the Susitna River on the right bank of the Susitna (Borrow Area 'E', see Plate D-12). Haul distance to the dam ranges from 3 to 5 miles. This area was explored by digging 5 test pits to a depth of 8 feet using a backhoe mounted on a small tractor.

The material in this area is composed of approximately 2 feet of organic, sandy silt overlaying 6 feet of clean, well graded sands and gravels having maximum size particles of up to 4 inches in diameter. The materials are sound, well rounded particles. The bottoms of the test pits indicate the possibility that the materials deeper than 8 feet below the ground surface contain up to 50 percent of boulders in excess of 8 inches in diameter and ranging up to 24 inches in diameter. The 6 feet of material which lies above the boulders may be used in the embankment with required processing limited to some blending and removal of material larger than 12 inches to produce fine filter material. An envelope of gradation curves derived from tests of samples from TP-1 through TP-5 is shown in Chart D-1. All of the samples are from the first 8 feet of material. All of this material lies above the water table and can be taken by front loaders. The quantity of material available in the first 8 feet is approximately 3.7 million cubic yards. After the boulders are encountered at a depth of 8 feet, the oversize material will have to be removed and material below the water table will have to be bailed from the area. A dike will be maintained to separate the borrow operations from the river so that all turbidity created by the excavation of materials will be filtered or settle prior to entering the Susitna River. In terms of grading, particle soundness and proximity, this area represents an excellent source of essential filter materials.

The second area in which clean sands and gravels were located is in the upper reaches of Tsusena Creek, north of Tsusena Butte (Borrow Area 'C'). The materials are sound, well rounded particles and are well graded with maximum sizes generally less than 4 inches. Considerable exploratory effort would be necessary to ensure quality and quantity of materials before this could be considered an acceptable source. Because of the haul distance of 12 miles, this source will not be considered unless further explorations and testing indicate that adequate materials may not be obtained from the sources closer to the damsite.

Exploration at Site 'C' was accomplished by digging one test pit, reconnaissance of the area on foot and from helicopter, and with a seismic survey.

Concrete Aggregates: Approximately 310,000 cubic yards of concrete will be required to construct the appurtenant structures for an embankment dam at Watana damsite. Most of this will be structural concrete placed in tunnel linings, the powerplant, gate structures, intake structures, and spillway channel lining. Maximum size aggregate will be 3 inches in all but the smaller structures or those with closely spaced reinforcing. The most readily available source of concrete aggregate is available at the confluence of Tususena Creek and the Susitna River (Borrow Area 'E'). The materials from the first 8 feet in the alluvium can be utilized with only limited screening. As oversize materials are encountered at greater depths, the larger particles will be crushed for use in the concrete aggregate, thereby achieving maximum utilization of gravels from the area and also to increase the tensile strain resistance of the concrete which will lessen problems with thermal cracking in the more massive sections. Since Borrow Area E represents the most economical source of concrete aggregate and the nearest acceptable source of essential filter material, maximum utilization of the material in this area is required.

A petrographic analysis of sands and gravels from Borrow Area E was conducted by the Missouri River Division Laboratory at Omaha, Nebraska. The results show the material to be approximately 70 percent granitic rock with the remainder composed of basalt, andesite, and ryholite. Chert is present in such small quantities as to be nondeleterious.

The quarry site on the left abutment (Quarry Source 'A') is considered an alternate source of concrete aggregate. If material from the quarry were used in the embankment dam aggregate could be produced by placing a crushing and screening plant in the quarry and producing the concrete aggregate incidental to the production of embankment material. The concrete aggregates would be produced from the diorites in the quarry to avoid the potential of problems caused by the reaction of the alkalis in the concrete with the rhyodacite porphory in the eastern half of the hill.

The materials in upper Tsusena Creek (Borrow Source 'C') would produce excellent concrete aggregate; however, because of the haul distance involved (10 miles), it is not anticipated that this source would be exploited to produce concrete aggregate unless embankment materials are also taken from the same source.

It is anticipated that because of the relatively small quantities of required concrete aggregate compared to the large quantities of the various classes of embankment materials, that concrete aggregates will be produced incidental to the production of embankment material and stockpiled adjacent to the batch plants used.

The first concrete required on the project will be that required to line the diversion tunnels and form gate and trashrack structures for river diversion. The aggregate for this work could be produced from Borrow Area E with a resulting haul distance of 2.3 miles.

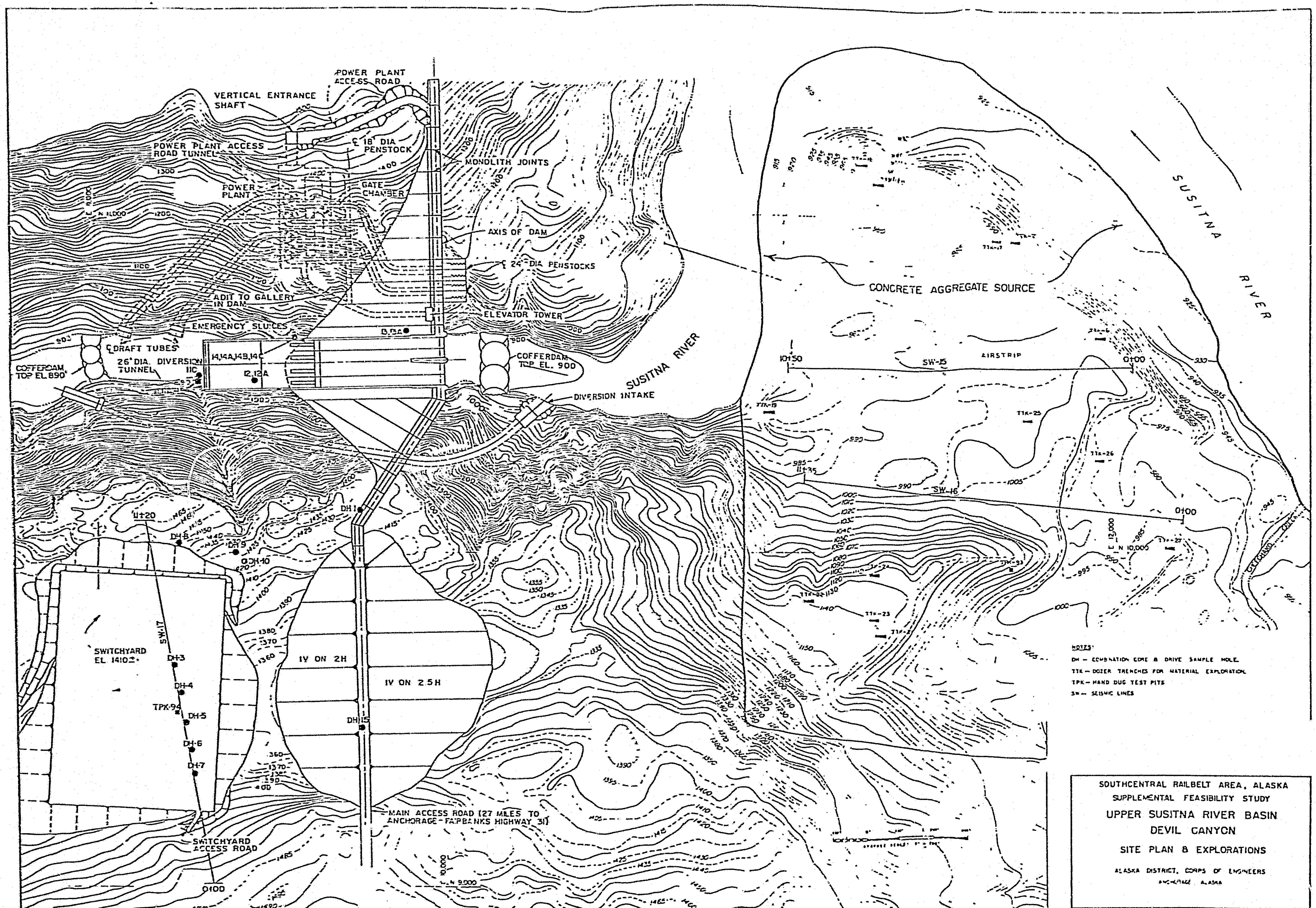
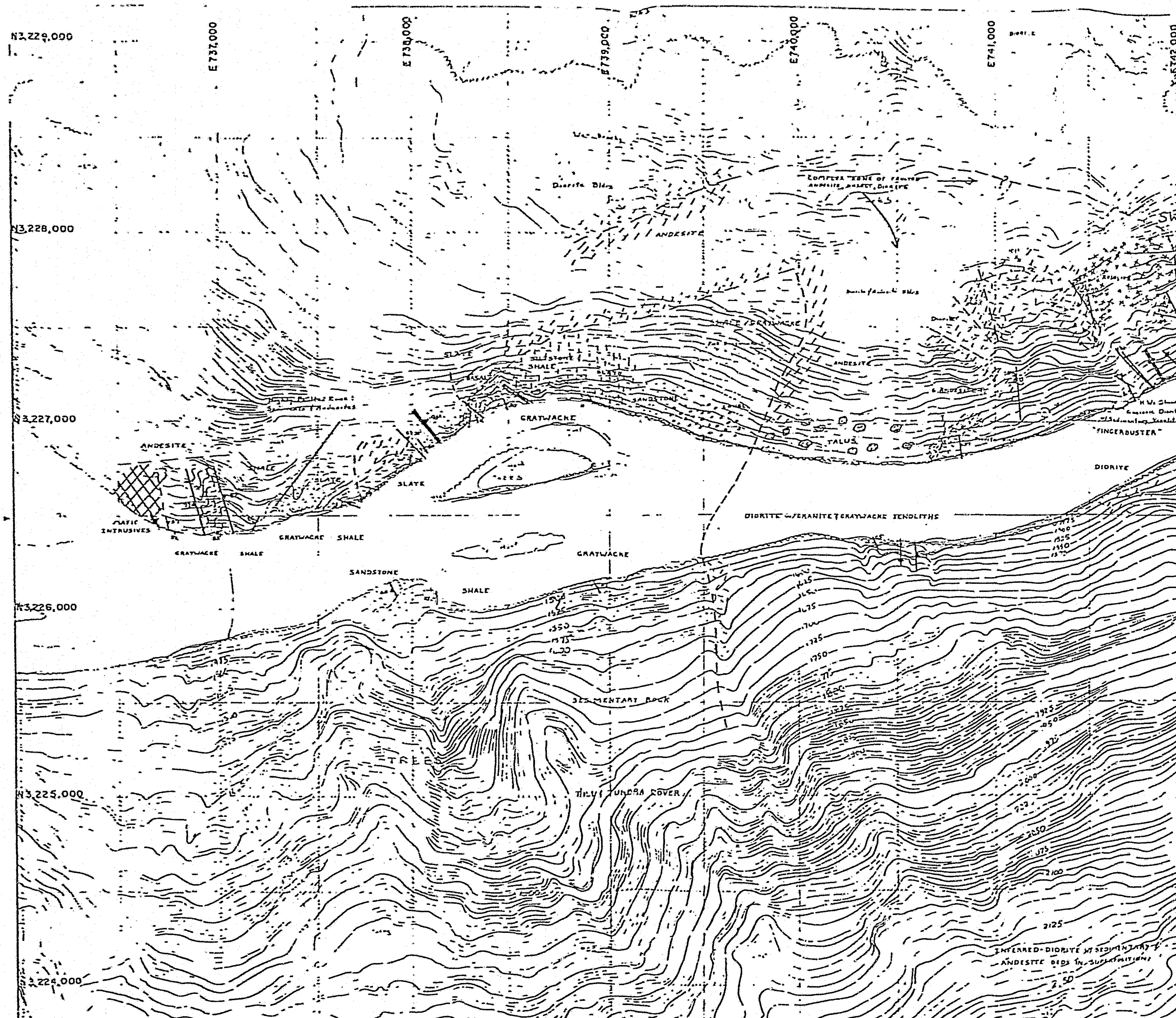

POWER PLANT ACCESS ROAD
VERTICAL ENTRANCE SHAFT
POWER PLANT ACCESS ROAD TUNNEL
18' DIA PENSTOCK
MONOLITH JOINTS
POWER PLANT
GATE CHAMBER
AXIS OF DAM
24' DIA PENSTOCKS
ADIT TO GALLERY IN DAM
ELEVATOR TOWER
EMERGENCY SLUICES
DRAFT TUBES
26' DIA. DIVERSION TUNNEL
COFFERDAM TOP EL. 890'
COFFERDAM TOP EL. 900
SUSITNA RIVER
DIVERSION INTAKE
CONCRETE AGGREGATE SOURCE
AIRSTRIP
SW-15
SW-16
SW-17
SUSITNA RIVER
SWITCHYARD EL 1410±
IV ON 2H
IV ON 2.5H
MAIN ACCESS ROAD (27 MILES TO ANCHORAGE-FAIRBANKS HIGHWAY 3)
SWITCHYARD ACCESS ROAD
NOTES:
DH – COMBINATION CORE & DRIVE SAMPLE HOLE
TTK – DOZER TRENCHES FOR MATERIAL EXPLORATION
TPK – HAND DUG TEST PITS
SW – SEISMIC LINES
SOUTHCENTRAL RAILBELT AREA, ALASKA
SUPPLEMENTAL FEASIBILITY STUDY
UPPER SUSITNA RIVER BASIN
DEVIL CANYON
SITE PLAN & EXPLORATIONS
ALASKA DISTRICT, CORPS OF ENGINEERS
ANCHORAGE, ALASKA

PLATE D-1



LEGEND

ACIDIC INTRUSIVES GRANITE, DIORITE	INTENSE SHEAR ZONE
ACIDIC EXTRUSIVES RHYOLITE, DACITE	GEOLOGIC CONTACT OR INFERRED
MAFIC INTRUSIVES GABBRO	SIGNIFICANT WATER SEEPAGE
MAFIC EXTRUSIVES ANDESITE, BASALT	EROSIONAL FEATURE INFERRED TO INDICATE A SHEAR ZONE
PORPHORITIC ANDESITE, BASALT	BEDDING WITH DIP VERTICAL
GRAVEL, CONGLOMERATE	JOINT WITH DIP VERTICAL
SAND, SANDSTONE	FAULT, WITH DIP VERTICAL INFERRED
SILT, SILTSTONE	DIKE WITH DIP, ROCK TYPE PER SYMBOL
CLAY, SHALE	QUARTZ VEINS, WITH DIP
BOULDERS (ROCK TYPE SHOWN)	DH-25 DRILL HOLE
ROCK FRAGMENTS	M01 SURVEY POINT
BRECCIA (USED W/ROCK TYPE)	WA-5 AIR PHOTO CONTROL POINT

ABBREVIATIONS

ALT	ALTERED	G	GREEN
B	BLACK	GR	GRANITE
BIO	BIOTITE	H	HIGHLY
BLDR	BOULDER	QTZ	QUARTZ
BR	BROWN	R	RED
CL	CLAY	S	SAND
DIOR	DIORITE	SS	SANDSTONE
FRAC	FRACTURED	WX	WEATHERED

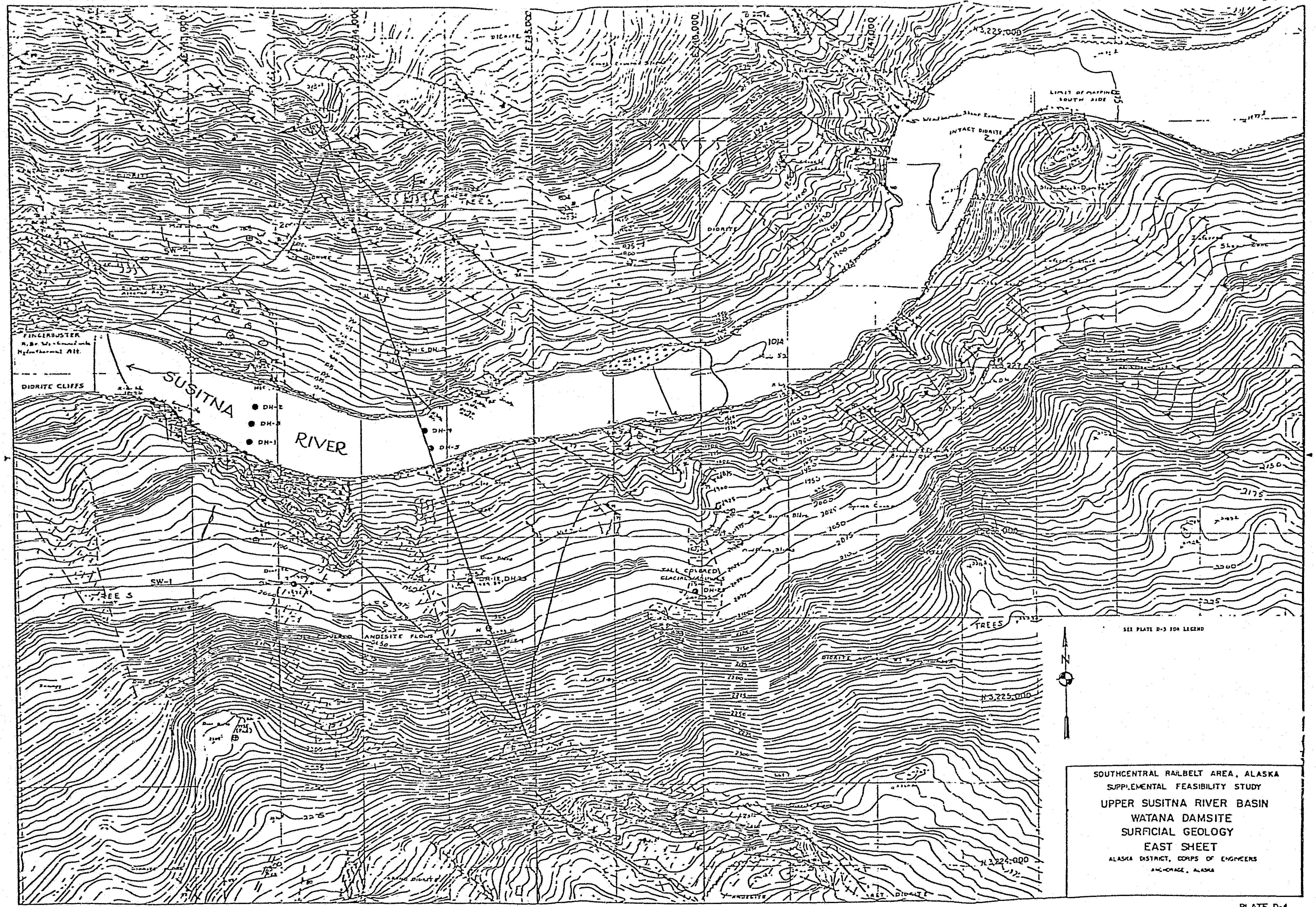
NOTES:

1. DIORITE HAS INTRUDED AND UPLIFTED SEDIMENTS AND ANDESITES. ANDESITES ARE INFERRED TO BE A PRE-PLUTONIC INTERCANYON FLOW UPLIFTED AND ALTERED BY DIORITE EMPLACEMENT.
2. GLACIAL CLAY AND ALLUVIUM APPEAR TO FILL PREEXISTING EROSIONAL CHANNELS IN UPPER CANYON WALLS.

SOUTHCENTRAL RAILBELT AREA, ALASKA
SUPPLEMENTAL FEASIBILITY STUDY
UPPER SUSITNA RIVER BASIN
WATANA DAMSITE
SURFICIAL GEOLOGY
WEST SHEET
ALASKA DISTRICT, CORPS OF ENGINEERS
ANCHORAGE, ALASKA

PLATE D-3

CORPS OF ENGINEERS U S ARMY

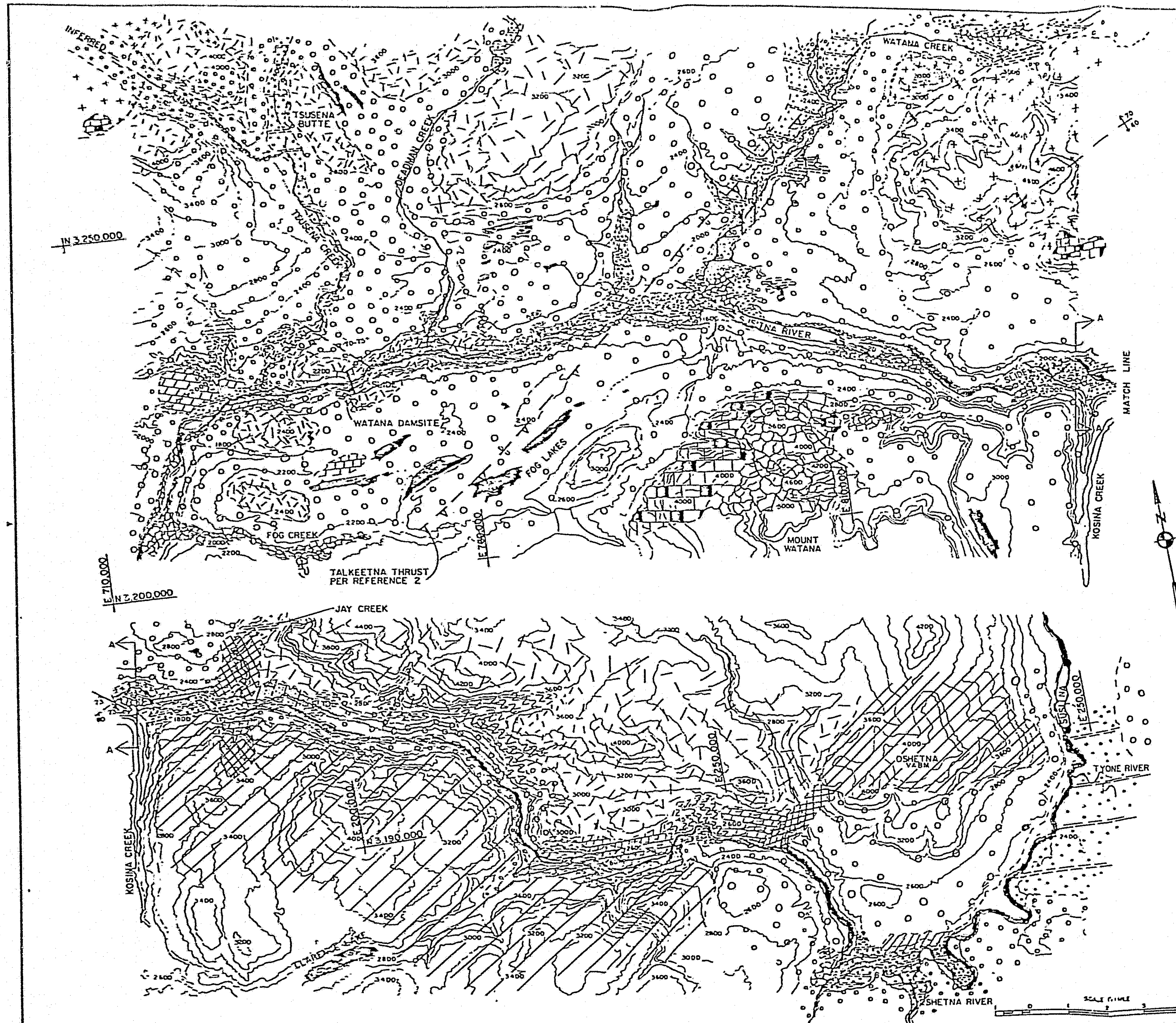


SOUTHCENTRAL RAILBELT AREA, ALASKA
SUPPLEMENTAL FEASIBILITY STUDY
UPPER SUSITNA RIVER BASIN
WATANA DAMSITE
SURFICIAL GEOLOGY
EAST SHEET
ALASKA DISTRICT, CORPS OF ENGINEERS
ANCHORAGE, ALASKA

PLATE D-4

CORPS OF ENGINEERS

U S ARMY



NOTES

1. THIS SURFICIAL GEOLOGY MAP REPRESENTS GROSS LITHOLOGY AND STRUCTURE BASED ON LIMITED GROUND MAPPING. UNIT BOUNDARIES ARE APPROXIMATE.
2. LIMITS OF MAPPED UNITS CONFORMS WITH REFERENCE 2 EXCEPT AS NOTED — ARE DEFINED BY CORPS OF ENGINEERS GEOLOGISTS. EXTENSIONS OF UNITS BEYOND 3 MILES FROM RESERVOIR BOUNDARY WERE BASICALLY DRAWN FROM REFERENCE.
3. BASE MAP (REFERENCE 1) IS NOT DUPLICATED IN FULL DETAIL. MAJOR [illegible] OF WATER ARE SHOWN. ISLANDS, SMALL STREAMS AND MINOR TOPOGRAPHIC FEATURES HAVE BEEN DELETED.
4. 2200 FOOT CONTOUR HAS BEEN ACCEPTED AS APPROXIMATE LIMIT OF RESERVOIR EFFECT.
5. NO PERMAFROST OR INTERMITTENT FROST ACTION AREAS ARE SHOWN.
6. SLIDES ARE AS INDICATED BY SURFACE EXPRESSIONS. MINOR AND INCIPIENT SLIDE AREAS AND AREAS SUSCEPTIBLE TO MASS MOVEMENT UNDER RESERVOIR INFLUENCE HAVE NOT BEEN SHOWN.
7. MANY AREAS SHOWN AS GLACIAL TILL COVERED HAVE MINOR OUTCROPS THAT [illegible] NOT DETECTED IN MAPPING. DETAILED MAPPING IS REQUIRED TO DEFINE CONTACTS, ZONES OF DISTURBANCE, AND TILL-COVERED AREAS.

TOPOGRAPHIC SYMBOLS

WATER - LAKE, STREAM OR RIVER

N 3 200,000 REFERENCE MARKS

2200 200' CONTOUR INTERVALS IN FEET ABOVE MEAN SEA LEVEL (REF. 1)

STRUCTURAL SYMBOLS

CONTACT SURFACE EXPRESSION

SHEAR OR FAULT, WITH DIP (1), VERTICAL (2)

APPROXIMATE LOCATION OF FAULT OR SHEAR (ARROW DOWN DIP OF SHEAR PLANE)

BEDS - SEDIMENTARY OR FLOW STRUCTURE; WITH DIP (1), VERTICAL (2)

BEDS - APPROXIMATE DIP

SYNCLINE, SHOWING AXIS (APPROXIMATE LOCATION)

ANTICLINE, SHOWING CREST (APPROXIMATE LOCATION)

FLOW FOLIATION, SCHISTOSITY, INCLINE (1), VERTICAL (2)

JOINTS, INCLINED (1); VERTICAL DIPS (2)

LITHOLOGIC SYMBOLS

GLACIAL TILL

UNCONSOLIDATED CLASTIC ALLUVIAL DEPOSITS

UNCONSOLIDATED FINE ALLUVIAL DEPOSITS - CLAY, SILT, VARVED CLAYS

CONSOLIDATED BEDDED SEDIMENTARY DEPOSITS - ALL CLASTIC TYPES

LIMESTONE AND MARBLE

ALL TYPES ARGILLACEOUS ROCK INCLUDING METAMORPHIC FORMS THROUGH PHYLLITE

SCHIST INCLUDING LIT-PAR-LIT SCHIST, GREEN SCHIST AND CONTACT METAMORPHIC FORMS

AMPHIBOLITE, PYROXENITE, GABBROS, GNEISS, MAFIC INTRUSIVES AND HIGH GRADE METAMORPHICS

VOLCANIC FLOWS AND SILLS, ANDESITES AND BASALTS WITH INTERBEDS

HYPABYSSAL INTRUSIVES - DIABASE, DACITE, APLITE AND NEAR SURFACE PORPHRY.

GRANITICS - GRANITES, MONZONITES, DIORITES

ZONES OF VERY HIGH-GRADE ALTERATION AND METAMORPHISM TO INCLUDE SERICITIZATION, SERPENTIZATION, SAUSSURITIZATION AND PRODUCTS OF CONTACT REMELTING.

REFERENCES

1. US GEOLOGICAL SURVEY 1:63,360 SERIES (TOPOGRAPHIC), TALKEETNA MOUNTAIN QUADRANGLE, SHEETS C1, C2, D3, D4.
2. "RECONNAISSANCE GEOLOGIC MAP AND GEOCHRONOLOGY, TALKEETNA MOUNTAINS QUADRANGLE, NORTHERN PART OF ANCHORAGE QUADRANGLE, AND SOUTHWEST CORNER OF HEALY QUADRANGLE, ALASKA." OPEN FILE REPORT 78-558A (PRELIMINARY), US GEOLOGICAL SURVEY, MENLO PARK, CALIFORNIA 1978. CSEJTEY, ET AL.

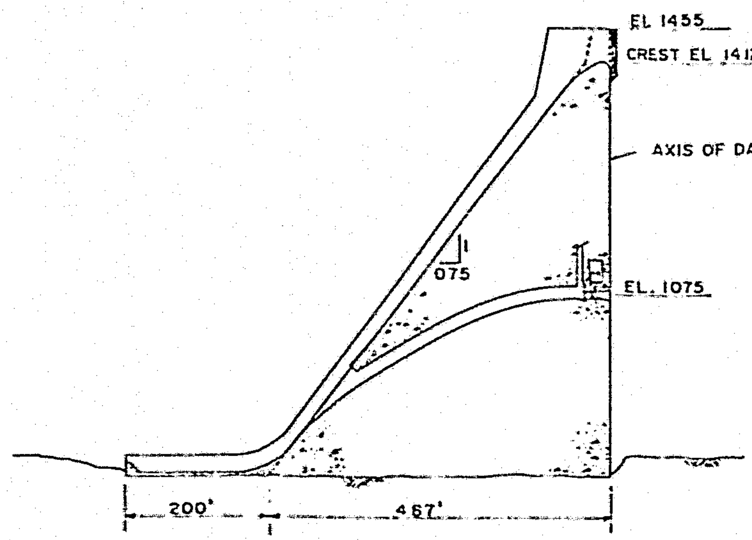
SCALE (MILES)

SOUTHCENTRAL RAILBELT AREA, ALASKA
SUPPLEMENTAL FEASIBILITY STUDY

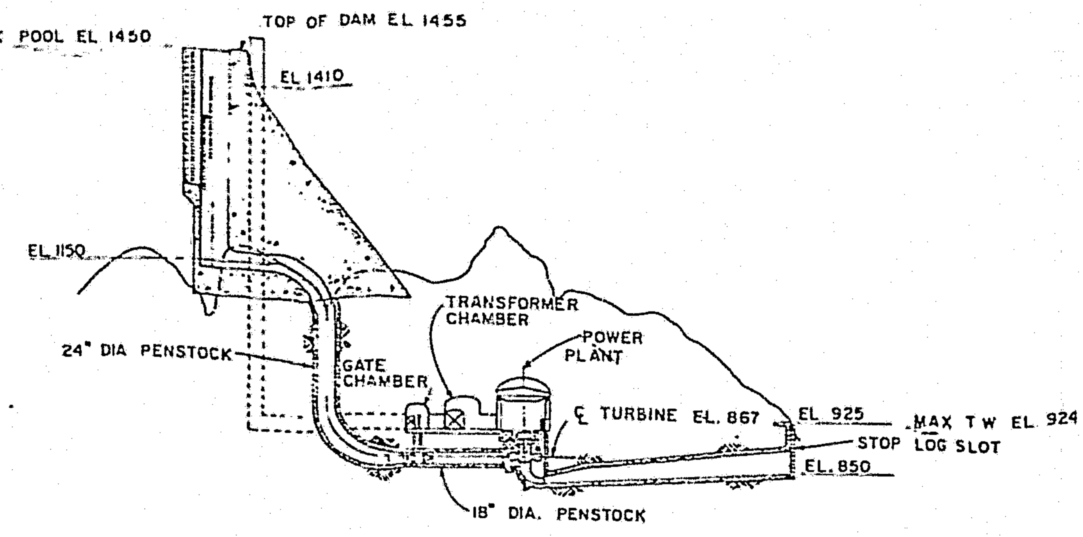
UPPER SUSITNA RIVER BASIN
WATANA RESERVOIR
SURFICIAL GEOLOGY

ALASKA DISTRICT, CORPS OF ENGINEERS
ANCHORAGE, ALASKA

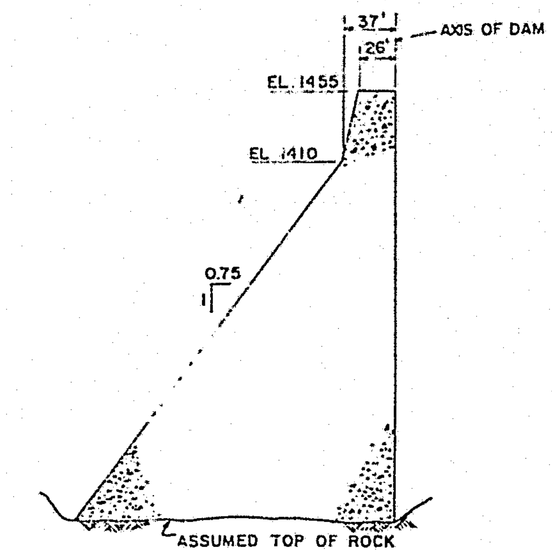
PLATE D-5



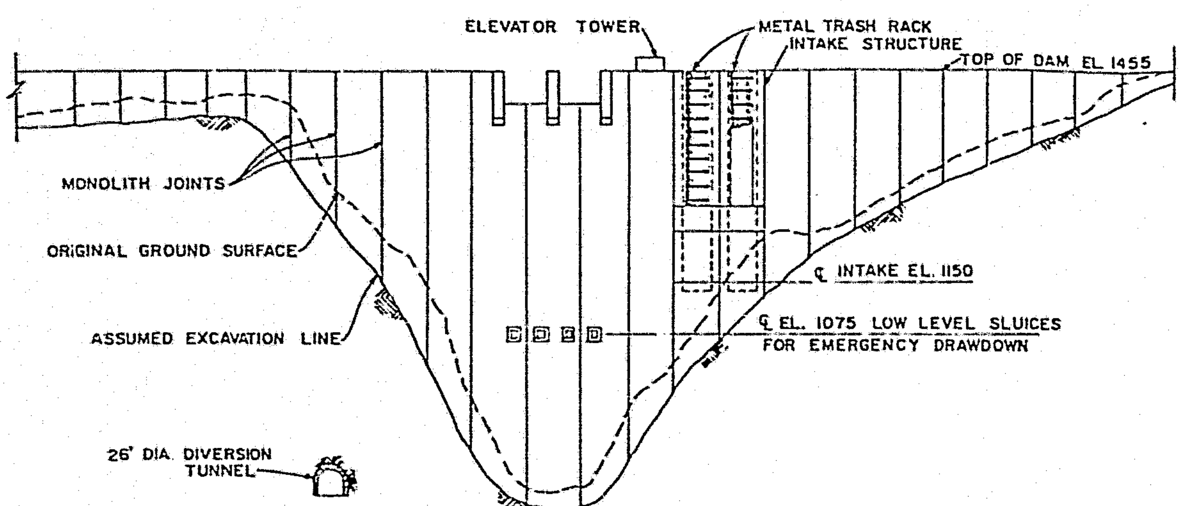
SPILLWAY SECTION



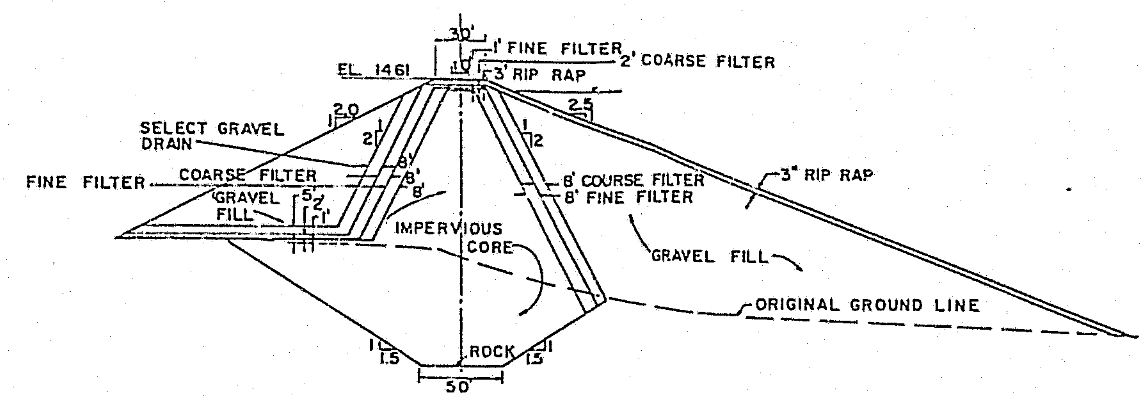
SECTION THRU PENSTOCK AND POWER PLANT
SCALE: 1" = 100'



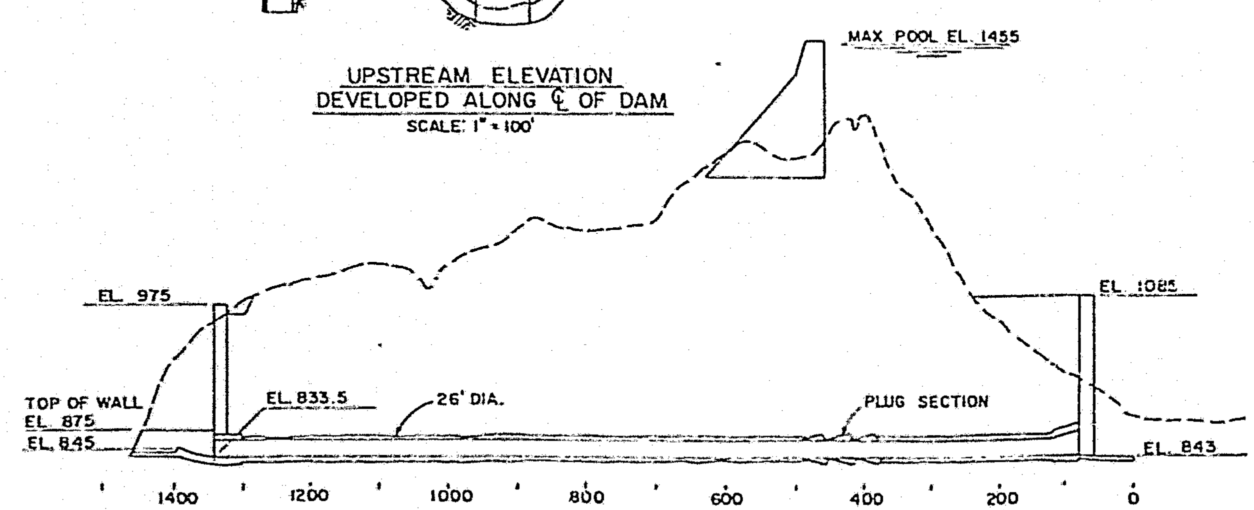
TYPICAL NON-OVERFLOW SECTION



UPSTREAM ELEVATION
DEVELOPED ALONG ℄ OF DAM
SCALE: 1" = 100'



DEVIL CANYON AUXILIARY EARTH FILL DAM



DIVERSON TUNNEL PROFILE
SCALE: 1" = 100'

SOUTHCENTRAL RAILBELT AREA, ALASKA
SUPPLEMENTAL FEASIBILITY STUDY
UPPER SUSITNA RIVER BASIN
DEVIL CANYON DAM
CONCRETE GRAVITY DAM
ELEVATION AND SECTIONS
ALASKA DISTRICT, CORPS OF ENGINEERS
ANCHORAGE, ALASKA
FEBRUARY 1979

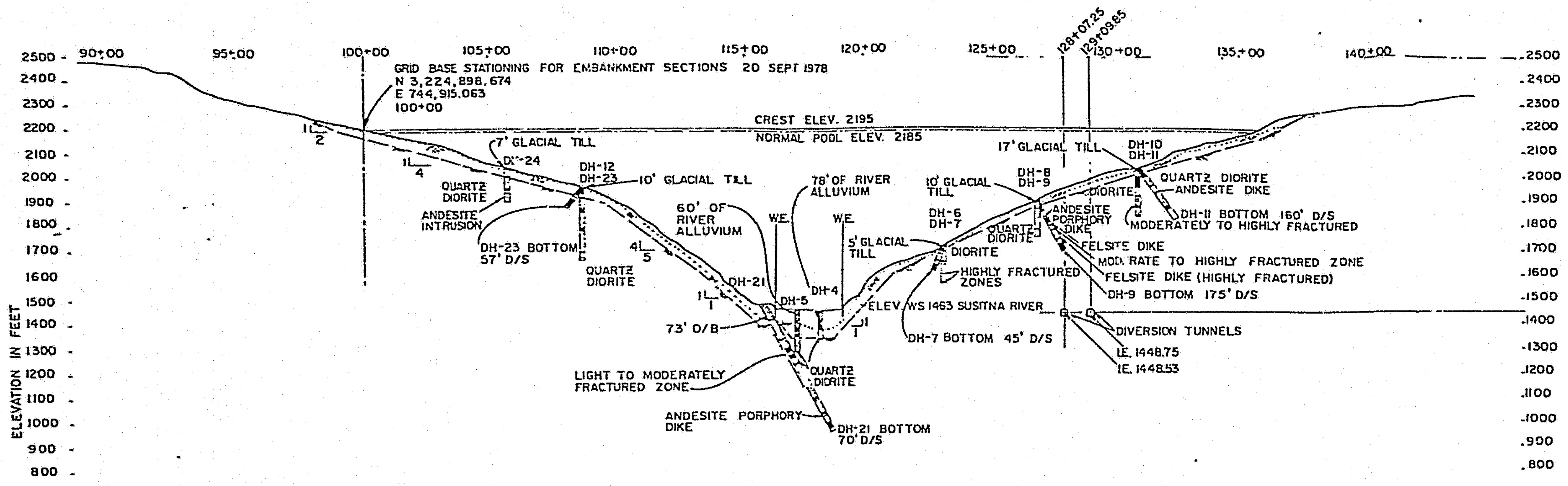
PLATE 6

LEGEND

- —— SURFACE LINE
- - - - TOP OF ROCK LINE
- FOUNDATION BEDROCK EXCAVATION LINE
- SHEAR ZONE
- D/S DOWNSTREAM
- U/S UPSTREAM
- O/B OVERBURDEN
- WE. WATERS EDGE
- DH DRILL HOLE
- I.E INVERT ELEVATION
- ------ TOP OF ROCK
- — — EXCAVATION LINE

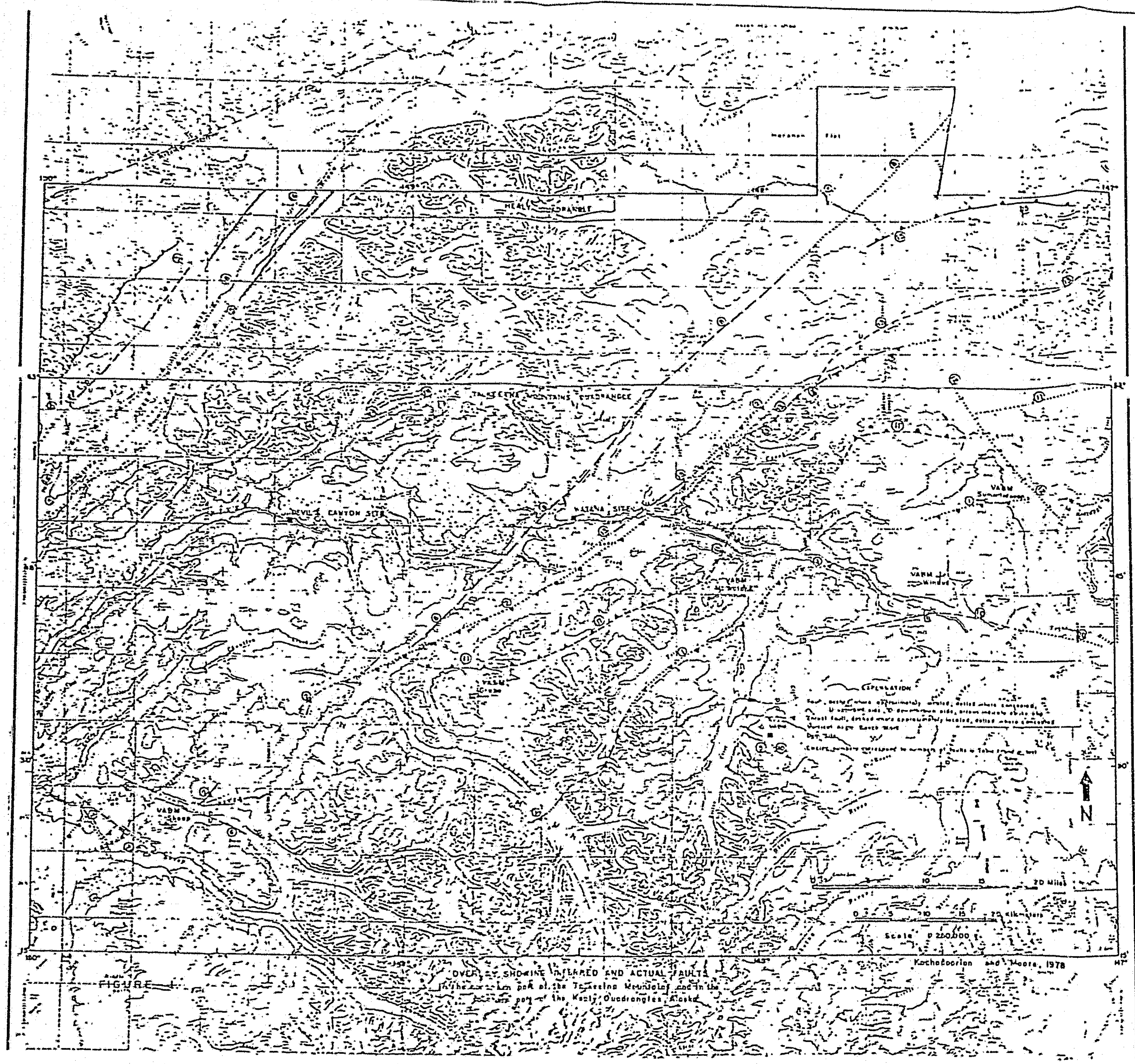
NOTE:
TOP OF ROCK LINE & EXCAVATION LINE SUBJECT TO CHANGE.

FOR LOCATION OF CROSS-SECTION SEE PLATE D-4



SECTION A-A

SOUTHCENTRAL RAILBELT AREA, ALASKA
SUPPLEMENTAL FEASIBILITY STUDY
UPPER SUSITNA RIVER BASIN
WATANA DAM
SECTION ALONG DAM AXIS
ALASKA DISTRICT, CORPS OF ENGINEERS
ANCHORAGE, ALASKA



FIGURE

OVERLAY SHOWING INFERRED AND ACTUAL FAULTS

PRELIMINARY REPORT OF THE RECENT GEOLOGY

OF THE PROPOSED DEVILS CANYON AND WATANA

DAMSITES, SUSITNA RIVER, ALASKA

by

Reuben Kachadoorian and Henry J. Moore

ABSTRACT

At the request of the Corps of Engineers, the U.S. Geological Survey conducted a reconnaissance of the recent geology of the proposed Devils Canyon and Watana damsite areas, Susitna River, Alaska. The purposes of the reconnaissance were to look for active faults and other geologic hazards. Field work by the Geological Survey was conducted between July 25, 1978 and August 7, 1978 using a helicopter which was shared jointly and in cooperation with personnel of the Corps of Engineers.

The geologic reconnaissance of the proposed Devils Canyon and Watana damsite and reservoir areas did not uncover any evidence for recent or active faulting along any of the known or inferred faults. Recent movement of surficial deposits has occurred as the result of mass wasting processes and, possibly, by seismic shaking and minor displacements of bedrock along joints.

Landsliding has occurred in the past and future landsliding appears probable. The occurrence of unconsolidated glacial debris, alluvium, and Tertiary sediments at elevations below the proposed reservoir water levels may slump and slide into the reservoirs when they are inundated. Some of these sediments may be permanently frozen and, locally, may be

ice-rich which increases the probability of slumping and sliding when the sediments are thawed by the water impounded behind the dams.

The tectonic framework of the Devils Canyon and Watana damsite areas is not well understood. The present knowledge of the area indicates that the seismicity of the region ranges in depth from less than 10 km to greater than 175 km.

Additional detailed geologic and seismic studies are necessary in order to reliably evaluate the potential geologic hazards in the region of the proposed dam and reservoir sites.

RECOMMENDATIONS

The conclusions presented in this report are based on a reconnaissance study of the proposed Devils Canyon and Watana dam and reservoir sites, and, therefore, should be considered to be preliminary. A thorough evaluation of the geotechnical problems of the proposed dam and reservoir sites will require more data. It will be necessary to (1) map the Healy, Alaska, Quadrangle, at a scale of 1:250,000, from the Talkteena Mountains Quadrangle to the Denali Fault, about 80 km (48 miles) north of the damsites, (2) map the proposed Devils Canyon and Watana damsites at an appropriate scale to determine the bedrock structure and distribution of unconsolidated sediments overlying the bedrock, (3) map the reservoir sites at a scale of 1:63,360 in order to (a) establish the type and distribution of unconsolidated sediments and bedrock, (b) locate additional potential landslide areas, and (c) determine the nature and distribution of permafrost, (4) initiate a seismic monitoring program of the dam and reservoir areas, (5) continue the active fault study, (6) redetermine the altitudes of the Vertical Angle Benchmarks, and (7) collect detailed data on the suspended loads and bed loads of the Susitna River in order to determine if the reservoir filling rates are acceptable.

PART VI: CONCLUSIONS

58. The geological-seismological investigations to date were made on reconnaissance levels. The Devils Canyon and Watana damsites are in a region of high seismicity and major faults. However, no movements were found on the faults that might be indicative of earthquakes. Also, no seismic activity was identified as associated with these faults, though the data suffers from inexactness in the accuracy of locations. No active faults were found at the damsites. Active faults of appreciable length are required if large earthquakes are to be generated in close proximity of the proposed structures.

59. The area was provided with a floating earthquake of magnitude 7 placed at a short distance from the damsites. The magnitude 7 is in conformity with general fault lengths in this area and with worldwide experiences between such faults and resulting earthquakes. However, further field studies will be made to determine conclusively whether or not there are faults closer to the sites with possible more severe motions. An earthquake of magnitude 8 from the Denali fault at a distance of 80 km was evaluated by attenuating the event to the damsites.

60. Peak motions were assigned for the earthquakes following the practices of the Corps of Engineers. The magnitude 7 earthquake near the damsites has motions that are: acceleration 0.68 g, velocity 68 cm/sec, displacement 30 cm, and duration 12 sec. An earthquake at the Denali fault attenuated to the sites provides motions of 0.28 g, 40 cm/sec, 22 cm, and 10 sec.

61. A closer specification of which sets of peak motions to apply and the appropriate time histories will await further field studies.

62. Possible induced seismicity from reservoir loading is not a factor needing additional design but is accounted for in the existing motions. However, water waves from possible earthquake-triggered landslides and possible overstressed conditions in rock pose problems for which at present there is a paucity of data and a need for further evaluation.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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ENGINEERING GEOLOGY REPORT
FEASIBILITY STAGE
DEVIL CANYON DAM
DEVIL CANYON PROJECT

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Alaska Geologic Report No. 7

Alaska District Headquarters
Juneau, Alaska
March 1960

CONTENTS

CONTENTS--Continued

CONTENTS--Continued

DEVIL CANYON PROJECT
DEVIL CANYON DAM
FEASIBILITY REPORT
ENGINEERING GEOLOGY APPENDIX

Abstract

It is believed sufficient geological and laboratory studies were performed to provide adequate data for feasibility designs and estimates. Both abutments of the damsite are almost devoid of overburden; the rock is a very hard phyllite. It is complexly fractured, and broken by three joint sets. The bedding dip causes the strata on the left abutment to overhang the Susistna River. At least 35 or more feet of broken, loose blocks of phyllite will have to be removed to provide a satisfactory dam foundation on the abutments. The center portion of the dam axis is underlain by 35 or more feet of alluvial materials; the exact thickness of the deposit and the water depth at the axis could not be determined. No major geological problems appear to exist; some dental work will be required in shear and fault zones that interlace both abutments. Extensive grouting will be required to effectively seal the foundation.

The rock in the right abutment spillway and diversion tunnels appear sufficiently competent to minimize the need for extensive steel supports. The earth dike required on the left abutment saddle will be founded on a deep deposit of highly compact, partially pervious glacial deposits. A surface powerhouse at the toe of the right abutment will require extensive scaling of the cliffs above it and some deep footings to reach firm rock under the river. The geological situation appears excellent for the consideration of an underground powerhouse on the right abutment; the problems involved appear less costly than those likely to be encountered in a surface powerhouse.

Ample supplies of concrete aggregate are available close to the dam. Impervious materials can be obtained only by selective processing of the glacial debris in the general area. There are ample supplies of materials for construction of either an "Upper" or "Lower" access road from Gold Creek. Portions of the proposed transmission lines to Anchorage, Fairbanks, and Denali Dam will traverse permafrost, muskeg and bogs, and mudflows and landslides.

Considerable additional detailed foundation investigation will be required prior to completion of final designs.

GENERAL GEOLOGY

The area has been extensively glaciated. Giant striations evidenced by numerous east-west depressions (Plate 1) can be attributed to glacial erosion of steep-dipping metamorphic beds with an east-west strike and a varying hardness.

Bedrock

The bedrock generally is termed a phyllite, probably of Mesozoic age. (In one of the drill cores at the dam a small fossil was found; this was sent to the Alaskan Branch of the USGS who have tentatively identified it as being of Cretaceous age.) This rock has a bedded and laminated appearance similar to the shale from which it was derived; however, these small laminae generally are at an angle to the strike and dip of the present massive beds. The rock is very hard and brittle (see Appendix--Laboratory Report No. C-933). It contains numerous quartz stringers that were injected soon after consolidation of the beds and again after the beds were upturned to their present position. Detailed descriptions of the phyllite and complementary rocks are in the petrographic memoranda in the appendixes of this report.

Structure (Figure 3). Throughout the immediate area, the bedrock has an approximately east-west strike with a dip of 55° to 75° south (Plate 12). It is difficult to obtain accurate dips because of the cross-laminations and accompanying jointing in the outcrops.

One well-developed and two poorly-developed sets of joints occur in the damsite area. The master joint set has a strike that averages N25W but varies between N10W and N45W (Plate 13). The dip of this set averages 80° east but varies from 75° east to vertical. These joints generally are spaced about 4 to 5 feet apart, although from 2-inch to 15-foot spacing has been noted. Many of these joints are filled with quartz that often contains minute pyrite crystals. The two minor joint sets strike almost parallel to the bedding; one of them is almost horizontal but with occasional dips between 15° north and 15° south and an east-west strike. The other set has a steep north dip. The spacing of these minor joints varies from 3 inches to as much as 30 feet in the set that strikes east-west. A fourth, apparently isolated, joint set occurs in the vicinity of the Shag triangulation station. This set strikes N55E, dips 80° north, and has a spacing of from 3 to 15 feet.

Several well-developed shear or fault zones occur in the cliffs on both sides of the canyon. They all appear to have a general strike of S25E and a dip of from 80° northeast to vertical.

On the left abutment, the larger zones contain gouge up to 2 feet thick. The zones on the right side of the canyon, although containing intensely sheared rock, generally are very tight, well healed, and extremely hard (Plate 14). These zones have caused the formation of steep V-shaped gullies in the canyon walls. Their trace above the canyon rim is concealed by overburden. Because of the lack of marker beds, it was not possible to determine if the faulting resulted in major displacement of the beds.

Permafrost

According to present information on the limits of continuous permafrost in Alaska and as a result of our investigations, the damsite area appears to be south of this zone. It is, however, in the zone of sporadic permafrost. Shallow and apparently thin lenses and pockets of permafrost were encountered occasionally in the road construction. These sporadic occurrences were evidenced by lenses of ice, frozen soil, and continuously thawing frozen ground. Permafrost was not encountered in the bench area adjacent to the left abutment. It is doubtful if any permafrost occurs at the damsite proper although there may be occasional pockets in the dike area south of the left abutment. Temperature measurements were not made in the drill holes on the axis because practically all of them were in hard rock; thus, even if permafrost was present, it would have no destructive influence on the proposed structures.

Recent Deposits

The areas north and south of the canyon rim often are mantled with glacial and nonglacial deposits of Quaternary age. The glacial materials primarily consist of outwash (Plate 10) and moraines (Plate 16); these are composed of erratic lenses and layers of sand, rounded to angular gravel and cobbles, boulders, a small amount of silt, and considerable rock flour. Some of the older glacial deposits exhibit considerable weathering; this is evidenced by heavy iron stains and the almost complete alteration of pebbles and cobbles. The nonglacial materials primarily are river terraces and fans, talus (Plate 11), outwash, and swamp deposits. Their constituents range from rock flour and silt to sand, gravel, and boulders.

In many areas it is not possible to immediately differentiate the glacial and nonglacial materials; a distinction generally can be made only by a broad inspection of the morphological characteristics of the various types of deposits. The most distinguishing feature of the nonglacial deposits is their common occurrence in strata or layers. However, this same identification method seldom can be applied to the fine-grained materials because turbulence in the depositing waters has resulted in minute crossbedding and folding of these materials.

A third category of unconsolidated deposit is alluvial material now being deposited or moved by the Susitna River. For the most part, this deposit is granular with numerous boulders, and heavily contaminated by rock flour.

Moraines. These glacial deposits predominate north of the Susitna River and cover a considerable portion of the area south of the river. They are from a few inches to several feet thick. Owing to comparatively recent surface erosion processes, they have lost distinguishing surficial characteristics. They contain materials ranging from rock flour up to boulders 8 feet in diameter (Plate 15). In the mapped area, there was a high percentage of material larger than 4 inches in diameter, and the largest boulder seen was 3 feet. Because of the high content of rock flour, and with the exception of occasional granular pockets or stringers of sand, the moraines should be impervious.

Outwash. A thin layer of this material mantles a portion of the westernmost part of the bench south of the left abutment. Elsewhere in this area, the outwash may be as much as 90 feet thick but is veneered by moraine. It consists primarily of fine- to medium-grain sand, with rounded to subrounded pebbles, cobbles, and boulders up to 14 inches in diameter. The material apparently was deposited in a V-shaped valley in front of an advancing glacier (Plate 10). The weight of the glacial ice and subsequently deposited morainal material consolidated the outwash to a relatively high density.

Terraces. River-deposited terraces occur south of the river in the eastern part of the mapped area. They are composed of coarse and fine sand, subrounded to rounded gravel, and boulders up to 3 feet in diameter. The terrace gravels on the canyon floor (referred to throughout this report as a "fan") extend to about 65 feet above river level, with an unknown thickness below river level. The gravel in the fan at the floor of the canyon is overlain by 3 to 5 feet of clean, medium- to coarse-grained sand. Approximately 210 feet of gravel occurs above river level in the terrace remnant upon which Triangulation Station Ho is located (Plate 16).

The terraces formed by Cheechako Creek occur about 22 feet below the fan terrace on the floor of Devil Canyon and about 27 feet below the first terrace. The highest Cheechako terrace is a flat about 270 feet wide, and the lower and youngest terrace is about 140 feet wide. The gravel in these terraces is coarser than the gravel in the previously mentioned Susitna River terraces. Granite boulders up to 10 feet in diameter mantle the surface.

Talus and rubble. This unsorted, angular to subangular material occurs in the southwestern part of the left abutment bench, with occasional deposits near the base of the gullies and cliffs in the canyon (Plate 11). This material is derived from the adjacent outcrops, and the blocks range from a few inches to 15 feet in maximum dimension. The deposits in the bench area probably do not exceed 10 feet in thickness, whereas those in the canyon average about 20 feet in thickness and may be as much as 40 feet.

Swamp deposits. Rimming the lakes on the bench of the left abutment and in areas of poor drainage are deposits of moss and shrubs mixed with fine sand and silt. These deposits generally are less than 3 feet thick and are underlain by moraine and outwash.

Seismic Activity (Figure 60-2)

The damsite is in a zone of major seismic activity. According to U. S. Coast and Geodetic Survey reports, U. S. Geological Survey Professional Paper No. 69 (1912), and Gutenberg and Richter's book, Seismicity of the Earth and Associated Phenomena, there have been at least 45 earthquake epicenters within a radius of 150 miles of the site. Twelve of these quakes had a Richter-Gutenberg magnitude of 2.0 or greater. The remaining 33 earthquakes had a magnitude of 5.0 to 6.9. Two epicenters were located within 25 miles of the site. On May 29, 1931, an earthquake of unknown magnitude occurred near the Chulitna River about 15 miles northeast of the site; on July 3, 1929, a 6.5-magnitude earthquake occurred near the Talkeetna River about 25 miles southeast of the site. Some of these shocks caused considerable major damage to structures in Anchorage and Fairbanks, and major earth movements and landslides along the highways and railroad.

ENGINEERING GEOLOGY

Reservoir

Time limitations and access difficulties did not permit a ground inspection of the reservoir basin. However, aerial reconnaissance and a study of existing geological data indicate the reservoir basin will be tight. Since the basin is rimmed by the high uplands of the Talkeetna Mountains, there appears no possibility of loss into other drainage basins. Any ground-water percolation into fractures in the reservoir rock would be stored and would drain back into the reservoir during low water.

Extensive dense timber occurs along the lower elevations in the reservoir basin. The vegetation is similar to that described in previous parts of this report.

Damsite

Left Abutment (Plate 17)

The most critical engineering geological problems occur on this side of the canyon. These are a result of the overhanging cliffs formed by the southerly dipping beds; and what appears to have been more structural disturbance in this abutment (shown in DH-9 and DH-10 and in Figure 4). Faulting has caused shear zones that are approximately normal to the river (Plate 18) and also roughly parallel the canyon rim. The sheared rock is not well healed; thus, extensive fracturing with open crevices is common. However, pressure tests in DH-9 and DH-10 did not result in severe water losses, even in faulted zones in the holes. DH-8 apparently encountered only minor faulted areas and showed heavy water losses to a depth of about 118 feet; but, from this point to the bottom of the hole at 150 feet, or within about 15 feet of the cliff face, there was practically no water lost in the pressure tests. (This angle hole was drilled toward the cliff face for the specific purpose of determining the decrease or increase in fracture openings in the direction of the cliff face.) DH-1 apparently encountered little or no faulting; however, severe water losses occurred throughout all but the last 10 feet of the hole.

The overhanging beds on this side of the canyon have resulted in large blocks (Plate 6) that, in some cases, are distinctly separated from the adjacent bedrock. Some of these blocks are as much as 25 feet in horizontal dimension and 50 feet in vertical dimension. During small earthquake tremors, slight movements of these blocks can be felt. Because of these loose blocks and the variable results from the water pressure tests, shelves ("kitchens") were excavated into the abutment face (Figure 4). The initial plan was to determine the depth to sound rock from the canyon face. The first shelf, S-1, was started about 60 feet below the canyon rim on the nose of a ridge downstream from the downstream toe of the dam. This excavation had to be abandoned before reaching unbroken, massive rock, because the blasting loosened great quantities of loose rock above the shelf. Loose rock for about 10 feet in a horizontal direction was removed before the excavation had to be abandoned. Excavation then was started at S-2, about 170 feet below the canyon rim on the cliff face (Plate 19) of the left abutment. This excavation also had to be halted because each blast loosened increasing quantities of rock above the shelf, and it became too dangerous for further work. This shelf is believed to have actually penetrated about 20 feet into the cliff face; however, an accurate measurement or a log of the shelf was not possible because of the covering of loose rock after the final blast. Removal of this loose material could not be attempted because of danger from overhanging blocks.

Based upon the aforementioned investigations, it is estimated that a minimum of 35 to 50 feet of rock will have to be removed from the present surface before firm rock is reached. It will not be possible to obtain a "clean" excavation surface because of the blocky and overhanging nature of the formation; therefore, extensive dental work may be required. bad news for field hands & leaves big opening for claims.

The left abutment of the arch is near a fault zone trending southeast from DH-9 and the shear or fault zone that roughly parallels the canyon rim in this same area (Figure 4). Shifting the left abutment upstream would require construction of a thrust block (because of the loss of topographic elevation), but the thrust from the arch then could react against a considerably larger and firmer rock mass.

"Spillway" Saddle

Because of favorable topography, it initially was planned to use a controlled overflow spillway chute across the north-south saddle to the left of the left abutment (Plate 4 and 4A). Several drill holes in this saddle disclosed a deep buried channel apparently striking about east and west through the lake-filled depressions on both sides of the saddle (Figure 5, Section BB) and overlying a severely faulted area. The maximum depth of the valley fill in this channel is about 90 feet. The fill material is composed primarily of well-consolidated outwash, with about a 10-foot veneer of moraine (Plate 15). Continuous strata of pervious material probably occur in the outwash. The moraine veneer may have sufficient impervious material to form a moderately effective blanket. It is necessary to effectively seal this channel fill, as the lowest point in the underlying bedrock surface is almost 170 feet below the maximum water surface in the reservoir. The percolation path from the reservoir probably would not exceed 3,000 feet.

The lack of suitable foundation and other design considerations resulted in the abandonment of this saddle area for a spillway. However, since the lowest elevation in the saddle is 1375, it will be necessary to construct a dike across it approximately 800 feet long with a maximum height of 80 feet. The area selected for the dike is slightly upstream from the saddle (Figure 5, CC). Because the foundation materials have been compacted by relatively high ice loads, they appear to be satisfactory insofar as bearing capacity is concerned for the aforementioned dike. Water measurements in the drill holes throughout the left abutment areas indicate the ground water is tributary to the small lakes in the depression. This also may indicate that some of the underlying materials are relatively impervious.

Right Abutment (Plate 20)

Only a minor amount of dental work should be required for the dam foundation in this abutment. The abutment is intersected by shear zones striking almost normal to the stream; however, Shelves S-3 and S-4 disclosed that the rock in these zones is competent with only thin seams of gouge (Plate 14). The only problem of any magnitude will be the scaling of loose blocks in the knife ridges on the right abutment in order to protect the powerhouse and dam excavation against rockfalls. Seepage through the abutment should be an acceptable minimum as the joints on this side of the canyon are well healed. The dip of the bedding is favorable for shaping this abutment for the arch (Figure 5, Section AA).

River Section

The high velocity of the river in the canyon made it impracticable to drill holes in the center of the river. An attempt was made to determine at least a rough bedrock profile under the river by means of angle holes drilled from each bank. Because of vertical cliffs to the water edge (Plate 21), it was not possible to drill intersecting angle holes: That is, holes started on directly opposite sides of the river drilled at angles to intersect each other under the river. The drilling that was accomplished appears to give an approximation of the maximum depth to bedrock beneath the river (Figure 7). According to this drilling, the maximum depth to bedrock from the water surface is about 85 feet (Figure 7, Section BB). Because it was not possible to measure the depth of water, the streamfill can be estimated only roughly as about 35 feet in maximum thickness. According to pressure tests in these holes, severe fractures and open joints occur from the bedrock surface to about 25 feet below this surface. Below this 25-foot depth, however, the rock tightens and only nominal water losses occurred (Figure 7, Sections AA, BB, CC). None of the holes indicated faulting paralleling the river.

General

To expose firm foundation rock, particularly on the left abutment, will require the removal of up to 35 or 50 feet of loose blocks. There is no appreciable depth of weathered rock. Because of the extensive fracturing and open joints (Plate 22) considerable grout take can be expected. Such grouting is necessary to consolidate the fractured rock and reduce seepage through the foundation.

Laboratory tests (Appendix--Laboratory Report No. C-933) on cores representative of the foundation rock have disclosed that Young's modulus for unfractured foundation rock exceeds 7,000,000 psi. Poisson's ratio is about 0.18. The unconfined compressive strength is as high as 37,000 psi. These tests disclosed that the rock acts primarily as an elastic material and practically no permanent "set" occurs. Although these initial tests indicate excellent foundation conditions, it is highly desirable that during final design investigations, in-situ measurements are taken of the elastic properties of the rock. This recommendation is based upon the fact the severely fractured in-place condition of the rock may result in lower moduli than obtained in the laboratory tests.

Powerhouse

Present plans establish the powerhouse location along the toe of the right wall of the canyon, downstream from the dam (Plate 23, Figure 3). This will require extensive excavation into the right abutment to obtain sufficient room for the structure (Figure 5, Section AA). Considerable scaling will be required on the cliffs and knife ridges above this excavation to provide protection during construction and to prevent major rockfalls during operation. The powerhouse and tailrace structures should be founded on the bedrock below the streamfill.

Underground Powerhouse

The restricted topography, the possible need for extensive scaling, and favorable geological conditions indicate the desirability of considering an underground powerhouse in the right abutment. The unusual competency of the rock indicates the possibility of excavating an underground chamber with a minimum of roof and wall support (Figure 8). Additional investigation of the chamber site by deep drill holes and a pilot tunnel will be required to fully outline potential roof and wall support problems. Because portions of the excavation will be below river level, extensive grouting may be necessary for the lower part of the chamber to prevent water inflows through the open fractures.

The topography on the right side of the river is particularly favorable for the construction of short penstock and tailrace tunnels. The drilling done to date lends further support to an underground plant as the core indicates the rock tightens with depth and the fracturing decreases. Furthermore, the size of installation required for a 580,000-kw powerplant may preclude the construction of a surface plant because of numerous and costly excavation difficulties that will result from the steep terrain and extensive fracturing of bedrock near the surface.

Spillway and Diversion Tunnels

In present plans, these structures are located in and on the right abutment (Figure 6, Section DD and D'D). The spillway intake can be founded on bedrock with a minimum amount of overburden excavation. Rock cuts of 1/4:1 to 1/2:1 should be feasible in the intake area (Plate 24). Some difficulty may be experienced with overexcavation on the southeast or left side of the excavation, owing to the adverse dip of the bedding. Prior to final design of the intake excavation, sufficient drilling should be performed in this area to determine the depth of overburden and extent and severity of the jointing and fracturing in the bedrock. Because cuts of 50 and more feet in height will be required, extensive jointing in the rock on the right side of the intake may result in movement of loose blocks during construction. This problem is not believed to be too serious as no clay seams are known to exist in the bedrock.

The diversion and spillway tunnels will penetrate the same type of rock. Nothing is known at present of the characteristics of the phyllite bedrock at diversion tunnel gradient; however, as mentioned in the powerhouse discussion, it is believed that this rock would have a minimum of fracturing and be exceedingly competent for tunnel operations. With the exception of steel supports for about 100 feet of the inlet (Plate 24) and outlet areas and in narrow shear zones, rock bolting for about 75 percent of the tunnel length should be adequate. This bolting is suggested because of the blockiness caused by the three joint sets. If the nature of the shear zones on this abutment is the same at tunnel depth as it is at the surface, these zones should offer only minor difficulty in the tunnel excavation.

The occasional open joints, surface springs, and snowmelt indicate that minor waterflows will be encountered in the tunnels. As the rock is very competent, none of these flows should be of sufficient magnitude to seriously interfere with construction.

One problem requiring further study is the closeness of the large diameter tunnels. The rock is of a nature that would transmit blasting vibrations with only nominal dampening effects. Therefore, blasting in one tunnel could cause rockfalls in the adjacent tunnel. Extensive rock bolting would offer considerable protection against such an eventuality.

The comments made in regard to the spillway intake excavation also would apply to the excavations required for the intakes and outlets of the tunnels. The only difference may occur at the outlet of the tunnel if it daylights into an open channel cut through a talus deposit of undetermined depth (Plate 25).

Highway Geology

Two possible routes have been suggested for the access highway to the damsite. One route would closely parallel the existing road high on the slope of the Talkeetna Mountains, whereas the second or lower route would be along the south bank of the Susitna River.

The Lower Route

The lower route will traverse terrace deposits immediately south of the river from Gold Creek to about MP-6, with a stretch of bedrock from MP-2.5 and MP-3. At MP-6, the road leaves the river and climbs a bench that may require numerous switchbacks because of the steep gradient. From the top of the bench to the damsite, the road will follow the south rim of the canyon; although long stretches of bedrock will occur, swamp and muskeg areas will have to be bypassed (Plate 17). This section of the road also will have to bridge deeply incised gullies.

The lower route will require placement of embankments on swamp and muskeg areas. It is believed that such areas are probably not over 15 or 20 feet deep; thus the soft material could be completely removed, or consolidated by overloading of the embankment. The latter method has been used with considerable success in similar situations, particularly when it is accompanied by the detonation of low-velocity charges along the toes of the proposed embankments and at varying depths from the surface to underlying sound material.

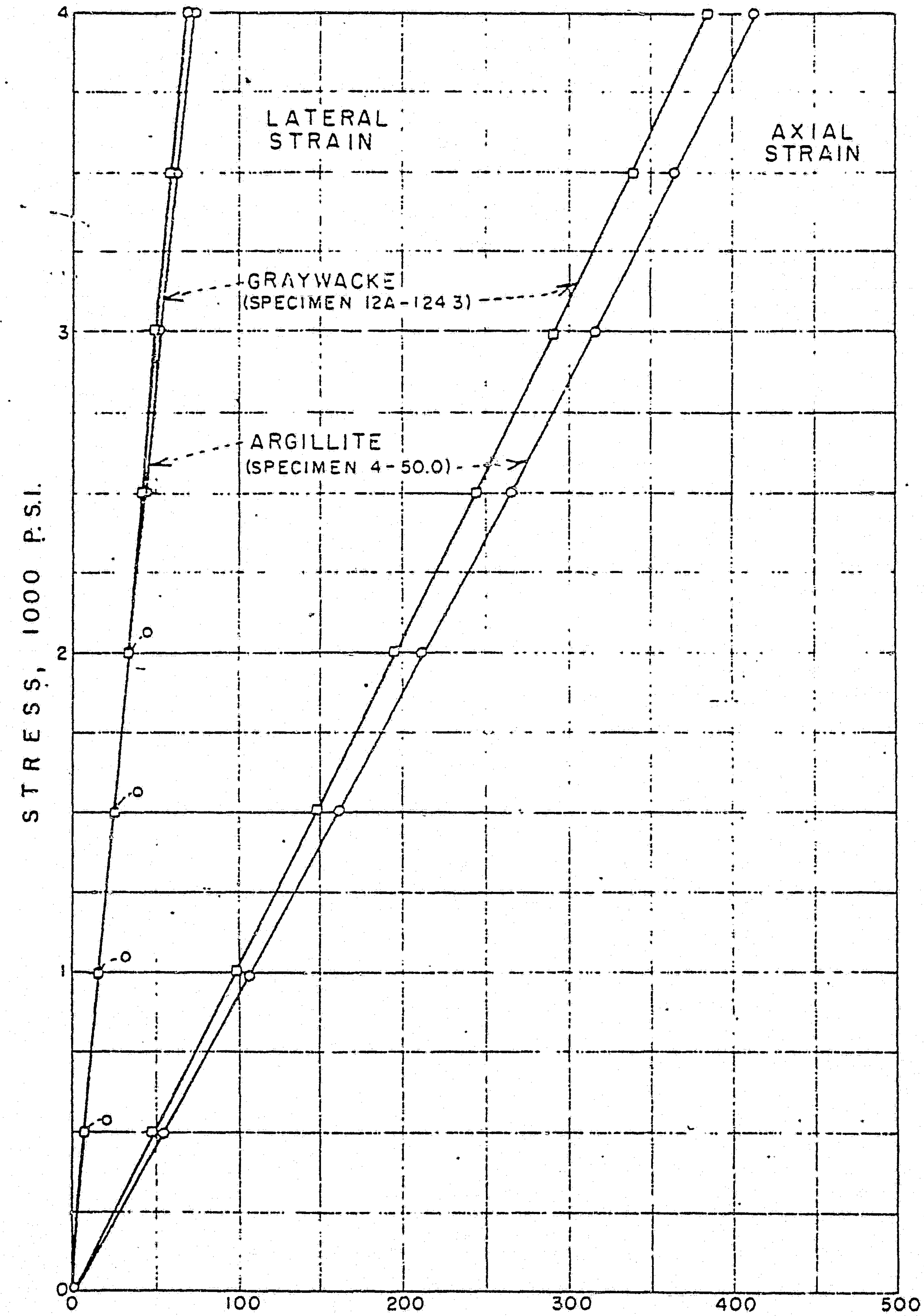
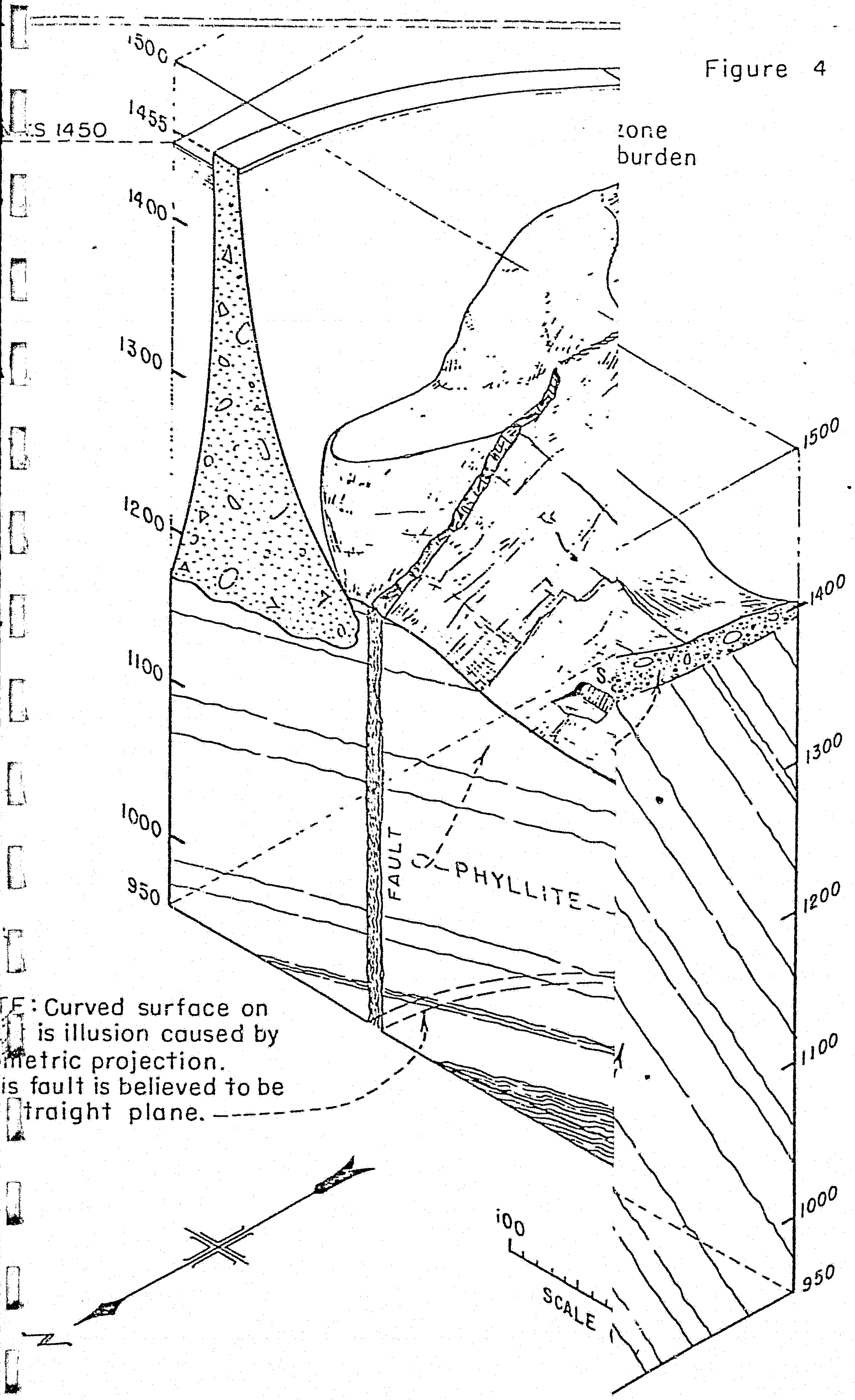


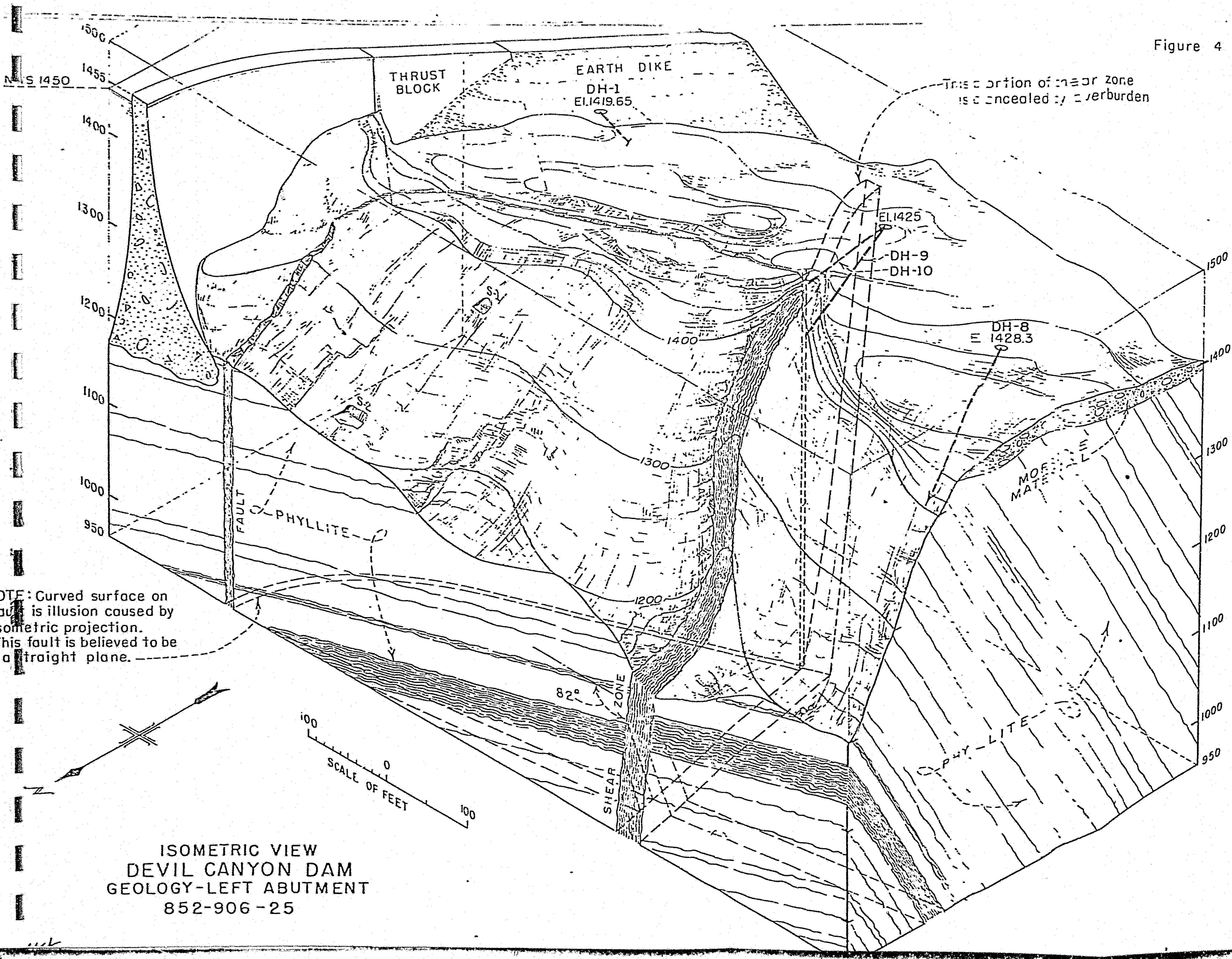
FIGURE 5
TYPICAL STRESS STRAIN CURVES, FIRST LOADING CYCLE
DEVIL CANYON DAM SITE FOUNDATION ROCK

Figure 4



ISOMETRIC VIEW
DEVIL CANYON DAM
GEOLOGY-LEFT ABUTMENT
852-906-25

Figure 4



ISOMETRIC VIEW
DEVIL CANYON DAM
GEOLOGY-LEFT ABUTMENT
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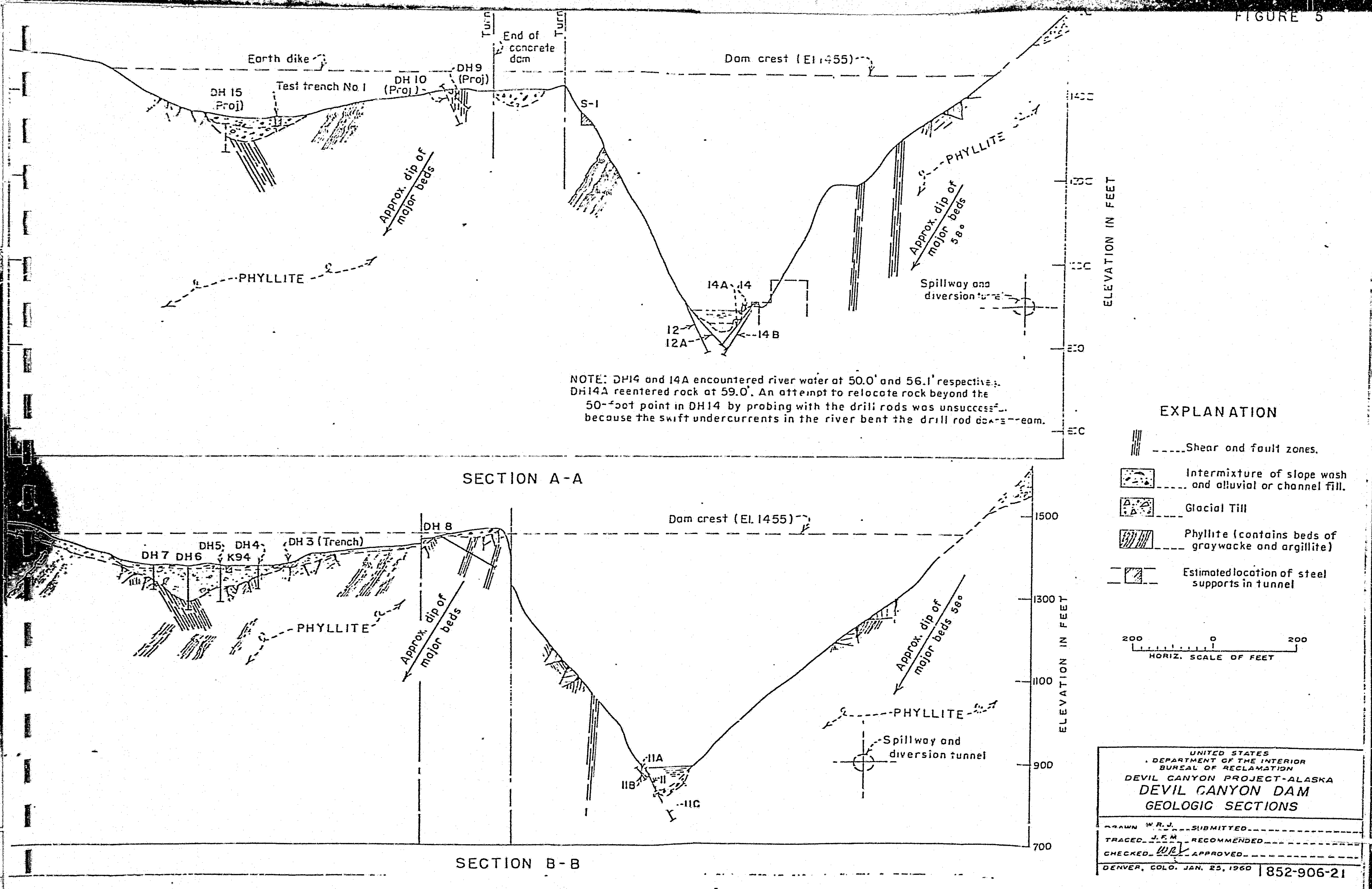
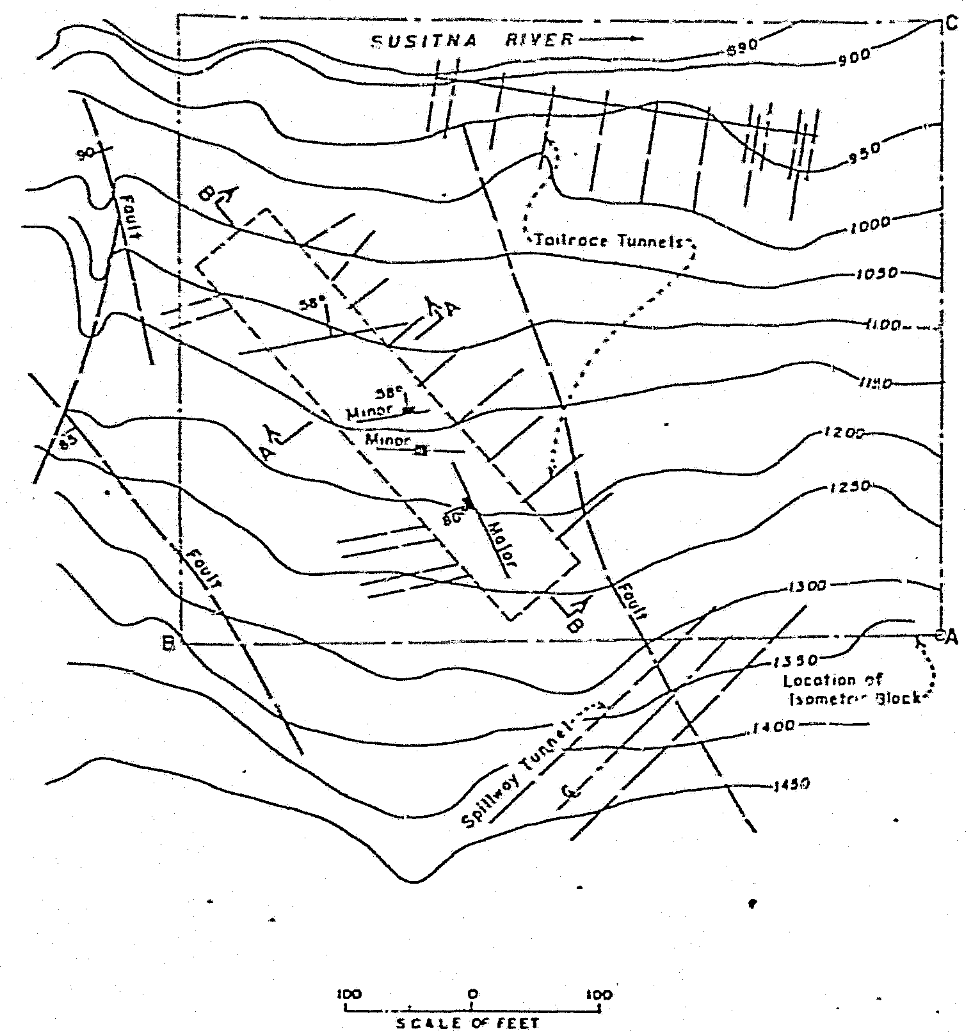
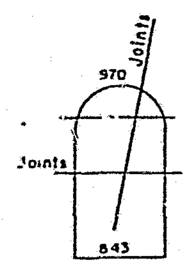


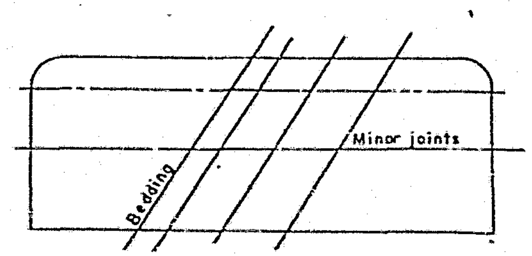
FIGURE 5
Turn
Turn
End of concrete dam
Earth dike
Dam crest (El 1455)
DH 15 (Proj)
Test trench No. 1
DH 10 (Proj)
DH 9 (Proj)
S-1
PHYLLITE
Approx. dip of major beds
Approx. dip of major beds 58°
14A
14
12
12A
14 B
Spillway and diversion tunnel
ELEVATION IN FEET
NOTE: DH14 and 14A encountered river water at 50.0' and 56.1' respectively. DH14A reentered rock at 59.0'. An attempt to relocate rock beyond the 50-foot point in DH14 by probing with the drill rods was unsuccessful because the swift undercurrents in the river bent the drill rod downstream.
SECTION A-A
Dam crest (El. 1455)
DH 8
DH 7
DH 6
DH 5
DH 4
K94
DH 3 (Trench)
1500
1300
1100
900
700
11A
11
11B
11C
SECTION B-B
EXPLANATION
Shear and fault zones.
Intermixture of slope wash and alluvial or channel fill.
Glacial Till
Phyllite (contains beds of graywacke and argillite)
Estimated location of steel supports in tunnel
200
0
200
HORIZ. SCALE OF FEET
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DEVIL CANYON PROJECT-ALASKA
DEVIL CANYON DAM
GEOLOGIC SECTIONS
DRAWN W.R.J. SUBMITTED
TRACED J.F.M. RECOMMENDED
CHECKED APPROVED
DENVER, COLO. JAN. 25, 1960
852-906-21

FIGURE 6

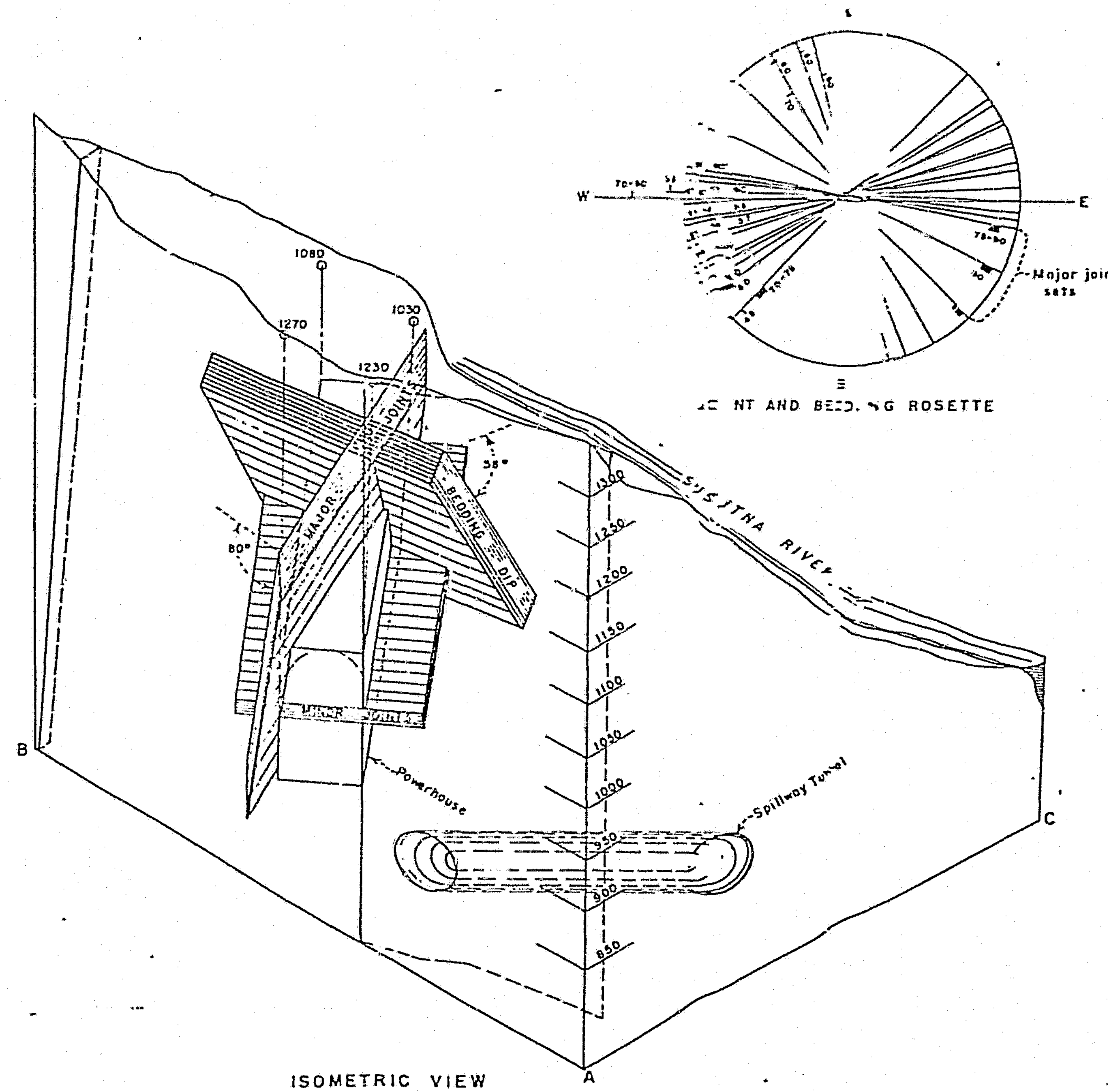




SECTION A-A



SECTION B-B



ISOMETRIC VIEW

JOINT AND BEDDING ROSETTE

EXPLANATION

- 58° Average dip and strike of phyllite
- Average dip and strike of joints
- Faults or shear zones.
- 1080 Surface elevations above corners of powerplant chamber

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DEVIL CANYON PROJECT—ALASKA

DEVIL CANYON DAM

GEOLOGY OF UNDERGROUND POWERHOUSE

DRAWN W.J.P.	SUBMITTED
TRACED L.F.S.	RECOMMENDED
CHECKED	APPROVED
DENVER, COLORADO, FEB. 4 1952	852-906-24