Engineering Geology
Technical Feasibility Study
Makushin Geothermal Power Project
Unalaska, Alaska

A Report Submitted to

Alaska Power Authority

Division of Geological & Geophysical Surveys

Public Data File 86-60

SEPTEMBER 1986

THIS REPORT HAS NOT BEEN READ BY THE DIRECTOR, HAS NOT RECEIVED OFFICIAL DGGS PUBLICATION STATUS, AND SHOULD NOT BE QUOTED AS SUCH.

Alaska Department of
NATURAL
RESOURCES

LETTER OF TRANSMITTAL

15 September 1986

TO: BRENT PETRIE
DIRECTOR OF RURAL TECHNICAL SUPPORT
ALASKA POWER AUTHORITY

DAVID DENIG-CHAKROFF
UNALASKA GEOTHERMAL POWER PROJECT MANAGER
ALASKA POWER AUTHORITY

FROM: RANDALL UPDIKE
CHIEF, ENGINEERING GEOLOGY SECTION
DIV. OF GEOLOGICAL & GEOPHYSICAL SURVEYS
ALASKA DEPARTMENT OF NATURAL RESOURCES

Attached herewith please find a report in two (2) volumes entitled: "ENGINEERING GEOLOGY TECHNICAL FEASIBILITY STUDY, MAKUSHIN GEOTHERMAL POWER PROJECT, UNALASKA, ALASKA." This report is a result of a Reimbursable Services Agreement between the Alaska Power Authority and the Alaska Department of Natural Resources. You will find that the report addresses twelve technical topics which have direct relevancy to determining the engineering feasiblity design of the Makushin Geothermal Power Facility. Each of these studies was conducted by a professional on our staff specifically trained in that discipline. No technical or editorial review of the report was made outside of the members of the technical team, but I am confident that you will find each task report to be a quality product. From start-up to completion the study required six weeks, including one week in the field in mid-July. Most of the team members would liked to have performed more exhaustive work on their tasks, but we have all agreed, instead, to strive to meet the mid-September deadline and remain below the budget we had originally proposed to you.

The technical team hopes that the report meets with your approval and will provide a meaningful benchmark document for future work on this very worthwhile project. We will be happy to meet with you and your consultants to discuss specific questions about the project.

It has been a decided pleasure working with both of you. The support and patience you have provided has been invaluable in getting a tough job done well. We look forward to working with you on other projects in the future. Until then, if there is additional effort we can provide on this project please don't hesitate to call on us.

TABLE OF CONTENTS - VOLUME I

TABLE OF CONTENTS - VOLUME II (PLATES)

PROJECT OVERVIEW

By Randall G. Updike

INTRODUCTION

During the past decade, the State of Alaska has been engaged in identifying and developing indigenous energy sources for local communities throughout the State. Geothermal energy has been particularly sought after because it typically has long-term reliability and its development yields minimal environmental impacts. The numerous active volcanoes of the Aleutian Island Arc have long been considered to have the essential geologic parameters necessary for productive geothermal reservoirs.

Approximately 800 miles southwest of Anchorage, Makushin Volcano on Unalaska Island has been recognized to have geothermal resources since the early work of Madden (1919) followed by the more detailed studies of Drewes and others (1961). More recently, Alaska Division of Geological and Geophysical Surveys (ADGGS) geologists, particularly J. Reeder and R. Motyka, mapped specific fumarole fields on the lower flanks of the volcano. One of these, herein termed the Makushin geothermal field and the focus of this report, is situated only 14 miles from the communities of Unalaska and Dutch Harbor. In 1981 the State funded the Alaska Power Authority (APA) to conduct a geothermal exploration project on Unalaska Island. APA contracted Republic Geothermal, Inc., to conduct the exploration, which occurred from February 1982 to December 1984. The discovery geothermal well was drilled during the summer of 1983. That well site is referred to in the following report as the "power site" (Plate A-1).

The power site is located on a broad, gently sloping bench on the east flank of the volcano, at an elevation of about 1,180 ft overlooking the headwater drainages of Makushin River Valley. Access to the site by other than helicopter is exceedingly difficult due to the lack of roads and steep slopes surrounding the power site bench (fig. 1). Although a few decades ago a road was constructed up Makushin Valley from Broad Bay, over a broad divide, and down Driftwood Valley to Driftwood Bay (Plates A-1 and A-2), that road is now impassable for considerable distances throughout its extent (fig. 2). Although land access is a clear challenge, the power site itself is located in terrain excellent for the design and construction of a power plant facility (fig. 3). APA recognized early in the project that the power facility would be located in one of the most geologically-active environments in North America, being subjected to the juxtaposition of forces such as earthquakes, volcanism, landslides, glaciation, and stream erosion, and that technical feasibility of the project beyond the geothermal resource issue would need to be addressed.

SCOPE OF WORK

Fundamental to the economic and engineering design for the construction of the Makushin Geothermal Field power plant, transmission line, and access road corridors, is an evaluation of the varied aspects of the local geology which will substantially dictate the siting and construction of that facility. At the request of and under a Reimbursable Services Agreement with APA, ADGGS has been assigned the task of conducting an engineering geologic technical feasibility study of the power site, surrounding upland terrain, Makushin Valley, and Driftwood Valley. Twelve specific tasks are included in this feasibility study:

1. Volcanic hazard constraints. An assessment of the potential for volcanic eruptions that could influence the project due to flows (lava, base surge, ashflows), airfall deposits (ballistic or ash fallout), directed blasts, or the formation of vents, craters, and fissures.

2. Glacial hazard constraints. An assessment of the potential for glacially related hazards that include both the ice (surges, gradual advances, rapid ablation) and glacio-volcanic meltdown resulting in outburst floods (Jokulhlaup) and mudflows (lahar).

3. Slope stability. A consideration of the stability of rock slopes and unconsolidated deposits including rockslide, rockfall, talus, debris flow, mudflow, subsidence, and cutbank stability.

4. Geohydrology. An examination of the surface waters draining the area including drainage patterns, flow characteristics, surface supply, stream water chemistry, and soil/bedrock drainage characteristics.

5. Avalanche hazard constraints. An assessment of slopes having potential for snow avalanche, travel paths, runout zones, and estimated kinetic energy.

6. Regional seismicity. A state-of-art summary of subduction zone and volcano-tectonic sources of earthquakes that could influence the project due to ground acceleration, ground failure, and tsunami.

7. Construction materials resources. An evaluation of locally accessible resources of sand and gravel, and bedrock which could then be used during various phases of construction.

8. Geothermal plant site geotechnical study. A reconnaissance-level evaluation of the plant site for foundation conditions (e.g., bearing strength, ease of excavation, depth to bedrock, static and dynamic stability).

9. Transmission/road corridor geotechnical study. A reconnaissance-level evaluation of Makushin Valley from the plant site to Broad Bay relative to variations in the geotechnical properties of the valley floor to aid in the selection of center line for the transmission line and feasibility of a constructed all-weather road.

10. Coastal engineering. A preliminary evaluation of coastal conditions for construction of facilities at Broad Bay, Driftwood Bay, and a submarine transmission line to Unalaska.

11. Low-enthalpy resources in Makushin Valley. An assessment of the potential for shallow, low-temperature, geothermal resources in the valley that could be directly used in local greenhouse agriculture.

12. Archaeological survey. A systematic examination of the project area to locate and identify archaeological sites (prehistoric to 20th century) which could require salvage excavations prior to project construction.

REPORT FORMAT

Because of the diversity of topics included in the above list, and also because of tight time constraints, a large technical team was assembled to execute all tasks within a two month period. In the following report, each chapter is authored by the team member(s) responsible for that aspect of the study. Throughout the field period of one week in mid-July 1986, team members often served as field assistants for other team members, particularly for types of investigation requiring two or more persons (e.g., surveying, seismic refraction, power auger drilling). Each task investigator is solely responsible for what is reported herein for that topic. The separate chapters are each assigned a letter prefix which are given in the table of contents. This is a two-volume report. The first volume is the text and accompanying tables, figures, references, and appendices for each task. Volume two consists of the oversize plates which were prepared by authors where appropriate to map geotechnical information, geologic constraints, and resources. Not all chapters make use of plates. Although this is not an official ADGGS publication, the report has been assigned Public Data File Number 86-60 for reference. Individually authored chapters may be referenced by the PDF number followed by the letter prefix, for example PDF 86-60B would be the Engineering Geology (site geotechnical) chapter by Rod Combellick.

ACKNOWLEDGEMENTS

The authors wish to express particular appreciation to three individuals who accompanied the team to Unalaska and were invaluable for the talents and enthusiasm they brought to the team effort: Roger Allely, ADGGS Water Resources Section; David Denig-Chakroff, APA; and James Beget, University of Alaska-Fairbanks. The excellent cooperative rapport that developed between APA and ADGGS staff, and the solid support provided by APA to ADGGS made execution of the work a pleasure for the entire team. We wish to express special thanks to the Unisea Hotel, Dutch Harbor, for providing accommodation and uniformly good food. Chris Soloy and Soloy HeliOps provided us with an aircraft that performed flawlessly.

Two individuals must be particularly acknowledged because they were indispensable to the project's success. Ken Barnes, pilot of the Hughes 500-C helicopter, was supurb in keeping track of 14 scientists all over the mountain, in Aleutian weather that changes every 15 minutes. He was always first up in the morning and last to dinner at night. And finally, thank you Jennifer Weir for all your efforts in typing, collating, and duplicating this report single-handedly.

AN INTRODUCTORY DISCUSSION

The project team has made a serious effort over the past six weeks to maintain a multiple-working hypothesis on the alternative designs for the power facility. Three main variables have yet to be resolved and the team hope that the following chapters will benefit the actual design/construction decisions. These variables are: (1) location of the power generation plant, (2) location of the electrical transmission line corridor, and (3) location of off-loading port and road access corridors.

Location of the Power Plant

It would at first seem obvious that the power plant should be constructed at the well site, particularly in light of the physical qualities of the site. In fact, the team did focus on the power site bench. However, we do recognize two alternatives if the hot fluids can be pumped several thousands of feet:

(a) Construction of the power plant on the volcanic flow uplands to the east toward Sugarloaf (fig. 4). The obvious advantage is ease of access by road to the power plant. The major disadvantage is construction of a rigid pipeline several thousand feet across a gorge and up a steep cliff face.

(b) The second alternative is to construct the plant on the floor of Makushin Valley near the mouth of its incised canyon. Again, road access would be far easier but the pipeline would again cross very steep terrain. Furthermore, there is substantial concern that flash floods may severely impact the upper segment of the river and facilities could be in severe jeopardy.

Location of the Transmission Corridor

We have been considering three options here also: (1) down Driftwood Valley to the bay thence by underwater cable to Unalaska, (2) down Makushin Valley to Broad Bay, then by underwater cable to Unalaska, and (3) an overland route making use of ridges and summits on the south side of the valley. Although each has some merit, cost benefit and ease of construction would favor option (3).

Location of Access Roads

Selection of road corridors is primarily dictated by (1) location of power plant and transmission lines, (2) method of power site construction (e.g., helicopter sling, tractor-sledge haulage from dock), and (3) geologic constraints and construction resources. The corridor geotechnical study (Chapter C) offers several optional routes and staging areas. It should be noted that the existing road in Driftwood Valley is for the most part in very good condition (fig. 5). As noted earlier, the existing road in Makushin Valley is in large part unusable at present (fig. 2).

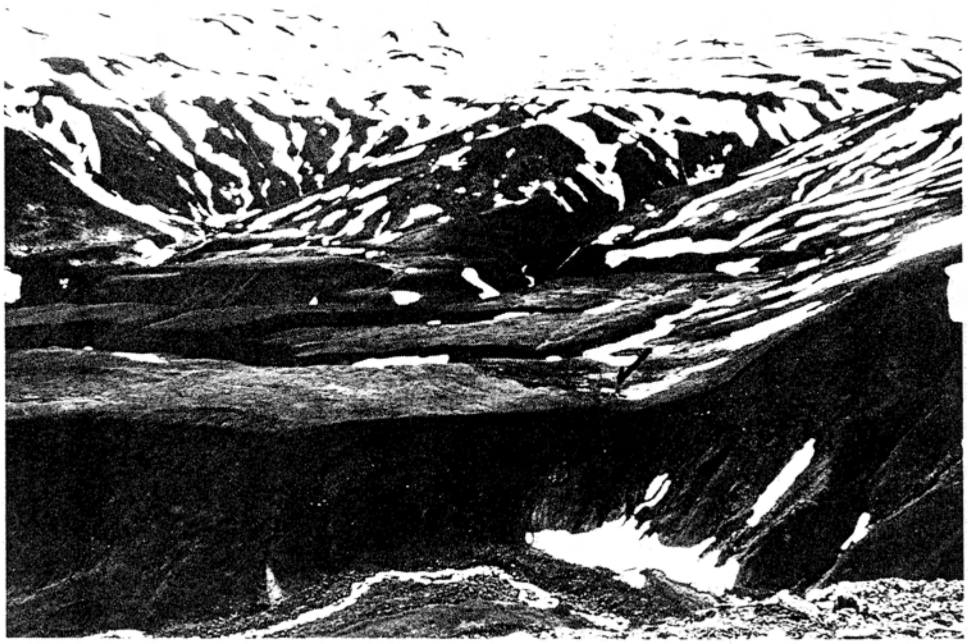


Figure 1. Oblique aerial photograph of the power site (arrow). View south toward Makushin Volcano. Note steep bluffs surrounding power site.

Figure 2. Oblique aerial photograph of a segment of the Makushin Valley River. Segment of old Makushin Valley Road (A-A'), road section removed by lateral erosion (B), and gravel borrow pit (C) are visible.

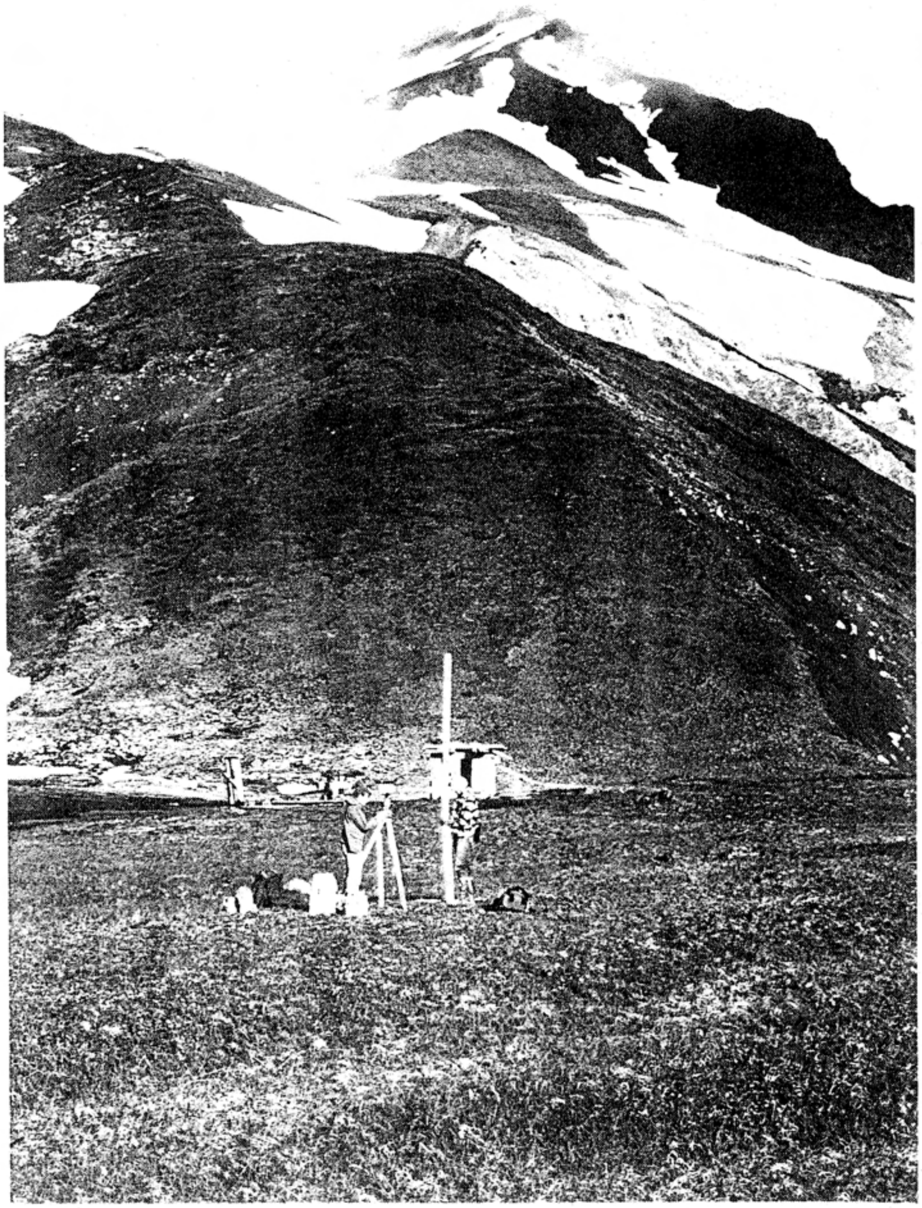


Figure 3. Surface topography of power site bench, gently sloping toward the camera. Personnel are preparing to conduct EDM-theodolite survey of the bench. Well-head shack visible in background.

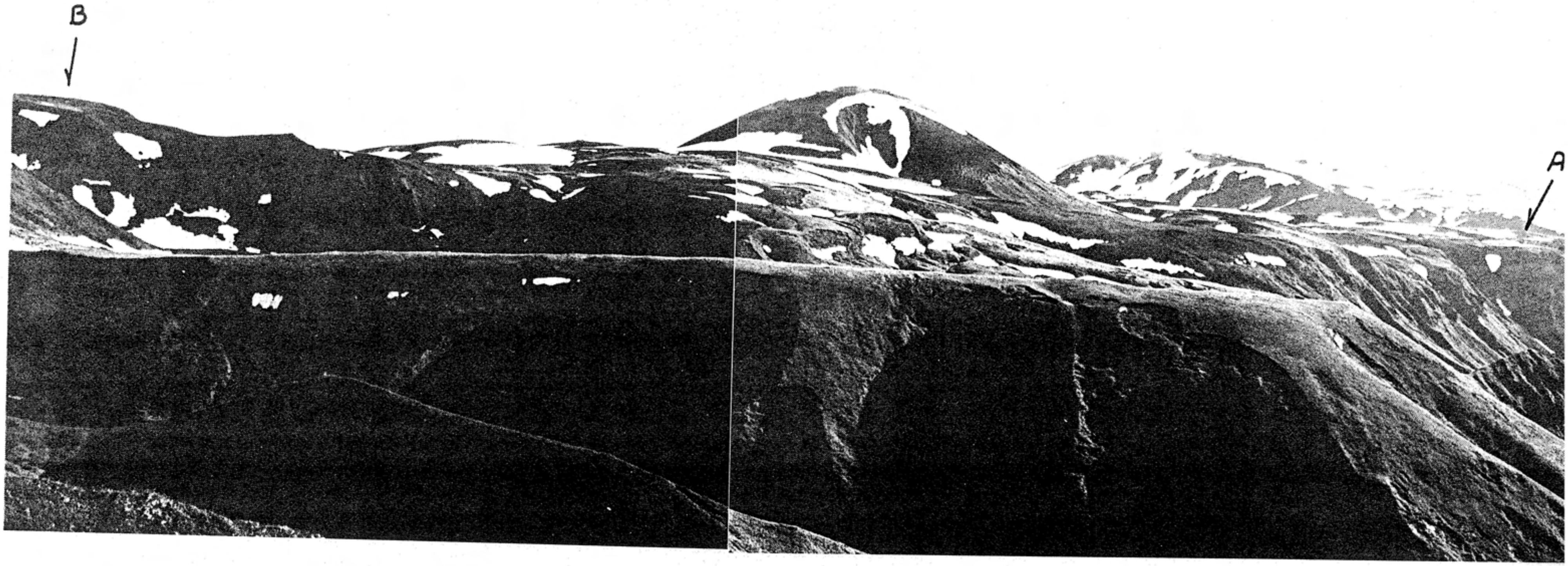


Figure 4. Panorama of volcanic uplands northeast of the power site. Sugarloaf, a subglacial volcanic cone, is at center. A road access route option (see Section C) joins the Makushin Valley-Driftwood Valley road near "A" and would proceed around the far side of Sugarloaf to "B".

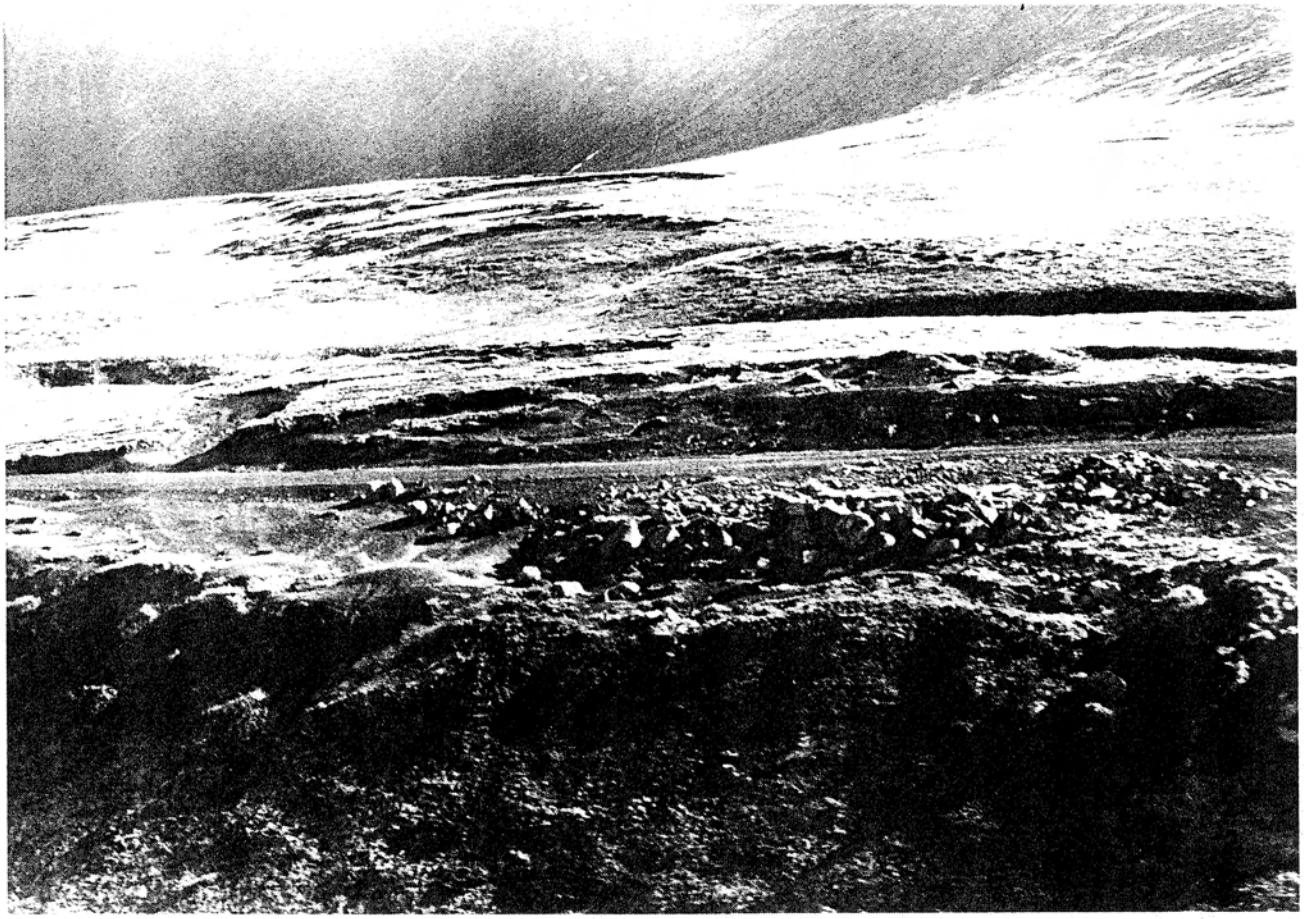


Figure 5. A segment of the existing road in Driftwood Valley. Most of this road requires only culvert and grade repair to be operational.

APPENDIX

COMPUTER-GENERATED OBLIQUE VIEW OF MAKUSHIN VALLEY AREA

By Gail March

SCOPE OF WORK

A 3-D view of Makushin Valley was generated by computer as part of a geotechnical assessment of a geothermal power plant site and transmission line corridor serving the cities of Unalaska and Dutch Harbor, Alaska (Plate A-3).

METHODOLOGY AND TECHNIQUES

Points were digitized along contour lines in the Makushin Valley area on 1:24,000 maps of the Mt. Makushin Area, Unalaska, Alaska (Republic Geothermal, 1984) and Makushin Valley and Vicinity, Unalaska, Alaska (ADGGS, 1984) using AMS, a digitizing software package by Autometric, Inc., on a Data General S250 minicomputer. Although the maps display 40 ft contours, 200 ft contours were used for digitizing in most cases, as the terrain is very steep. Where the terrain is unevenly sloping, points were added along intermediate contours. Summits and valley bottoms were also recorded with the digitizer. About 10,000 points were digitized in all.

Digitized points were then transferred to MOSS (Map Overlay and Statistical System), a map analysis package by Autometric, Inc. An interpolation program produced a continuous raster grid, 117 rows by 252 columns, with a cell size of 1 acre from the points.

RESULTS OF INVESTIGATION

Several types of maps can be generated from the raster grid. For this project slope and aspect maps and a 3-D view were produced. The slope and aspect maps were examined in the avalanche mapping portion of this project, but were not reproduced. The 3-D view is shown as Plate 1. It has a vertical exaggeration of 2, a rotation of 60° from north, and a viewing angle of 20° above the surface.

CONCLUSIONS AND RECOMMENDATIONS

The 3-D view of Makushin Valley shows graphically the steepness of the terrain involved in the project. It can be used to plot avalanche areas, landslide areas, geology, or anything else that would be more easily seen in 3-D than in map form.

REFERENCES CITED

Alaska Division of Geological and Geophysical Surveys, 1984, Makushin Valley and Vicinity, Unalaska, Alaska: 1:24,000, North Pacific Aerial Surveys, Inc.

Republic Geothermal, Inc., 1984, The Mt. Makushin Area, Unalaska, Alaska: 1:24,000, North Pacific Aerial Surveys, Inc.

ENGINEERING GEOLOGY OF THE PROPOSED SITE FOR A GEOTHERMAL POWER PLANT ON UNALASKA ISLAND, ALASKA

by R.A. Combellick

SCOPE OF WORK

The proposed site for a geothermal power plant on Unalaska Island is on the east flank of Makushin volcano about 12 mi west of Dutch Harbor (figs. 1 and 2). The site is on a gently-sloping terrace underlain by tephra, ash-flow tuff, and till. Site elevation is approximately 1,160ft above sea level. This report describes the results of a reconnaissance engineering-geologic study of the proposed power-plant site and its immediate vicinity. The study addressed site geology, topography and surface drainage, subsurface geology, engineering characteristics of near-surface soils, ground water, erosion, and slope instability. Field work was performed July 14-18, 1986. Although limited engineering-property data (grain-size distribution, density, and water content) were obtained for subsurface materials at the site, in-situ and laboratory strength tests were beyond the scope of the project.

Because of the large distances to possible alternative sites and the need to avoid excessive loss of pressure and temperature of the geothermal fluids enroute to the electrical-generating facility, production will most likely take place where the resource is proven at stratigraphic-test well ST-1, which was drilled by Republic Geothermal, Inc. in 1983 (Republic Geothermal, Inc., 1984). The study for this report was restricted to an area of approximately 7 acres immediately adjacent to ST-1.

METHODOLOGY AND TECHNIQUES USED

Topographic Mapping

A large-scale (1:480) topographic map was prepared for the 7-acre study area encompassing the ST-1 well site (Plate B-1). The purpose of this mapping was to provide location and elevation control for soil sampling and seismic-refraction profiling during the study and to provide topographic information that can be used for planning cut and fill, controlling drainage, and locating structures during subsequent planning of the power facility.

Elevation control was obtained from a survey stake near marker HV-3 (fig. 1), which was used by North Pacific Aerial Surveys to prepare a 1:24,000-scale topographic map. The elevation of this survey stake could not be verified in the field, so map elevations in relation to mean sea level may be in error by as much as 20ft. An altimeter survey performed by J.W. Reeder in 1983 yielded elevations that were 20to 40ft higher than those obtained during this survey. Although elevations above the datum may not be accurate, elevation differences between contours on the map are accurate to within 2 ft. Accurate location control (latitude and longitude) was not obtained.

Topographic mapping was done primarily with a plane table and alidaide, supplemented in some areas of the map with a theodolite and electronic distance-measuring instrument. Approximately 170 points were plotted. Some contours were drawn in the field, and notes were taken to assist in completing the contouring that could not be done in the field because of limited time.

Geologic Investigation

The regional geology of Unalaska Island and the Makushin geothermal area has been described by Arce (1983), Drewes and others (1961), Nye (this volume), Nye and others (1984), and Reeder and others (in press). This study also benefited from field discussions on regional and local geology with C.J. Nye, J.W. Reeder, and J.E. Beget.

Subsurface geology at the proposed power-plant site was studied by inspecting the stratigraphy exposed in river cuts and gullies along the margins of the terrace and by auger drilling in an area of several acres encompassing well ST-1. Drilling was performed with a gasoline-powered hand-operated auger using a 3-in.-diameter helix in 3 ft lengths. A total depth of 18ft was possible with the equipment available. Six holes were drilled and samples were obtained from all but one of these holes. Volumetric samples of the sandy volcanic ash in the upper several feet of soil were obtained using 6 3/4-in. long, 2-in. diameter thin-walled steel tubes pushed or pounded in by hand. These samples were used to determine density and moisture content of the soil.

At all but one location, the auger could not penetrate into the dense ash-flow tuff underlying the upper 9 to 13 ft of tephra, and the gravelly sand comprising the ash-flow tuff could not be sampled using the push tubes. Bag samples of this material were obtained from an exposures in the gully along the southern margin of the study area and from the auger tip in two holes.

Seismic-refraction Profiling

Two intersecting seismic-refraction profiles were made at the proposed power-plant site using data from the auger holes for depth control to the first refracting surface (Plate B-2). Profiles were obtained using two shots of about 6 lb Kinepak explosive mixture at 3-ft depth, one at each end of each line. The east-west profile (AA') used a 550-ft, 12-channel geophone line with 50-ft detectors spacings. The north-south profile (BB') used a 220-ft, 12-channel geophone line with 20-ft detector spacings. The shots were recorded on a Geometrics/Nimbus ES-1210 12-channel seismograph and the records were printed from its internal oscillograph.

Arrival times were corrected for elevation and plotted versus distance, then best-fit lines were drawn to determine refractor depths and P-wave velocities for each layer (Appendix A). The results were used in conjunction with the auger-hole data and observed stratigraphy to interpret and plot the profiles.

Laboratory Analyses

Grain-size analyses were performed at the Alaska Department of Transportation and Public Facilities materials laboratory in Fairbanks. All soil samples were analyzed using the U.S. standard sieve series. The fines were washed through the 200- mesh sieve, dried, and weighed. Grain-size distributions were not determined for the material passing the 200-mesh sieve. Results of the grain-size analyses are reported in Appendix B.

Wet densities were determined for the push-tube samples by weighing the sealed samples, subtracting the weights of the sample tubes, and dividing the weights by the known sample volumes. Water contents were determined by weighing the samples after drying and dividing the weight differences by the dry sample weights. Dry densities were calculated from the wet densities and water contents, then checked by dividing the dry sample weights by the sample volumes. These results are reported on Plate B-2.

Air-photo Interpretation

Vertical aerial photographs of the study area were examined stereoscopically to aid in interpreting the local geology and to assess potential erosion and slope-instability problems. Two series of photographs, one taken by the U.S. Geological Survey in 1950 (mission M467) and the other by North Pacific Aerial Surveys, Inc. in 1982, were compared to determine the amount of change, if any, during that 32 yr period. Both series of photographs are approximately 1:24,000 scale. Measurements were made using a micrometer-equipped parallax bar, and land forms and vegetation were examined closely for evidence of significant changes between 1950 and 1982.

RESULTS OF INVESTIGATION

Regional and Site Geology

The geology of the area surrounding the proposed power-plant site is dominated by the Tertiary Unalaska formation that forms the mountains to the east, Tertiary gabbronorite intrusive rocks that comprise the hillside sloping upward immediately west of the site, early-Holocene andesitic lava flows that fill Driftwood valley to the north, and mid- to late-Holocene glacial and pyroclastic deposits that underlie the site. Andesitic intrusive and extrusive rocks of the Unalaska formation are the oldest rocks on the island and are probably Miocene to early Pliocene age. The gabbronorite intrudes and complexly interfingers with the Unalaska formation in the vicinity of the site. Consequently, rocks of the Unalaska formation near the site have been metamorphosed to hornfels facies (Drewes and others, 1961; Nye and others, 1984).

Andesitic lava flows of Driftwood valley unconformably overlie the Unalaska formation and gabbronorite, and probably erupted from a vent on the east flank of Makushin volcano in late-Pleistocene or early-Holocene time (Nye, this volume). Although the terrace at the proposed power-plant site was directly in line with the upper portion of this flow as the flow moved down the flank of the volcano, the flow deposits are confined to the area north of the river in upper Makushin valley and do not underlie the younger pyroclastic deposits at the site. The question of why the flow did not enter this basin in the upper part of upper Makushin valley remains unanswered, but the most likely explanation is that a glacier occupied the head of the valley and diverted the flow to the north.

Early- to mid-Holocene glaciers scoured the surface of the lava flow and deposited till in upper Makushin valley. The till unconformably overlies altered gabbronorite bedrock beneath the proposed power-plant site and comprises the lower one half to two thirds of the terrace, which stands roughly 200 ft above the valley bottom at the site. Drilling logs indicate that the till is 90 ft thick at well site ST-1 and was initially interpreted as a lahar (Republic Geothermal, Inc., 1984). Other investigators who have recently examined the deposit in outcrops along the terrace margin interpret the deposit as till (J.W. Reeder, C.J. Nye, and J.E. Beget, oral commun., 1986). Nye (this volume) argues that there is little evidence of Holocene lahars in the area.

Between about 4,300 and 8,000 yr ago, volcaniclastic debris was deposited in upper Makushin valley during caldera collapse associated with one or more explosive eruptions (Reeder, 1983; Nye, this volume). This deposit overlies the till and forms the broad, flat surfaces of the terraces in upper Makushin valley upon which a thin (10 ft) layer of stratified air-fall ash was deposited in late-Holocene time. At the ST-1 well site, the volcaniclastic deposits consist of lightly welded ash-flow tuff.

Late-Holocene air-fall ash (tephra) blankets most of the area, including the older ash-flow tuff at the site and the gabbronorite on the hillside adjacent to the site. Instability of this material is responsible for many shallow slope failures in the area (see Reeder, this volume). Approximately 75 ft south of well ST-1 is the northern margin of a small debris-slide deposit that originated on the steep slope west of the terrace. This deposit is composed of fine volcanic ash, organic material, and occasional cobbles and boulders derived from the bedrock in the source area of the landslide.

Postglacial streams have incised deeply into the Quaternary volcanic and glacial deposits, carving the canyon in the lava flow between lower and upper Makushin valley and dissecting the volcaniclastic terraces in upper Makushin valley. Steep river cuts form the margins of these terraces and remain unvegetated in many places, suggesting that the streams continue to undercut the banks.

Topography and Surface Drainage

The terrace underlying the proposed power-plant site slopes gently to the southeast and has a surface relief of less than about 3 ft, except where incised by gullies that reach depths of 80 ft or more along the eastern margin (figs. 1 and 2, Plate B-1). The proposed site occupies the extreme northwest corner of the terrace, where the surface slope is 3 to 5 degrees (5 to 9 percent) (fig. 3). The portion of the terrace surface adjacent to well site ST-1, where the power plant would be located, is about 380 ft wide between the steep river cut on the north side of the terrace and the north margin of a gully that dissects the terrace (Plate B-1). The gully is about 30 ft deep and 50 ft wide near the site. A landslide deposit occupies most of the southwest quarter of the area of plate 1 and has a low, hummocky surface with some closed depressions.

The base of the hillside at the western margin of the terrace is about 40 ft west of ST-1. The lower part of the hillside slopes 25 to 35 degrees (47 to 70 percent) to the east.

Natural surface runoff at the site is to the southeast into the central gully. During the mid-July field work for this project, meltwater from snow on the hillside adjacent to the site was draining along the northeastern margin of the landslide deposit into the small tributary gully in the south center of the map area (Plate B-2).

Subsurface Geology

Stratigraphy

The proposed power-plant site is underlain by a thick section of late-Quaternary till, ash-flow tuff, and tephra (C.J. Nye, oral commun., 1986; J.W. Reeder, unpublished data) (fig. 4). These deposits overlie altered gabbronorite bedrock of Tertiary age. The glacially scoured bedrock surface slopes approximately 15 degrees west at a depth of 136 ft below the ST-1 well site, based on logs from ST-1 and the shallow abandoned well 20 ft to the east (Republic Geothermal, Inc., 1984). The well logs also indicate that the bouldery till overlying bedrock is 90 ft thick and the ash-flow tuff overlying the till is 36 ft thick at ST-1. The till and ash flow tuff thin out to the west at the margin of the terrace, where the bedrock surface rises abruptly and forms the steep hillside west of the site. A tephra deposit approximately 10 ft thick overlies the ash-flow tuff on the terrace and blankets the gabbronorite on the hillside.

The stratigraphy of the upper 29 ft of deposits near the site is exposed in a gully about 350 ft south of ST-2 (fig. 5). At this location, 7 ft of loose, stratified tephra overlie compact ash-flow tuff. The tephra consist of thinly bedded (1/4- to 6-in. thick) intermediate to mafic volcanic ash with occasional 3- to 6-in. layers of silicic lapilli. This material is easily excavated. A sharp contact separates the surface tephra unit and the underlying ash-flow tuff, which consists of angular lapilli and ash with no visible bedding. The tuff is lightly welded and is very difficult to excavate by hand.

Six auger holes drilled in the study area indicate that the shallow stratigraphy beneath the proposed power-plant site is very similar to that exposed in the gully to the south (Plate B-2). In all auger holes, 9 to 13 ft of sandy tephra overlie gravelly ash-flow tuff, which was impenetrable by power auger in all but one location. The relatively consistent thickness of tephra in the auger holes and in seismic-refraction profiles indicates that the surface of the underlying ash-flow tuff has a similar degree and aspect of slope as the terrace surface (3 to 5 degrees to the southeast).

Engineering Characteristics

The tephra deposit comprising approximately the upper 10 ft of material at the site is predominantly silty fine sand (SM, Unified Soil Classification). Grain-size distributions of the auger-hole samples in this upper layer are remarkably consistent and range from 51 to 69 percent fine to medium sand (ash) and 31 to 49 percent nonplastic fines (silt or volcanic dust) (Plate B-2). The exposure in the gully south of the site indicates that there are probably some lapilli (gravelly) layers in the soils at the site that were not sampled in the auger holes. Based on grain-size characteristics, the silty fine sand comprising most of the shallow subsurface soils at the site is inferred to have relatively low permeability and, therefore, poor to fair vertical drainage (Lambe and Whitman, 1969, table 19.3 and fig. 19.6).

Wet densities of the tephra samples from the auger holes range from 95.1 to 107.7 lb/ft^3. Water contents of these samples range from 39.4 to 73.7 percent, yielding dry densities of 54.8 to 77.31b/ft^3 (Plate 2). These densities are surprisingly low, considering the effort required at several locations to drive the push-tube sampler. The dry densities are much lower than the theoretical minimum densities for typical silty sand in its loosest state (Lambe and Whitman, 1969, table 3.2). Examination of the soil particles under a binocular microscope reveals that they are mostly very angular, irregularly shaped grains of pumice, volcanic glass, andesite(?), and lightly cemented aggregate particles. Most grains can be broken easily with a knife. Apparently the irregular shape and vesicular nature of many of the particles are responsible for the anomalously low densities. Considering the grain characteristics and moderate effort required to drive the push-tube sampler, the soil could be close to its maximum dry density. Compaction tests were not performed to determine optimum moisture content and maximum dry density.

Soils in the upper 9 ft of auger hole AH5, in the landslide deposit, were very soft. The water table at this location was 2.5 ft below the ground surface. The upper 4 ft of soil are organic-rich, and a layer of peat was encountered from 3.5 to 4 ft. The peat layer probably represents buried soil at the base of the landslide deposit. At 9 ft, the soils become noticeably firmer. No usable soil samples were recovered from this auger hole because of the looseness of the soil and the large quantity of water, which washed the soil from the sampler.

The ash-flow tuff underlying the tephra is predominantly silty gravelly sand (SM, Unified Soil Classification). Grain-size compositions of samples in the gully exposure (fig. 5) and in the auger-hole samples (Plate B-2) are 9 to 34 percent gravel (lapilli), 59 to 70 percent sand (ash), and 7 to 21 percent nonplastic silt (volcanic dust). The coarse grains are predominantly pebble size, subrounded to very angular, and supported by a highly compacted and lightly welded fine-grained matrix. The deposit was very difficult to excavate by hand in the gully exposure south of the ST-1 well site and could not be penetrated with a power auger except at location AH5. No controlled-volume samples of the ash-flow tuff were collected for density determinations.

Geologic Cross Sections

Data from the auger holes and seismic-refraction lines were used to plot two intersecting geologic cross sections of the site (Plate B-2). These cross- sections show that the tephra layer has a relatively uniform thickness of 6 to 10 ft, thinning to the south and east. At the south end of line BB', a discrepancy is evident between the thickness of the tephra layer indicated on the seismic-refraction profile (6.8 ft) and the depth to the top of the gravelly layer in auger-hole AH5 (13.0 ft). This discrepancy may be due to uncertainty about the depth to the gravel in the auger hole, where the soils were very wet and soft during sampling. Alternatively, the 6.8 ft depth may correspond to the transition from soft, organic-rich soils of the landslide deposit to the firmer, undisturbed tephra below.

The ash-flow tuff is 29 ft thick at the west end of line AA' and reaches a maximum thickness of 61 ft near the east end of the same line. Thicknesses of this layer calculated from the seismic-refraction profiles compare favorably to its thickness of 36 ft in well ST-1. The top of the underlying till layer undulates somewhat along line AA', with an overall slope to the east. Depth to bedrock, as calculated from the seismic-refraction data, ranges from 114 ft at the west end of line AA' to 224 ft at the east end. This also appears consistent with the 136 ft depth reported in well ST-1.

An apparent transition in seismic velocity of the tephra and ash-flow units from north to south complicates interpretation of line BB' (Plate B-2). This transition from lower velocities on the north end to higher velocities on the south end may be related to the higher saturation of the soils toward the south. Returns at three geophones on line BB' also indicate the presence of a higher-velocity layer in the ash-flow tuff at a depth of about 27 ft. This may be a zone of cobbles or boulders in the ash-flow tuff, which would be consistent with observations in the river-cut and gully exposures.

Slope Instability

Numerous slope failures have occurred in Makushin valley and elsewhere in the northern part of Unalaska Island, particularly where thin tephra deposits overlie bedrock on steep slopes (Reeder, this volume). One such failure occurred on the slope above the proposed power-plant site (fig. 3). The resulting debris-slide deposit covers most of the southwest quarter of the study area (Plate B-2). Its northern margin is approximately 75 ft south of well ST-1. This slide occurred before September 1950, because it appeared on the U.S. Geological Survey aerial photography taken at that time.

The headwall of the debris slide at the site extends about 100 ft above the base of the slope. The failure plane is probably less than 10 ft below the surface, at the base of or within the tephra. The transition from very loose to firm soils in auger-hole AH2 is probably the failure surface below the debris-slide deposit and suggests that the deposit is 9 ft thick at this location (Plate B-2).

Additional slides are possible, if not likely, on this slope and may occur north of the previous slide on the slope above the ST-1 well site. However, the source area above the well site is much smaller because the slope extends only about 50 ft above terrace level. Consequently, the volume of a slide originating above the well would be small (probably less than 2,000 yd^3, assuming the failure plane is at 10 ft depth).

Strong earthquakes may trigger many of the tephra slides on steep slopes in the region, although saturation during heavy precipitation or snow melt is probably sufficient. Earthquake-induced liquefaction of tephra on the terraces is conceivable if a major earthquake occurs when the tephra is saturated, but no evidence of past failures of this type were observed. Because of the high angularity of ash particles, cyclic stresses from an earthquake probably would have to be stronger to cause rearrangement of particles in the tephra than in alluvial silty sand of similar grain-size characteristics and degree of compaction.

With the exception of talus resulting from surface rock falls (fig. 4), there is no evidence of slope instability below the proposed power-plant site along the northern terrace margin. The till and ash-flow tuff comprising most of the geologic section under the site are very compact, include a wide range of grain sizes and shapes that form an interlocking fabric, and are resistant to water infiltration. Major slope failures along the terrace margins that would threaten the site seem unlikely.

Ground Water

Water was encountered in auger holes AH1 and AH2 near the base of the slope and in AH5 in the landslide deposit (Plate B-2). Water content of the soil was relatively high in samples collected from all auger holes. In the gully and river-cut exposures, the lower part of the tephra layer is wet, in contrast with the dry underlying ash-flow tuff unit. At some locations in the gullies, water emanates from springs at the base of the tephra deposit. The water is apparently perched above the ash-flow tuff and saturates the tephra near the water source. During the time of observations and auger drilling, the source of this water appeared to be melting snow on the slope above the site.

The water-table levels and degree of saturation of the soil probably fluctuate substantially throughout the year with variations in precipitation and snow melt. Considering the high annual precipitation at Dutch Harbor (58 in., including 81 in. of snow), which may be considerably higher at the site, ground water is probably present in the tephra unit year round.

Erosion

Wind Erosion

Because of the sparseness of vegetation on the terrace and the small grain size and low density of the ash on the surface, the tephra deposit is highly susceptible to wind erosion. Surface features on the terrace provide some evidence that there has been reworking of the tephra by wind. The higher, more irregular topography along the north margin of the terrace near ST-1 may be wind-redeposited ash derived from the adjacent river-cut exposure (J.W. Reeder, oral commun., 1986). During field observations, moderate winds (estimated 10 to 20 mph) blew ash from gully exposures several tens of feet into the air.

River-bank and Gully Erosion

The dissected morphology and fresh river-cut exposures on the terrace at the proposed power-plant site suggest that river-bank and gully erosion might threaten the site. Considering that the volcaniclastic deposits comprising the terraces in upper Makushin valley probably were contiguous and covered a much larger area when initially deposited, a substantial, but unknown, amount of erosion has occurred during the last 4,300 to 8,000 yr. Many of the exposures around the margins of the terrace are devoid of vegetation, indicating some degree of erosion of the soils on the slopes. One of these exposures is the high river cut on the north terrace margin adjacent to the site. The top of this exposure is within about 90 ft of the ST-1 well site.

To determine rates of river erosion and gully development, observations and measurements were made of features on 1:24,000-scale vertical aerial photographs taken in 1950 (U.S. Geological Survey) and 1982 (North Pacific Aerial Surveys). No discernible changes in morphology of the gullies or terrace margins were observed between the two series of photographs, and no headward progression of active cutbanks was evident within the accuracy of measurements. Additionally, positions of the major unvegetated river cuts along the terrace margins were the same in 1982 as in 1950, indicating that the probable areas of erosion had not changed during that period. The conclusion that can be drawn from these observations is that rates of erosion and gully development are too low to be detected on aerial photographs for the 32-yr period between these aerial surveys.

CONCLUSIONS AND RECOMMENDATIONS

Results of this reconnaissance engineering-geologic study indicate that the terrace surface adjacent to resource-confirmation well ST-1 is a favorable site for the proposed geothermal power facility. The terrace surface at this location is approximately 1,160 ft above sea level, 200 ft above the adjacent valley bottom to the north, and slopes 3 to 5 degrees to the southeast. Because of the height of the terrace above the valley floor and the steepness of the terrace margins, difficult access is probably the most serious drawback of this site.

Selection of the exact site for the facility should take into consideration surface drainage, ground-water conditions, and slope instability on the hillside west of ST-1 (including snow-avalanche potential; see March, this volume). With the exception of possible engineering effects of spatial variations in ground-water conditions, the foundation suitability of the tephra and underlying ash-flow tuff appears good and does not vary substantially with location. Soils in the landslide deposit south of ST-1, however, are organic-rich and very soft and are much less suitable as a bearing material.

By locating the structure(s) directly east of the ST-1 well site, potential problems with landslides or snow avalanches can be avoided. A deflecting wall designed to divert snow avalanches and small landslides could be installed upslope from the well to protect well-head structures. If structures are placed on or near the landslide deposit to the south, drainage from the hillside should be intercepted and diverted into the gully at the base of the slope in the southwest corner of the map area (Plate B-2). Structures south of the well site would be more vulnerable to snow avalanches and further landslides because of the larger source area.

Subsurface soils at this site, in the vicinity of auger holes AH3 and AH4 (Plate B-2), consist of 10 ft of air-fall volcanic ash (tephra) overlying about 40 ft of lightly welded ash-flow tuff. Below the ash-flow tuff is about 100 ft of bouldery till overlying altered gabbronorite bedrock. The tephra is composed of stratified loose to firm silty fine sand and is easily excavated by hand. The underlying ash-flow tuff is composed of very compact silty gravelly sand that is difficult to excavate by hand and impenetrable by small power auger. Coarse grains in the ash-flow tuff are mostly pebble size and very angular.

The low density of the tephra is not necessarily an indication that the deposit is poorly compacted, which would cause it to be prone to settlement under load. Irregular shapes and vesicular nature of the soil particles are probably responsible for the low density. If the natural soil is near its maximum density, it should be suitable for conventional footing or slab foundations. Compaction and compression tests should be performed on samples of the tephra to determine its maximum density and bearing capacity.

Depending on the types of structures contemplated and the results of further laboratory tests, the underlying ash-flow tuff may prove preferable as a bearing material. Judging from the grain-size composition and compactness of the ash-flow tuff, its bearing capacity is probably very high. It, too, should be tested in the laboratory to confirm its load-bearing properties. The silt and fine sand comprising the tephra is susceptible to wind erosion, because of the low density of the particles. Erosion by wind and surface water can be minimized by planting grass or covering soil with a suitable coarse material in exposed areas. Comparative observations of aerial photographs taken in 1950 and 1982 indicate that erosion of the terrace margins should not threaten the site for the near future (30 years or more), but the position of the steep river cut adjacent to the site on the north side of the terrace should be monitored.

ACKNOWLEDGEMENTS

This study was funded by the Alaska Power Authority. I thank R.D. Allely, G.D. March, D.F. Jones, David Denig-Chakroff, W.E. Long, C.E. Holmes, and S.J. Carrick for their assistance in the field, and T.C. Harwood for providing laboratory services at the Alaska Department of Transportation and Public Facilities in Fairbanks. I also thank R.G. Updike for providing base maps, aerial photographs, and many useful suggestions. R.D. Allely processed and interpreted the seismic-refraction data with the assistance of J.W. Reeder.

REFERENCES CITED

Arce, G.N., 1983, Volcanic hazards from Makushin volcano, northern Unalaska Island, Alaska: Fairbanks, University of Alaska unpublished M.S. thesis, 142 p.

Drewes, H., Fraser, G.D., Snyder, G.L., and Barnett, H.F., Jr., 1961: Geology of Unalaska Island and adjacent insular shelf, Aleutian Islands, Alaska, U.S. Geological Survey Bulletin 1028-S, p. 583-676.

Lambe, T.W., and Whitman, R.V., 1969, Soil Mechanics: New York, John Wiley & Sons, 553 p.

Nye, C.J., Queen, L.D., and Motyka, R.J., 1984, Geologic map of the Makushin geothermal area, Unalaska Island, Alaska: Alaska Division of Geological and Geophysical Surveys Report of Investigations 84-3, 2 sheets, scale 1:24,000.

Reeder, J.W., Preliminary dating of the caldera-forming Holocene volcanic events for the eastern Aleutian Islands [abs.]: Geological Society of America Abstracts with Programs, v.15. no.6, p. 688.

Reeder, J.W., Denig-Chakroff, David, and Economides, M.J., in press, The geology and geothermal resource of the Makushin volcano region of Unalaska Island, Alaska: Transactions of the 1985 International Symposium of Geothermal Energy, Kailua-Kona, Hawaii.

Republic Geothermal, Inc., 1984, The Unalaska geothermal exploration project Phase II final report: Santa Fe Springs, California, 106 p. plus appendices.

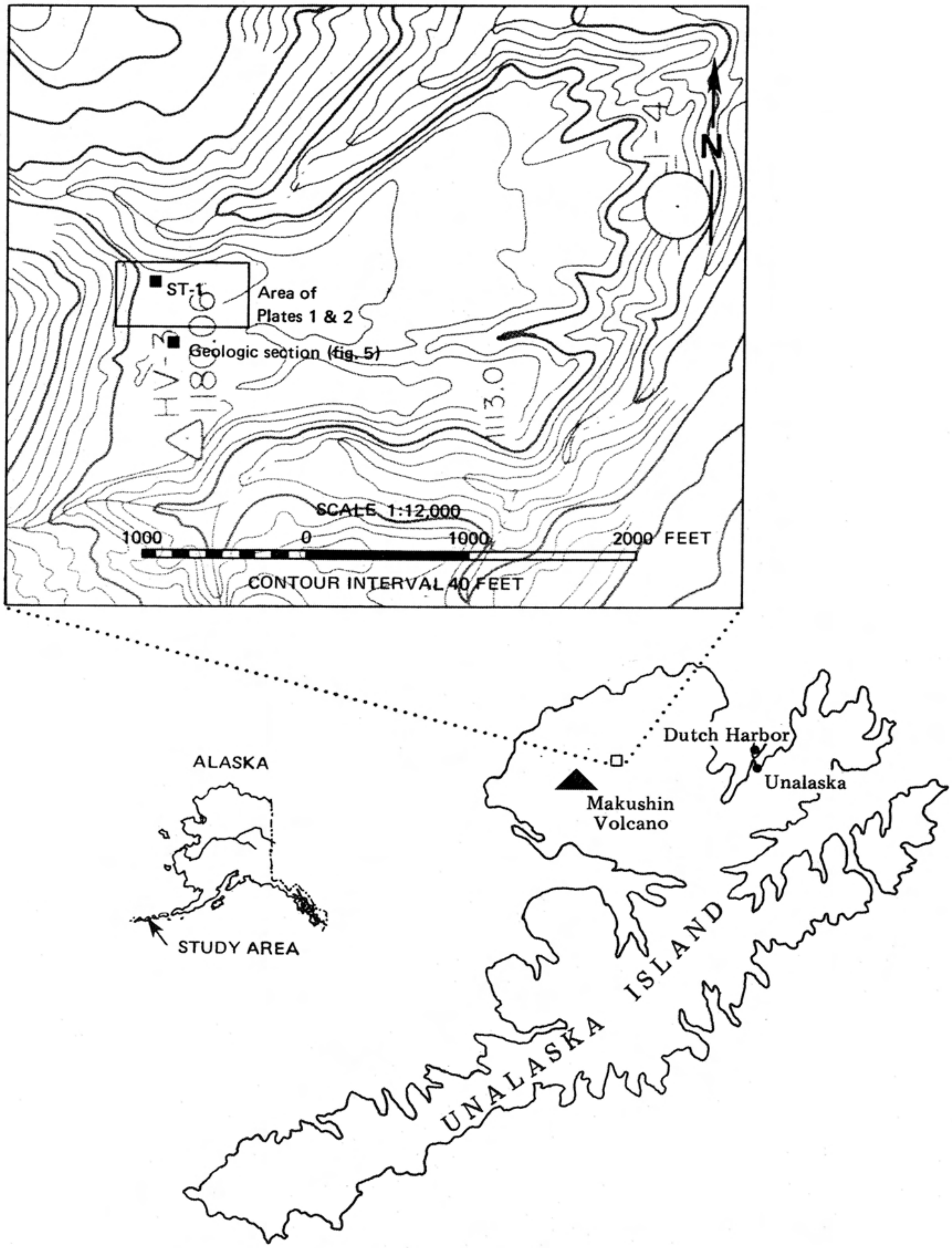


Figure 1. Location of study area and resource-confirmation well ST-1.

Figure 2. View southwest of volcaniclastic terrace in upper Makushin valley, showing (A) proposed power-plant site, (B) location of photograph in figure 4, and location of resource-confirmation well ST-1.

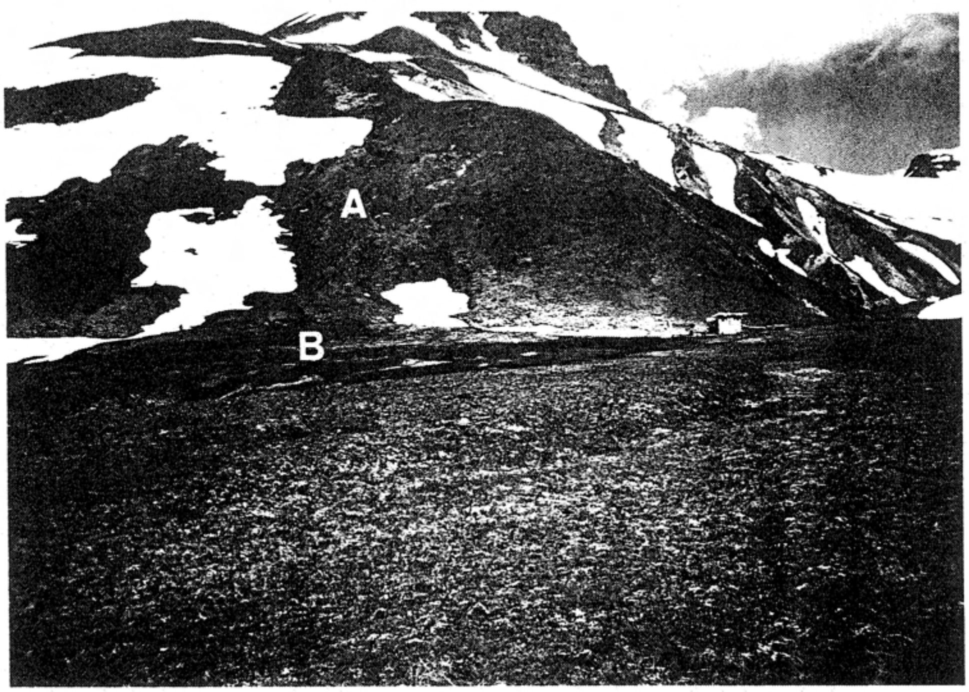


Figure 3. View west of proposed power-plant site, showing well-head shelter at ST-1, (A) slide scar, and (B) landslide deposit south of the well site.

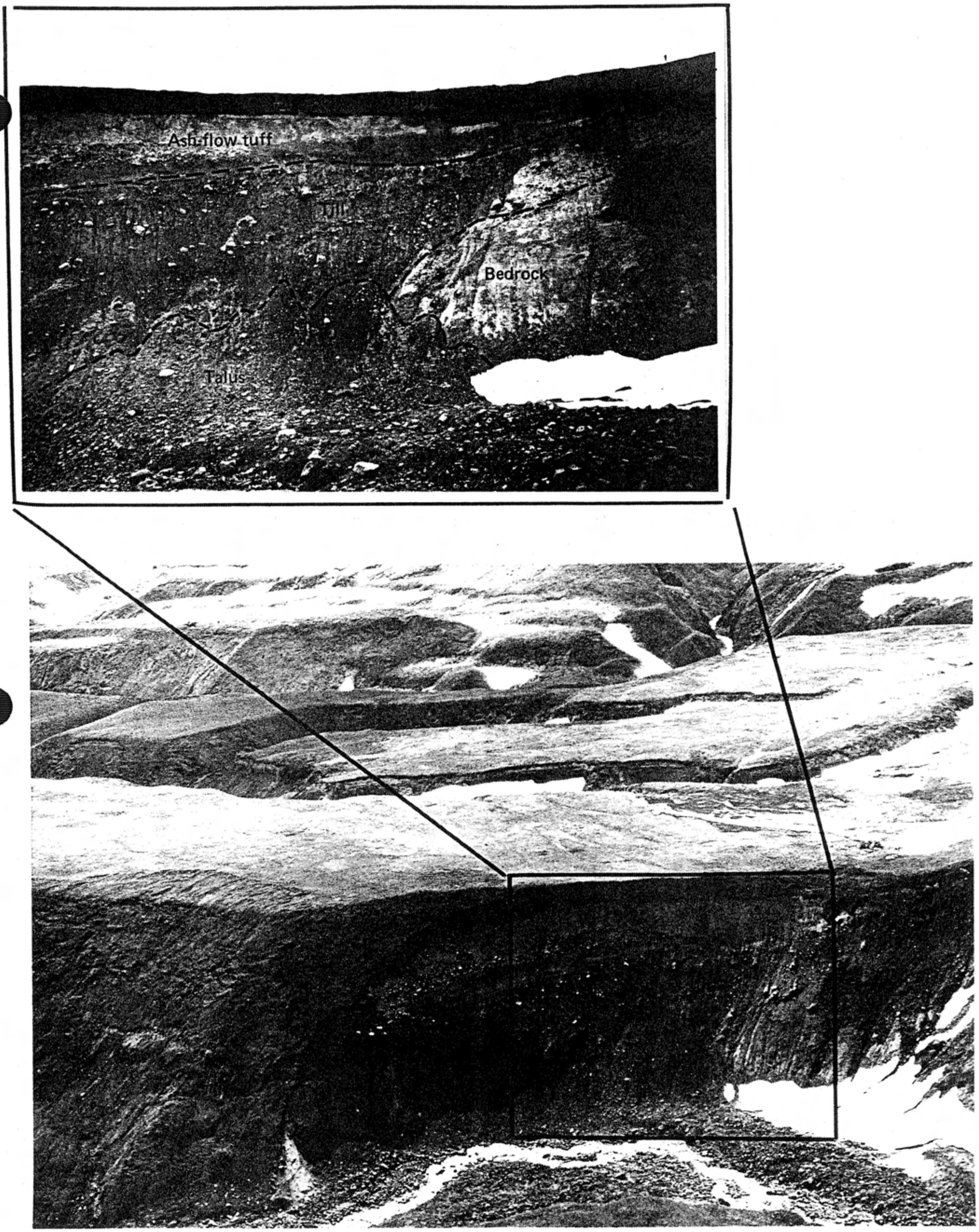


Figure 4. View south of exposure in northern margin of terrace near resource-confirmation well ST-1 (see fig. 2 for location).

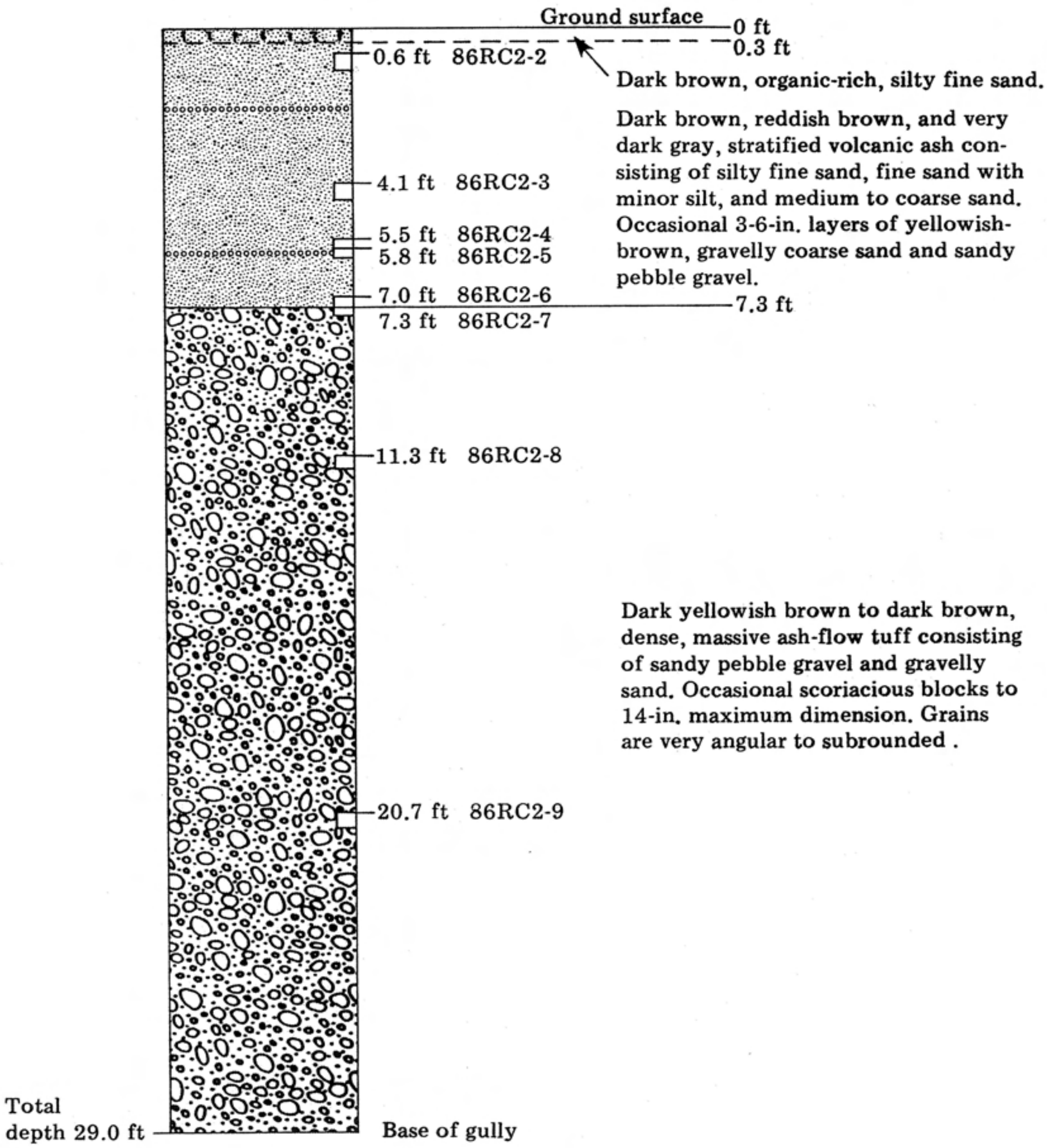


Figure 5. Geologic section exposed in gully, about 350 ft south of resource-confirmation well ST-1 (see fig. 1 for location). Grain-size composition of samples from the upper volcanic-ash unit (excluding occasional gravel layers) averages 51% sand and 49% silt. The underlying ash-flow tuff averages 24% gravel, 65% sand, and 11% silt at this location (see appendix B for results of the grain-size analyses).

APPENDIX A of SECTION B

INTERPRETATION OF SEISMIC-REFRACTION PROFILES AT THE PROPOSED SITE FOR A GEOTHERMAL POWER PLANT ON UNALASKA ISLAND, ALASKA

By R.D. Allely

INTRODUCTION

Two intersecting, reversed seismic-refraction lines were surveyed at the proposed power-plant site on July 17, 1986 to profile surficial tephra, ash-flow tuff, and till deposits (Plate B-2). The east-west profile (AA') used a 550-ft line with 50-ft geophone spacing, which was crossed at station 135 by a 220-ft north-south line (BB') with 20-ft geophone spacing. Shots consisting of 5 to 6 lb of high-velocity Kinepak explosive mixture were detonated at both ends of each geophone line. Near-shot geophones were inset short distances to determine shallow overburden velocity. Shot-point and geophone locations and elevations were surveyed using a plane table and alidade. Refraction data were collected using a Geometrics 12-channel signal-enhancement seismograph.

METHODS OF ANALYSIS

Theory

First-arrival times of the seismic waves were determined from paper copies, aided by video-screen traces. These were plotted versus geophone distances from the shot points (figs. A1 and A2). Lineups of these arrival times along best-fit straight-line segments represent returns from refracting layers, with line slope equal to the inverse of apparent velocity. Two velocity segments representing the same refractor shots in opposite directions can have significantly differing velocities. If this is due to dip of the refractor surface, true layer velocity is calculated using a dipping-layer solution (Dobrin, 1960). True velocities are then used with time intercepts from projections of each refractor velocity segment to the time axis to calculate time-intercept depths perpendicular to the interface from the shot point.

Deviations from straight-line segments are usually present on travel-time curves, generally due to variations in refractor seismic velocity or topography. Where arrival-time returns representing the same refractor for a given pair of shots cross each other (refractor overlap), differences in arrival times can be plotted versus distance to produce lines that have a slope equal to half the true velocity of that refractor. Topographic effects cancel, then deviations from a straight line are due only to laterally varying velocities for a return pair in the same refractor, or to two geophones receiving signals from a mix of two refractors. Ambiguities on arrival time-distance plots are often resolved when used in conjunction with the arrival time-difference plot.

A reduced arrival-time plot yields the same information, and more. Delay times (propagation time downward through overlying layers) are computed for layers overlying a refractor along a segment where a reversed arrival-time pair exhibits refractor overlap. When subtracted from arrival times, reduced arrival times result. They are the equivalent of placing the shots and geophones directly atop the refractor. These line up at true refractor velocity, should be identical to arrival time-difference velocities, and are useful in the same ways. This reduced arrival curve can be extrapolated beyond the calculated segment beneath arrival time-distance returns for the same refractor. Overlying layer delay times are then read as differences between the two curves. All delay times are then used to calculate refractor thicknesses.

Application

Raw arrival times were plotted on arrival time-distance graphs. Seismic velocity of the surface tephra was calculated from returns on the first geophones. Best-fit apparent-velocity line segments for ash-flow tuff, till, and bedrock yielded apparent velocities and intercept times for those layers. Arrival time-difference plots facilitated assigning ambiguous geophone returns to specific layers. Dipping-layer solutions were used to calculate true velocities from apparent-velocity refractor pairs. Time-intercept layer thicknesses were then calculated. Resulting depths did not always correspond to known stratigraphy, so arrival times were vertically corrected for variations due to surface topography. Corrected arrival-time plots gave different apparent velocities, true velocities, and time intercepts, which yielded better profile models. On line AA', refractor overlap for the till layer allowed calculation of delay-time depths. Combined delay times were calculated for overlying tephra and ashflow layers from arrival-time pairs and by extrapolation. Then first-layer delay times for the surface tephra were calculated for each station using auger-hole, seismic, and interpolated thicknesses. These were subtracted from the combined times, and the differences used to calculate ash-flow tuff thickness at each station.

DISCUSSION

Line AA'

Tephra overburden velocities at each end of line AA' agree closely and are typical of loose soil or weathered surface material (Redpath, 1973). The auger holes provided excellent thickness control for time-intercept depth correlation in the western portion of the line and for interpolating thickness from stations 0 to 350 (plate B-2). Thickness was tapered to a seismic depth of 6 ft at station 550. These depths were used in conjunction with an average velocity of 1,095 ft/s and dip-averaged velocity of 3,736 ft/s for the ash-flow tuff to calculate delay times for the tephra.

Combined delay times for first and second layers were calculated for arrival-time pairs in the till overlap segment, using dip-averaged velocities for the ash-flow tuff and till (3,736 and 8,905 ft/s, respectively). At some stations, calculated ash-flow tuff thickness variations appeared excessive, so were smoothed out. This is justifiable given errors that may be present in estimating overburden thickness or calculating refractor velocities.

Delay-time depths of the interface between ash-flow tuff and till on line AA' agree well on the west end with the time-intercept depth. On the east end, the time-intercept depth was about 10 ft deeper than the delay-time solution, probably due to an erroneous extrapolation of reduced time-velocity lines. The interface was flexed downward on its eastern 100 ft to average the difference. The approximate 6-degree dip of the profile agrees well with dips of 7 degrees seen aerial photographs in two large canyon exposures.

The data suggest that the ash-flow tuff velocity may vary laterally. Tephra thickness appears uniform west of station 350 but the underlying interface is interpolated from station 350 to station 550. Lithology, moisture content, and degree of consolidation may also vary along the eastern segment. Without interior shots, we lack velocity and time intercept-depth control, and shallow-refractor overlap necessary to discern these differences.

Using apparent velocities for the ash-flow tuff, the time-intercept solution is nearly flat, descending from 1,100-ft elevation at station 0 to 1090-ft elevation at station 550. This agrees with the faster (up-dip) apparent velocity of the till toward the east, because in this model the ground surface dips more steeply to the east than does the till surface. However, the delay-time solution calculated from apparent velocity exhibits topographic extremes in the western 150 ft, and shows a 40-ft rise to 1090-ft elevation at station 550. This conflicts with the relatively smooth surface of consistent eastward dip seen in the canyon exposures, so the dip-averaged velocity model for the ash-flow tuff is favored.

The bedrock solution is generalized. A surface dip of approximately 16 degrees was observed at the two ST-1 wells (Republic Geothermal, Inc., 1973), and assumed for the entire line. Given this dip, a true velocity of 16,724 ft/s was calculated from an apparent up-dip velocity of 31,900 ft/s. This is a typical lower-range velocity for fresh granitic rocks (Redpath, 1973) and appears reasonable for the altered gabbronorite underlying the power-plant site. The profile compares favorably with a three-point bedrock-surface solution used to contour bedrock-surface elevations. Elevation contours at the top of the till also agree with the general picture seen along the profile, reflecting underlying bedrock configuration in subdued fashion.

Line BB'

This line exhibits more variation in surface-layer velocity, and an apparent intermediate refractor on the south-end shot (Plate B-2, fig. A2). Lacking refractor overlap, profile interpretation of line BB' is more tenuous.

Raw arrival-time apparent velocities yielded north-end depths that did not compare will with canyon-wall stratigraphy (47 ft vertical from surface to top of till). However, dip-corrected velocities yielded more comparable depths. South-end seismic depths were similar in both cases, yet puzzling. A seismic first-layer thickness of 6.8 ft did not agree with observations in auger hole AH5 (Plate B-2). Either tephra was absent, or stratigraphically obscured by moisture content, as suggested by the higher overburden velocity.

Arrival times were then vertically corrected to a sloping datum. New apparent and true velocities gave similar time-intercept thicknesses for both ends, supporting south-end seismic-depth calculations. An ash-flow tuff thickness of 46 ft was calculated using dip-averaged ash-flow tuff and till velocities, and projected to station 60, where this till return segment is seen (fig. A2). The ash-flow tuff then appears as a southward-thickening wedge north of the velocity-transition zone.

The intermediate 6,350-ft/s segment became more evident on the corrected arrival-time graph. When treated as a third layer, it projects to the south with a 20-ft thickness. If this return represents the gravel layer seen at 13-ft depth in AH5, it comes up even farther at station 220, and the ash-flow tuff thins to only 11 ft.

South of the transition zone, interpretation is more difficult. Surface saturation seen from stations 80 to 220 suggests the presence of a wet-dry transition between stations 80 and 100 as the cause of the apparent slowdown of the south-end shot as it locally exits the saturated zone. Lacking this, only a transition in refractors from shallow on the south to deeper on the north would explain this velocity difference. The 6,350-ft/s segment probably represents a wet, denser lower unit of the ash-flow tuff. The returns slow considerably between stations 100 and 60, where they exit the inferred wet ash zone. To the north, intermediate-segment returns are overtaken by faster arrivals from the underlying till. The north-end shot does not show evidence of the intermediate layer because the geophones received returns from the underlying till before they arrived at this segment. This suggests that the inferred intermediate layer does not exist north of the transition zone.

The chief problem on the southern half of line BB' is how to interpret depth to till. Using an apparent-velocity three-layer solution for the south-end shot that ignores the intermediate layer, a south-end ashflow thickness of 56 ft is calculated and projected to station 220. This agrees with the southward-thickening picture on the north end, which projects through the delay-time thickness at the intersection with line AA'. The profile then shows till overlain by a discontinuous, indeterminate length of a 6,350-ft/s layer, and upper ash-flow tuff and tephra layers. A four-layer solution yields an unlikely intermediate-layer thickness of about 80 ft, for a depth of 110 ft to till.

Although the till surface should rise gradually toward the south as it approaches the bedrock slope, line BB' is located far enough east that projections have little meaning without depth control. More profiling or drilling is needed for better refractor definition south of the velocity transition.

REFERENCES CITED

Dobrin, M.B., 1960, Introduction to geophysical prospecting: New York, McGraw-Hill, 446 p.

Redpath, B.R., 1973, Seismic-refraction exploration for engineering site investigations: Livermore, California, Exploration Excavation Research Laboratory, 51 p.

Republic Geothermal, Inc., 1984, The Unalaska geothermal exploration project - Phase II final report: Santa Fe Springs, California, 106 p. plus appendices.

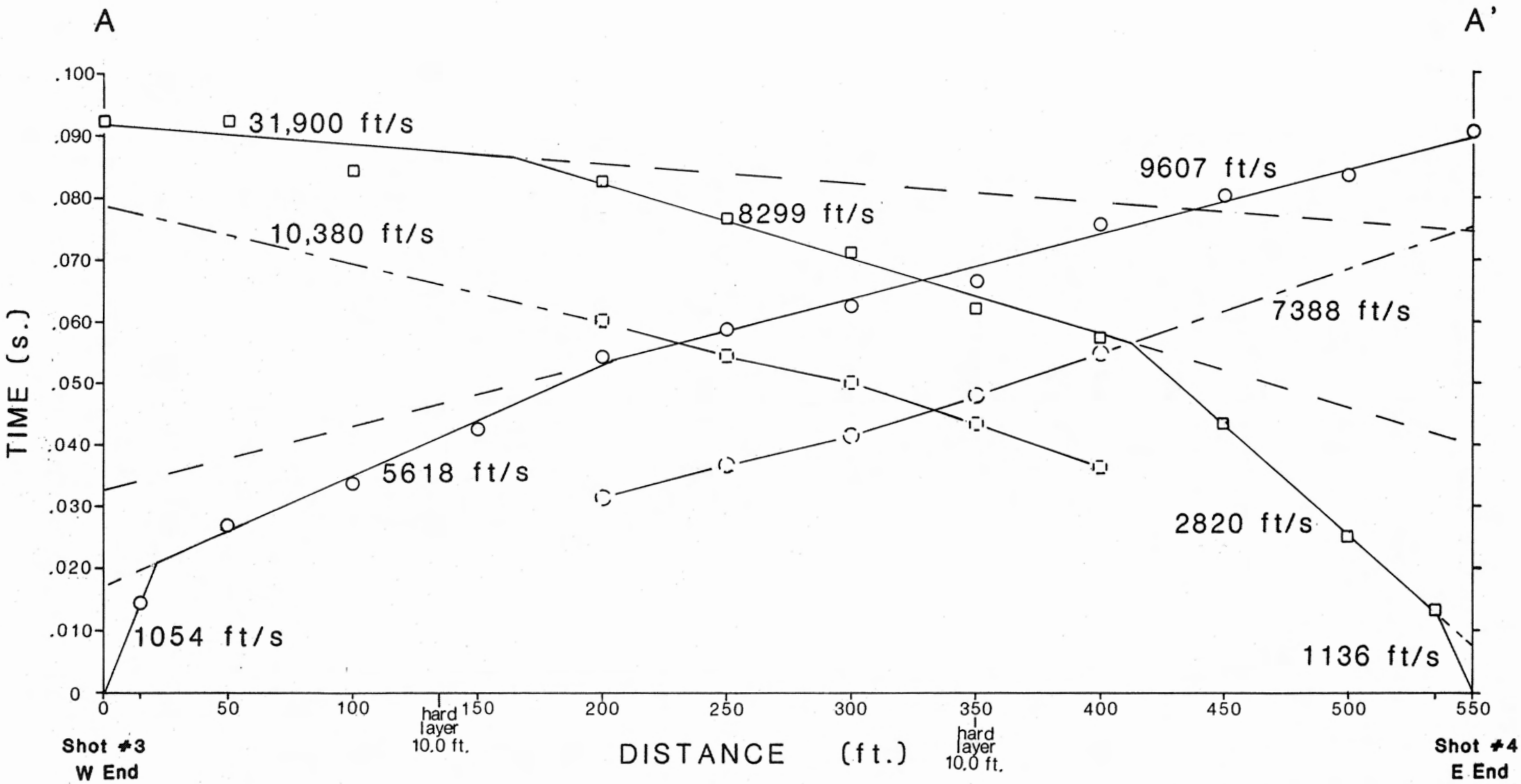


Figure A1. Plot of datum-corrected arrival times versus distance, line AA' (see plate 2).

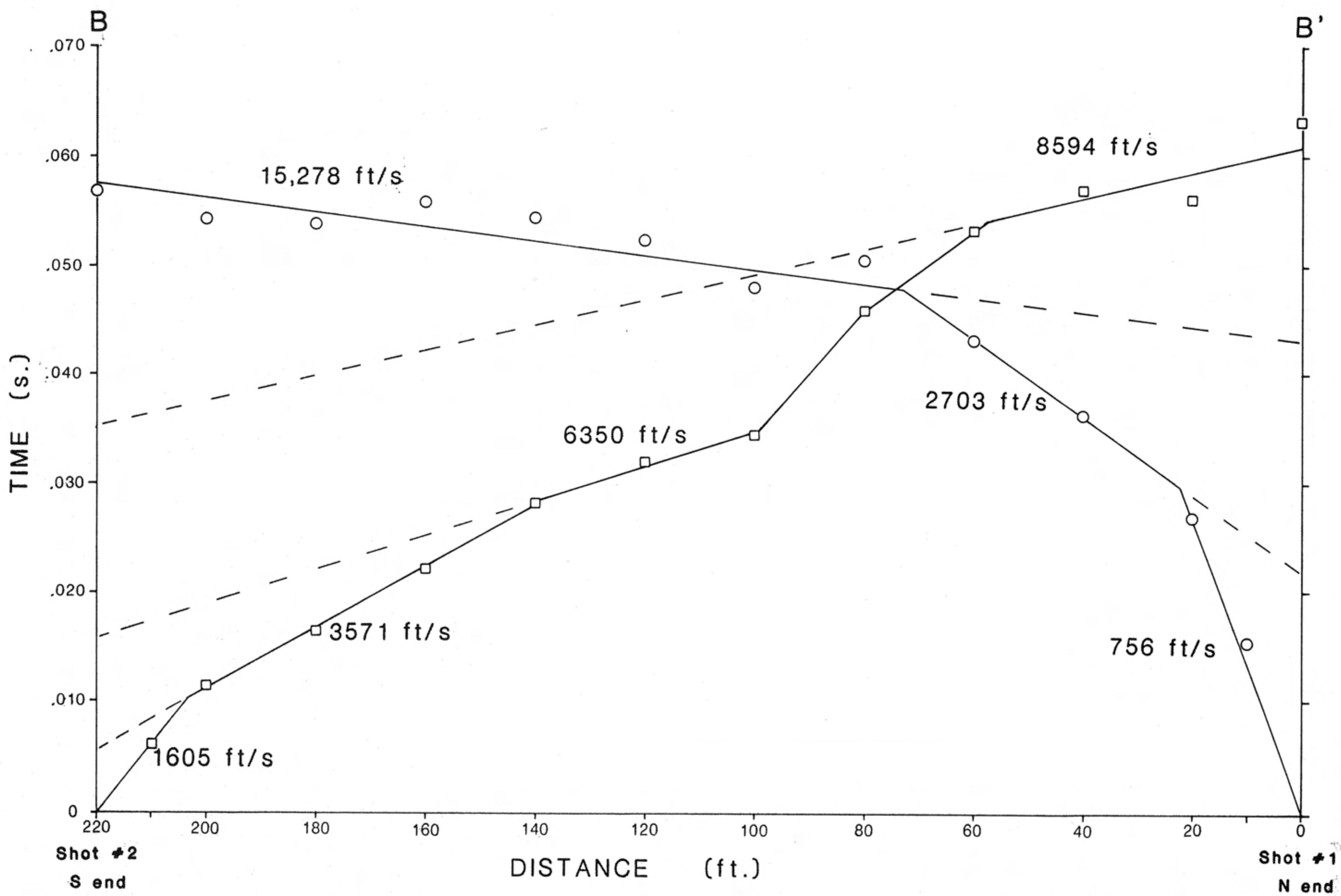


Figure A2. Plot of datum-corrected arrival time versus distance, line BB' (see plate 2).

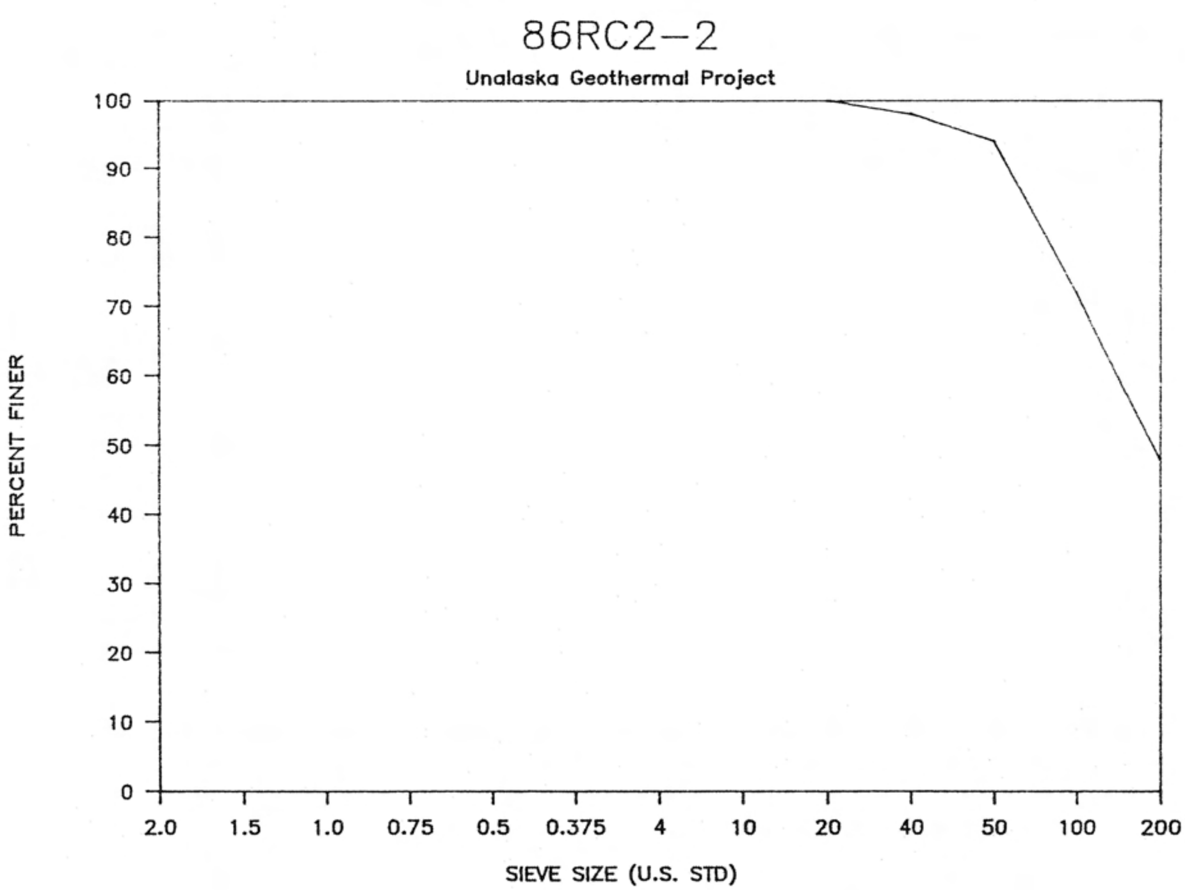
APPENDIX B of SECTION B

GRAIN-SIZE ANALYSIS

GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: 86RC2-2

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26		
0.5	12.7	-3.67		
0.375	9.5	-3.25		
4	4.76	-2.25		
10	2.00	-1.00		
20	0.84	0.25	100	2
40	0.42	1.25	98	4
50	0.30	1.75	94	22
100	0.149	2.75	72	24
200	0.074	3.75	48	48

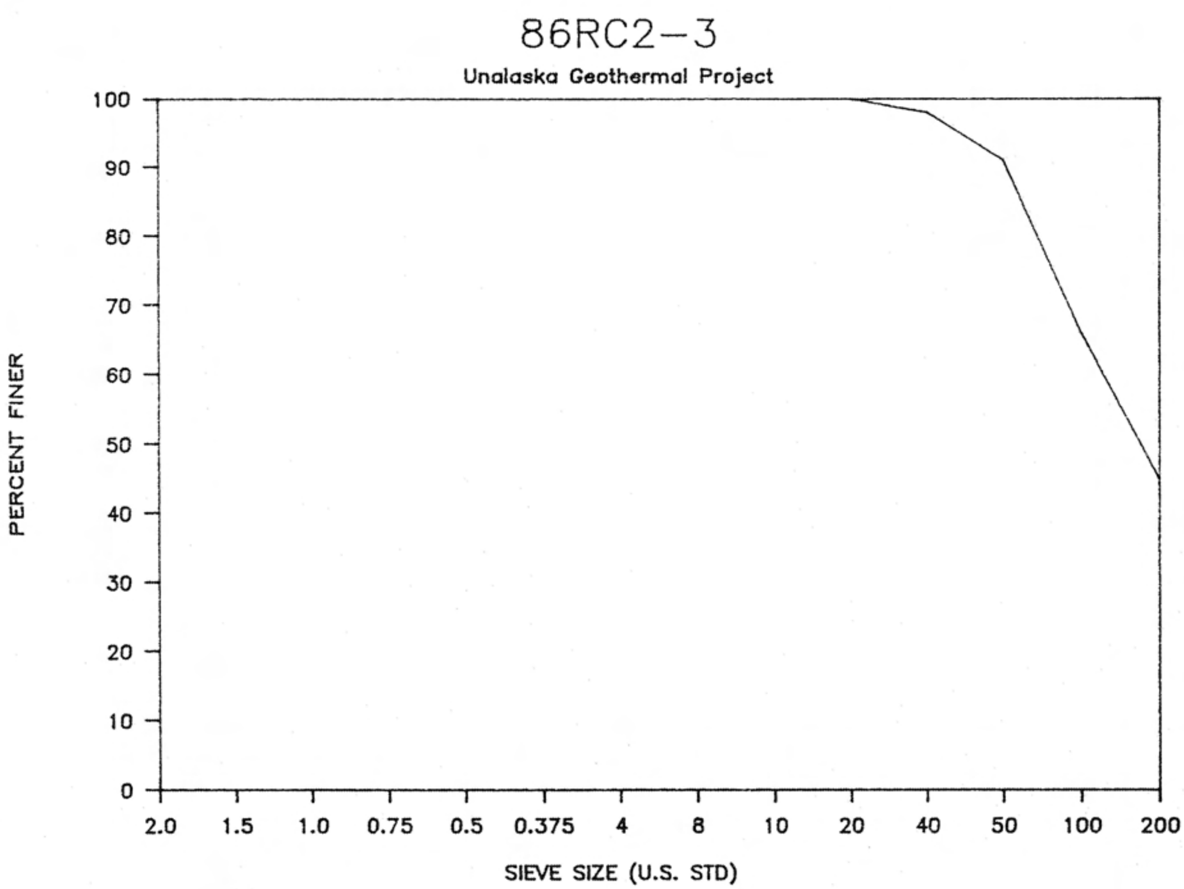
GRAVEL (#4+)	0
SAND (#4-, #200+)	52
SILT+CLAY (#200-)	48
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: 86RC2-3

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26		
0.5	12.7	-3.67		
0.375	9.5	-3.25		
4	4.76	-2.25		
10	2.00	-1.00		
20	0.84	0.25	100	2
40	0.42	1.25	98	7
50	0.30	1.75	91	25
100	0.149	2.75	66	21
200	0.074	3.75	45	45

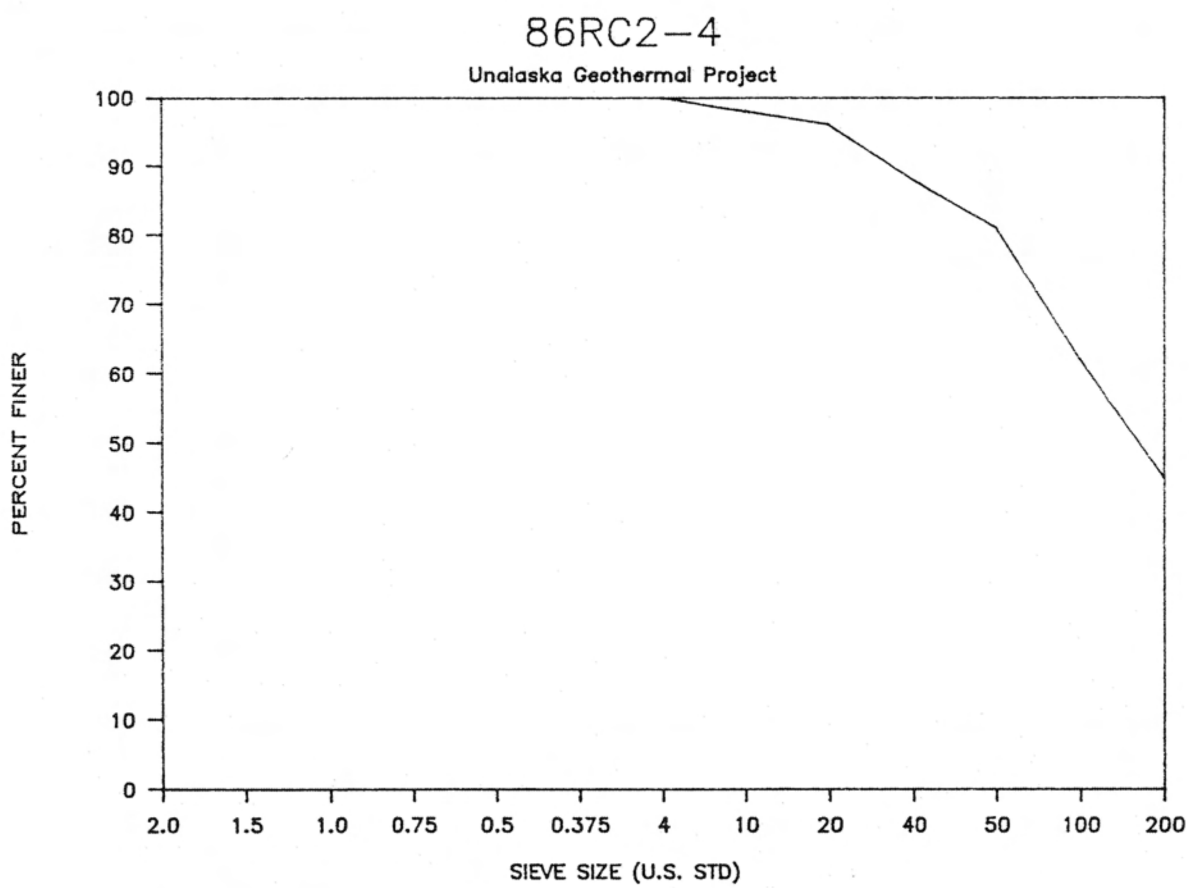
GRAVEL (#4+)	0
SAND (#4-, #200+)	55
SILT+CLAY (#200-)	45
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: 86RC2-4

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26		
0.5	12.7	-3.67		
0.375	9.5	-3.25		
4	4.76	-2.25	100	2
10	2.00	-1.00	98	2
20	0.84	0.25	96	8
40	0.42	1.25	88	7
50	0.30	1.75	81	19
100	0.149	2.75	62	17
200	0.074	3.75	45	45

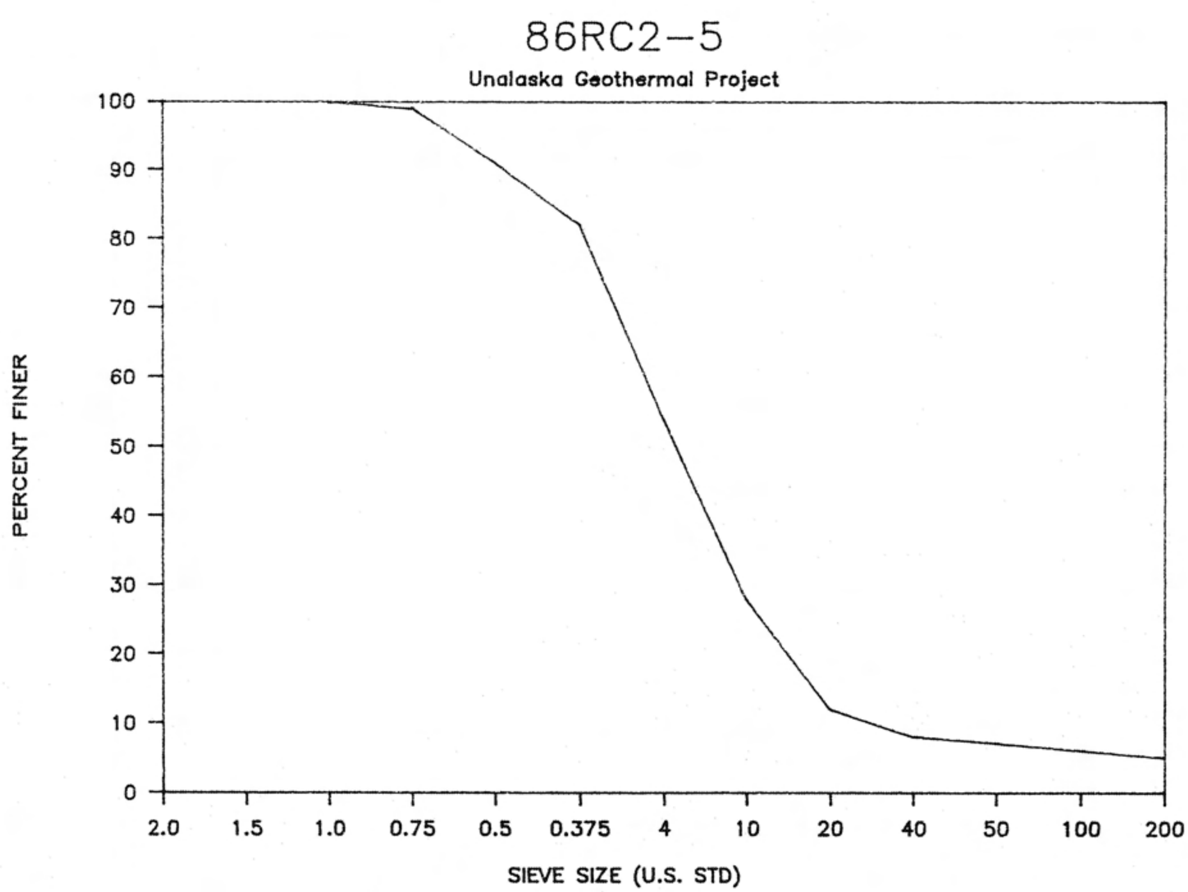
GRAVEL (#4+)	0
SAND (#4-, #200+)	55
SILT+CLAY (#200-)	45
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: 86RC2-5

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67	100	1
0.75	19.1	-4.26	99	8
0.5	12.7	-3.67	91	9
0.375	9.5	-3.25	82	28
4	4.76	-2.25	54	26
10	2.00	-1.00	28	16
20	0.84	0.25	12	4
40	0.42	1.25	8	1
50	0.30	1.75	7	1
100	0.149	2.75	6	1
200	0.074	3.75	5	5

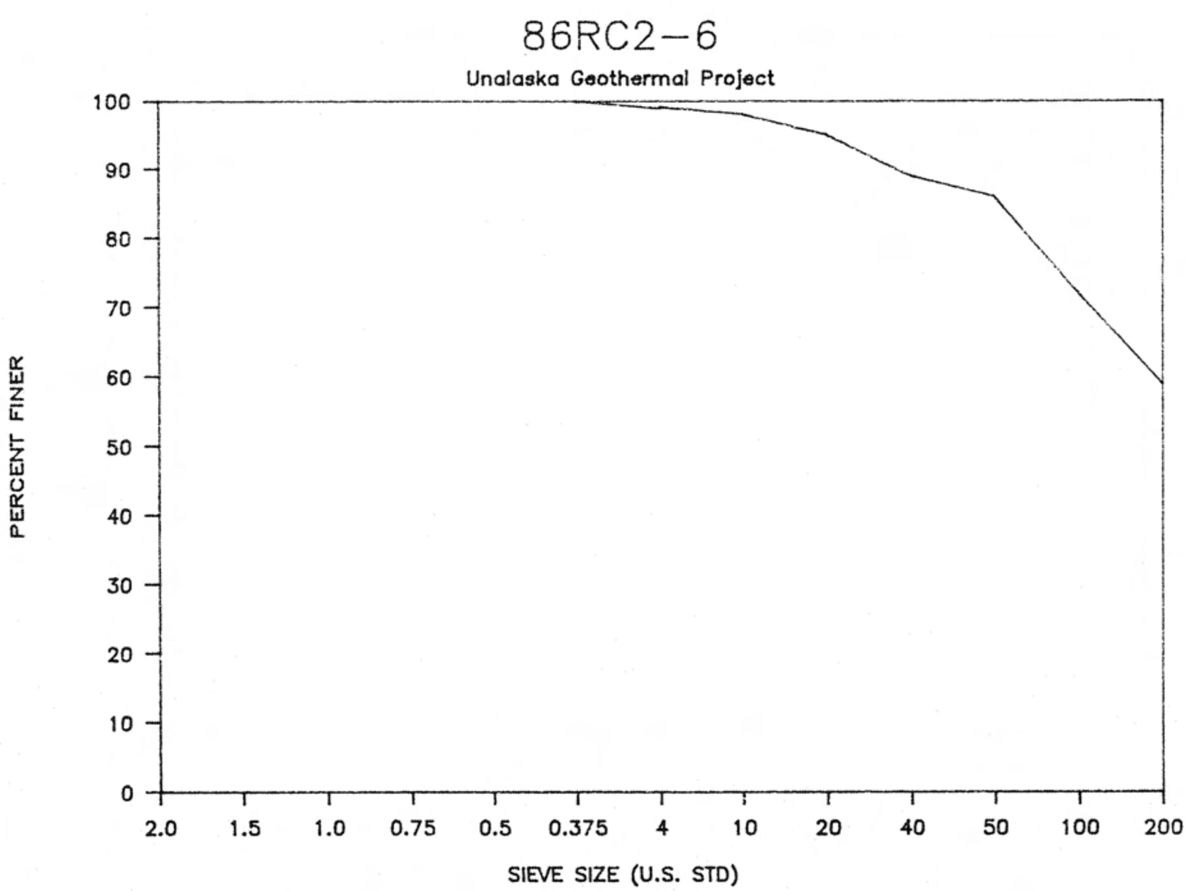
GRAVEL (#4+)	46
SAND (#4-, #200+)	49
SILT+CLAY (#200-)	5
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: 86RC2-6

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26		
0.5	12.7	-3.67		
0.375	9.5	-3.25	100	1
4	4.76	-2.25	99	1
10	2.00	-1.00	98	3
20	0.84	0.25	95	6
40	0.42	1.25	89	3
50	0.30	1.75	86	14
100	0.149	2.75	72	13
200	0.074	3.75	59	59

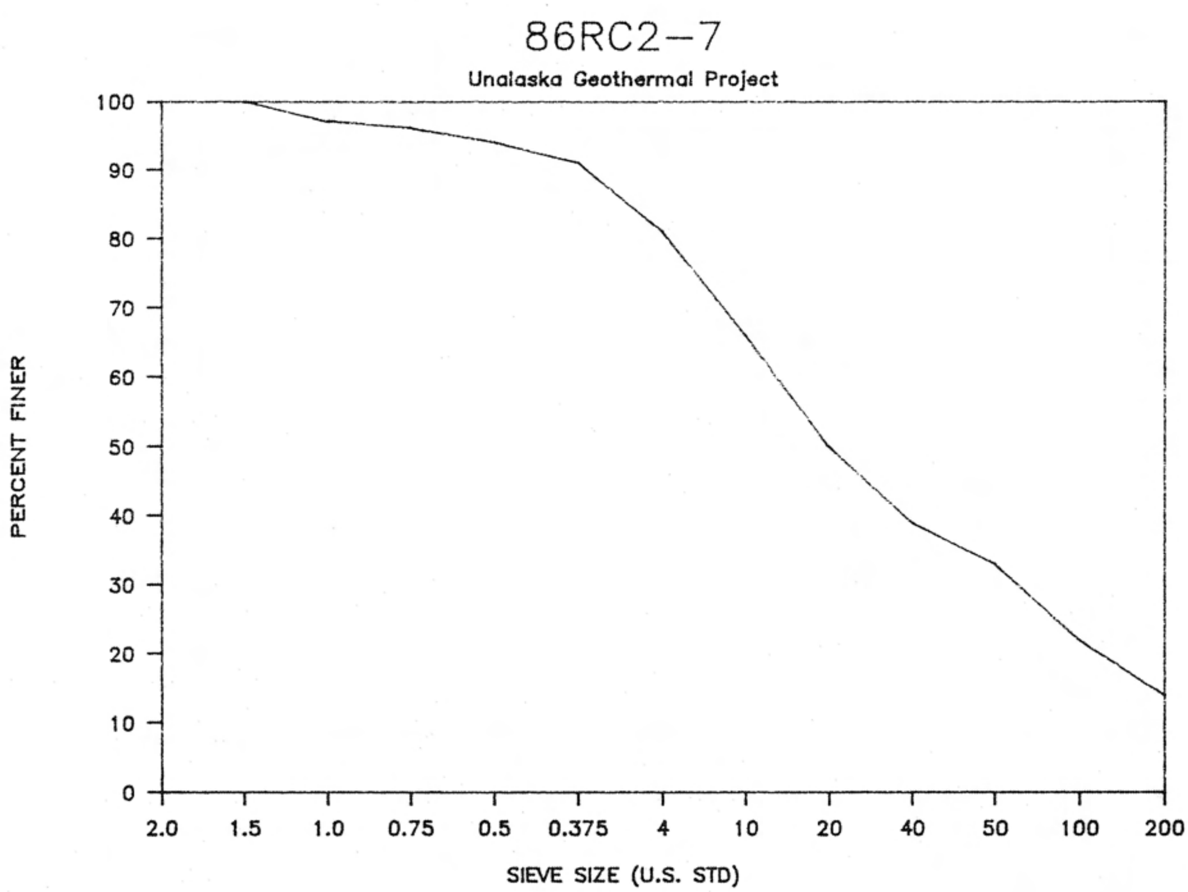
GRAVEL (#4+)	1
SAND (#4-, #200+)	40
SILT+CLAY (#200-)	59
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: 86RC2-7

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25	100	3
1.0	25.4	-4.67	97	1
0.75	19.1	-4.26	96	2
0.5	12.7	-3.67	94	3
0.375	9.5	-3.25	91	10
4	4.76	-2.25	81	15
10	2.00	-1.00	66	16
20	0.84	0.25	50	11
40	0.42	1.25	39	6
50	0.30	1.75	33	11
100	0.149	2.75	22	8
200	0.074	3.75	14	14

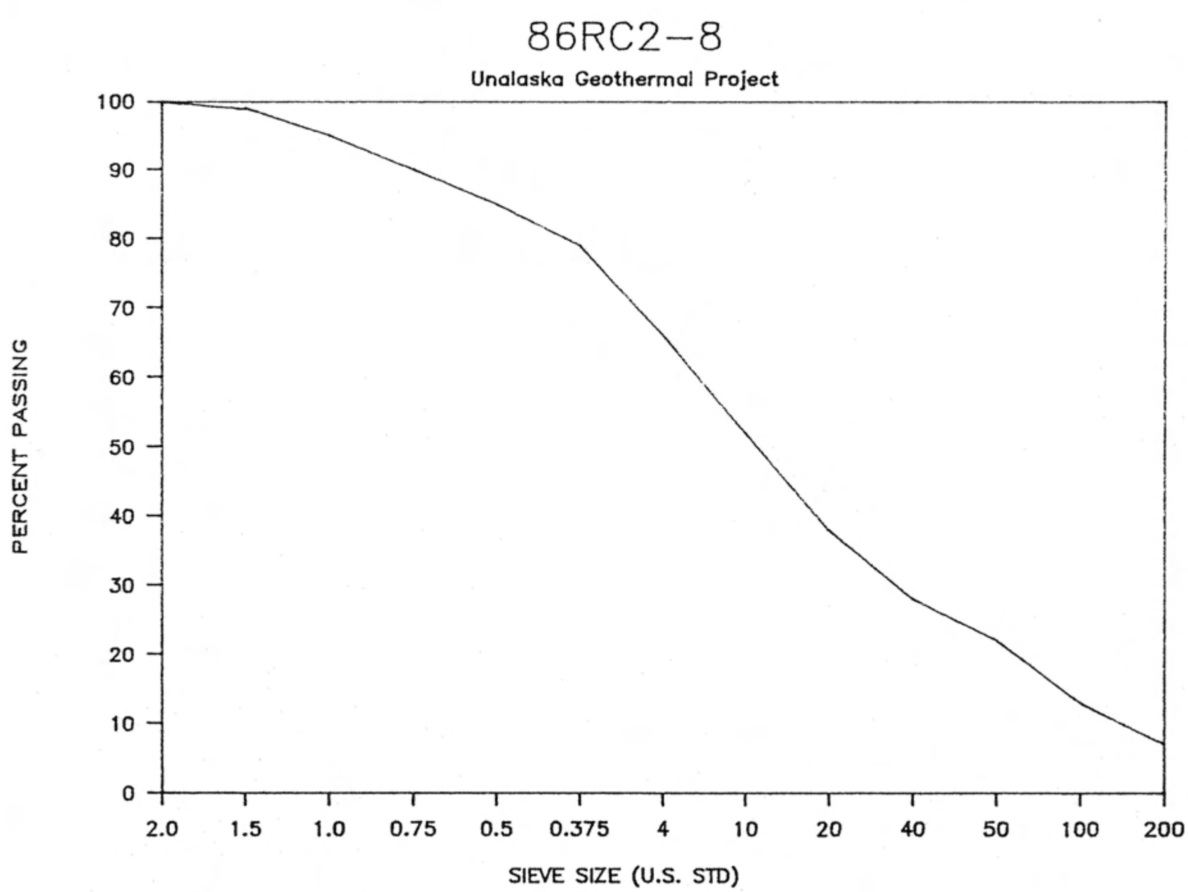
GRAVEL (#4+)	19
SAND (#4-, #200+)	67
SILT+CLAY (#200-)	14
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: 86RC2-8

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67	100	1
1.5	38.1	-5.25	99	4
1.0	25.4	-4.67	95	5
0.75	19.1	-4.26	90	5
0.5	12.7	-3.67	85	6
0.375	9.5	-3.25	79	13
4	4.76	-2.25	66	14
10	2.00	-1.00	52	14
20	0.84	0.25	38	10
40	0.42	1.25	28	6
50	0.30	1.74	22	9
100	0.149	2.75	13	6
200	0.074	3.76	7	7

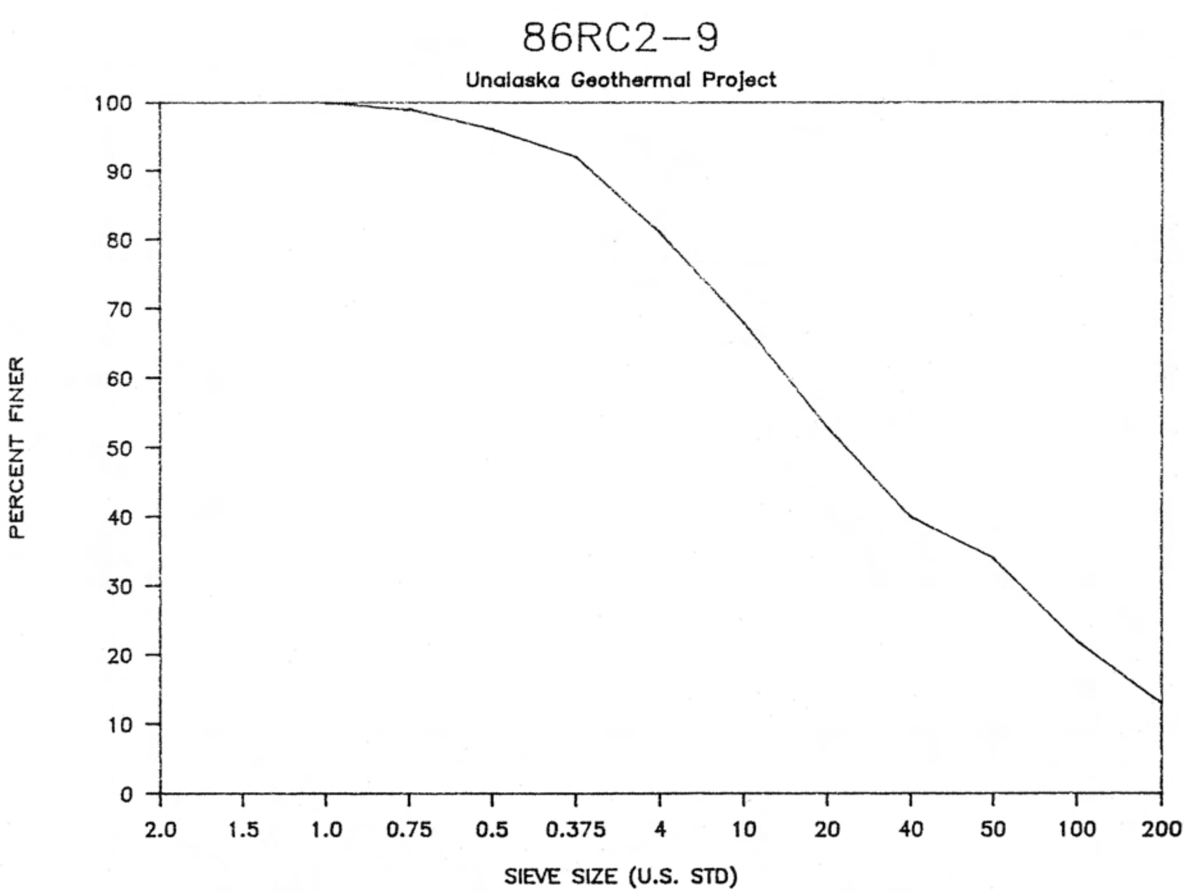
GRAVEL (#4+)	34
SAND (#4-, #200+)	59
SILT+CLAY (#200-)	7
ORGANICS (WT%)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: 86RC2-9

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67	100	1
0.75	19.1	-4.26	99	3
0.5	12.7	-3.67	96	4
0.375	9.5	-3.25	92	11
4	4.76	-2.25	81	13
10	2.00	-1.00	68	15
20	0.84	0.25	53	13
40	0.42	1.25	40	6
50	0.30	1.75	34	12
100	0.149	2.75	22	9
200	0.074	3.75	13	13

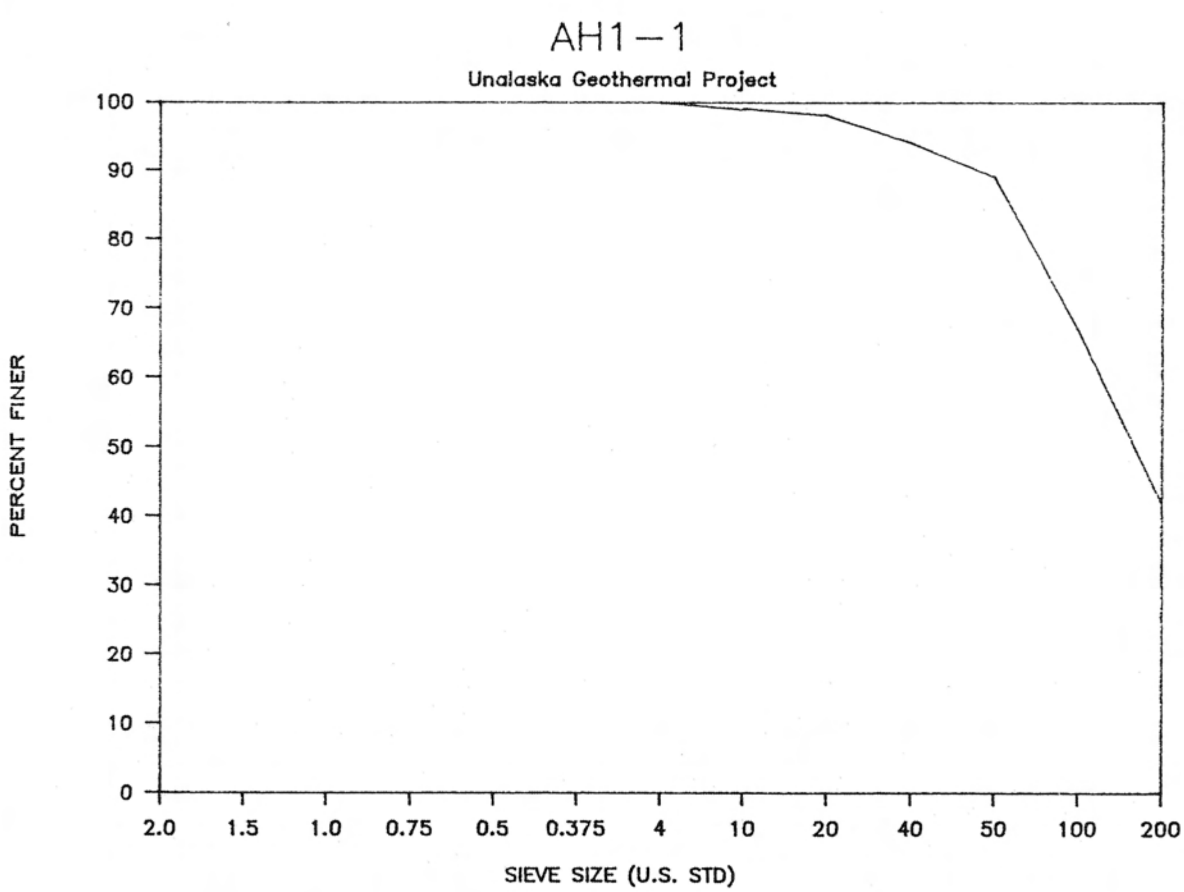
GRAVEL (#4+)	19
SAND (#4-, #200+)	68
SILT+CLAY (#200-)	13
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: AH1-1

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26		
0.5	12.7	-3.67		
0.375	9.5	-3.25		
4	4.76	-2.25	100	1
10	2.00	-1.00	99	1
20	0.84	0.25	98	4
40	0.42	1.25	94	5
50	0.30	1.75	89	22
100	0.149	2.75	67	25
200	0.074	3.75	42	42

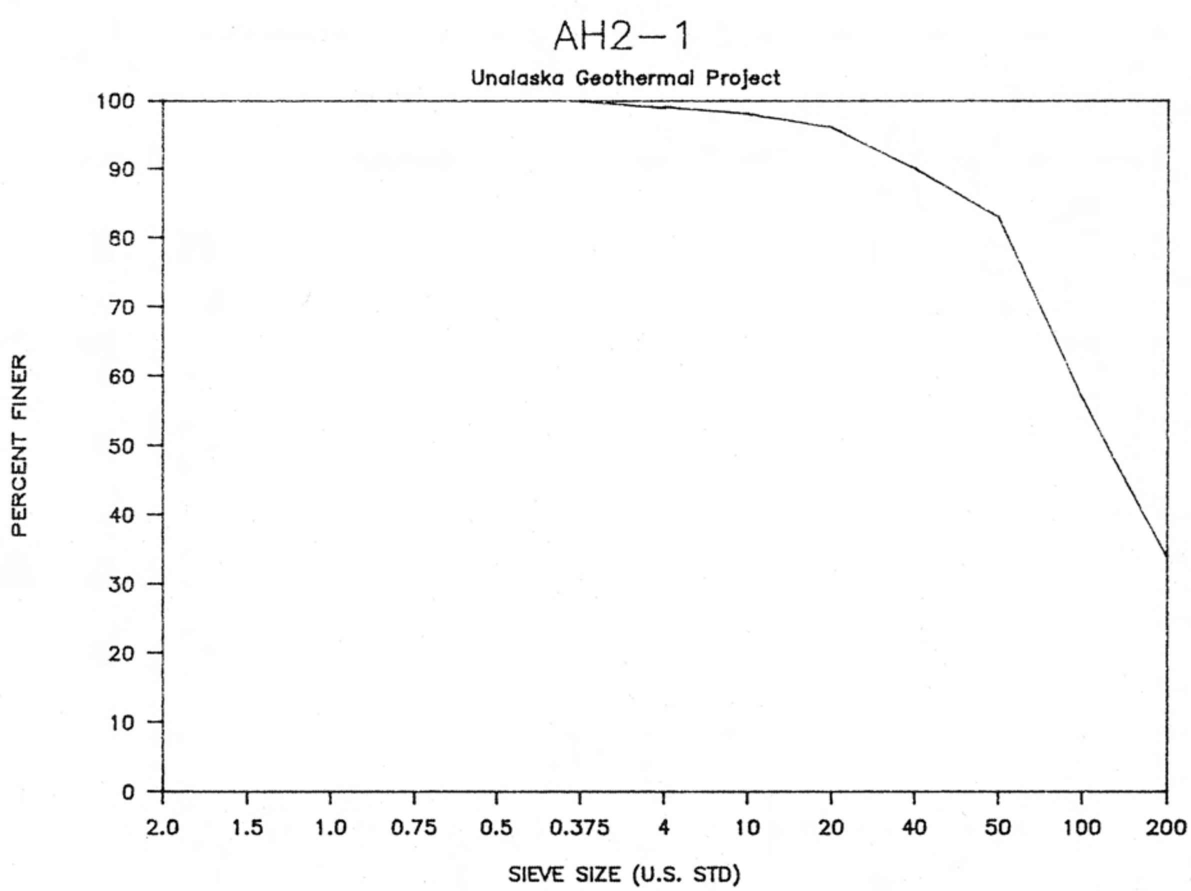
GRAVEL (#4+)	0
SAND (#4-, #200+)	58
SILT+CLAY (#200-)	42
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: AH2-1

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26		
0.5	12.7	-3.67		
0.375	9.5	-3.25	100	1
4	4.76	-2.25	99	1
10	2.00	-1.00	98	2
20	0.84	0.25	96	6
40	0.42	1.25	90	7
50	0.30	1.75	83	26
100	0.149	2.75	57	23
200	0.074	3.75	34	34

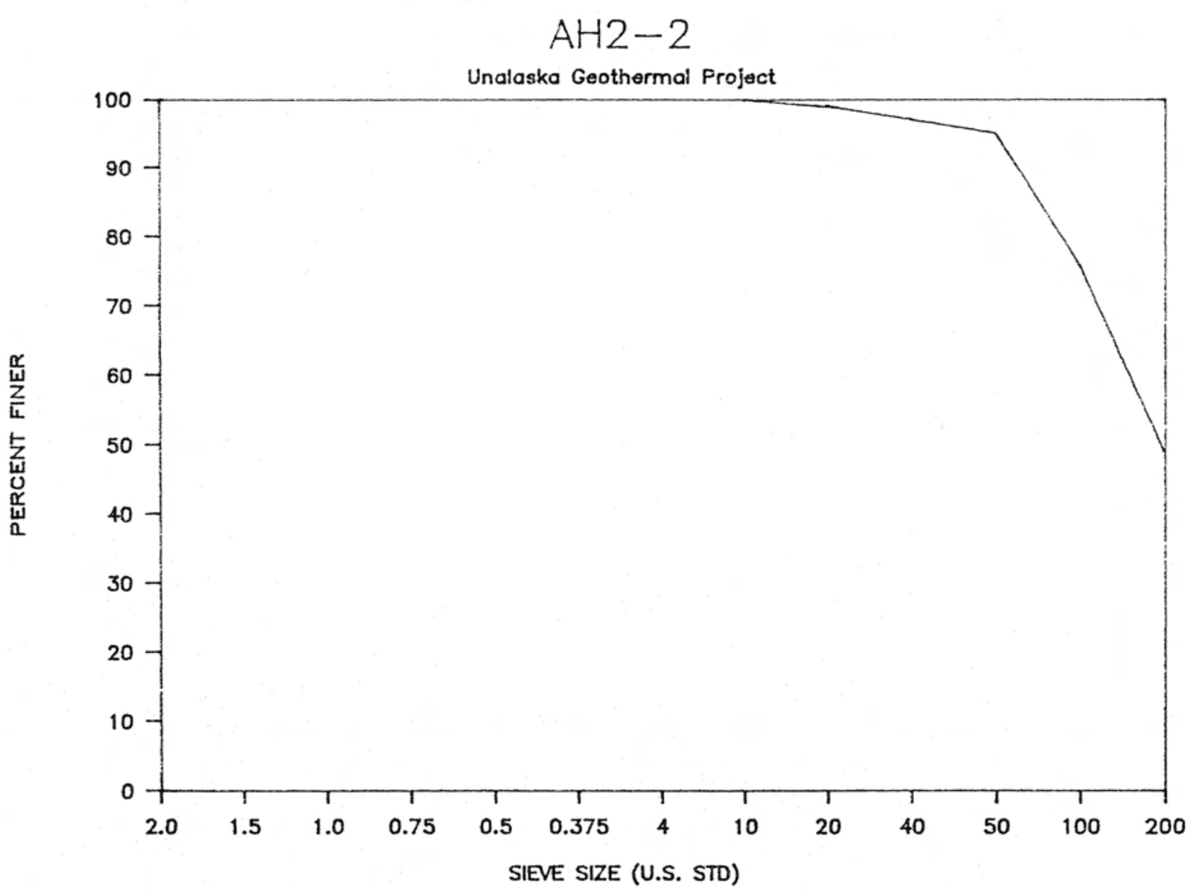
GRAVEL (#4+)	1
SAND (#4-, #200+)	65
SILT+CLAY (#200-)	34
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: AH2-2

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26		
0.5	12.7	-3.67		
0.375	9.5	-3.25		
4	4.76	-2.25		
10	2.00	-1.00	100	1
20	0.84	0.25	99	2
40	0.42	1.25	97	2
50	0.30	1.75	95	19
100	0.149	2.75	76	27
200	0.074	3.75	49	49

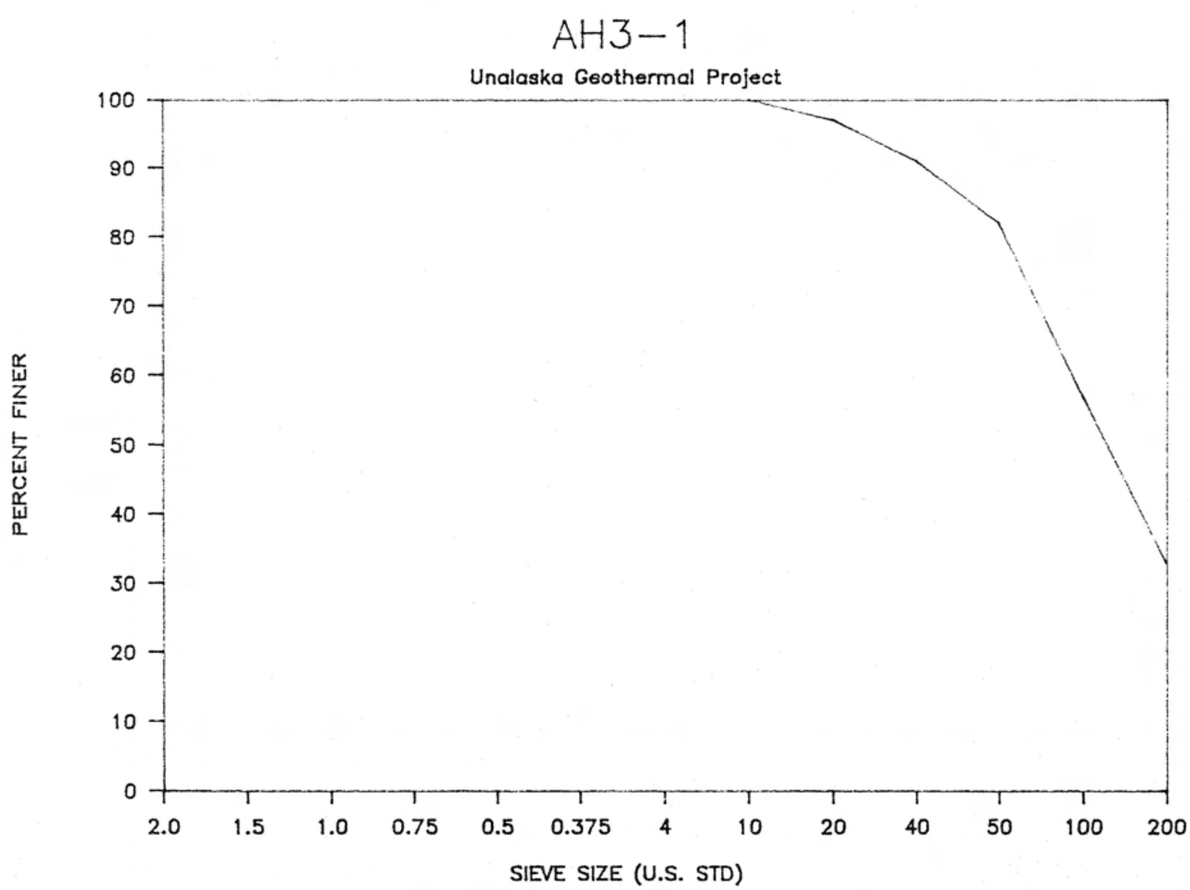
GRAVEL (#4+)	0
SAND (#4-, #200+)	51
SILT+CLAY (#200-)	49
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: AH3-1

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26		
0.5	12.7	-3.67		
0.375	9.5	-3.25		
4	4.76	-2.25		
10	2.00	-1.00	100	3
20	0.84	0.25	97	6
40	0.42	1.25	91	9
50	0.30	1.75	82	25
100	0.149	2.75	57	24
200	0.074	3.75	33	33

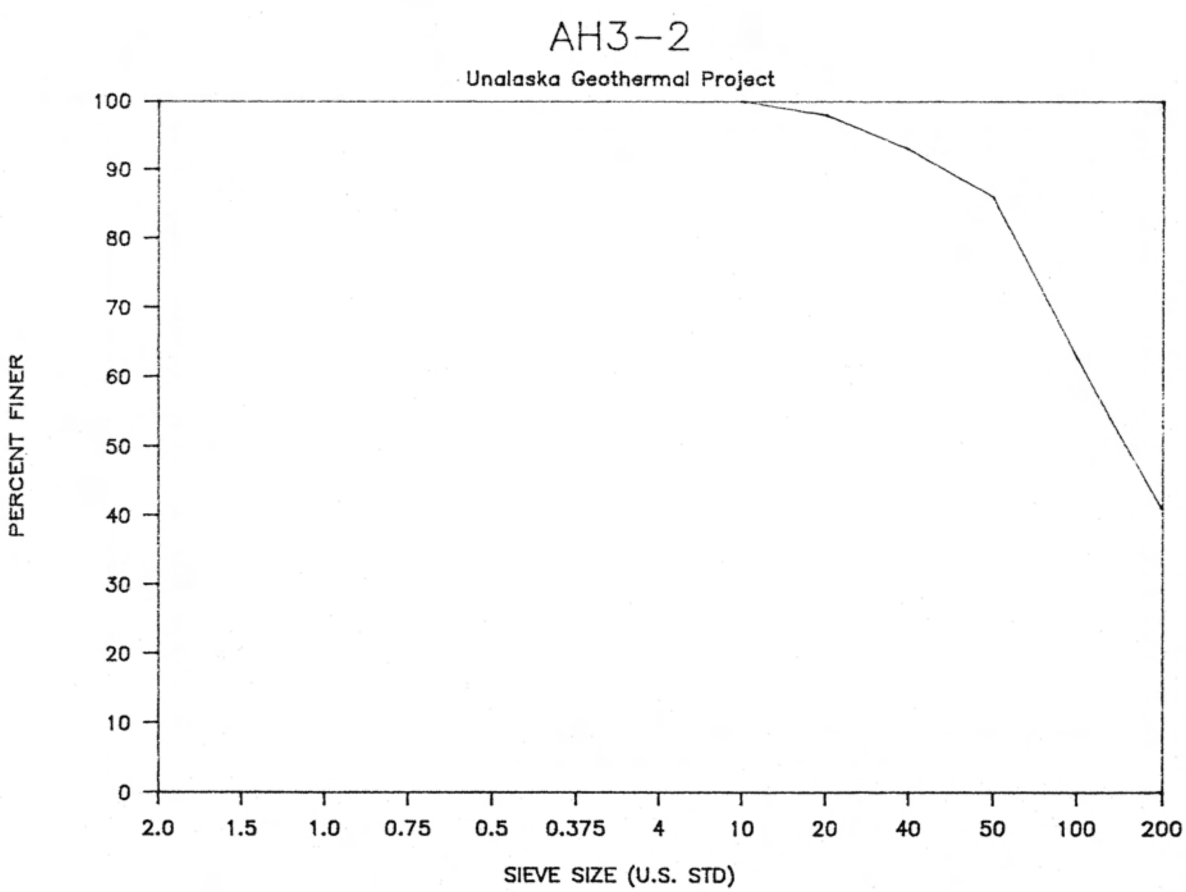
GRAVEL (#4+)	0
SAND (#4-, #200+)	67
SILT+CLAY (#200-)	33
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: AH3-2

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26		
0.5	12.7	-3.67		
0.375	9.5	-3.25		
4	4.76	-2.25		
10	2.00	-1.00	100	2
20	0.84	0.25	98	5
40	0.42	1.25	93	7
50	0.30	1.75	86	23
100	0.149	2.75	63	22
200	0.074	3.75	41	41

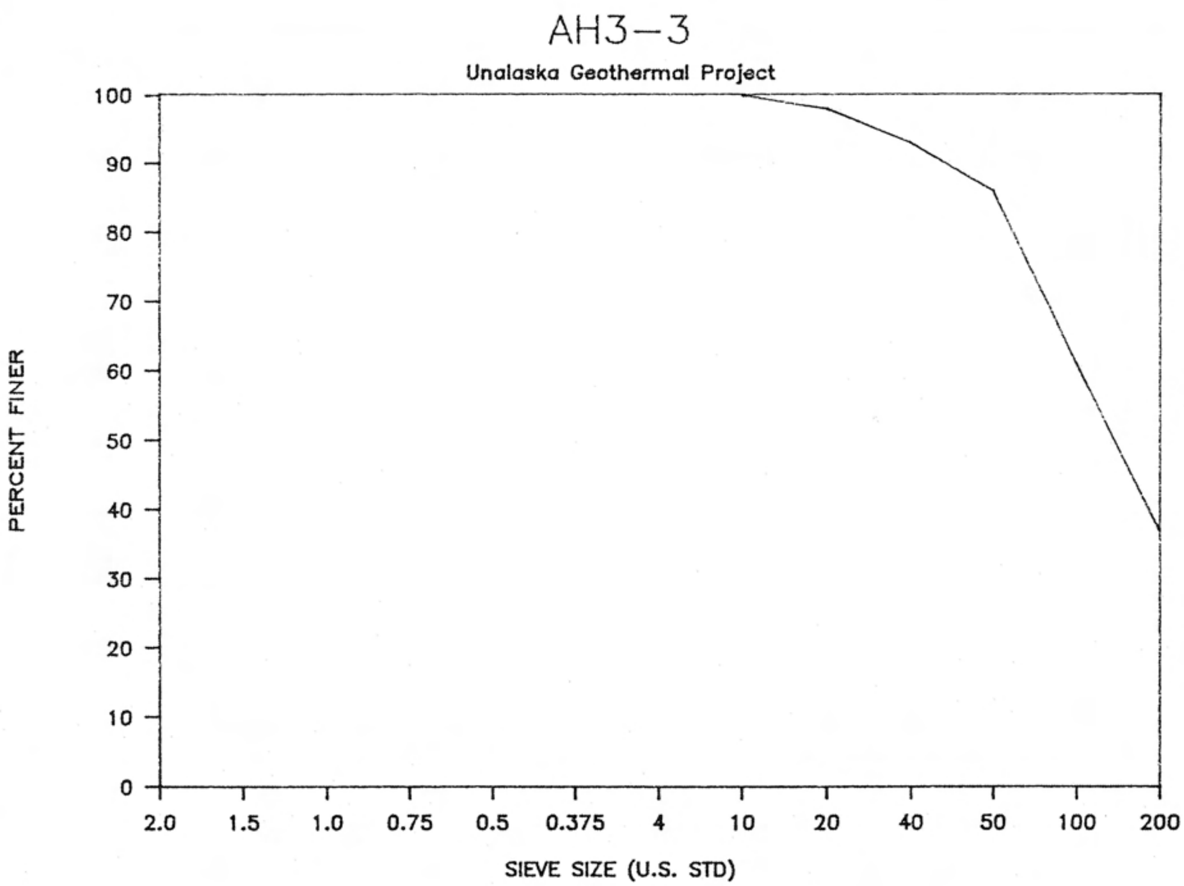
GRAVEL (#4+)	0
SAND (#4-, #200+)	59
SILT+CLAY (#200-)	41
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: AH3-3

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26		
0.5	12.7	-3.67		
0.375	9.5	-3.25		
4	4.76	-2.25		
10	2.00	-1.00	100	2
20	0.84	0.25	98	5
40	0.42	1.25	93	7
50	0.30	1.75	86	25
100	0.149	2.75	61	24
200	0.074	3.75	37	37

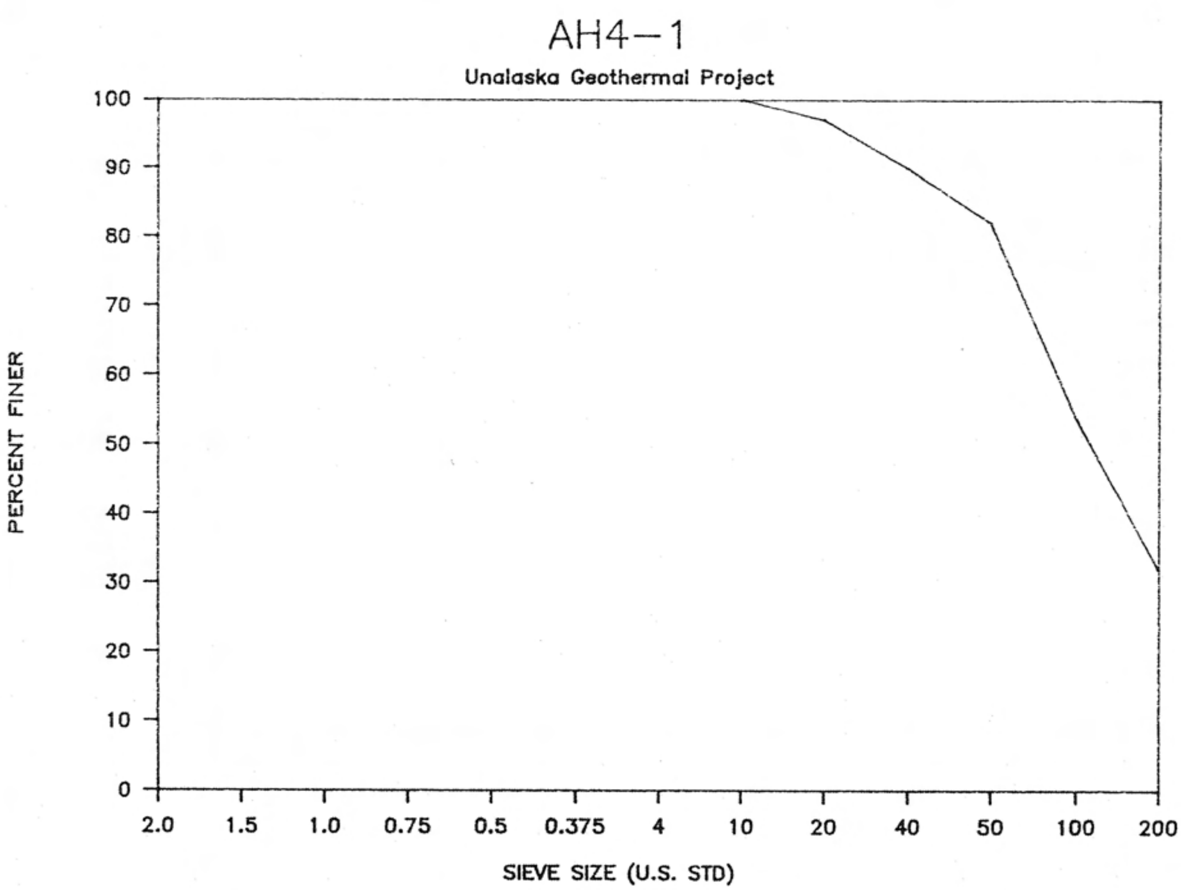
GRAVEL (#4+)	0
SAND (#4-, #200+)	63
SILT+CLAY (#200-)	37
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: AH4-1

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26		
0.5	12.7	-3.67		
0.375	9.5	-3.25		
4	4.76	-2.25		
10	2.00	-1.00	100	3
20	0.84	0.25	97	7
40	0.42	1.25	90	8
50	0.30	1.75	82	28
100	0.149	2.75	54	22
200	0.074	3.75	32	32

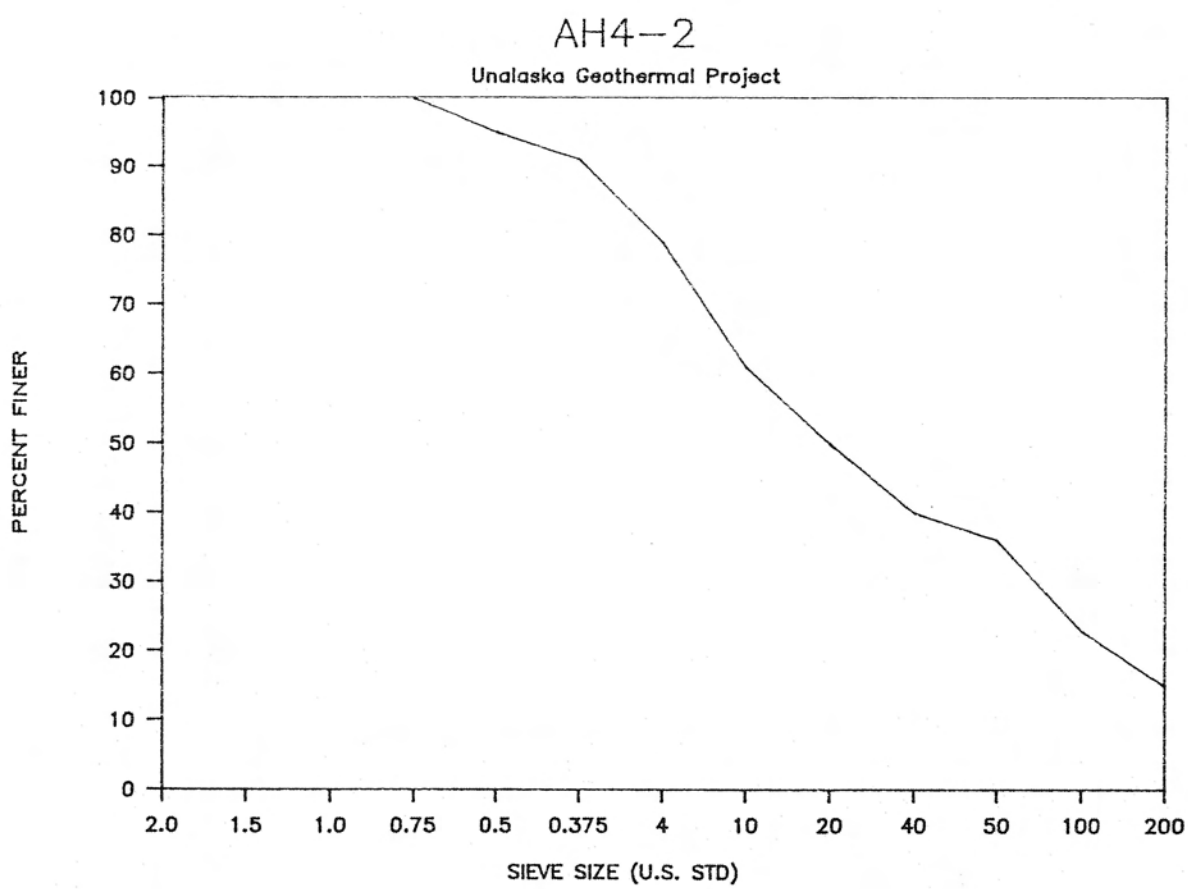
GRAVEL (#4+)	0
SAND (#4-, #200+)	68
SILT+CLAY (#200-)	32
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: AH4-2

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26	100	5
0.5	12.7	-3.67	95	4
0.375	9.5	-3.25	91	12
4	4.76	-2.25	79	18
10	2.00	-1.00	61	11
20	0.84	0.25	50	10
40	0.42	1.25	40	4
50	0.30	1.75	36	13
100	0.149	2.75	23	8
200	0.074	3.75	15	15

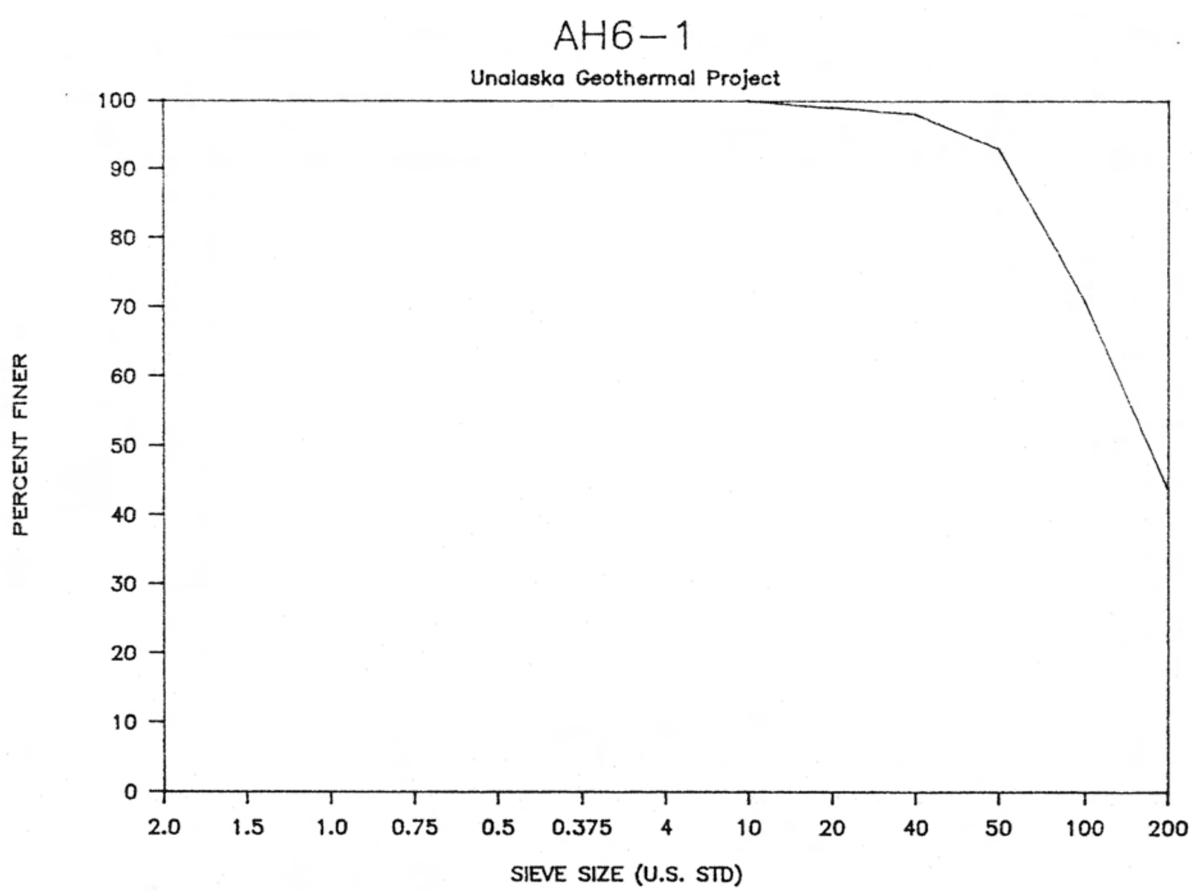
GRAVEL (#4+)	21
SAND (#4-, #200+)	64
SILT+CLAY (#200-)	15
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: AH6-1

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26		
0.5	12.7	-3.67		
0.375	9.5	-3.25		
4	4.76	-2.25		
10	2.00	-1.00	100	1
20	0.84	0.25	99	1
40	0.42	1.25	98	5
50	0.30	1.75	93	22
100	0.149	2.75	71	27
200	0.074	3.75	44	44

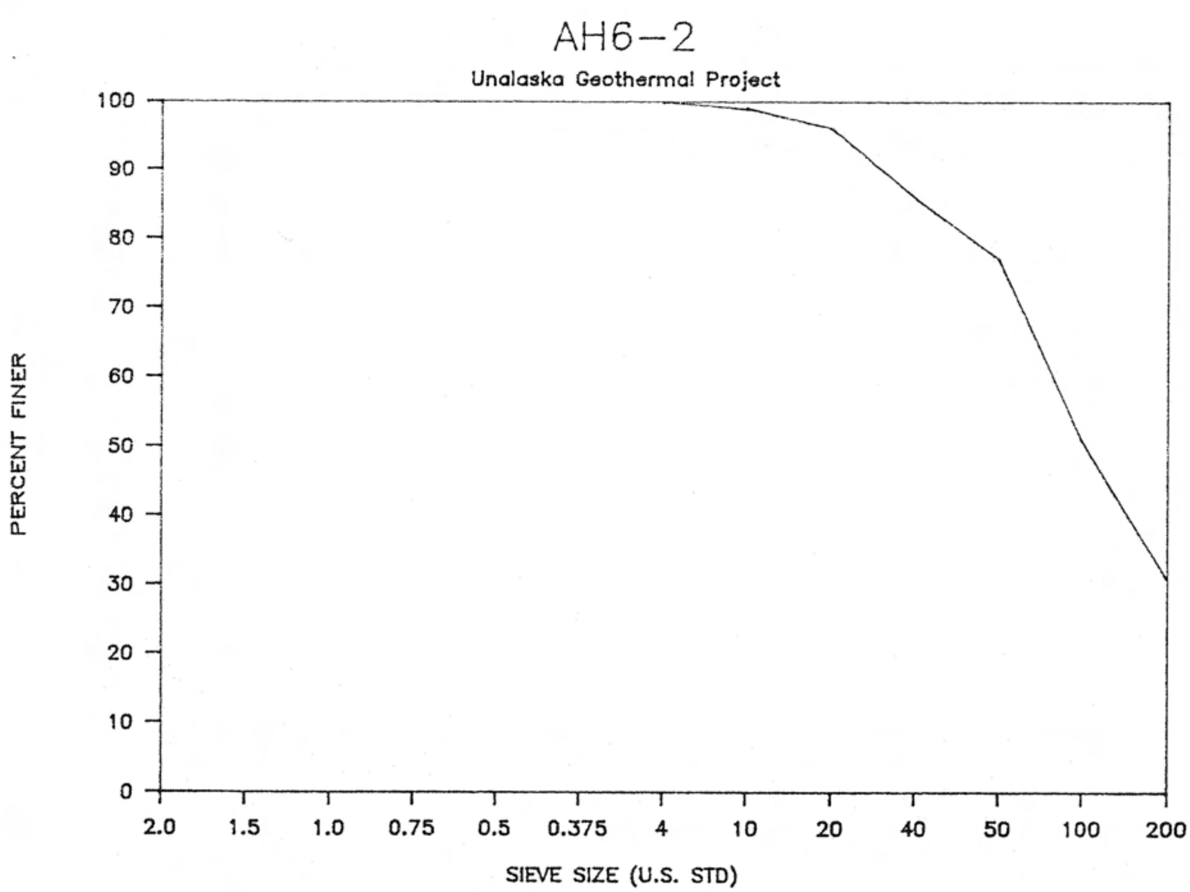
GRAVEL (#4+)	0
SAND (#4-, #200+)	56
SILT+CLAY (#200-)	44
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: AH6-2

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26		
0.5	12.7	-3.67		
0.375	9.5	-3.25		
4	4.76	-2.25	100	1
10	2.00	-1.00	99	3
20	0.84	0.25	96	10
40	0.42	1.25	86	9
50	0.30	1.75	77	26
100	0.149	2.75	51	20
200	0.074	3.75	31	31

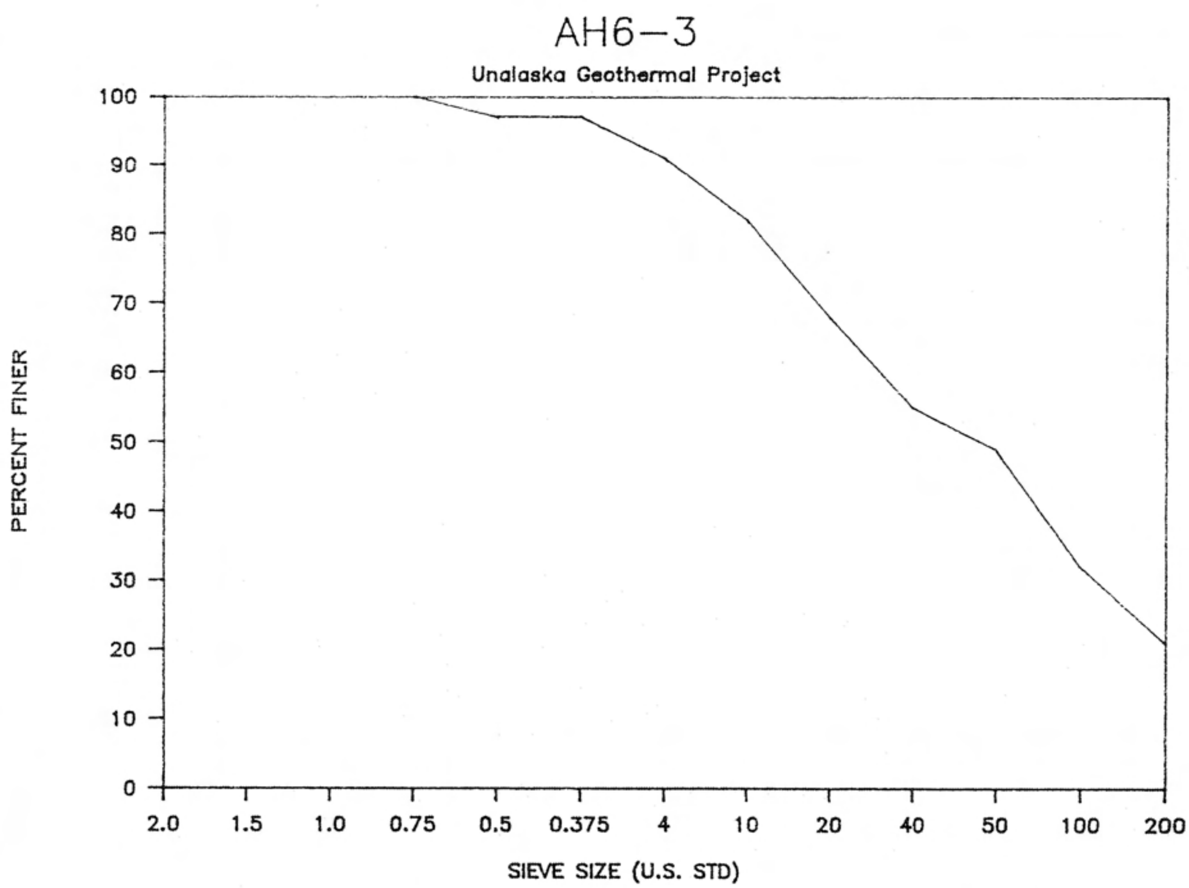
GRAVEL (#4+)	0
SAND (#4-, #200+)	69
SILT+CLAY (#200-)	31
ORGANICS (WT %)	<5



GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: AH6-3

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26	100	3
0.5	12.7	-3.67	97	0
0.375	9.5	-3.25	97	6
4	4.76	-2.25	91	9
10	2.00	-1.00	82	14
20	0.84	0.25	68	13
40	0.42	1.25	55	6
50	0.30	1.75	49	17
100	0.149	2.75	32	11
200	0.074	3.75	21	21

GRAVEL (#4+)	9
SAND (#4-, #200+)	70
SILT+CLAY (#200-)	21
ORGANICS (WT %)	<5



TRANSMISSION POWERLINE AND ROAD CORRIDOR GEOTECHNICAL STUDY FOR THE PROPOSED MAKUSHIN GEOTHERMAL FIELD POWER FACILITY ON UNALASKA ISLAND

by Kerwin Krause

INTRODUCTION

This study was conducted as part of an engineering geologic feasibility study for the proposed Makushin geothermal field power facility on Unalaska Island. The transmission powerline and road corridor geotechnical study is task number 9 identified in the proposal to Alaska Power Authority (APA) by Dr. Randall G. Updike, Chief, Engineering Geology Section, Alaska Division of Geological and Geophysical Surveys dated 12 June 1986. If the Makushin geothermal resource is developed then a transmission powerline corridor would have to be selected. The reconnaissance level geotechnical data presented in this study will aid future geotechnical and design feasibility consultants in selecting powerline corridor routes. Another purpose for this study was to select possible road corridors that could be used during construction of the transmission powerline and powerhouse facility, and also for future operation of the powerhouse facility. At first glance the floor of Makushin Valley looks like an ideal road and powerline corridor. Reconnaissance level geologic floodplain mapping and soil sampling was undertaken to help evaluate the surficial geologic stratigraphy and geotechnical conditions in Makushin Valley.

The study area includes the floor of Makushin Valley and its southern valley slopes between Broad Bay and the proposed powerhouse site, and Driftwood Bay Valley.

METHODS

The first phase of this study involved doing preliminary stereo aerial-photo interpretive geologic mapping of the Makushin and Driftwood Bay Valley regions. Mapping was done on color infrared aerial photos with a scale of 1 inch = 2,000 ft. Existing road routes and potential routes for new roads and transmission powerlines were investigated.

The second phase of the study involved five days of field investigations. Limited helicopter support was utilized for this phase. Floodplain alluvial deposits were studied first. This involved walking along and across important alluvium contacts and spot checking other floodplain contacts by helicopter. One rather large floodplain deposit was identified early on as having unstable surface soil conditions. Subsurface alluvium in this deposit was sampled at three locations using a 3-inch portable power auger. Two seismic refraction studies were also conducted across this alluvium to supplement the power auger sample data. Existing road routes were studied by walking and evaluating the road conditions. Three potential road corridor routes were studied also by walking and helicopter reconnaissance spot checks. Road route evaluations involved studying existing slopes, surface soil conditions, depth to bedrock or gravel, slope instability and avalanche hazards, road grade, erodability and number of stream crossings. Problem areas were noted and described. A hand auger was used to evaluate surface soils along potential road routes where there were no natural cut banks. Two transmission powerline routes were briefly studied. One day was spent evaluating a possible upland transmission line corridor. Full helicopter assistance was utilized for this work. Seventeen stations were evaluated along this upland corridor. These stations represent potential transmission tower sites. Preliminary surveying and evaluation of surface and foundation soils was done at each of these sites.

The third phase of this study involved mapping the floodplain alluvium in Makushin Valley using the information gained from the field investigations. Consultation with several other project team members over possible road and transmission powerline corridor routes was conducted during this phase.

RESULTS OF INVESTIGATION

Road Corridors

Condition of existing roads and areas needing improvement

The old road up Makushin Valley is washed out along most of its length. The road was built in 1963 and paralleled the river up most of the valley. The road was built on active bar deposits, bankfull bar deposits, low overbank flood bar and channel deposits, high overbank flood bar deposits, and levee deposits (Aa, Ab, Alo, Aho, and Al, consecutively; Plate C-1). The deposits all contain good gravel for road construction and they are overlain or capped by minimal amounts of fine sand and silt. The road crossed the Makushin Valley River about half way up the valley where an old bridge remains are located. Cut bank erosion along the river has removed most of the road. Further up valley, the road leaves the floodplain and ascends a low, broad alluvial fan before it switch-backs up the steep valley wall slope into Driftwood Bay Valley (fig. 1). The alluvial fan (Af, Plate C-1) contains good gravel for road construction.

The road is in poor shape where it switch-backs up the steep slope above the alluvial fan. The road has four switch-backs and four straight segments. The lowest straight segment needs major grading work done. The second straight segment needs major grading and a culvert installed. The third straight segment contains a major wash-out which would require a culvert, several dozen cubic yards of fill and possibly a small, pile-supported retaining wall as well as major grading (fig. 2). The road at the third switch-back is deeply eroded down to bedrock and will require fill and two culverts. Grading will also be required at the fourth switch-back. The road has an average 10 percent grade.

The road from the top of the switch-backs to Driftwood Bay is in fairly good shape except for the noted repair sites (see Plate C-1).

Repair site 1. Road is moderately gullied but can be repaired with three culverts and a drainage ditch.

Repair site 2. Road gullied and needs two culverts.

Repair site 3. Two road wash-outs which require fill only.

Repair site 4. Road wash-out which will require fill and one culvert.

Repair sites 5, 6, and 7. Road wash-outs which will require one culvert and a drainage ditch each.

North of Repair site 7 the road drops down off of a lava flow onto the Driftwood Bay Valley floodplain. A bridge would have to be constructed where the road crosses the river on the floodplain (fig. 3). The airstrip at the end of the road in Driftwood Bay Valley is in good shape and would require only minor grading to be usable.

Possible new corridor routes requiring moderate fill and slope excavation (R-1 and R-2)

The Makushin geothermal well site is several miles further up Makushin Valley to the southwest from the existing Driftwood Bay Valley road and Makushin Valley road. The terrain between the well site and existing roads is very rugged. There are two possible upland road corridor routes to the geothermal well site from upper Makushin and Driftwood Bay Valleys. Another route would be along the river bank in the bottom of Makushin Valley River canyon. This route would require numerous stream crossings and be susceptible to numerous wash-outs. The Makushin Valley River canyon is an area that has frequent snow avalanches in the winter and spring months. The two upland road corridor routes are less susceptible to snow avalanches and landsliding hazards than the valley bottom route. The two upland routes are on opposite sides of Makushin Valley River canyon. Route 1 (R-1, see Plate C-1) is on the south side of the valley and Route 2 (R-2, see Plate C-1) is on the north side.

Corridor Route 1 would start in the bottom of Makushin Valley where the existing road leaves the floodplain and begins ascending the alluvial fan. The route would go up-valley paralleling the thick volcanic lahar deposit. The road would be built on high overbank flood bar deposits (Aho, see Plate C-1). The road would cross the river to the south side of the valley near the canyon area. A bridge would be required for this river crossing. From the river the road would switch-back up the slope to the large bench area as shown on Plate C-1. This slope has approximately 1 to 3 meters (3 to 10 ft) of colluvium, ash, and glacial overburden on top of bedrock. The lower portion of this slope has potentially unstable soils (see Ground Stability section). A road constructed up this slope would have less grade, fewer cutbanks, and fewer sharp switch-backs than the existing road across the valley. Snow avalanche hazards would be minimal up this slope (see Avalanche Hazard section). On top of the large bench area, the road would parallel the rim of the canyon. Overburden is 1 meter (3 ft) or less thick in this area. This bench could be used as a helicopter staging area (Staging Area A, see Plate C-1) for construction of the powerhouse facility and transmission powerline if the road ended here. Constructing a road beyond this bench becomes more difficult. The road would descend the bench area and cross a ravine that would require a large culvert. From the ravine the road would cut across a relatively long and moderately steep slope before intersecting a small bench (see Plate C-1). Numerous small intermittent streams occur along this slope. The streams have gullied the overlying ash and colluvial deposits. Culverts would be needed for each stream crossing. Reeder (see Ground Stability section) has identified this slope as having potentially unstable soils. March (see Avalanche Hazard section) has also identified this slope as being prone to snow avalanches. From the small bench the road would descend rather steeply down into the valley bottom. Again, Reeder and March have identified this slope as having potentially unstable soils and being prone to snow avalanches. Intermittent streams have gullied this slope also, so several culverts would be required for construction. In the valley bottom a bridge would have to be built across the river. On the other side of the river the road would ascend the side slope of a steep ravine onto the large bench where the powerhouse site is planned (see Plate C-1).

Corridor route 2 takes off from the existing road near Sugarloaf Cone in Driftwood Bay Valley (see Plate C-1). This area could serve as a helicopter staging area for construction of the powerhouse facility (Staging Area B, see Plate C-1). The best route for the road in this area is north of Sugarloaf Cone as shown on the map. Cinder and ash deposits overlie glacial till in this area. Road construction would progress rapidly across this area. West of Sugarloaf Cone, the road could end at Staging Area C or continue as shown on Plate C-1. Between here and Staging Area D the road would have to cross several large, very deep, perennially snowfilled ravines. Bridges would probably be necessary at these crossings. The road would also have to traverse a steep slope which Reeder and March have identified as hazardous for slope failures and snow avalanches. This area is free of snow for only a few months each year, thus a road built across the area would require increased maintenance. Staging Area D (see Plate C-1) is on the bench above the geothermal well site. This would make a good helicopter staging area. Continuing the road from here to the well site would be difficult. Fox River canyon, which contains steep, unstable slopes and snow avalanche hazards, would have to be crossed. If a road was continued, a bridge or culvert would be required for the river crossing in the canyon bottom.

Possible new route requiring extensive base fill and underlayment (R-3)

Building a road up lower Makushin Valley will require extensive base fill unless the road is built immediately adjacent to the active channel. The floodplain in lower Makushin Valley consists mainly of floodbasin alluvium (Af, see Plate C-1) that is underlain by lacustrine/lagoonal sediments. The floodplain in this area is flat and marshy. If a road is built on the floodbasin alluvium, it should not be built next to the valley wall slopes on the south side of the valley. Snow avalanches frequently occur along these slopes in winter (see Avalanche Hazard section).

One of the first tasks attempted during the field investigation was to determine the thickness of the marshy floodbasin alluvium. With the aid of a power auger (fig. 4) it was found that the marshy deposits were quite thick. The surface of these deposits consisted of water saturated grass and sedge sod that was bound together by roots. This sod was 0.5 to 1.0 meter (1.5 to 3 ft) thick. Beneath the sod was 6 meters (19 ft) of muck (water saturated organics mixed with mineral matter). At 7 to 8 meters (23-26 ft) depth the alluvium was much more silty and cohesive (stiff). Some ash was also encountered at this depth. A second hole was augered near the south valley wall slope (Power Auger Site 2) to see how thick the marshy deposits were. Practically the same situation was found in this hole as in the first hole. Below the surface sod there was 5 meters (16 ft) of muck and at 6 to 7 (20-23 ft) meters deep increasing silt and ash was encountered. A third hole was augered further up the valley adjacent to the Makushin River active floodplain alluvium. Again, beneath the surface sod layer 5 to 6 meters (16-20 ft) of muck was encountered before reaching more cohesive (stiff) silt and clay. Grain size analyses were performed on samples from the second (sample K-2, fig. 5) and third (sample K-3, fig. 6) auger holes. The cumulative probability plots and organic contents reflect the composition of the muck and silt sampled from the bottom of these two holes. Two seismic refraction studies utilizing a twelve channel Geometrics seismograph, a 550 foot geophone spread, and explosive charges were also done across this marshy floodplain area. The seismic data interpretation matches closely with what was found in the auger holes. Seismic Refraction Line 1 was oriented north-south across the valley at about the same location as Power Auger Hole 1 (see Plate C-1). Figure 7 shows the time/distance plot and interpreted material velocity profile for line 1. The data suggest there is 4.5 meters (15 feet) of water saturated organic rich silt on the north end of the line which is near the center of the valley and close to the river. The data also indicates that the deposits thicken away from the river which is typical of alluvial floodbasin deposition. The data also indicate that near the center of the valley there is 100 feet of water saturated silt and fine sand. Some of this silt and fine sand would probably be ash. Glacial till is probably present beneath the alluvium as shown in the figure. Figure 8 shows the time/distance plot and interpreted material velocity profile for line 2 (see Plate C-1). This interpretation is similar to what was found in the nearby auger hole except that the interpreted thickness for the sod and organic rich silt is thinner than what was actually found in the auger hole. The water saturated silt and fine sand was just as thick along the edge of the valley as it was in the center which lends support to a lacustrine/lagoonal origin for these deposits. Bedrock was detected at about a 100 foot depth beneath this area.

The marshy and mucky floodbasin and underlying alluvium is thick and areally extensive in lower Makushin Valley. The marshy deposits have extremely low bearing capacity, so if a road were to be built on top of these deposits a thick basal fill material would be needed along with some type of underlayment mat. Several small distributary flood channels and tributary streams cut across the floodbasin area. Culverts would be needed at each one of these crossings. The Ground Stability section identifies this area as having potential for subsidence under man-made surface loads.

Possible new route requiring extensive slope excavation (R-4)

Another road route up lower Makushin Valley would be along the base of the south valley wall slope (R-4, see Plate C-1). This route is an alternative to constructing a road across the floodbasin below. The surficial geology along the base of this slope consists of colluvium and glacial deposits. Small, gently sloping benches are present along most of the slope. A road constructed along the base of this slope would probably be situated on these colluvial and glacial bench-like deposits. A hand auger was used to sample the sediments on one of these small benches (Hand Auger Site, see Plate C-1). Four shallow holes were augered on this bench. A shallow reddish brown soil horizon, 0.25 to 1.0 meter (0.8-3.2 ft) deep exists on this bench. Beneath the soil was mixed rock and soil (colluvium). The auger was unable to penetrate the sediments beneath the soil because of increasing pebbles and cobbles which are of colluvial or glacial origin. A road constructed along the base of this slope would require extensive slope excavation. This slope is prone to snow avalanches in the winter and the base of the slope is identified as having potentially unstable soils which could fail if excavated for road construction (see Avalanche Hazards and Ground Stability sections). A road constructed along this slope would also require 3 culverts at tributary stream crossings.

The existing road at the entrance to Makushin Valley is in fair condition. The road needs some improvement where it parallels the beach and would connect to whatever road route is chosen for lower Makushin Valley. The best route for a road in central Makushin Valley is between the two active channels. The floodplain is highest between these two channels and the deposits consist of bankfull bar deposits, low overbank flood bar and channel deposits, and high overbank flood bar deposits (Ab, Alo, and Aho; see Plate C-1). These deposits would provide good foundation material for road construction. Two bridges would be required for the two major river crossings in this area. The active channels at these two crossings are wide so, some dredging and channel confinement work would be necessary.

Transmission Powerline Corridors

Possible valley floor route

The floor of Makushin Valley between Broad Bay and the Makushin River canyon could serve as a possible transmission powerline corridor. If a road was constructed in the bottom of Makushin Valley it would be most economical to construct the transmission powerline here. Selection of the transmission tower sites and the road may or may not coincide. Transmission towers should be situated at a safe distance from valley wall slopes which are prone to snow avalanches and landslides. Wind in the bottom of Makushin Valley would probably be less than along upland slopes. Transmission tower foundations (probably on piles) in lower Makushin Valley would have to be engineered for thick marshy alluvium as described on the map and discussed under the previous road corridor section. Alluvium capable of bearing transmission tower foundations is at least 8 meters (26 ft) deep beneath the lower Makushin Valley marsh. Good foundation materials exist near the surface farther up Makushin Valley. The floodplain in upper Makushin Valley consists of coarse textured bedload sand and gravel alluvial deposits. The best corridor for the transmission powerline between upper Makushin Valley and the proposed powerhouse facility is an upland route above the Makushin River canyon. The Makushin River canyon is deep and the canyon wall slopes are steep. These slopes are prone to snow avalanche and landslide hazards (see Avalanche and Ground Stability sections). The river floodplain in the canyon is narrow and subject to frequent flooding and channel bank erosion.

Possible upland route

The decision to select and study a possible upland transmission powerline corridor route was made during a brief helicopter reconnaissance flight around the study area with an APA electrical engineer. The engineer had worked on numerous other APA transmission powerline projects and was asked to comment on possible corridor routes for this project. During the flight the engineer indicated that the transmission powerline corridor could continue its route along the southern upland Makushin Valley slopes from the Makushin River canyon area to Broad Bay or Nateekin Bay. Selection of an upland route would require complete helicopter supported construction.

An upland corridor route would require fewer transmission tower sites than a valley bottom route. Most of the tower sites are separated by broad and deep valleys. Upland transmission towers would have to be bigger than towers in the valley bottom in order to support the increased electrical line weight. The towers would have to be securely anchored due to increased wind conditions. Tower sites would also have to be situated where snow avalanche and landslide hazards were not a threat. The shortest upland transmission line corridor route between the proposed powerhouse facility and upper Makushin Valley is along the southern valley wall slopes. There are several transmission line corridor routes between upper Makushin Valley and Broad Bay or Nateekin Bay. A possible upland transmission line corridor route from the proposed powerhouse facility along southern Makushin Valley slopes to Nateekin Bay is shown on the map. Seventeen possible tower sites were investigated along this route. Tower sites were selected in areas of thin overburden or where bedrock was exposed (outcrops). Tower sites coincide with bedrock plateau, bench, saddle, knoll, and ridge landforms. Some of the soil slopes where the possible tower sites are located have been classified as potentially unstable and prone to avalanche hazards (see Ground Stability and Avalanche Hazard sections). The possible tower sites are not prone to avalanche or landslide hazards even though they are located in hazardous areas. The tower sites are located on relatively small, flat bedrock benches, saddles, and ridges. Slopes above the possible tower sites are short and gentle. The possible tower sites and uphill slopes are too small to show on the Avalanche Map or the Ground Stability Map. Sixteen of the possible tower sites were reconnaissance surveyed during the investigation. Table 1 has elevations for each possible tower site, slope distance, and slope angle between tower sites, and comments on estimated overburden thickness. This information will aid electrical engineers in relating possible transmission tower sites to topographic conditions and constraints.

CONCLUSIONS AND RECOMMENDATIONS

The information presented in this report is based on reconnaissance level observations and data. Knowledge about different types of powerline construction would have helped define and narrow the objectives of this study. There are several potential transmission powerline and road corridor routes in the study area. Transmission powerlines can span deep ravines, gullies, and small valleys. Powerlines are always straighter and shorter between two points than roads. If the transmission powerline needs to be accessible by road for construction and/or maintenance reasons, then more spur roads and/or a longer powerline are required.

Before future geotechnical studies of powerline and road corridors continue there are several questions about powerline design and cost that need to be addressed. Information that is needed before studies continue includes: 1) should transmission powerlines be above ground, or can they be buried; 2) what type of powerline towers would be used; 3) how far apart can the towers be; 4) what type of foundations do the towers require; 5) how much elevation change can towers have between each other; 6) will the transmission powerline require frequent maintenance; 7) will the powerline need to be accessible by road; and 8) what is the most economical method of powerline construction. Meteorological wind data will be necessary in the preliminary design of transmission powerline towers. This information is lacking for the project area which means that data collection should begin as soon as possible and

Table 1. Tower site information.

Tower Site	Elevation of tower site	Slope distance between site & previous site	Slope angle between site & previous site	Comments on overburden and foundation soil conditions
TS-1	1,000 ft	n/a	n/a	see Engineering Geology section
TS-2	935 ft	1,052 ft	3.75°	Approx. 6-8' of soil, colluvium, ash, and glacial till overlying bedrock
TS-3	1,080 ft	1,620 ft	4.2°	Approx. 4-6' of soil, colluvium, ash, and thin glacial till overlying bedrock
TS-4	1,000 ft	3,120 ft	0.5°	Approx. 2-5' of soil, colluvium, ash, and thin glacial till overlying bedrock
TS-5	1,130 ft	1,469 ft	2.0°	same as TS-4
TS-6	1,110 ft	1,494 ft	2.25°	same as TS-4
TS-7	625 ft	3,236 ft	10.25°	Approx. 4-6 ft of soil, colluvium, ash, and glacial till overlying bedrock
TS-8	1,300 ft	2,250 ft	15.6°	same as TS-7
TS-9	1,500 ft	2,685 ft	5.75°	Approx. 2-3' of colluvium and ash overlying bedrock
TS-10	950 ft	2,790 ft	9.2°	Approx. 2-3' of soil, colluvium, ash, and thin glacial till overlying bedrock
TS-11	1,440 ft	2,920 ft	7.5°	Approx. 3-4' of soil, colluvium, ash, and thin glacial till overlying bedrock
TS-12	1,780 ft	5,275 ft	4.6°	same as TS-11
TS-13	1,825 ft	4,039 ft	0.8°	same as TS-11
TS-14	1,440 ft	1,935 ft	12.5°	same as TS-11
TS-15	650 ft	3,860 ft	11.15°	Approx. 6-8' of soil, colluvium, ash, and glacial till overlying bedrock

continue for at least a year. Because of the project location, design of the powerline towers should take into account the hurricane-force winds than can blow up to 150 mph in this area.

The APA electrical engineer who visited the project area during the field work indicated that most large and relatively inaccessible transmission powerline construction in Alaska is helicopter supported because, in the long run, it is the most economical construction method. Knowing whether or not a road is needed for this powerline construction would be helpful in selecting road corridor routes. The two possible new road corridors on both sides of Makushin River canyon would not be all-weather routes. Both routes would be susceptible to snow avalanche hazards in the winter and spring. Neither one of these routes could actually be used to reach to powerhouse site in winter and spring. The routes could be used for some powerline maintenance in the winter and spring if the road and powerline were the same route. If the possible transmission powerline and road corridors in the bottom of Makushin Valley are selected for future study, then closer spaced and deeper soil auger borings should be done along the center of the corridor. Weight limit and compaction studies should be done on the marshy floodplain alluvium where it is underlain by lacustrine and lagoonal sediments. It would be a good idea to trench and make short roadcuts into the base of the southern Makushin Valley wall slope at several locations to see how avalanche and slope stability hazards may affect the roadcuts during a year's period. Another area where experimental roadcuts would be helpful is along the steep slope above Staging Area C on possible corridor route 2 (R-2). Both of these areas could be reached by a small caterpillar tractor. If a road would only be needed during transmission powerline construction to move materials to helicopter staging areas, then the existing road should be utilized from Driftwood Bay to Staging Area B. This may be the most economical approach to construction.

It is said that almost any construction problem can usually be engineered around if cost is not a problem. This ideology probably doesn't apply to this project. Once an economical transmission powerline and road design is decided upon, the best transmission powerline and road corridors for the project can be selected. After the corridor selection, geotechnical studies can be conducted along the corridors. Information from these geotechnical studies could then be used for final powerline and road design work.

If the transmission powerline will need only minimal and periodic maintenance then a helicopter operation may be more economical than building and maintaining a road. A helicopter could be used to periodically check and maintain the powerline once it was built. Powerhouse operations and maintenance could also be serviced by helicopter or fixed wing aircraft if a small airstrip was constructed near the powerhouse site.

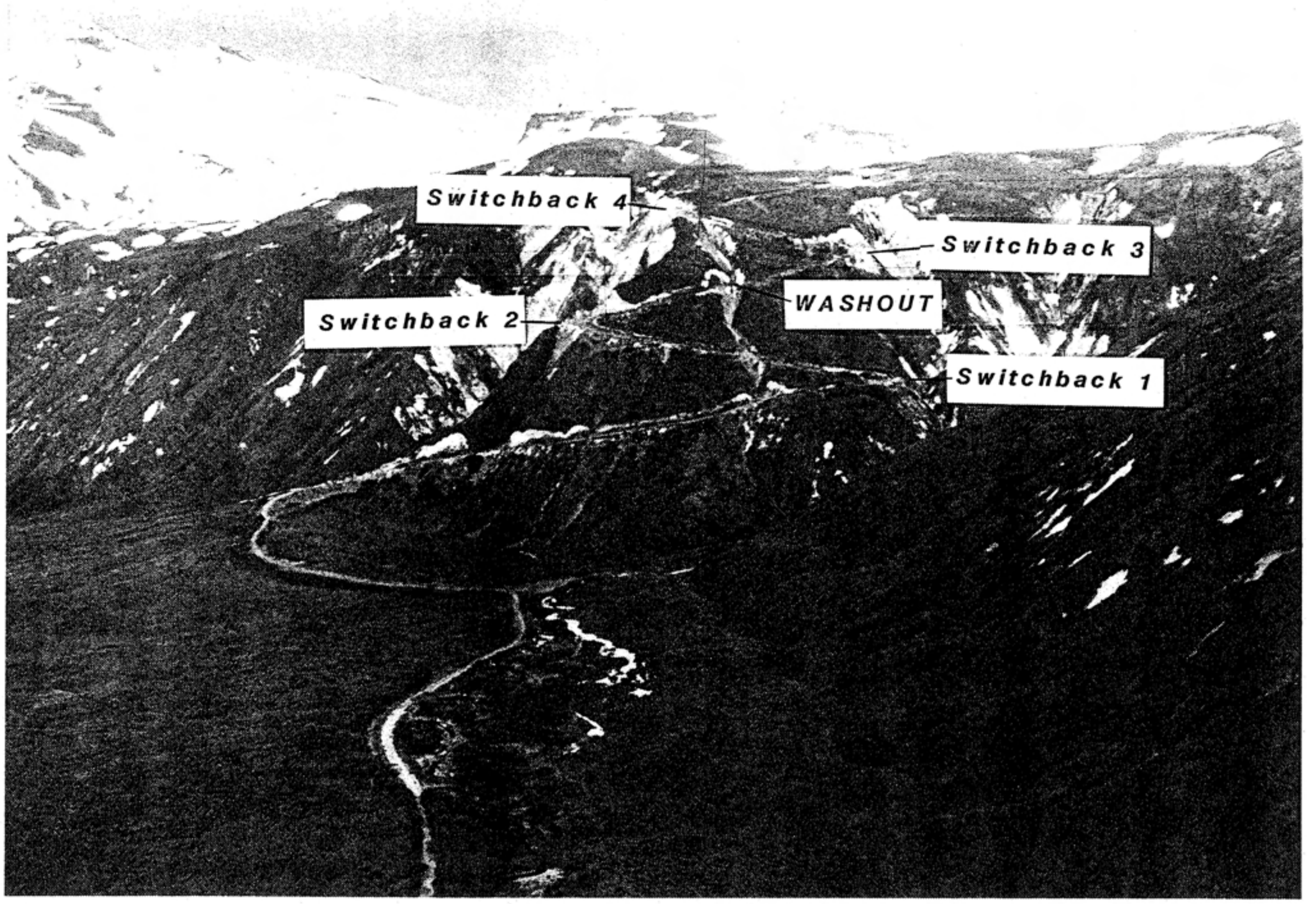


Figure 1. Existing road between Makushin Valley and Driftwood Bay Valley.

Figure 2. Road wash-out. Location shown on Figure 1 above.

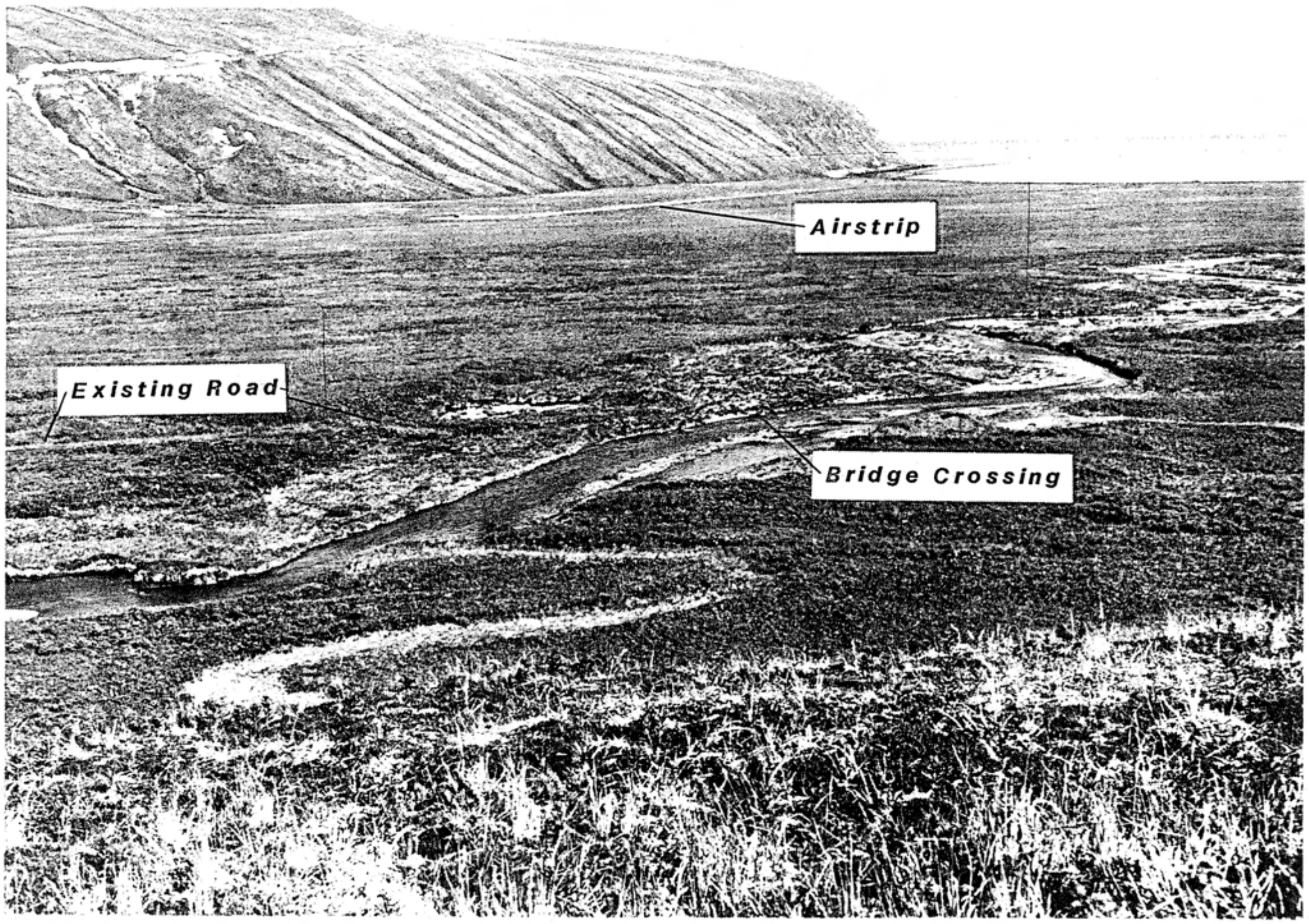


Figure 3. Driftwood Bay Valley floodplain.

Figure 4. Power auger site 1. Floodbasin deposits in lower Makushin Valley.

GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: K-2

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26		
0.5	12.7	-3.67	100	1
0.375	9.5	-3.25	99	2
4	4.76	-2.25	97	0
10	2.00	-1.00	97	1
20	0.84	0.25	96	1
40	0.42	1.25	95	2
50	0.30	1.75	93	14
100	0.149	2.75	79	19
200	0.074	3.75	60	60

GRAVEL (#4+)	3
SAND (#4-, #200+)	37
SILT+CLAY (#200-)	60
ORGANICS (WT %)	10

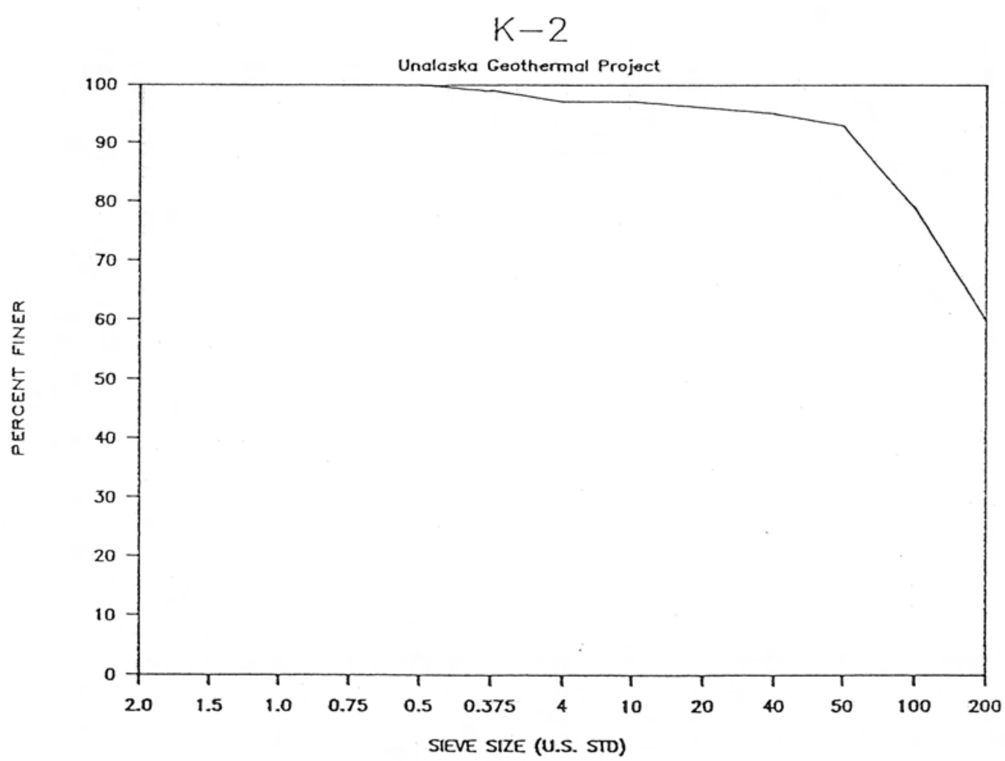


Figure 5. Grain-size analysis and cumulative probability plot for power auger site 2 (sample K-2).

GRAIN-SIZE ANALYSIS
Unalaska Geothermal Project
Sample: K-3

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67		
0.75	19.1	-4.26		
0.5	12.7	-3.67		
0.375	9.5	-3.25		
4	4.76	-2.25		
10	2.00	-1.00		
20	0.84	0.25	100	1
40	0.42	1.25	99	2
50	0.30	1.75	97	6
100	0.149	2.75	91	11
200	0.074	3.75	80	80

GRAVEL (#4+)	0
SAND (#4-, #200+)	20
SILT+CLAY (#200-)	80
ORGANICS (WT %)	24

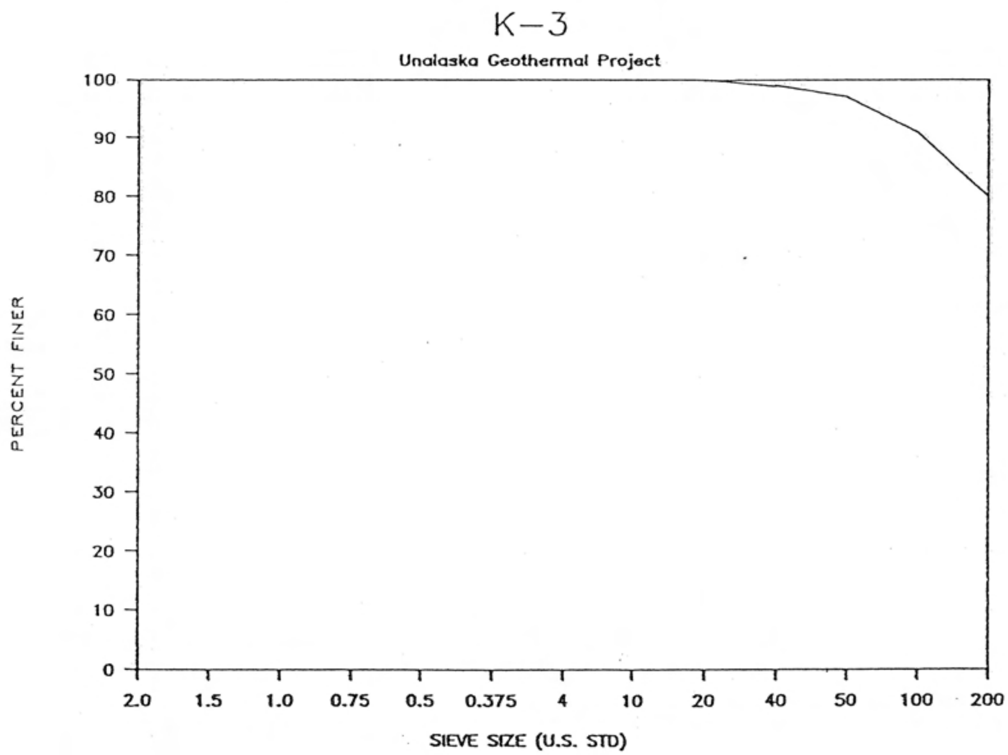


Figure 6. Grain-size analysis and cumulative probability plot for power auger site 3 (sample K-3).

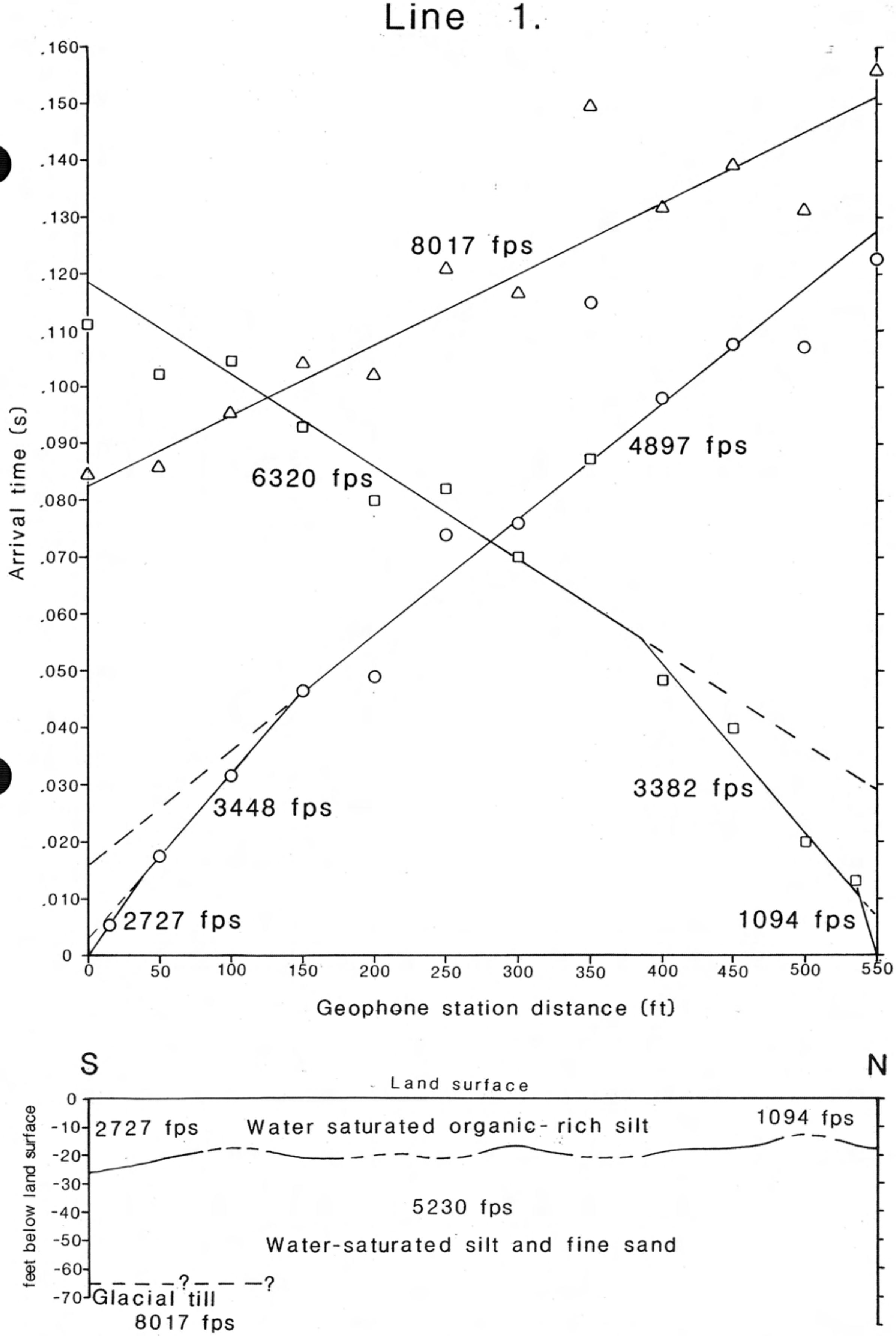
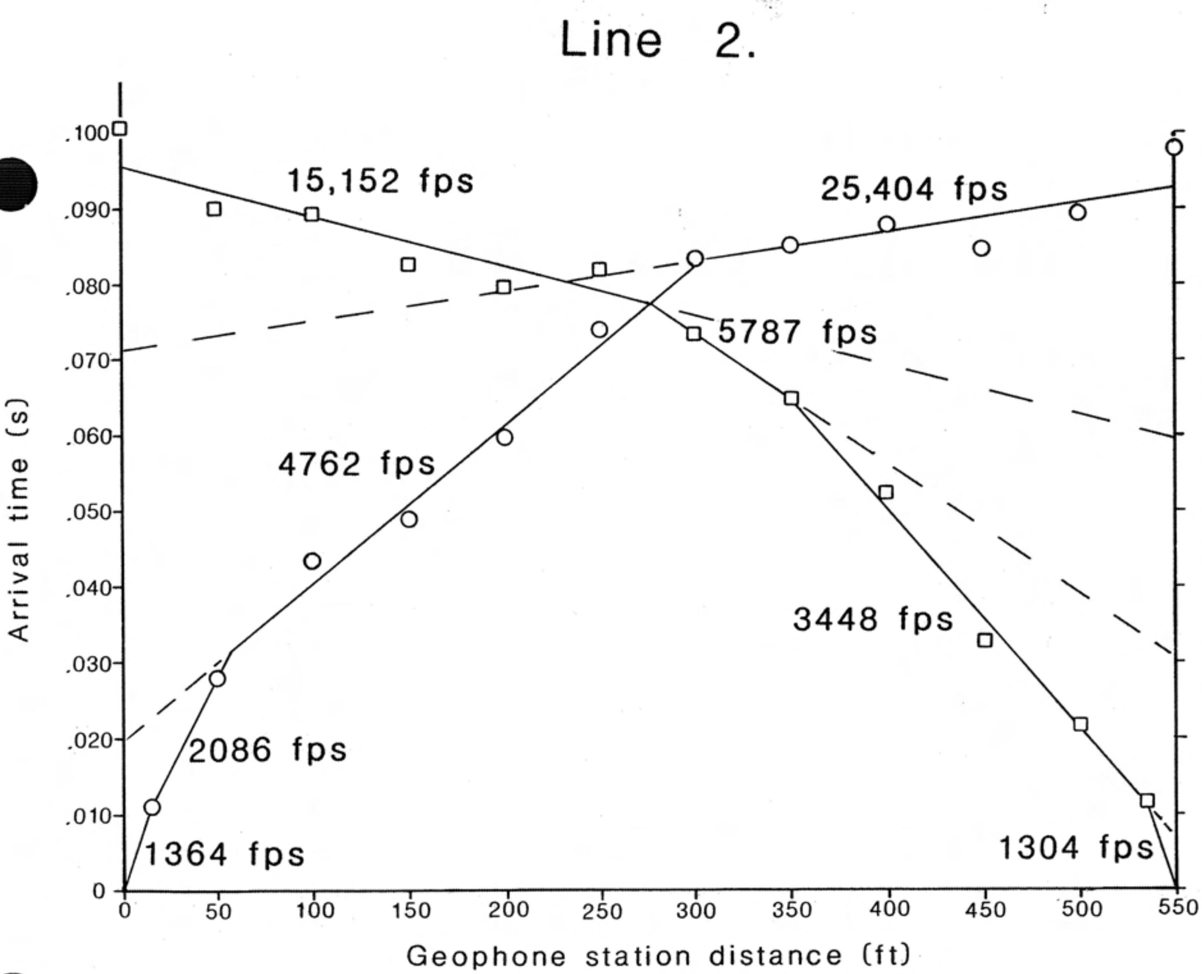


Figure 7. Time/distance plot and interpreted material velocity profile for seismic line 1.



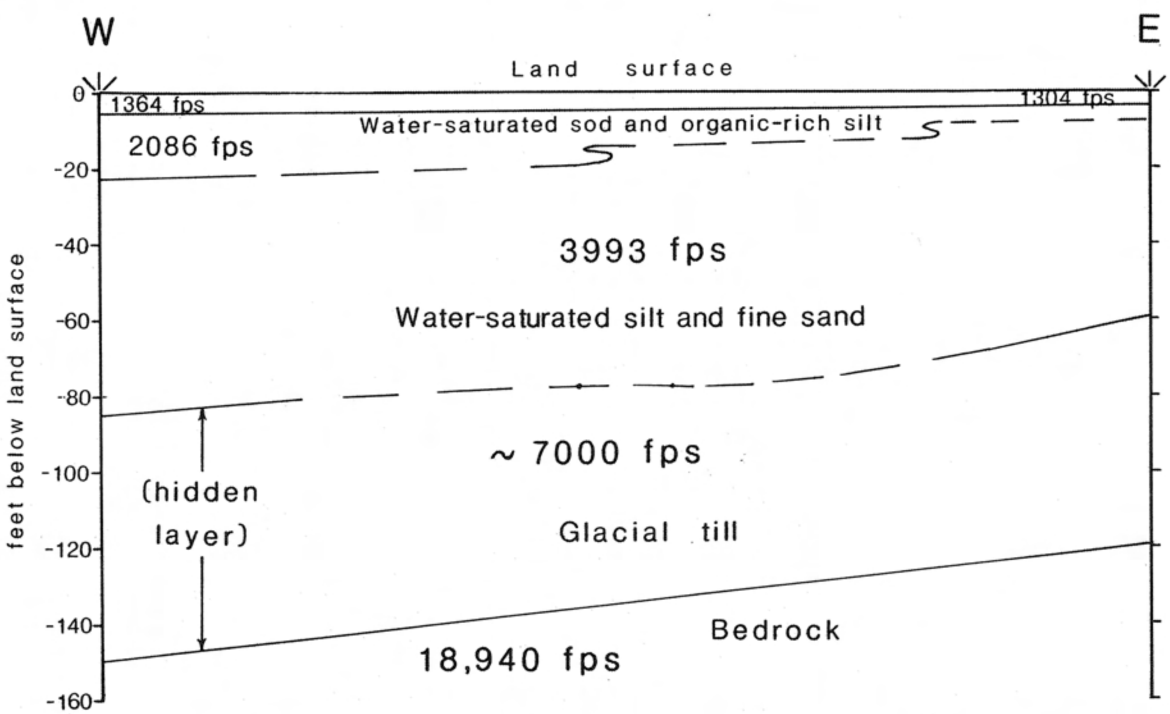


Figure 8. Time/distance plot and interpreted material velocity profile for seismic line 2.

COASTAL ENGINEERING

By Doug Jones

INTRODUCTION

APA is about to conduct a detailed feasibility study for an electric power generator on Unalaska Island. The energy source will be geothermal which has been identified and tested near Makushin Volcano. A preliminary design of the equipment and its location will also be included in that APA study. The basic components of the power generating plant will be a generator, located at or near the geothermal source; transmission lines to the population centers at Dutch Harbor and Unalaska; and one or more transformer stations on the transmission line corridor. This section of the auxiliary report on the physical environment will address three coastal areas which could impact development schemes for this project.

The three areas to be described are Driftwood Bay, to the north of Makushin Volcano (fig. 1); Broad Bay, at the end of Makushin Valley to the west (fig. 2); and Nateekin Bay, adjacent to and south of Broad Bay (fig. 2). Both Driftwood and Broad Bays were visited between July 14-19. We, on the other hand, did not believe that Nateekin would be considered and did not investigate its coastal characteristics on this trip. However, between maps, photographs, and observations from those who have visited the site, we can adequately describe that bay.

Driftwood Bay

Driftwood Bay is the farthest from the power user centers, being just over 11 miles by water from Dutch Harbor/Unalaska. Driftwood is less than 2 miles wide at its mouth and indented inland by no more than 1 mile. It is exposed to the Bering Sea to the north allowing direct attack by large storm waves. The steeply-sloping beach is composed of well-rounded boulders from a few inches to over a foot in diameter; the beach slopes between 40 and 50 degrees. This large rock size and steep beach are indicative of the high energy environment presented by the Bering Sea exposure.

A large stream enters the bay from the east side of the valley. The mouth of the stream, being tucked against the cliffs on the edge of the valley, indicates eastward migration from the center of the valley. This location also indicates that the dominant longshore drift direction is to the east. However, the extreme roundness of the beach rock would also indicate that the material probably remains in the system for a long time. The beach material probably does not leave the system via longshore transport but remains until waves abrade the rocks small enough to be transported offshore.

There is also an excellent, but at this time, unmaintained airstrip which was built in support of the former Dewline site, now abandoned. There is a road from the airstrip up to the probable geothermal power site, albeit in disrepair.

Drift material such as large logs, parts of fishing gear, and even a bale of cotton, high on the backshore, indicate heavy and recent storm activity.

Therefore, beach facilities would require substantial protection from wave attack.

Broad Bay

Broad Bay is about 8 miles east of Makushin Volcano and about 3 1/2 miles west of Dutch Harbor/Unalaska. It is the seaward extension of Makushin Valley. As its name implies, it is a rather broad, poorly defined bay within the larger Unalaska Bay. It is sheltered from direct exposure to the Bering Sea; a fact reflected in its beach characteristics. The beach is composed of medium to fine sand and slopes 15 to 20 degrees.

Judging from the location of the Makushin River, the longshore drift direction is from the northwest to the southeast. This appears to be the longterm trend, but reversals, probably lasting only during storms, are indicated by the erratic appearance of the channels near the river's mouth.

Several indicators suggest that wave activity is much less than at Driftwood Bay: the backshore ridge shows no recent overtopping; the beach is gently sloping and composed of fine material; and the only manmade structure, a dock presumably built during the early forties, shows no discernable longshore transport activity.

One to three sets of concentric ridges are set back but roughly parallel to the present beach. They are similarly vegetated to the surrounding terraine and could be former storm berms or spits which developed as the beach grew seaward. If they were former spits, they could have been left as relict features after they closed, or nearly closed, the bay; at which time, the dynamics for creating the spit would have ceased. Either the storm berm or spit ideas could also have been accompanied by uplift of the land. Regardless of the beach development at Broad Bay, it is clearly a quiescent coastline and ample construction material can be found both on the backshore and at the nearly vertical cliffs to the southeast.

Nateekin Bay

The third area under consideration is Nateekin Bay south of Broad Bay. This bay was the only one not examined, on the ground, specifically to evaluate its suitability for siting shore facilities. Clearly, it is well protected from storm activity and is probably much like Broad Bay in character. I think it is fairly safe to say that the physical environment of this bay would support facility siting for the geothermal power generator. It is situated only about 2 miles by water from the Dutch Harbor/Unalaska area. Mountainous terraine separate this bay from the probable geothermal source area.

Storm Activity

So far nothing has been mentioned about storm surge or of wave setup, both of which can increase water levels several feet above tide level and both often occur simultaneously. Driftwood Bay is more susceptible to both of these phenomena than either Broad or Nateekin Bays. This is due to its somewhat shallower water offshore, which generates higher storm surges; and its direct exposure to the Bering Sea, which results in larger waves, and therefore, higher wave setup. However, even with Driftwood Bay, the water directly offshore is, in all probability, too shallow to permit much of a storm surge. Wave setup, on the other hand, probably can increase the water levels several feet in this bay. Broad and Nateekin are less susceptible to either storm surge or wave setup and elevations in Broad Bay should not exceed 2 feet above normal and, even less, probably no more than 1 foot in Nateekin.

Transmission Corridors

Without having detailed bathymetry, it is not possible to determine precisely the preferred transmission-line corridor. Only distance to Dutch Harbor and Unalaska was used to compare the sites. An examination was also made of the NOAA's Nautical Charts for the area (Nos. 16518 and 16528), and no obvious obstacles to transmission-line construction were seen. A detailed route survey would have to be conducted before construction.

Construction Materials

Near-vertical cliffs close to all 3 possible coastal sites indicate that harbor protection and beach access could be made possible from locally-derived material. A more thorough analysis of possible wave heights and periods would probably be needed at Driftwood Bay, owing to its obviously higher-energy environment. It is possible that large enough armor rock for direct wave protection could not be obtained locally. In that case, larger quantities of less than optimum rock would be needed which could severely escalate construction costs. At Broad Bay, the rock in the nearby cliffs (to the southwest) produced a good solid ringing sound when struck with a hammer. This indicates competent material. The material has a slight greenish tint and is probably an andesite which is common in the area. Judging from the material in the talus piles, 3- to 4-ton rock should be easily obtainable. This would be of adequate size to protect facilities in the rather sheltered area. No direct knowledge of construction materials are known for Nateekin Bay. I suspect that construction material is also locally available there.

PREFERRED SITE

Of the 3 sites, overall preference might be aided by ranking several variables among the sites. The following self-explanatory matrix will help with the ranking, with 1 being most favoarable and 4 least desirable.

	Developmental Variable				
Bay	Storm Severity	Construction Materials	Generator Access	Transmission Line	Docksite Potential
Driftwood	4	2	1	4	3
Broad	2	1	2	2	1
Nateekin	1	2	4	1	1

As can be seen, a simple 1-2-3 ranking was not used. A somewhat weighted ranking was used because, in certain cases, one site was clearly inferior or superior to another site. Broad Bay, having the lowest total score, was determined to be the best site based on the coastal environment and access to the generator; Nateekin Bay was a close second and Driftwood Bay last.

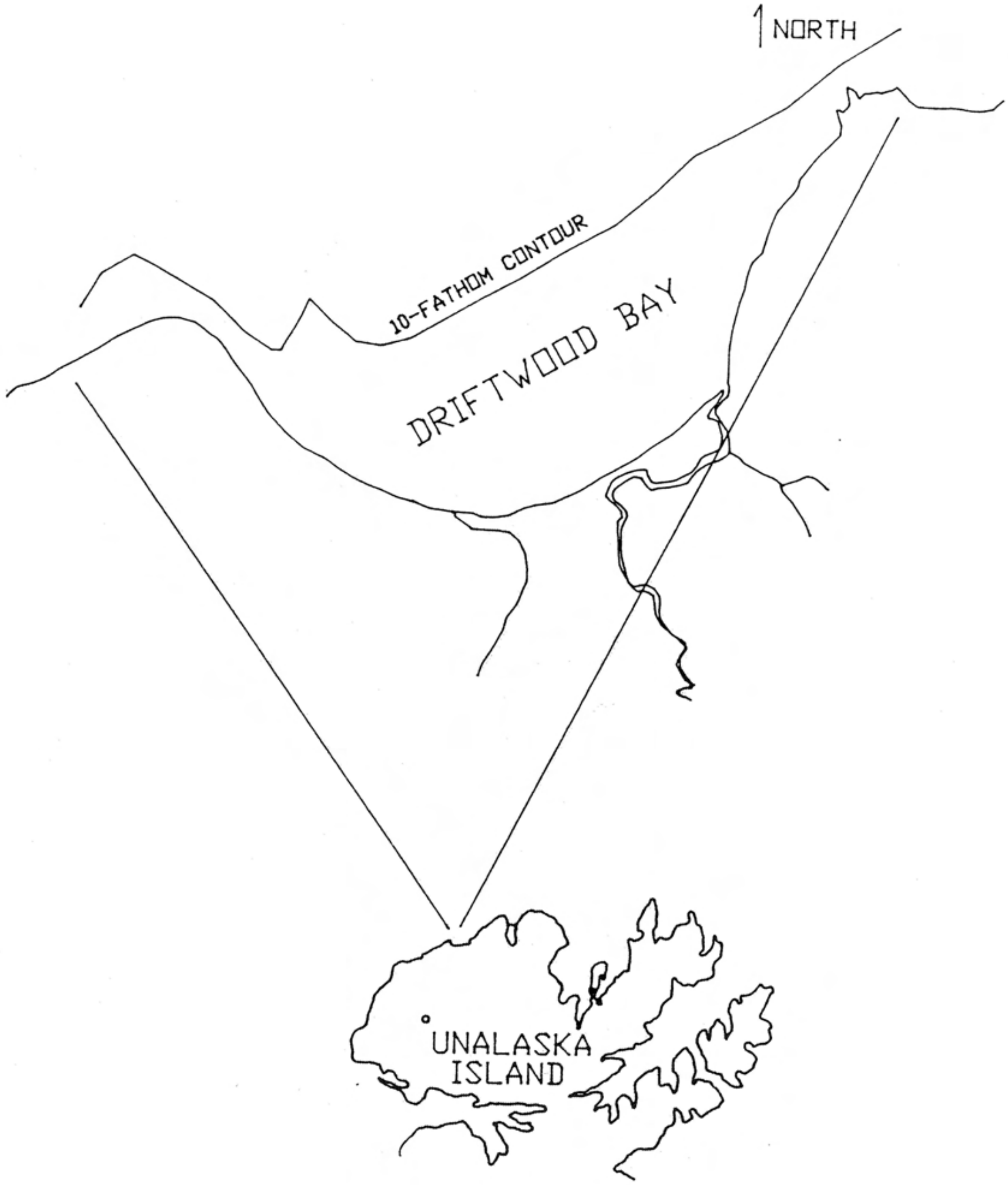


FIGURE 1: DRIFTWOOD BAY

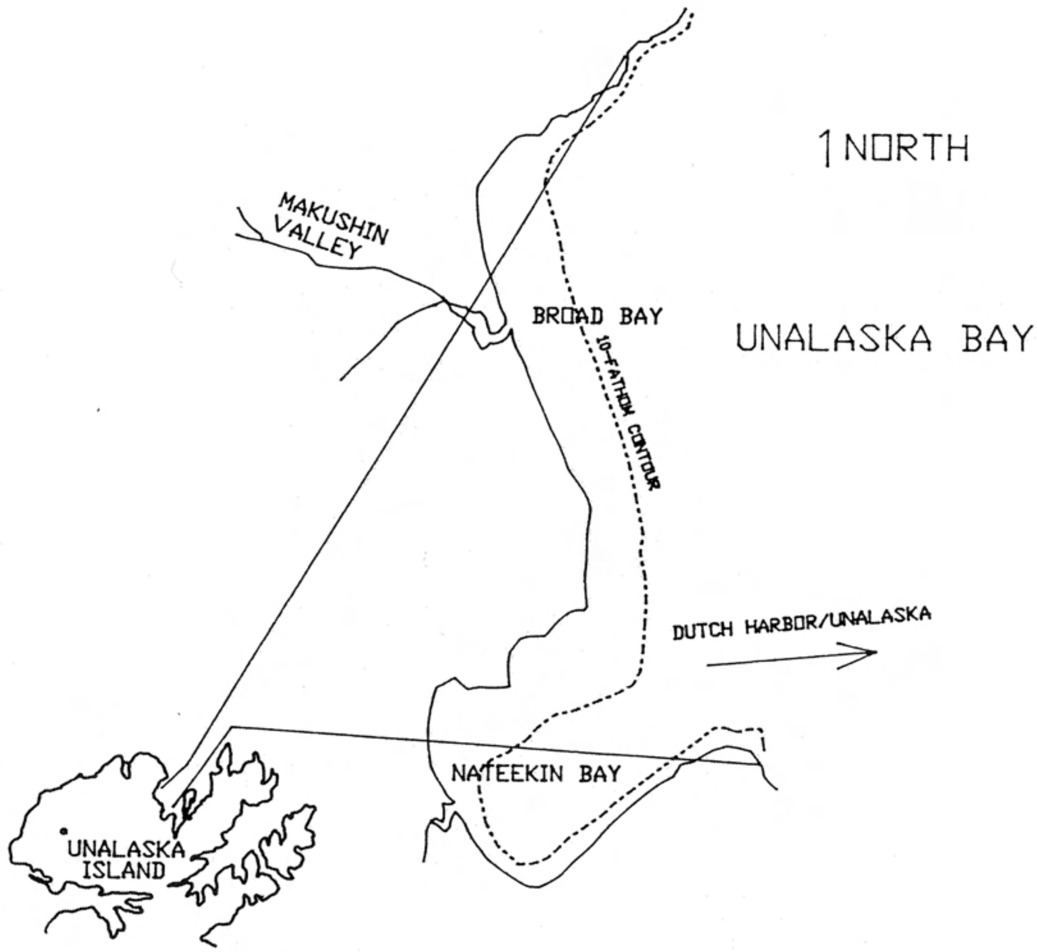


FIGURE 2: BROAD BAY AND NATEEKIN BAY

VOLCANIC HAZARD CONSTRAINTS

By Chris Nye

SCOPE OF WORK

The proposed geothermal power-generating facility is on the flank of an active volcano. Any future development must recognize the possibility of future eruptions and the hazards that those eruptions would pose for facilities and personnel.

This report summarizes the current state of our knowledge about the eruptive history of Makushin Volcano and its flank vents, presents our best estimate of what future eruptions might be like, and specifies especially hazardous areas near the proposed power plant.

We also specify volcano monitoring activities that we feel are essential to safe operation of any development on the slopes of the volcano.

METHODOLOGY AND TECHNIQUES USED

This report is based our interpretation of the eruptive history of Makushin Volcano and its flank vents. This view is a result of field observations which have been acquired during geological investigations of the area over the past few years, aided by reinvestigation of problem areas in the course of the current study, and previously published information (e.g. Drewes and others, 1961; Reeder, 1983; Reeder and others, in press). A special focus of the current work was an investigation of the Holocene eruptive history using tephrachronology and the morphology and composition of unconsolidated deposits. This work was done in the company of Dr. James Beget of the University of Alaska, Fairbanks. We are very grateful for his participation. Much of our interpretation of the volcanic stratigraphy is based on the previous work of Nye and others (1986), and Nye and Swanson (1986), which were detailed chemical investigations of about 165 samples of the volcanic products of Makushin and its flank vents. The chemistry of those samples were used to track the evolution and history of the magmatic system. All discussions of the petrology and chemistry of volcanic products in this report are drawn from these studies.

RESULTS OF INVESTIGATION

Nature of the Makushin Volcanic Field

The Quaternary geology of northern Unalaska Island is dominated by the eruptive products of Makushin Volcano and associated satellitic and flank vents (fig. 1). These vents are collectively termed the Makushin Volcanic Field (MVF). The MVF is a transitional tholeiitic/calcalkaline province of basalt through low silica dacite whose composition is broadly typical of Aleutian magmas (fig. 2).

Makushin Volcano is the largest and longest lived center. It is 2055 m high and a few to several tens of km^3 in volume. Makushin Volcano and its precursors have been active over at least the last million years. Lavas form isolated erosional remnants as well as the active Makushin Volcano. Nye and others (1986) and Nye and Swanson (1986) infer, on the basis of extreme chemical variation among lava flows in single stratigraphic packages and widespread mineralogical disequilibrium, that Makushin lava flows have been fed from a relatively small shallow magma chamber which is frequently reinjected by new magma derived from a deeper chamber. These deposits are shown as QTvc on figure 1. They are overwhelmingly lava flows of basalt and andesite, although there is some low silica dacite, especially among more recent eruptive products.

The MVF also contains several late-Pleistocene to early-Holocene monogenetic satellitic vents which, along with Makushin Volcano itself, form a broad SW-NE trending band (fig. 1). These vents are, from the SW, Pakushin Cone (about 1050 m, 1-2 km^3), Sugarloaf (580 m), Table Top Mtn (800 m, about 1 km^3) and Wide Bay Cone (about 640 m, about 0.5 km^3). There are also extremely small volume eruptive centers at Cape Wislow and on a linear fracture radiating from near the summit of Makushin Volcano to the NW. Small explosion pits and cinder cones along this fracture are termed the Pt. Kadin Vents (Drewes and others, 1961). A large volume (at least 5 km^3) package of coeruptive flows, termed the Lava Ramp, erupted from Makushin Volcano and fills upper Makushin and Driftwood Valleys. The products of these satellitic and flank vents are shown as Qhv in figure 1. Nye and others (1986) infer on the basis of chemical homogeneity within each center, and chemical heterogeneity between centers, that these lavas were erupted from spatially discrete magma reservoirs over a relatively short period of time. Thus the satellitic centers are monogenetic cones, whereas Makushin Volcano is a polygenetic stratocone. Qhv lavas are basalt and low silica andesite.

Pyroclastic deposits are relatively uncommon in the MVF, especially in the older portions of the field. Of notable exception, however, are the young terraces of pyroclastic debris found in the heads of many of the major drainages of Makushin Volcano, such as the terrace under the ST-1 wellhead. These deposits are probably related to Holocene caldera collapse at Makushin (Reeder, 1983), and will be discussed in more detail below.

Eruptive History

Historic Eruptions

The historic eruption record at Makushin is summarized by Simkin and others (1981) and Arce (1983). Over the 200 odd years for which there are historic accounts Makushin has been frequently active. Arce (1983) found over 20 reports of eruptions or "smoking". The references to "smoking" probably represent exceptionally vigorous fumerolic activity, much of which probably went unreported. Seven events were vigorous enough to produce ash, and are probably the only true eruptions. Those eruptions were in 1768, 1802, 1826, 1883, 1926, 1936, and 1951. Arce (1983) finds a 30 year repose interval between eruptions which he believes is statistically significant. In a few instances the historic record mentions activity from other vents than the summit of Makushin Volcano. The locations of these vents are seldom specified, but appear to be parasitic vents near the summit of Makushin rather than any of the main satellitic vents within the MVF. The description of the 1980 plume is more specific. That plume is reported to have come from a parasitic vent on the south flank of the volcano 60 m below the summit (Simkin and others, 1981). This plume was probably from the currently active vent which is near the south rim of the caldera and appears, from the east, to be below the summit. In the spring of 1986 anomalously vigorous fumarolic activity was also noted (McClelland and others, 1986).

No historic eruptions have produced lahars, lava flows or pyroclastic flows. Ballistic blocks, bombs and ash which are the uppermost units at Makushin, and may be a product of historic eruptions, are silicic-andesite or low-silica dacite.

Late-Holocene Tephra

Late-Holocene tephra blanket older features in the area. Those tephra which overlie the valley-filling pyroclastic fans provide a record of Makushin volcanism since the violent caldera forming eruptions. At the site of the proposed power plant these tephra are a series more than a dozen interbedded black and orange ash layers with a few interbedded thin tan pumice layers. The total thickness of tephra is about 2 meters.

The impact, at the plant site, of the eruptions which produced these tephra was relatively minor. This is because most of the eruptions were minor. The few major eruptions were directed away from the site. One pumice layer thickens from 2 cm at the site to 40 cm on the northern flank of the volcano.

The recurrence interval for the eruptions which produced the late-Holocene tephra is on the order of a few to several hundred years.

Mid-Holocene Valley-filling Volcaniclastic Deposits

The heads of many of the major drainages of Makushin Volcano are filled with Holocene volcaniclastic units which form conspicuous terraces as much as 90 m thick. These are shown as Qvp on figure 1, and are mapped in more detail by Drewes and others (1961) and Nye and others (1984). These deposits typically have basal till, mudflows, flood deposits, or lightly welded ashflow tuffs, overlain by lightly welded or sintered ashflow tuffs, which are in turn overlain by about 2 m of late Holocene tephra. Most deposits, such as the one at the head of Makushin Valley, are dominated by ashflow tuffs. Some of the deposits are retransported, presumably by gravity flow off surrounding hills, and are now chaotically mixed. Juvenile clasts within these units are high-silica andesite and low-silica dacite, and are among the most silicic which have erupted from Makushin (fig. 2).

All of these Holocene volcaniclastic deposits were formed during exceptionally violent eruptions of Makushin and, as suggested by Reeder (1983), were most likely emplaced during caldera collapse. If all these deposits were emplaced during caldera collapse then they must all be the same age. A sample of organic soil from immediately beneath the volcaniclastic unit which is at the east end of the Makushin Valley canyon (east of Sugarloaf) was reported by Reeder (1983) to be 7950 ±90 radiocarbon years before present. A sample from organic material in the uppermost part of the debris flow at the head of Glacier Valley was reported by Nye and others (1984) to be 4280 ±280 radiocarbon ybp. These two ages bracket the age of emplacement of all the volcaniclastic deposits only if they are all derived from a single eruption.

A less likely possibility is that the deposits may have been derived from separate eruptions, and thus are not related to caldera collapse. In this case each deposit might have an age closer to its limiting radiocarbon age.

It is important from the standpoint of volcanic hazards to determine if these deposits are coeval. If they are, and if they are related to caldera collapse, then it is unlikely that similar eruptions will occur in the immediate future, since caldera collapse is an infrequent event. If, however, these deposits are not coeval, then there may have been as many as four exceptionally violent eruptions during the Holocene, and there is a much better chance that there will be another.

It seems most likely that these deposits are related to caldera collapse sometime during the interval 4300 to 8000 years ago, but it is important to be more confident in this conclusion. A program aimed specifically at dating and describing these deposits should be initiated. It may take extensive prospecting to find organic material in a suitable stratigraphic position to determine with confidence the age of these deposits.

Complications of internal stratigraphy within these fans suggest that fan formation may have been accomplished in a few pulses separated by an undetermined amount of time.

Pleistocene Eruptions of Makushin Volcano

Juvenile clasts within the valley-filling pyroclastic fans, ballistic bombs near the present ground surface on all flanks of the volcano, caldera rim fragments, and other units of Holocene age are predominantly high-silica andesite and low-silica dacite (fig. 2). 62 percent of all mid- to late-Holocene samples have less than 58 percent SiO_2 and 70 percent of all samples with over 58 percent SiO_2, and virtually all dacites, are mid- to late-Holocene (Nye and others, 1986).

During the Pleistocene (and earliest Holocene) Makushin magmas were more mafic, with only a handful of samples being high-silica andesite, and the rest low-silica andesite and basalt. Pleistocene magma virtually always erupted as lava flows; thick pyroclastic units are rare in older Makushin outcrops.

The chemical stratigraphy is consistent with a history in which a fairly mafic shallow-level system evolved to a more silicic composition, and then underwent caldera collapse, as is typical of silicic systems. Caldera collapse has already happened, thus we expect little probability of major vulcanian or plinian eruptions from Makushin.

Late Holocene tephra mantling most surfaces appears mafic and may represent renewed andesitic volcanism.

Eruptions of Satellitic and Flank Vents

Magma which was erupted from the satellitic and flank vents is typically fairly mafic, and overlaps the composition of Pleistocene Makushin Volcano magma. On the basis of chemical similarities between samples from the same vent and major chemical differences between vents Nye and Swanson (1986) and Nye and others (1986) inferred that the magma chambers feeding the satellitic centers were spatially discrete and evolved along separate pressure-temperature paths. The larger satellitic vents are typically lava and cinder cones with extensive skirts of lava flows. Smaller vents lack lava skirts.

The Lava Ramp is grouped with the satellitic vents because it shares the characteristic of compositional homogeneity, which suggests that it erupted in a single volcanic event of relatively short duration. Individual sections through the Lava Ramp (at thermal gradient hole at Fox Canyon and in Makushin gorge) are nearly identical in major and trace element composition, although different from each other. All samples from the Lava Ramp define a smooth compositional trend as a function of the distance from the summit of Makushin. These observations suggest that the Lava Ramp is the result of the emptying of a single large zoned magma body.

Most of the deposits of the satellitic and flank vents (Pakushin Cone, Lava Ramp, Sugarloaf and Table Top) have been glaciated, and also fill or blanket late Pleistocene topography. For this reason we believe that they are of approximately the same age and that that age is late Pleistocene to early Holocene. Sugarloaf is probably entirely late Pleistocene. Sugarloaf is made up of beds of fine-grained ash with a few included blocks and cinders. These fine grained beds are interbedded with volumetrically minor cinder beds in the upper part of the cone. This grain size distribution is typical of phreatomagmatic eruptions and is quite distinct from the coarser grain size of subaireal cinder and scoria cones. The phreatomagmatic eruptions were most likely subglacial, and thus late Pleistocene.

These deposits are all older than the valley-filling pyroclastic units, which have not been glaciated.

These deposits signal the late Pleistocene or early Holocene rise and eruption of several discrete, relatively large, magma bodies. They do not appear to be the result of continued satellite vent formation throughout the Holocene.

An exception is the Point Kadin vents, which are morphologically exceptionally fresh. These vents formed along a SE trending rift on the NW side of Makushin Volcano. The extension of this rift through Makushin comes close to the head of Makushin Valley and the proposed geothermal plant site. It would be prudent to monitor this rift and be alert to the possibility of future activity along it.

Model of Volcanic Activity within the MVF

Nye and others (1986) and Nye and Swanson (1986) have arrived at the following model of activity within the Makushin Volcanic Field, based on whole rock and mineral chemistry of all available samples. A diagram of this model is in figure 3.

Pleistocene activity was dominated by periodic eruptions of basalt and andesite flows from Makushin Volcano and its precursors. These eruptions were typically caused by the injection and mixing of relatively small volumes of mafic material from a deep magma chamber with more evolved material in a shallow magma chamber.

During the late Pleistocene and/or early Holocene several spatially discrete magma bodies rose through the crust and erupted to form the satellitic and flank vents. As is typical during eruptions not all of these magma bodies erupted. Under the satellitic centers, where the crust was relatively cool, the residual magma cooled and crystallized. However, under Makushin Volcano, the unerupted magma remained molten because of the elevated temperature of the crust caused by frequent magma transport through the crust at relatively frequent intervals throughout the Pleistocene.

The residual magma under Makushin fractionated, thus the mid- Holocene eruptive products are more felsic. The anomalously large, felsic shallow chamber underwent caldera collapse, probably after reinjection by more mafic material from depth (in the usual pattern of Makushin Volcano) and formed the thick valley-filling pyroclastic units. (Juvenile material within the valley-filling pyroclastic deposits shows extensive mineralogical evidence of magma mixing).

The apparently mafic tephra sequence which underlies the modern soils may indicate a return to more mafic volcanism.

Volcanic Hazards

Lava Flows

The possibility of new lava flows erupting at Makushin Volcano is remote, and even if new flows were erupted they would probably not be a serious hazard to the proposed power plant. The most recent eruptive products are dacite or andesite blocks, bombs and ash. We have been unable to identify any late-Holocene lava flows. The morphologically freshest flow we have found is on the north side of the island west of Bishop Point, and that flow is overlain by the same tephra that overlie the plateau near the site, thus this flow is older than 4280 years.

Activity at the satellite and flank vents is typical of monogenetic vents throughout the world. Such vents, like Paricutin, are formed by intense activity over a period of a few to several years. Such activity is a one-time event, and these vents seldom reactivate. The reawakening of vents such as Sugarloaf is a very remote possibility.

In the unlikely event that lava was erupted from Makushin's summit, and in the event that lava did start flowing down the east flank of the volcano, it would probably be confined to the stream bottoms below the site. The ridge of rock directly west of the site would protect the proposed power plant from all but extremely large flows (Plate E-1).

Formation of New Vents

Most of the major satellite vents have been glacially modified, but fill or blanket late Pleistocene topography. Therefore most of the satellite vent activity occurred between the late Pleistocene and the early Holocene glacial advance. We believe most of the satellite vents to be approximately the same age, and feel that they represent a single pulse of volcanism of anomalous volume. The satellite vents do not record a history of periodic vent formation throughout the Holocene. Thus satellitic volcanism seems to be, for the most part, a one-time event, and the possibility of the formation of new vents in the future is slight.

The formation of the Point Kadin Vents is an exception. Those vents are very probably more recent than most of the other satellitic vents. The location of the Kadin vents is structurally restricted by a northwest trending fault on the northern flank of the volcano. It is important to note that the geothermal site is almost on an extension of this fault. If the line of weakness which locallized the Kadin vents were to be reactivated new explosion pits and small centers might form on the southeast flank of the volcano. There is no way to quantitatively evaluate the possibility of such an event, but we consider it remote.

Pyroclastic Flows

Pyroclastic flows are hot density flows of quenched magma mixed with gases. They can travel at speeds approaching 200 km/hr and can be well in excess of 1000°C. Toxic gases accompanying pyroclastic flows, and in some cases the flows themselves, can surmount topographic barriers and thus escape confining channels. Pyroclastic flows may form from the gravitational collapse of an eruption column, failure of and rockfall from a growing lava dome, or from directed blasts. Because of their high speed, high temperature, and accompanying toxic gases, pyroclastic flows are among the most dangerous products of volcanism.

Pyroclastic flows do not exist in the late-Holocene deposits from Makushin, but are the major component of the ashflows in the thick valley-filling pyroclastic deposits. These ashflows, however, were most likely emplaced during caldera collapse, which is a very infrequent event during the life of any volcano. Because of this, we feel that there is a low probability of future pyroclastic flows, and for that reason do not expect pyroclastic flows to be a great hazard to the proposed power plant.

Airfall Ash and Bombs

The presence of a fairly thick mid- to late-Holocene tephra sequence at the site of the proposed power plant suggests that ash falls with a total accumulation of a few centimeters may be fairly common. There is no suggestion of a significant historic ashfall, but to expect a fall every few hundred years is not unreasonable. The Holocene record suggests that relatively minor ashfalls are the rule, which should not pose a major hazard to facilities, although toxic gases adsorbed on ash particles may make it uncomfortable or dangerous for people in the area.

Large ballistic bombs are not seen on the plateau where the proposed power plant would be. However, breadcrust bombs exceeding 1.5 m in maximum dimension can be found on higher surfaces within a few km north of the site (Plate E-1). These bombs are in the uppermost soil, and are presumed to be no more than several hundred years old. Because such bombs are found so close to the site, they could be expected to fall at the site. Based on the past record, however, bomb fall is much less likely than ash fall.

The recurrence interval for eruptions which would deposit significant amounts of ash at the plant site is probably on the order of a few to several hundred years. The recurrence interval for eruptions such as the one that deposited 40 cm of pumice on the north flank of the volcano is probably on the order of thousands of years.

Glacial Outburst Floods

Glacial outburst floods (jokulhlaups) are common in streams draining glacially-clad volcanoes and are the most likely highly destructive events that might occur near the power plant site. Such floods form when periods of high heat flow near the summit or on the flanks of the volcano melt the bottom of glacial ice. The melted water ponds under the ice until it can float the ice enough to open a passage. Water rushing along this channel then rapidly erodes a larger and larger channel, and all the ponded water is released over a very short time. Such a flood is much like floods which result from dam failure. A jokulhlaup can fill a streambed with several meters of boulder-laden mud and water in a few minutes, and can entrain boulders much bigger than possible for a fluvial stream.

Evidence for the possible past occurrence of such floods is common in all the streams draining the area between the mouth of Makushin canyon and the power plant site (Plate E-1). The evidence is in the form of terraces containing material too large to have been moved by the active streams. In the tributary valley to Makushin river just west of the head of Makushin canyon such terraces contain subrounded, subequant boulders exceeding 3 m in maximum dimension. Some of these terraces may be as young as a few hundred to several hundred years.

Jokulhlaups will be restricted to valley bottoms and could come down any of the streams which drain the icefield above the plant site. Runup onto the terrace of the plant site is extremely unlikely. The appearance of terraces at the lower end of Makushin canyon suggest that outburst floods rapidly widen and drop their suspended load after leaving the mouth of the canyon. Thus during a jokulhlaup the discharge in the main Makushin Valley would probably increase dramatically, but the river level would probably not rise by more than several cm. However, in the small drainages above the canyon, jokulhlaups could fill the stream valley to depths of a few meters and would be extremely destructive.

Lahars

Lahars are water-rich volcanic debris flows which carry particles in all sizes from boulders weighing tons to fine silt and clay. Lahars are confined to channels and may reach speeds of several tens of miles per hour. They may be cold or have temperatures approaching the boiling point of water. Lahars can form from a number of different processes all of which can be grouped into three main categories. First are those directly related to volcanic eruptions, such as eruptions through snow or ice, mobilization of ash by torrential rainstorms caused by eruptions, or flowage of ashflows into water or onto snow and ice. Lahars of this type could be closely associated with the glacial outburst floods described previously. Second are those indirectly related to eruptions, such as dumping of crater lakes during preeruptive tectonic deformation. The third class are those lahars which are not related to volcanic activity, but still arise from mass flow on volcanoes.

Although lahars are one of the most likely significant volcanic hazards at Makushin, there is little evidence that there have been lahars in the Holocene. Drewes and others (1961) suggested that much of the valley-filling pyroclastic debris might be lahars, but the presence of abundant radially fractured juvenile blocks within the units argues against their interpretation. Such blocks must have been emplaced at temperatures of several hundred degrees, and then fractured during cooling. There is one terrace in the tributary creek just west of the upper end of the Makushin River canyon which is very poorly sorted and contains extremely large boulders and a fine-grained, muddy, matrix (Plate E-1). This is the only evidence of lahars that we found, and may indicate a lahar recurrence interval of several hundred to a few thousand years.

CONCLUSIONS AND RECOMMENDATIONS

Summary of Volcanic Hazards

Makushin Volcano is active. In the future it will probably produce a wide range of volcanic products from a wide range of types of eruptions. Outburst floods, lahars, pumice falls, ashflows, debris flows and lava flows could all form. The proposed power plant site is on the flank of the volcano, and is on top of a large terrace that was formed during extremely large and explosive eruptions several thousand years ago. The location for the plant is protected from minor eruptions by the ridge of rock immediately to its west, but is close enough to be vulnerable to major eruptions. The part of the plateau surface west of Sugarloaf is much more protected from large volcanic eruptions, and it would be prudent to keep as much of the development as possible in this region.

The recurrence interval for very major eruptions is, however, fairly long, and it is unlikely that extremely destructive eruptions will occur in the next few decades. It is much more likely that future eruptions will deposit small amounts of ash at the site, as has been the rule for the last few thousand years. It is also more likely that there will be glacial outburst floods (jokulhlaups) which will be confined to the streams below the plateau where the power plant is sited. Ash fall will probably not be a serious hazard, but the outburst floods could be immensely destructive to any development in the stream bottoms between the proposed power plant site and the mouth of the Makushin River canyon. Below the mouth of the canyon jokulhlaups will probably result in much larger stream discharges with only moderate rise of stream level.

Volcanic Hazard Mitigation

In order to insure safe operation of a geothermal power plant on the flanks of Makushin Volcano it is essential that the volcano be closely monitored. This monitoring can provide enough early warning of an eruption so that people can be evacuated and as many steps as possible can be taken to protect the plant itself. Volcanic hazard mitigation should be undertaken in three major areas.

First, the morphology of the summit icefields should be closely monitored. This will allow zones of melting ice, which could generate jokulhlaups or lahars, to be detected. The monitoring can be accomplished by constructing a time series of high precision, large scale topographic maps.

The first map could probably be made from the existing photography, but ground control must be carefully surveyed first. Once the ground control is surveyed, new maps can be made after subsequent photographic missions. If the ground control is carefully enough chosen, it can form the basis of a surveyed volcano deformation network.

Second, geophysical monitoring equipment should be installed and maintained on all flanks of the volcano. Primarily, a detailed seismic network should be operated. This network must be able to provide data of suitable quality to locate small earthquakes (magnitude less than 1) with high precision, and must be suitable for monitoring events underneath the summit of Makushin, as well as the area near the Point Kadin vents. It may be necessary to conduct experiments to accurately determine the local velocity structure of the crust. Additional geophysical volcano- monitoring equipment, such as telemetered tilt meters, should either be installed, or be available for installation in the event of heightened volcanic activity.

Third, extremely detailed studies of the Holocene eruptive history, presumably through the use of tephrachronology, should be undertaken. In spite of the time several geologists have invested in the field, there are still gaps in our knowledge of the Holocene history which make it difficult to accurately determine recurrence intervals for volcanic events. Specific targets of such an investigation would be questions such as; are the valley-filling pyroclastic aprons the result of multiple eruptions? Do the jokulhlaup deposits in the creeks around the drill site represent one event or several? Are there deposits from recent, large, destructive eruptions elsewhere on the island? How many eruptions which deposited significant ash at the site have there been in the last thousand years? While the answers to these questions can be, to some extent, anticipated, it is important to know the answers with confidence in order to know the recurrence intervals for these events. Without a accurate knowledge of recurrence intervals it is difficult to predict the nature of future eruptions, and to insure the safe operation of developments on the flank of the volcano.

REFERENCES

Arce, G.N., 1983, Volcanic Hazards from Makushin Volcano, northern Unalaska Island, Alaska, University of Alaska, Fairbanks M.S. thesis, 142 pp.

Drewes, H., Fraser, G.D., Snyder, G.L., and Barnett, H.F.Jr., 1961, Geology of Unalaska Island and adjacent insular shelf, Aleutian Islands, Alaska, U.S. Geological Survey Bulletin 1028- S, pp. 583-676.

McClelland, L., Nielsen, E., Wegert, E., Duggan, T., Summers, M., 1986, Scientific Event Alert Network (SEAN) Bulletin v. 11, no. 4, p. 9-10.

Nye, C.J., Queen, L.D., and Motyka, R.J., 1984, Geologic Map of the Makushin Geothermal Area, Unalaska Island, Alaska, Alaska Division of Geol. and Geophys. Surveys Report of Investigations RI 84-3, scale 1:24,000, 2 sheets.

Nye, C.J., and Swanson S.E., 1986, Implications of Chemical Stratigraphy for Magmatic Plumbing Geometry at the Makushin Volcanic Field, Central Aleutians, EOS v.67, no.7, p.86.

Nye, C.J., Swanson S.E., and Reeder, J.W., 1986, Petrology and Geochemistry of Quaternary Volcanic Rocks from Makushin Volcano, central Aleutian Arc, Alaska Div. Geol. Geophys. Surveys Public-data file PDF 86-60, 123 pp.

Reeder, J.W., 1983, Preliminary dating of the caldera-forming Holocene volcanic events for the eastern Aleutian Islands, (abstract), Geological Soc. America abs. w/ programs v.15, no.6, p.688.

Reeder, J.W., Denig-Chakaroff, D., and Economides, M.J., in press, The geology and geothermal resource of the Makushin volcano region of Unalaska Island, Alaska, Transactions of the 1985 International Symposium of Geothermal Energy, Kailua- Kona, Hawaii.

Simkin, T., Siebert, L., McClelland, L., Bridge, D., Newhall, C., and Latter, J.H., 1981, Volcanoes of the World, Smithsonian Institution, Hutchinson Ross Co., Stroudsburg, Penn., 232 pp.

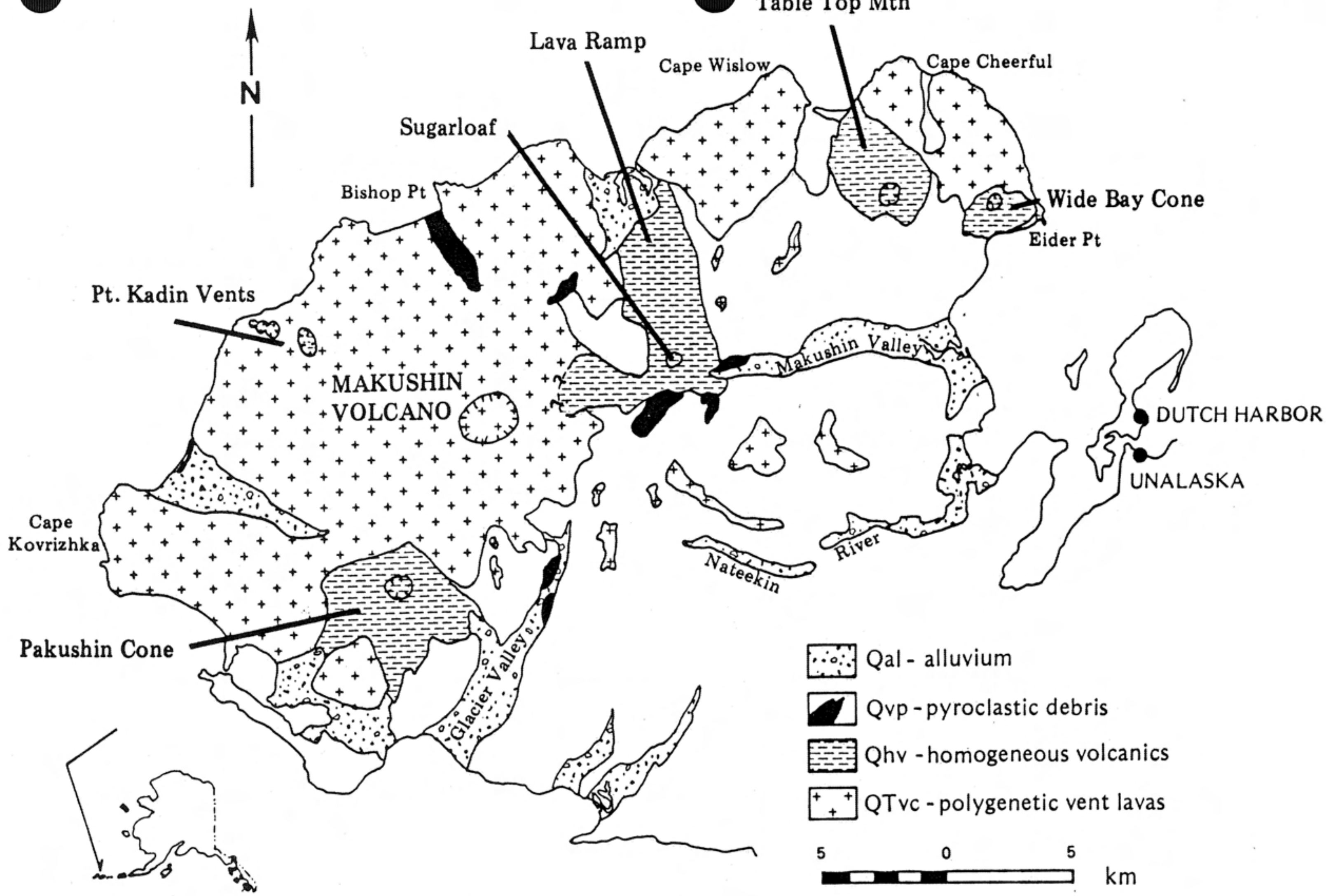


Figure 1. Map of northern Unalaska Island showing locations of volcanic vents, generalized geology of Quaternary units and geography.

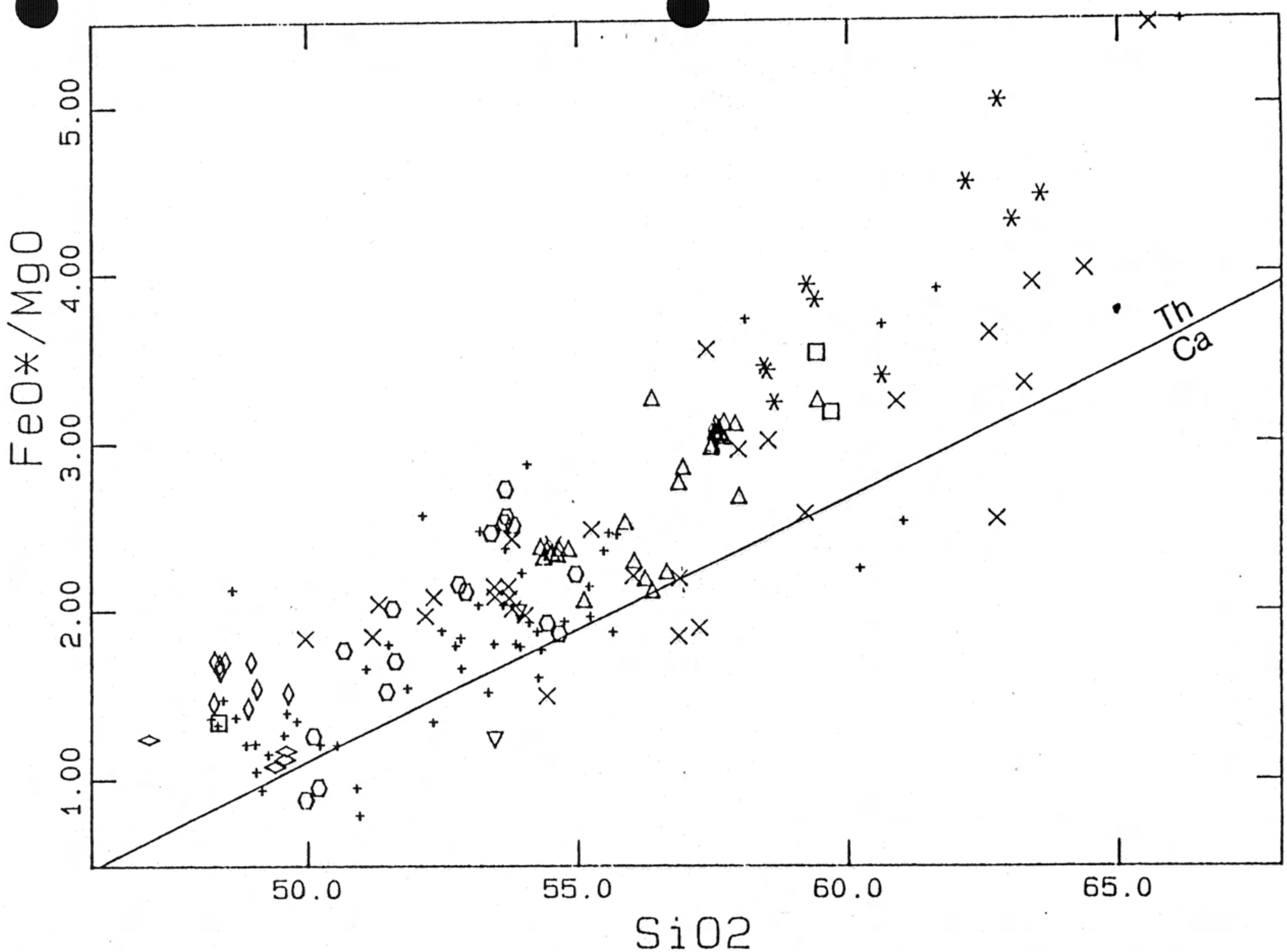


Figure 2. Plot of FeO*(total iron as FeO)/MgO versus SiO2 for all Makushin Volcanic Field samples. Symbols are as follows: stars, late Holocene Makushin Volcano; crosses, middle and early Holocene Makushin Volcano; small pluses, Pleistocene Makushin Volcano; triangles, Lava Ramp; inverted triangles, Sugarloaf; hexagons, Pakushin Cone; squares, Point Kadin vents; upright diamonds, Table Top Mountain; sideways diamonds, Wide Bay Cone.

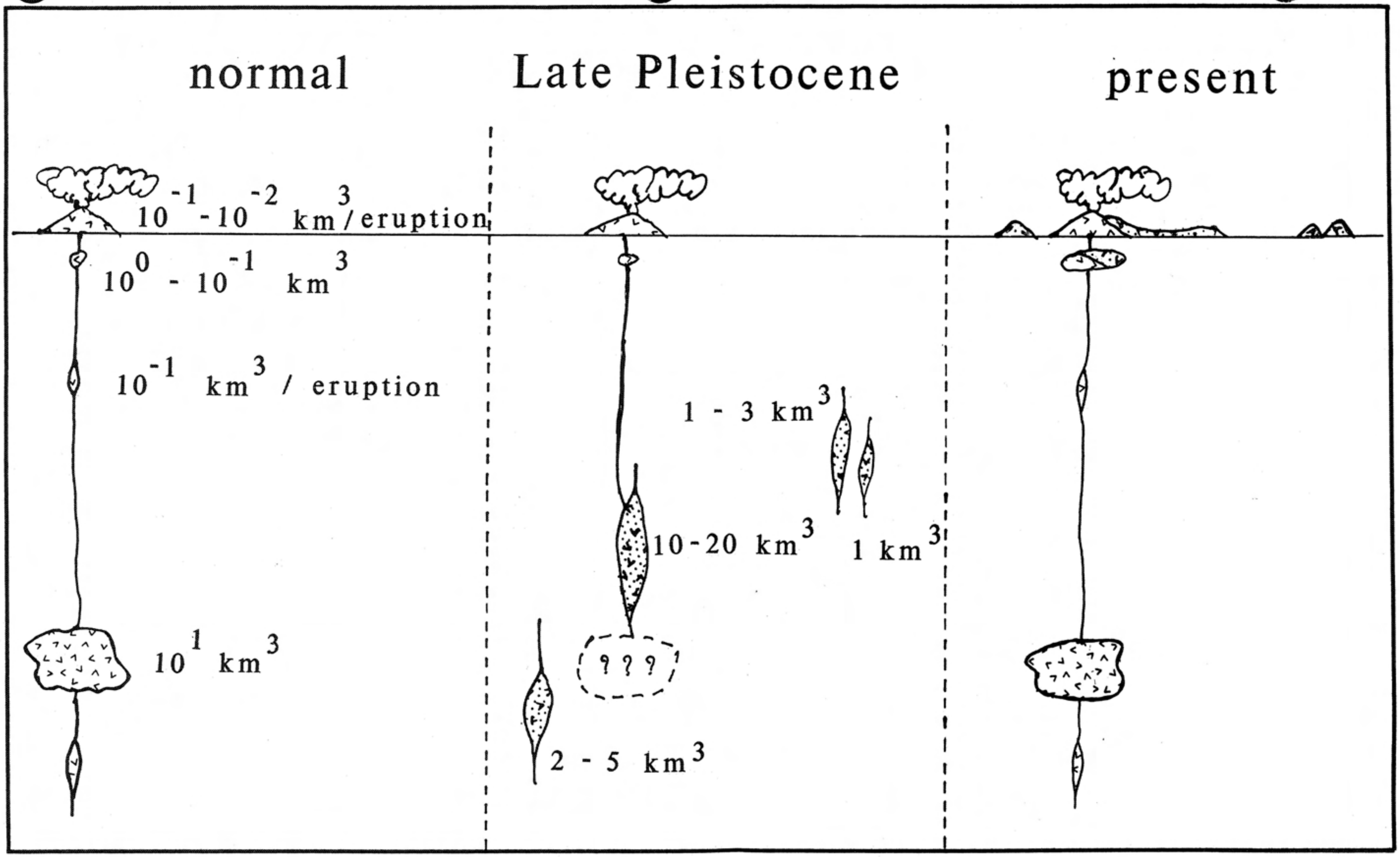


Figure 3. Model of the evolution of the Makushin Volcanic Field. Pleistocene eruptions are from a small upper level magma chamber which is frequently reinjected by material from a deeper magma chamber. During the late Pleistocene several large, spatially discrete, magma batches rose through the crust to erupt and form the satellite and flank vents. Residual magma from this event is still present in the upper level chamber, thus inflating it. Successive reinjections of material from the deeper chamber are small compared to the upper chamber, thus allowing it to fractionate more extensively and become unusually silicic.

GLACIAL HAZARD CONSTRAINTS

By William E. Long

INTRODUCTION

Glaciers fill the Makushin Volcano summit caldera and flow radially from the upper slopes. Two of the glaciers are located upslope from the geothermal well site and access road corridors. Evidence of current glacial processes as well as larger, more extensive glaciation is present in the terrain surrounding the geothermal well site and access corridors for roads and transmission lines. This investigation to evaluate glacially-related hazards potential considers potential rapid ice advances, gradual ice advances, and flooding caused by rapid ablation. Flooding caused by volcanic activity melting of glacial ice is a special hazard for glaciers on volcanos, with volcanic mudflows being a particularly dangerous process.

The glaciers within the drainage basin surrounding the geothermal well site and site facilities have been inspected via aerial photos, traverses on the glacier and the adjacent landforms, and from overflight by helicopter. General descriptions of the glaciers including accumulation and ablation zones, will allow interpretation of the general health or budget of the two glacier systems, thereby making rough predictions of advance or retreat possible.

Crevasse wall inspection provides evaluation of the last few years precipitation and crevasse wall density samples allow rough accumulation estimates to be calculated.

A glacier (informally called "Caldera Glacier) which flows from the summit caldera is one of the larger, more active glaciers on Mt. Makushin. It flows to the southwest in an adjacent drainage basin and is not evaluated in this report.

METHODOLOGY AND TECHNIQUES

General Glacier Description

Dimensions, elevations, and feature locations of the two glaciers upslope from the well site were determined using 1982 North Pacific Aerial Surveys' (NPAS, 2 Aug 82) aerial photographs and a topographic map produced for the Alaska Power Authority (APA) by Republic Geothermal, Inc. (October 1982; 1:24,000 scale), which was made from the 1982 NPAS aerial photography. Helicopter overflights and on-site inspection of the terminous, accumulation area, crevasse areas, moraines, aretes, and down valley bedrock/deposit locations supplemented map and aerial photo interpetation.

Evaluation of Glacial Advance Potential

The advance and/or retreat of the two glaciers above the well site were evaluated by using the following indicators of glacial budget: the terminous shape, firn line location, ice surface characteristics, moraine and groove features, crevasse wall inspection, and comparative aerial photographs (1950 vs 1982 photography, 1950 and NPAS 2 Aug 1985 aerial photography).

Short term advance (surges) potential was evaluated using indirect topographical characteristics of the glaciers and their associated glacier features. Long term advance/recession potential is evaluated by indicators of glacial budget, evidence of past glacial levels (such as grooves, striae), character of moraines, and comparative aerial photograph analysis. Outburst flood potential is addressed by analysis of ice volume, topographical location and physical characteristics of the glacial and stream basins. Volcanic eruption melting flooding must also involve the volcanic activity in the basin and such evaluation must be addressed relative to the volcanic activity of Mt. Makushin. Lahar (mud flow) evaluation will be based on availability of mud material, volcanic heat source and basin character. In order to observe, locate, and describe features of significance, traverses were made on the glacier surface in the ablation areas and in the accumulation area. Crevasse walls were inspected in order to estimate the 1985-86 accumulation layer. Samples of firn were collected for density determination.

RESULTS OF INVESTIGATION

The two glaciers above the well site are informally designated the "South Glacier" and the "Southeast Glacier" for the purposes of this report.

South Glacier Advances

The South Glacier is about 9,500 ft long and up to 4,500 ft in width, with the uppermost accumulation area at an elevation of 5,244 ft and the terminous reaching the 2,200 ft level. The glacier has a surface area of 1.4 sq mi and the surface is smooth with occasional steeper sections, but one can walk on nearly any part of this glacier without wearing crampons. Only a few minor crevasses were observed and Plate 1 shows their approximate location. A few small longitudinal moraines are present at the terminous, margins, and adjacent bedrock islands (cleavers).

The absence of crevasses, the low number of moraines and lack of evidence of active moraine building, and the smooth glacial surface are all indicators that the South Glacier is very inactive throughout its length. Indeed, it is so inactive that it could be called a firn field. Surges in such a glacier are extremely unlikely. However, climatic changes will cause small yearly ice mass changes.

Longer term fluctuations of the South Glacier depend on expansion or contraction of the ice mass and the resulting advance or retreat of the terminous.

Evidence of more extensive ice cover in past centuries is evident from glacial deposits and erosional features on the nonglacial terrain. Such evidence indicates that the present glaciers are remnants of a much larger system. 1982 and 1950 aerial photograph comparison shows that the adjacent Southeast Glacier has receeded during the last 30 years. Although aerial photograph quality was inadequate for South Glacier evaluation, it is reasonable to assume that the South Glacier has also retreated during the last few decades. The overall form and inactivity of the South Glacier indicate general recession of the glacier at the present time.

Southeast Glacier Advances

The Southeast Glacier is about 13,000 ft long and 5,500 ft wide filling a roughly rectangular glacial basin with ice elevations from 5,400 ft at the caldera rim to 2,600 ft at the terminous. The glacier surface covers about 2.5 sq mi in area with approximately 1.5 sq mi of accumulation zone and 1.0 sq mi of ablation zone. Crevasses are present on the upper third of the glacier where the slopes are steeper and accumulation dominates ablation. The lower half of the glacier is mostly ablation zone with gentle, smooth surface and relatively low surface gradients. Though larger and much more active than the South Glacier, the Southeast Glacier is a small, apparently receeding glacier flowing from the summit caldera rim in a poorly developed cirque valley. Glacial processes are subdued relative to larger, more dynamic glaciers. The moraines are small, oriented with long axes parallel to the valley and are composed of finer grained material than those of more active glaciers. The absence of lodgement till indicates warmer glacial temperatures, more melt water, and decreasing glacial activity. Limited number and development of end moraines also suggest reduced glacial ice movement, sediment transfer, and deposition, typical of a small glacier in a waning phase. The terminous is smooth and of low gradient, a condition typical of ablation-dominant glaciers (Flint, 1967).

Southeast Glacier glacial surges are therefore extremely unlikely. However, yearly glacial mass variation relative to climatic conditions should be expected. These ice mass variations should be too small to cause surge conditions to occur in the Southeast Glacier.

Accumulation on the upper glacier appears to be very significant. The 1985-86 accumulation layer displayed in the wall of a crevasse was 26 ft thick with a measured density in the upper most meter of 0.67 which calculates to about 17 ft of water accumulation at that location of the glacier. The same layer located an angular bedded firn on the divide between the two glaciers was only 9 ft thick with a similar density (0.62) or 5.5 ft of water.

"Blue" ice observed beneath the yearly accumulation layer at the interglacial divide (elevation about 4,500 ft) indicates that ablation is dominant at that ice divide. Such extensive ablation is further evidence of a receeding, shrinking, thinning glacier with negative glacial balances.

Longer term fluctuations have occurred. High "stranded" lateral moraines on down valley ridges as well as striated and grooved roche moutonees were formed during times when ice was much thicker and more active, filling the valley and extending to lower elevations. Accurate dating of such glacial advances has not been significantly studied although intermixed glacial with dated volcanic deposits have yielded clues as to the history of glacial fluctuation of the Southeast Glacier.

Field mapping by John Reeder (unpublished report) has identified three terminal or recessional moraines down valley from the present terminous. These moraines probably were deposited during the last few thousand years during the "Neoglacial" episode and would represent ice terminous positions and also indicate recession during the last few thousand years. Using soil and tephra dating Reeder estimates ages of less than 2000 and 5000 years for the two younger moraines. The moraines identified by Reeder fit the pattern of Holocene glaciation evidence observed on other large volcanos in the Aleutian Islands (Thorson and Hamilton, 1986). This pattern indicates a history of receeding glaciers during the last 8000 years.

The glacier terminous fluctuation through the last few decades, and possibly centuries, appears to be negative - that is, the glacier is shrinking. 1950 aerial photographs show glacial lobes extending 1,000 - 2,000 ft down valley from similar levels on 1982 photography (snow cover on each photograph set makes accurate comparison impossible).

The accumulation area of the Southeast Glacier is less than half of the area of ablation, a condition typical of glaciers with a strong negative balance, and further evidence of glacial retreat.

Flooding Potential, South and Southeast Glaciers

Flooding from either the South Glacier or the Southeast Glacier from non-volcanic processes should be of no great signficance. Streams draining the glacial termini flow in very adequate valleys to carry flood waters. Large boulders in the stream valleys and associated terraces suggest that large floods have occurred. Even though large floods have occurred, the canyons adequately contained these floods.

Three streams drain from two glaciers: Makushin River from South Glacier, Fox Creek and Sugarloaf Creek from Southeast Glacier. Of these, Fox Creek could possibly cause the most threat to the integrity of the well site because of the high gradient, steep canyon which is in direct alignment with the site. However, this canyon is about 200 ft deep where it changes direction adjacent the site.

Volcanic melting of significant parts of the glaciers could cause extreme volumes of water to be released into the drainage basins. A volcanic event of large enough magnitude to erode the canyon wall and jeopardize the well site complex would be so large that flooding would be a secondary concern. The volcanic event large enough to cause such an extreme flood would be large enough to threaten the site from volcanic activity as well.

The present vents of Makushin Volcano are located in the summit caldera which drains to the southwest down the Caldera Glacier valley, an adjacent and separate drainage system. Flooding from present vent activity should affect that valley system. Flank activity on the south or southeast would be required to cause floods which could threaten the well site. Volcanic mudflows from glacial melt also would require a very large volcanic event -- and would require abundant ash/soil material to mix with the melt water. Limited investigation of available "muddy" material has yet to be conducted. Glacial deposits in the valley below the Southeast Glacier are limited and not extensive. The glacier does provide a reservoir of water, available for mixing with volcanic material and creating large volumes of volcanic mud. Such an event could jeopardize and destroy anything in the path of the flowing mud.

CONCLUSIONS

1. Rapid glacial advances of the South Glacier and the Southeast Glacier will probably not occur. Therefore no hazard exists to the site or the transmission line or to the road.

2. Longer-term glacial advances probably will not occur in the next few decades. The glaciers appear to be receding. Therefore, no immediate hazard from glacial advance exists to the site, road or transmission line corridors. However, fluctuation within a century or centuries could occur. Such advances would reach any proposed facility on the slope directly below the Southeast Glacier.

3. Flooding from smaller volcanic events should not be of large enough magnitude to threaten the integrity of the well site. Roads crossing the Makushin River, Fox Creek and/or Sugarloaf Creek should be designed to withstand floods even larger than those typical of glacial streams. Erosion and deposition will be major factors.

4. Volcanic melting of glacial ice could create extreme floods, capable of damaging transmission and road corridors. However, volcanic-induced flooding of large enough magnitude to damage the well site area would be a catastophic volcanic event as well as a glacial-melt event. The glacial-melted flood waters would be only part of the catastrophe.

5. A volcanic mudflow (lahar) event large enough to threaten the site and corridors would require a major volcanic event. A major volcanic event causing large magnitude volcanic mudflows or lahars could threaten and destroy any facility in the Makushin Valley.

RECOMMENDATIONS

1. Glacial monitoring should be conducted to more accurately define the budget of the South and Southeast Glaciers. The very limited accumulation data suggest very large accumulation. If so, ablation must be very high and the glacial systems on Mt. Makushin must be very dynamic, even though the overall glacial budget is negative.

2. Aerial photography at the end of the summer melt season is needed to identify firn line location and improve remote glacial interpretation. Yearly or every two or three-year photography would allow glacial change evaluations to be made.

3. Glacial history/study of the Makushin Valley area, including mapping of glacial erosional and depositional features, is needed to develop a chronolgy of the South and Southeast Glaciers in order to more adequately interpret advance and recession cycles.

4. Stream gaging stations need to be established near the termini of the glaciers to evaluate fluctuations and monitor glacial melt contribution to the stream network.

5. A surficial deposits map in the glacial basin is needed to evaluate available mudflow material.

6. A seismic monitoring system is needed to monitor volcanic activity in order to predict catastrophic volcanic events capable of melting large parts of glaciers.

REFERENCES CITED

Flint, R.F., 1957, Glacial and Pleistocene Geology: John Wiley and Sons, Inc., 553 p.

Reeder, John, 1986, Personal communication and unpublished map: Alaska Division of Geological and Geophysical Surveys.

Thorson, R.M., and Hamilton, T.D., 1986, Glacial Geology of the Aleutian Islands, based on contributions of Robert F. Black: in Glaciation in Alaska, T.D. Hamilton and others, eds.: Alaska Geological Society, Anchorage, Alaska, p. 171-191.

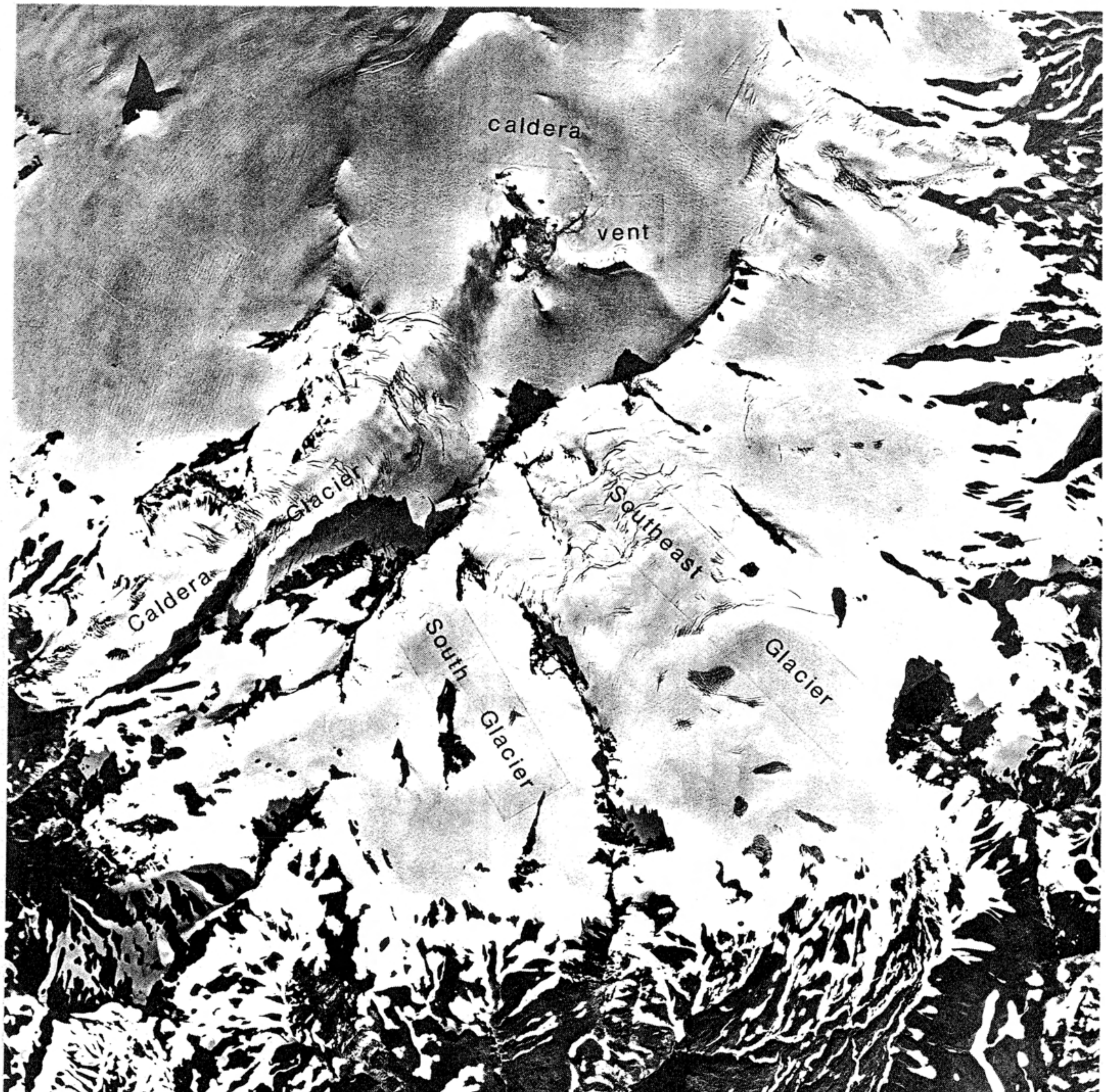


Figure 1. Aerial photo of Makushin Volcano shows summit caldera with vent near center; Caldera Glacier flowing to SW; South Glacier, Southeast Glacier, and geothermal well site. (North Pacific Aerial Surveys photo - 2 Aug 82)

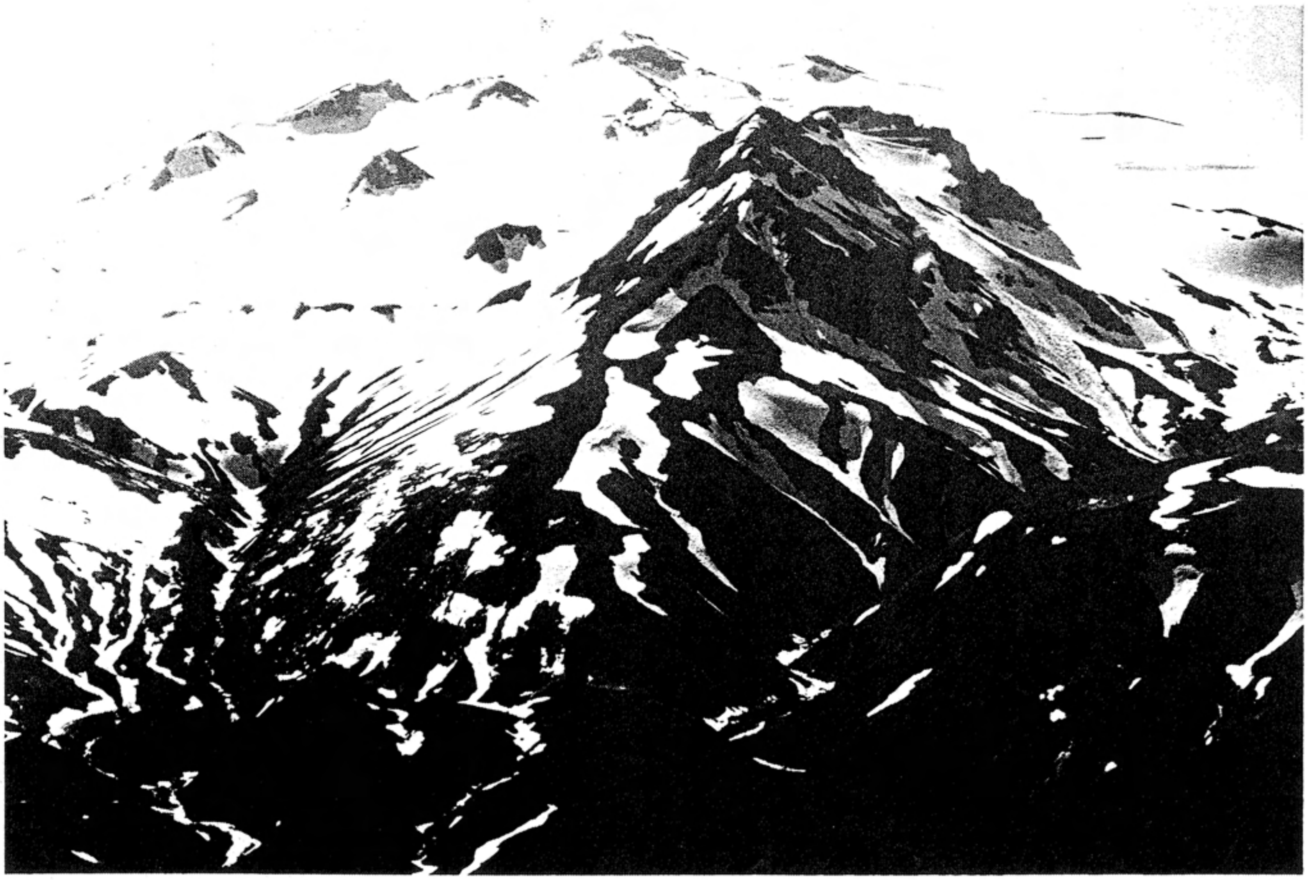


Figure 2. Southern slopes of Makushin Volcano showing relative positions of South Glacier, Southeast Glacier, and the geothermal well site.

Figure 3. Southeast Glacier terminous located on the lava plateau across Fox Canyon from the geothermal well site.

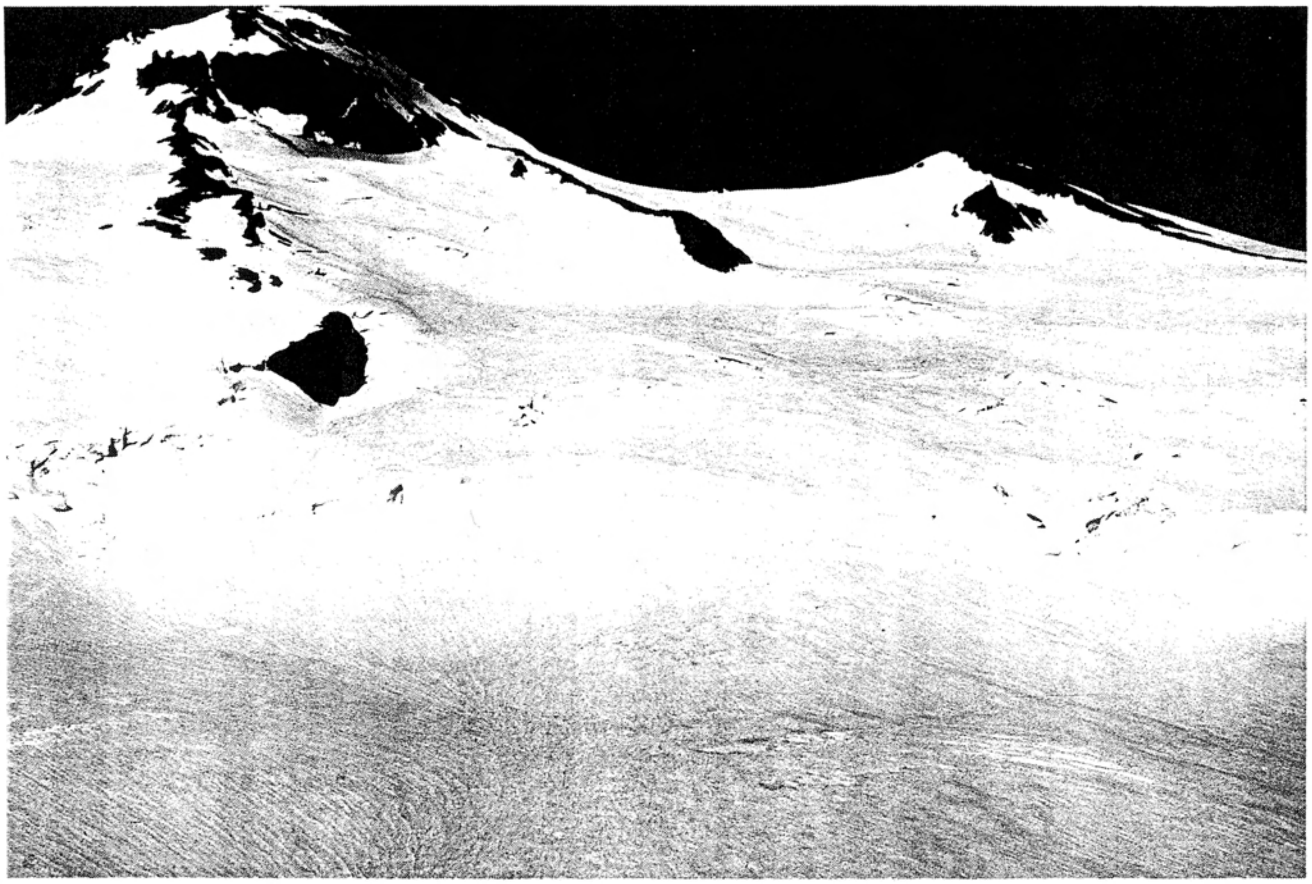


Figure 4. Southeast Glacier accumulation area. Last year's snow accumulation (1985-86) covers older firn in crevasse near left hand margin. Accumulation appeared larger in other parts of area.

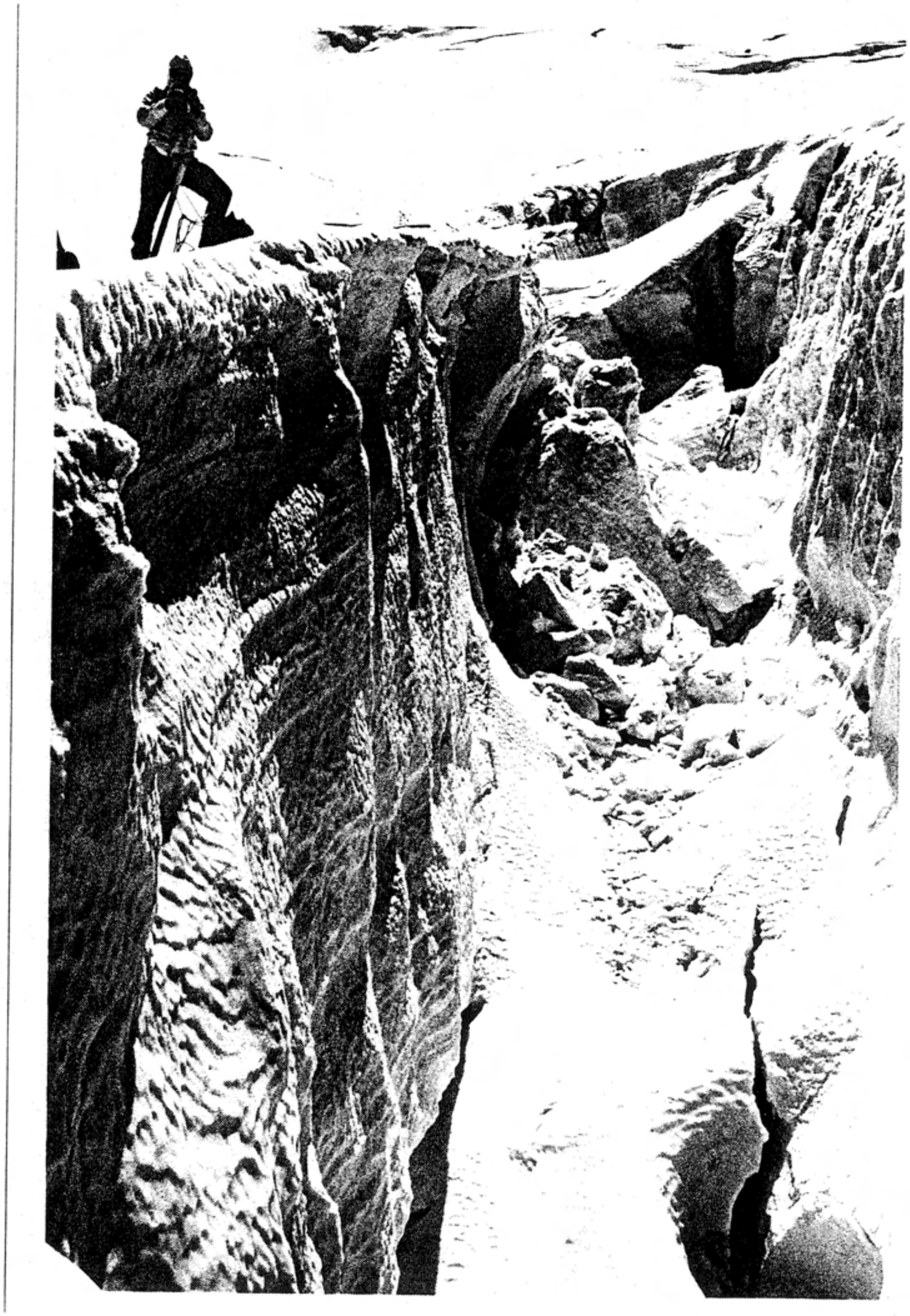


Figure 5. Crevasse wall (below observer) displays apparent 1985-86 accumulation layer measured at 26 ft thick.

Figure 6. Southeast Glacier 1985-86 accumulation layer about 6 feet thick cover older firn at extreme western edge, near a local ablation zone.

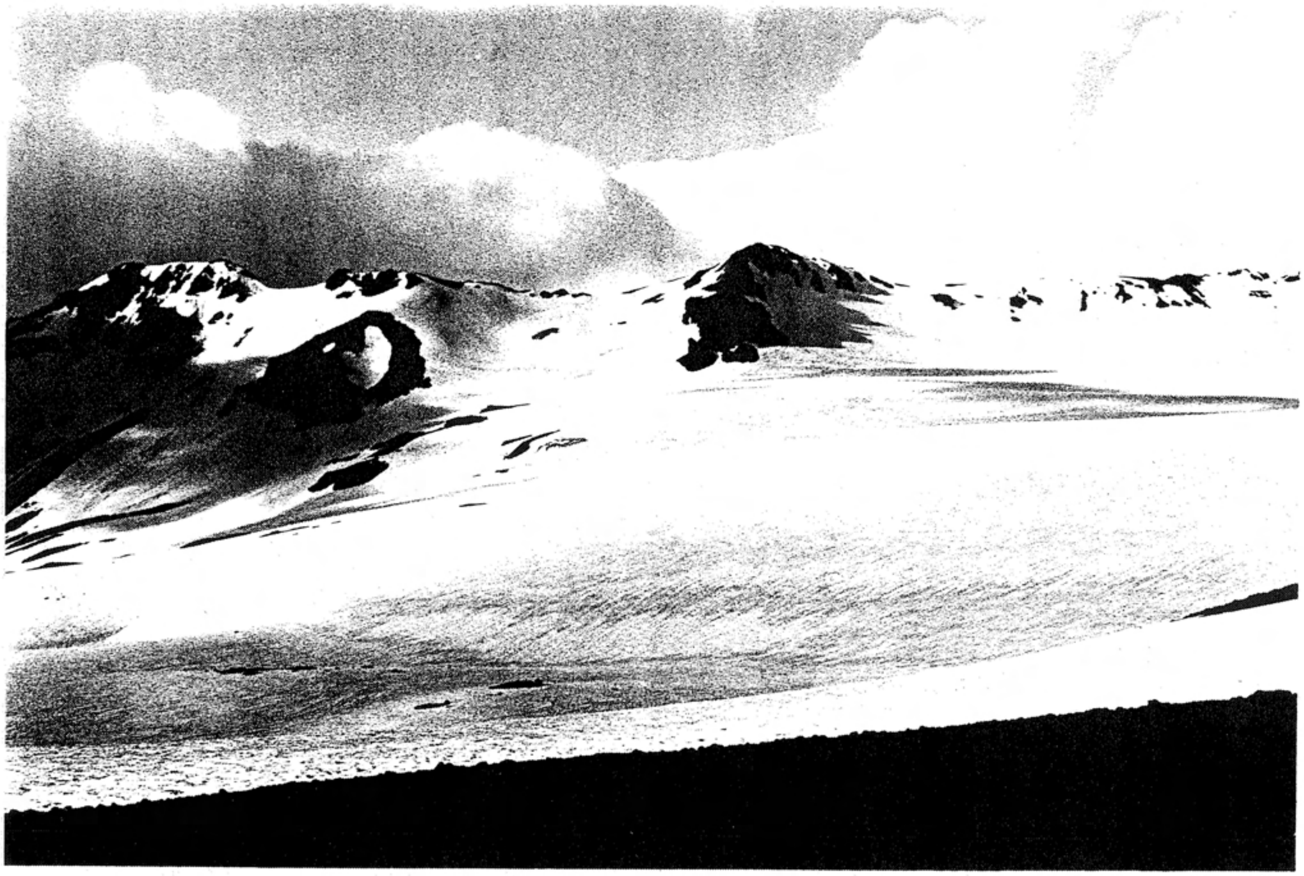


Figure 7. Southeast Glacier terminous is gentle and uncrevassed, typical of a glacier with negative mass balance (receeding).

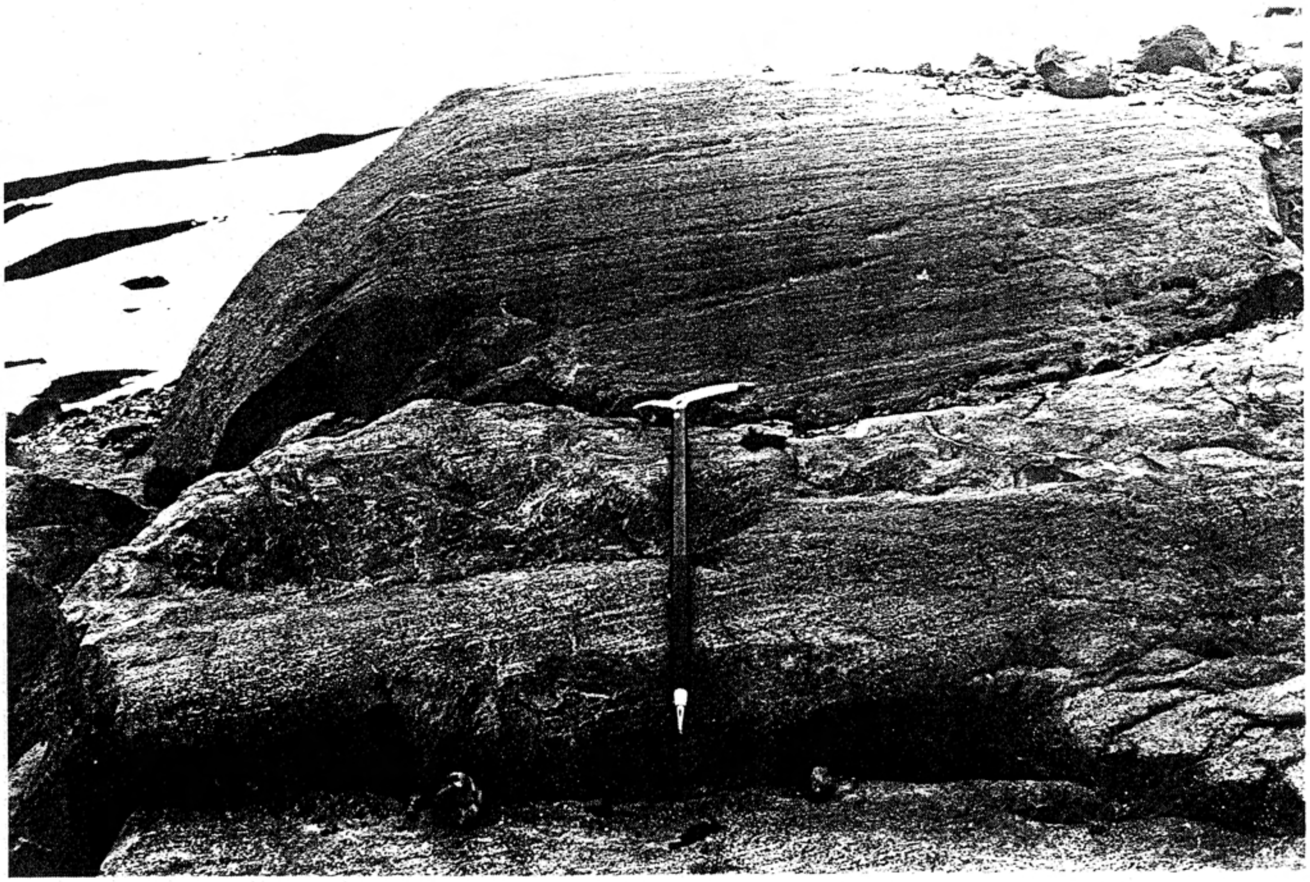


Figure 8. Striated roche moutonees down valley from Southeast Glacier terminous indicates a much deeper, extensive glacier covered area in the past.

Figure 9. Fox Creek Canyon adjacent geothermal well site could be the route of floods from glacial melting. The canyon is about 200 ft deep adjacent the site.

AVALANCHE HAZARD CONSTRAINTS

By Gail March

SCOPE OF WORK

Makushin and Driftwood valleys, Unalaska Island, Alaska, were examined for potential snow avalanche areas as part of a geotechnical assessment of a geothermal power plant site and transmission line corridor serving the cities of Unalaska and Dutch Harbor, Alaska. Probable avalanche areas were mapped by foot and helicopter with the assistance of low-altitude air photos during five days in the field. Weather records from Dutch Harbor were examined over a four- year period from 1982 to 1985 to see whether any conclusions could be drawn regarding amounts of snowfall in the study area.

METHODOLOGY AND TECHNIQUES

Avalanche Terminology

Snow failures are classified as loose snow or slab avalanches (Figure 1), and as wet or dry avalanches (Perla and Martinelli, 1975). Slab avalanches are far more dangerous to structures and people, though wet loose-snow avalanches can destroy structures purely from pressure resulting from a large mass of snow. Figure 2 shows the parts of a slab avalanche. Typically, slabs become dangerous when crown thickness exceeds 0.6 in. (15 cm).

Avalanche paths are divided into three parts (March and Robertson, 1982). The starting zone is the area where unstable snow usually breaks away from the slope and begins to move downhill. Starting zones tend to be steeper than 30° and must receive a large amount of snow. Gullies and bowls are well suited for this role, as wind can build up snow deposits in these areas. The track is the central portion of the avalanche path where the avalanche reaches its maximum velocity. The runout zone is the area at the bottom of the path where the moving snow and entrained debris decelerate and stop.

As soon as snow hits the ground it begins to undergo changes in shape. This metamorphism is designed to bring the snow crystals into equilibrium by rounding their sharp edges. Snow forms an insulating cover on the ground, causing the ground temperature to remain very close to the freezing point throughout the period of snow cover. Air temperature fluctuates throughout the season. If the air temperature remains close to ground temperature, the temperature throughout the snowpack remains roughly equal, and rounded snow grains are formed through equitemperature metamorphism. These rounded grains pack well and tend to be quite stable. If, however, the air temperature drops below the ground temperature, a temperature gradient is formed in the snowpack. This temperature gradient causes vapor to flow from high- to low-temperature regions in the pack. Temperature gradient metamorphism results in triangular to cup-shaped grains of snow that form a fragile skeleton very prone to avalanching. When air temperatures rise above freezing, conditions are right for melt-freeze metamorphism, which tends to sinter snow grains by freezing them together with meltwater present in the snowpack. This type of snowpack is stable when frozen but becomes dangerous during thawing cycles.

Methodology Used

Field observation was the primary method of determination of probable avalanche areas in this study. Air photos were used both to supplement the field observations and as a base for mapping. The first problem was to determine whether avalanches do indeed occur on Unalaska Island, as there appears to be no written record of any. Residents of Unalaska have reported isolated occurrences (John Reeder, personal communication), including a man-triggered slab avalanche above Wide Bay and several cornice collapses in various places on the Island, but few people have been in the mountains in winter. The road to the dump is reportedly closed in winter due to avalanche problems.

Several unmelted avalanche debris piles were observed in the field., chiefly in steep river canyons at the bases of long, steep slopes. It was therefore assumed from this evidence and from hearsay that avalanches do occur in the area, and the task became a definition of probable areas of occurrence. Most avalanche studies rely heavily on areas where trees have been knocked down for mapping runout zones (Mears, 1976). The absence of trees or even bushes on Unalaska leaves the extent of runout zones on the valley floors open to question.

Slope angles were the main basis for mapping avalanche areas, due to lack of any other criteria. Dangerous slabs are most likely to start on slopes of 30° to 45° (Perla and Martinelli, 1976). On slopes less than 30°, shear stress on the surface is not large enough to cause shear failure, while on slopes greater than 45°, snow tends to sluff off gradually, rather than building up slabs. Tracks tend to have slopes between 15° and 30°, while runout zones tend to have slopes less than 15°.

An attempt was made to examine amounts of snowfall in the area of Makushin Valley. The only available weather records are from Dutch Harbor since 1982 and from Cold Bay before that. As both stations are at sea level, limited conclusions can be drawn (see below). Available Landsat images were examined for snow cover.

RESULTS OF INVESTIGATION

There is no precipitation data for the proposed geothermal power plant site or for the Makushin and Driftwood Valley areas. Weather records for Dutch Harbor show little snowfall or snow on the ground for the period examined (1982-1985), although a significant amount of precipitation occurred in the form of rain. Accompanying temperature records show many maximum temperatures above freezing.

An examination of available Landsat images points out some discrepancies between amounts of snow at Dutch Harbor and in Makushin Valley and surroundings. On March 5, 1979 there was no snow in Dutch Harbor or on the floor of Makushin Valley, but all slopes above the valley floor were snow covered. The same was true on November 20, 1982. On January 20, 1982, there was no snow in Dutch Harbor, a thin snow cover on the floor of Makushin Valley, and a thick snow cover on surrounding slopes. The image from March 10, 1976 shows a light snow cover in Dutch Harbor, a heavier snow cover on the floor of Makushin Valley, and a thick snow cover on surrounding slopes. It appears from this evidence and from observation of avalanche debris that more snow falls and remains in Makushin Valley and on surrounding slopes than in Dutch Harbor.

February, 1984 showed the greatest amount of snow on the ground in Dutch Harbor for the months examined from 1982 through 1985. It is used as an example of the possibilities for extrapolation of weather records to the power plant site and transmission line corridor. Figure 3 shows snowfall and accumulated snow on the ground in Dutch Harbor in February, 1984. Figure 4 shows maximum and minimum daily temperatures during this time period. Above-freezing temperatures show some correlation to lessening snow depth during the month. This could be due to snow melt, but settling of snow due to warmer temperatures is probably more significant in this case.

Figure 5 is an extrapolation of temperatures in Dutch Harbor to temperatures at altitudes of 500 ft, 1000 ft, and 2000 ft, using a temperature gradient of 0.27°F/100 ft (0.5°C/100 m) (Carl Benson, personal communication). Precipitation normally falls as snow up to a temperature of 35.5°F (1.7°C) (Rod March, personal communication). Rainfall in Dutch Harbor does not necessarily indicate rainfall at higher elevations, as evidenced on February 15 and 20-21.

The aspect of a slope is the direction in which it faces (March and Robertson, 1982). Aspect can be important to avalanche formation because sun shining on the slope can affect temperature gradients and stresses. For instance, north-facing slopes tend to have higher temperature gradients in the snowpack, resulting in a less stable snow structure, due to lack of direct sunlight. Sun can also have a direct effect on melt-freeze metamorphism. These effects can probably be discounted on Unalaska, however, due to the generally present cloud cover. This view is reinforced by our observation that snow remaining in gullies at high altitudes in July, 1986 does not have the significant number of runnels and sun cups that a sunny weather regime would impose.

Deflation ridges on the sloping terrace west-southwest of Republic Geothermal's "D-1" exploratory hole (Republic Geothermal, 1985) show the prevailing wind direction to be S20°W. Slopes in gullies and bowls with aspects of N20°E and thereabouts are most likely to receive snow from wind loading. This can result in slab buildup or in cornice buildup with resulting cornice collapse. This is the general aspect of the ridge forming the south wall of Makushin Valley.

Plates G-1 and G-2 show areas where avalanches are likely. Because there are no winter observations, mapping is based primarily on slope and past experience. Areas safe from avalanche hazard may exist but be too small to show on the maps. In general, pockets of instability may exist on any slope steeper than 25° in dry snow or less in wet snow.

CONCLUSIONS AND RECOMMENDATIONS

Because there are no data available on past avalanche events or amounts of snowfall, conclusions in this report are based on best guesses as to what constitute probable avalanche areas in the vicinity of the proposed power plant site and transmission line corridor. We had hoped to be able to calculate dynamic forces on potential structures, but this requires knowing volumes of snow that might be part of an avalanche as well as the density of that snow and several other variables (Mears, 1976). Although the variables are often estimated, this is usually done under conditions in which average values for known avalanches are available.

As shown on Plates G-1 and G-2, most of the study area is included in probable avalanche zones. The terrain is very steep, generally over 30°, throughout the area, though several terraces exist, including that proposed for the power plant site. The proposed site itself is prone to hazard from small avalanches originating on the slope just above the site but is protected from larger slides that may impact the terrace to the south of the present well site. Away from the slope above it the terrace is flat and safe. A series of such terraces form a possible transmission line corridor above the main Makushin Valley.

The best available power plant site in terms of avalanche hazards is in the vicinity of drill hole "D-1". Driftwood Valley is free of avalanche hazards except directly under the valley walls. This route for the transmission line should be considered.

Many of the ridge tops on the mountains south of Makushin Valley have flat saddles that are considered free of avalanche hazard. They are generally too small to show on Plates G-1 and G-2, but are large enough for transmission line towers. Flatter spots on side hills are usually directly under steeper slopes and could serve as runout zones for avalanches from above.

Several protection methods are available for mitigation of avalanche hazards, including deflecting structures or snow fences in starting zones (Perla and Martinelli, 1976). Towers built in avalanche zones in Thompson Pass and along the Seward Highway could serve as examples engineered for avalanche hazards.

Because there are no data on avalanche occurrence or snowfall in the study area, we can make no guesses as to recurrence intervals of avalanches. We recommend strongly that data be collected on wind speed and direction, snowfall, and density of the snowpack throughout several winters at the proposed power plant site. Data on avalanche occurrences throughout the area also need to be collected over several winters. Only with these data in hand can the avalanche hazard be properly addressed.

REFERENCES CITED

March, G.D., and Robertson, L.G., 1982, Snow avalanche atlas, Seward Highway, South-Central Alaska: Alaska Division of Geological and Geophysical Surveys Professional Report 81, 168 p.

Mears, A.I., 1976, Guidelines and methods for detailed snow avalanche hazard investigations in Colorado: Colorado Geological Survey Bulletin 38, 125 p.

Perla, R.I, and Martinelli, M.,Jr., 1975, Avalanche Handbook: USDA Forest Service Agriculture Handbook 489, 238 p.

Republic Geothermal, 1985, The Unalaska geothermal exploration project, executive final report: Republic Geothermal, Inc., for Alaska Power Authority, 19 p.

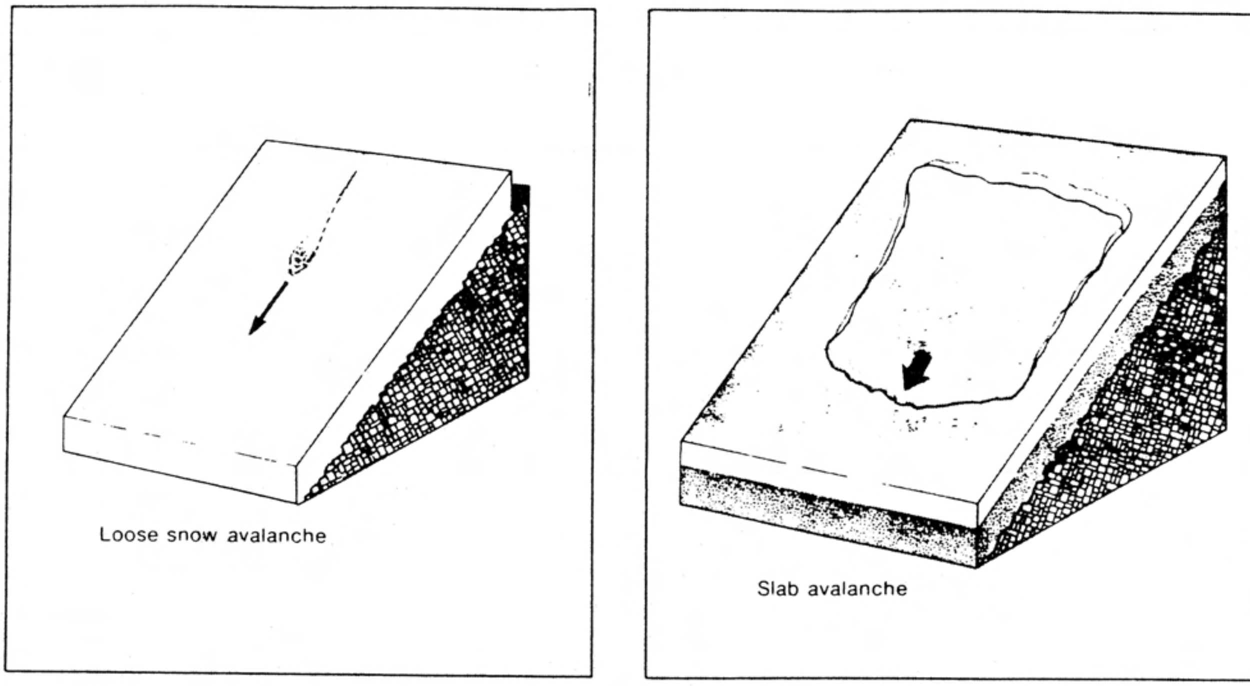


Figure 1. Two modes of snow slope failure: (left, loose- snow avalanche and (right), slab avalanche (Perla and Martinelli, 1976).

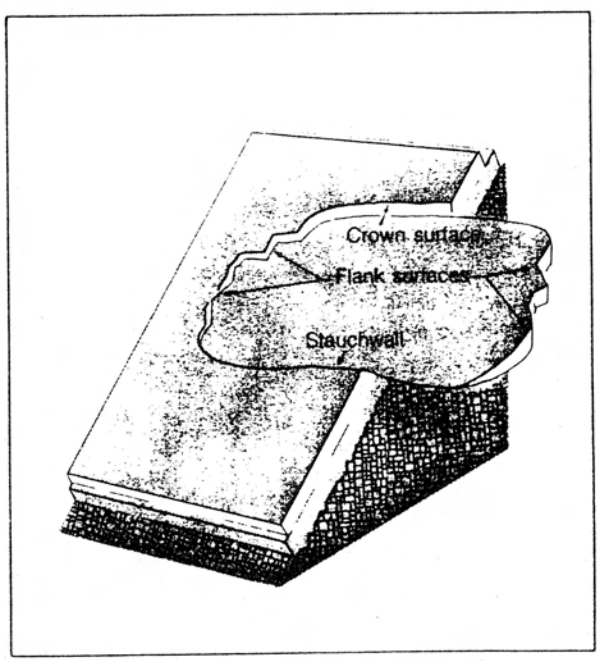


Figure 2. Nomenclature for boundary fracture surfaces of a slab avalanche (Perla and Martinelli, 1976).

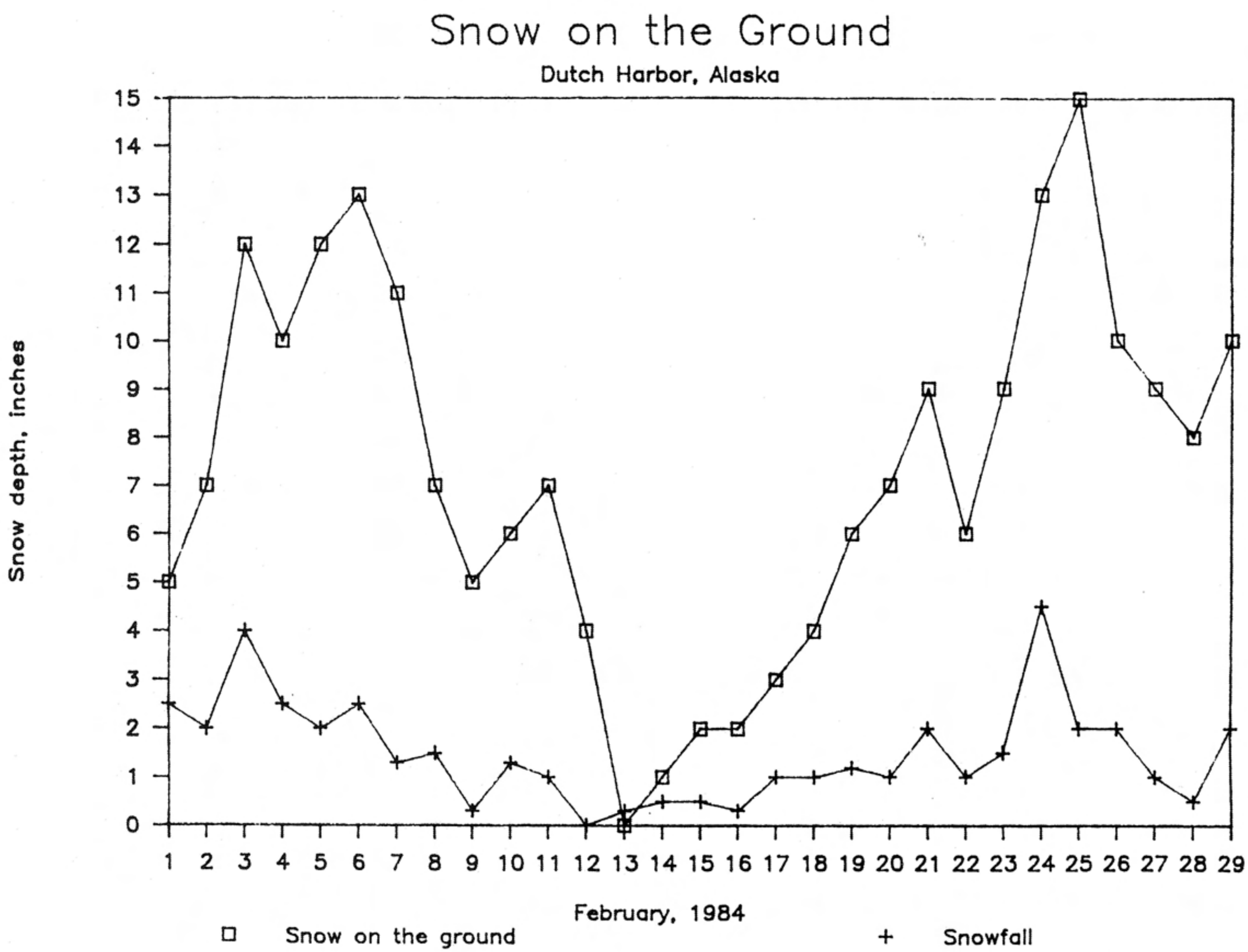


Figure 3. Snowfall and snow on the ground, Dutch Harbor, Alaska, February 1985.

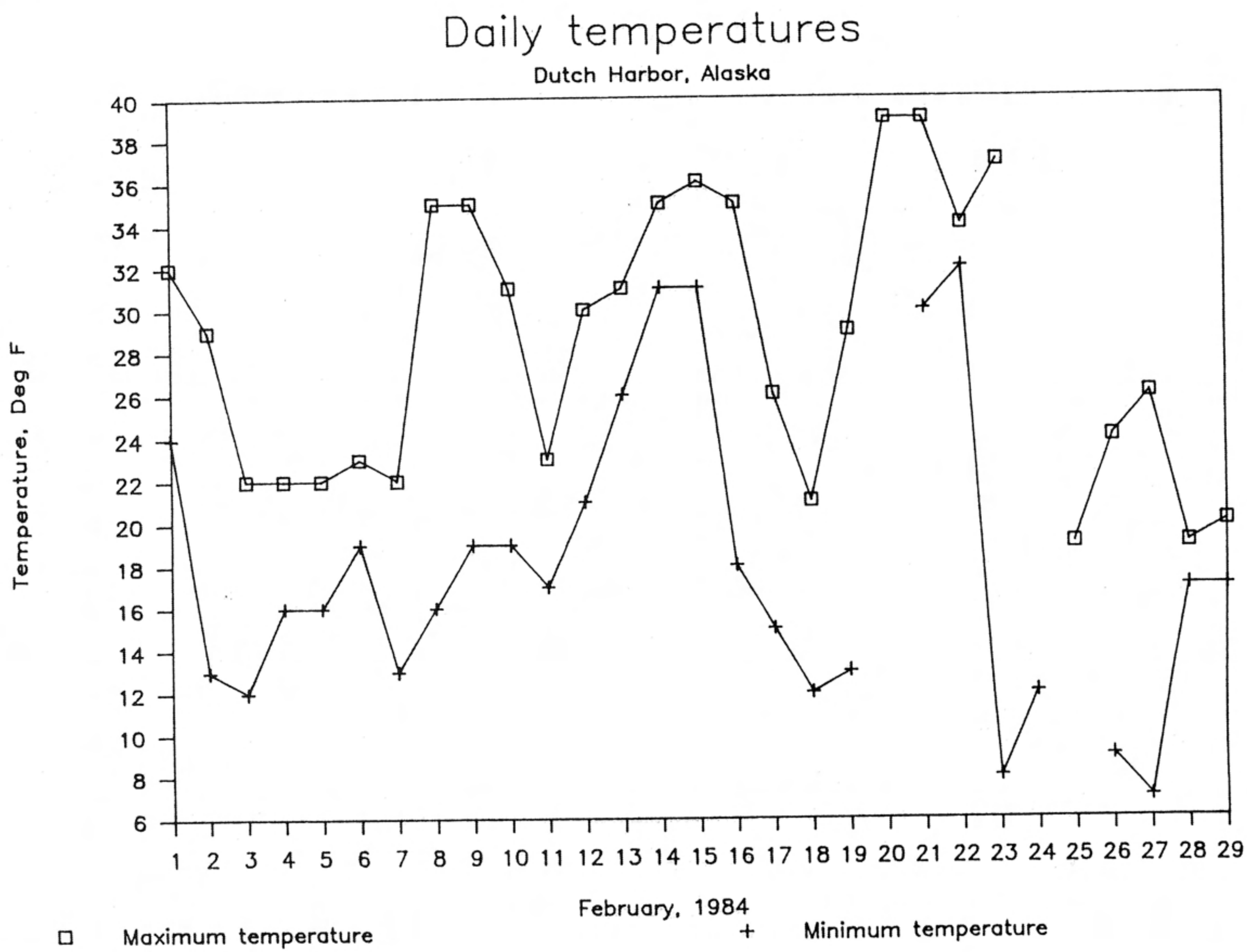


Figure 4. Daily maximum and minimum temperatures, Dutch Harbor, Alaska, February, 1985.

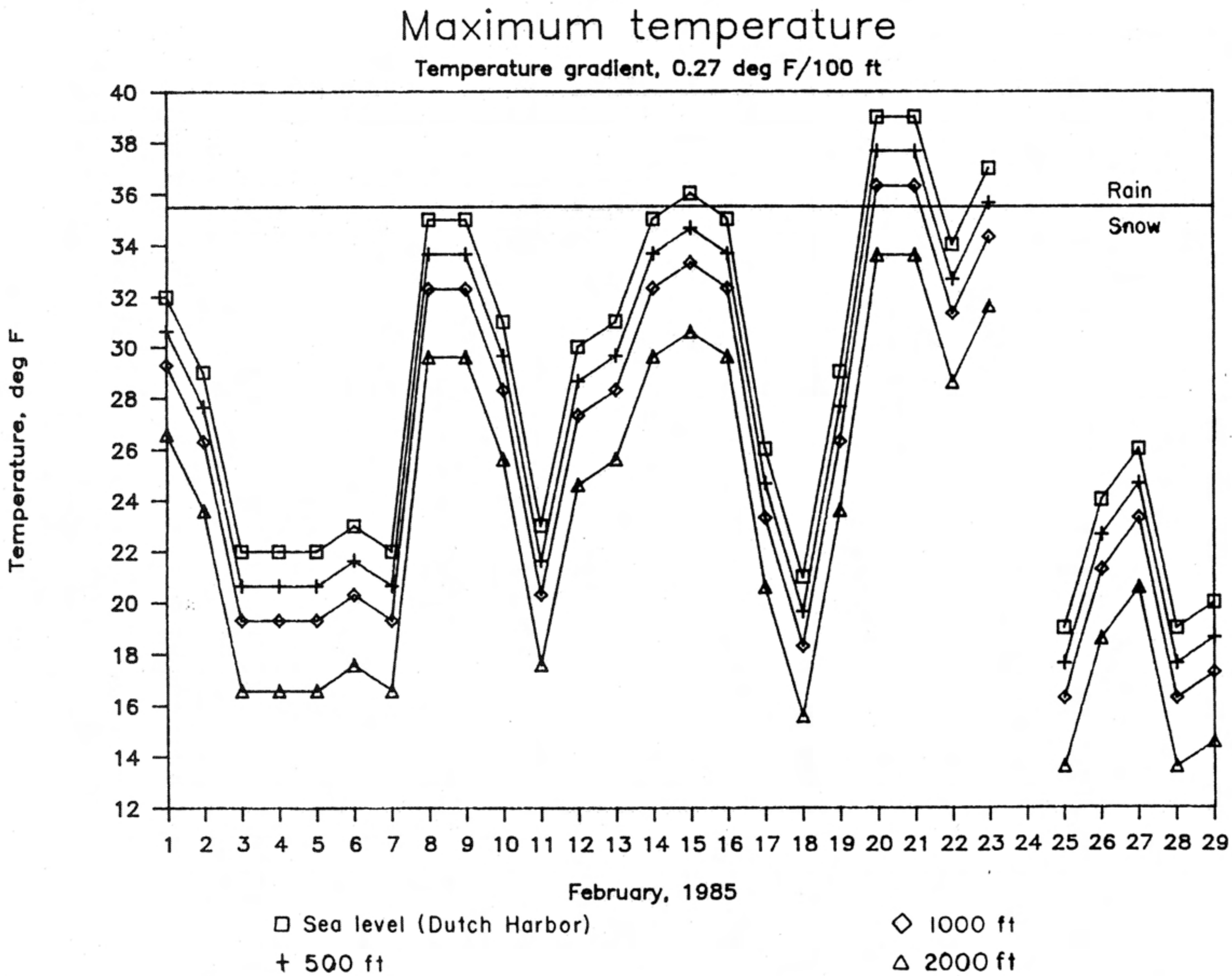


Figure 5. Extrapolated daily maximum temperatures, Dutch Harbor, Alaska, February, 1985.

GROUND STABILITY

by John W. Reeder

SCOPE OF WORK

Unalaska Island is one of the more geologically dynamic regions of Alaska, which is part of the glaciated and rugged Aleutian arc with its associated active volcanism and seismicity. The purpose of this section is to assess the Unalaska Island earth movement processes that could impact the proposed APA Unalaska geothermal power plant site as well as its possible transmission corridor and access road routes. This assessment includes bedrock and soil landslides, rock slides and falls, ice and rock flows (rock glaciers), seasonally unstable soils (solifluction), debris and mud flows, earth subsidence and fissuring, and fault movement processes. This assessment does not, except for generalized statements, include glacial flow, snow avalanche, lava flow, pyroclastic flow, pyroclastic fall, and lahar processes, which are or have been very common to the region.

METHODOLOGY

Regional surficial and bedrock mapping of the northern part of Unalaska Island was undertaken by air photograph examinations and by field observations and data collecting during the summers of 1980, 1981, 1982, 1983, and 1984. This work has resulted by the author in different unpublished data base maps (gravity, rock geochemistry, linear features, bedrock, and surficial). These maps, especially the surficial map, were then used to produce the enclosed three derivative maps:

(a) Ground stability constraints map of the Sugarloaf Cone region of Unalaska Island, Alaska (Plate H-1);
(b) Ground stability constraints map of the Makushin (Broad Bay) Valley region of Unalaska Island, Alaska (Plate H-2); and
(c) Bedrock landslides map of the northern part of Unalaska Island, Alaska (Plate H-3).

Recent field work by the author between 8 July and 22 July 1986 reconfirmed as well as refined the original information contained on these enclosed derivative maps.

RESULTS OF INVESTIGATION

Ten basic ground stability constraints have been recognized and are portrayed on Plates H-1 and H-2. These include (1) unstable rock slopes, (2) unstable soil slopes, (3) potentially unstable soil slopes, (4) seasonally unstable soils, (5) high potential for subsidence and fissuring, (6) potential for subsidence and fissuring, (7) potential for subsidence, (8) active fault zones, (9) potential for debris flows, and (10) rock glaciers.

The unstable rock slope constraint includes recent (Holocene or slightly older, 15,000± ybp to present) bedrock landslides and extensive rock falls (talus) deposits. Most of the bedrock landslides occur in an older (upper Oligocene to upper Miocene, 30 to 8 mybp) group of altered sedimentary and volcanic rocks designated the Unalaska Formation by Drewes and others (1961), which is the principal rock formation of the region. The Formation consists of altered conglomerate and sandstone units, and consists of altered volcanic lava and breccia flows with some volcanic dikes and sills. The bedding of this Formation in general dips to the north-northwest up to 50 degrees. As a result, most of the bedrock landslides in the northern part of Unalaska Island occur on north to west facing valley slopes (Plate H-3) that consist of Unalaska Formation. But, because the bedrock of Unalaska Island, especially the Unalaska Formation, is highly fractured by faults, dikes, and joints (Reeder, 1986), bedrock landslides and talus deposits do occur on slopes that face any direction. Three of the bedrock landslides of this region, which are in the Unalaska Formation and happen to face north-northwest, have dimensions of just over one mile.

The exact ages of the bedrock landslides on Plate H-3 are unknown, but all are considered to be Holocene or slightly older as based on the lack of any extensive glaciation. Many of the landlsides have been eroded by running water to the point that small canyons or valleys actually cut into them. Such landslides most likely have not had movements within the last several thousand years. In addition, many of the landslides lack the ash and organic stratigraphic sections observed in the region. Unpublished C-14 age dates have placed key tephra horizons at 10,500±, 8,000±, and 4,800± years before present. The lack of such sections would indicate such landslides would have formed after this time. A few landslides, such as the Devilfish Point landslide (Figure 1) and the between Cape Cheerful and Eider Point landslide, lack any well-established organic soils as presently found at the surface at low elevations throughout the region. This would imply that such landslides have had extensive movements within the last 1000 years, and could be presently active.

The talus (unstable rock slope) deposits consist primarily of angular cobbles and boulders that were derived from mechanical weathering of steep bedrock exposures of Unalaska Formation as well as of plutonic bodies that have intruded the Unalaska Formation and of young (Quaternary and slightly older) unaltered or only slightly altered volcanic deposits. Thicknesses of the talus range from 1 to 200 feet. Generally the talus overlies bedrock on steep slopes and till near the base of the slopes.

Colluvial-fan deposits are also fairly common in the region. Such deposits consist of some talus, but principally consist of fluvial deposits. Such deposits are as a whole fairly stable and their surfaces are usually fairly well vegetated. This type of deposit, although formed by presently active surficial processes, has been excluded from the ground stability constraint maps because of their fair degree of massive stability.

Following the 4.4 to 5.9 M_s shallow Unalaska Island earthquake swarm of 18-19 July 1986, the author had to remove rocks that had come down talus slopes during these earthquakes in order to drive an automobile over the Summer Bay/Unalaska community road. Numerous rock falls, and soil and bedrock failures also occurred during the recent 7 May 1986 7.7 M_s Andreanof Islands earthquake and during the 6.6 M_s Atka Island 17 May aftershock (unpublished data from author). It has been recently discovered that an approximately 7.3± magnitude earthquake occurred at Unalaska Island on 17 July 1865, which caused landslides and rock falls (unpublished Russian data from author). Unfortunately, it is not known where these movements occurred except that they did occur in the Unalaska Bay region. Because of this type of evidence, all recognized bedrock landslides and talus slopes should, for planning purposes, be considered unstable during earthquakes. Naturally, with more detailed site-specific investigations, particular landslides might actually be found to be quite stable even during very large earthquakes. But, with just the information at hand, all bedrock landslides should be considered unstable.

The unstable and potentially unstable soil (unconsolidated material) slopes consist of at times surface tephra-rich organic soil, and consist always of tills and/or undifferentiated drift over bedrock. The till and undifferentiated drift normally consist of a heterogenous mixture of poorly to moderately rounded gravel, boulders, sand, silt, and a limited amount of clay that were all deposited by glacial ice. The till and more commonly the undifferentiated drift may contain zones of sorted and bedded materials. Rarely are these glacial deposits more than 100 feet thick, and typically they are less than 20 feet thick. The tephra-rick organic soil, if present, is normally 1-6 feet thick, although thicker sections are common in the Makushin Volcano region. Tills and undifferentiated drift have been found to blanket a good part of the region because of the extensive Pleistocene glaciation of the entire Unalaska Island (Drewes and others, 1961; and Thorson and Hamilton, 1986).

On 8 November 1985, heavy rainfalls in the Unalaska Bay region triggered numerous soil failures such as the one shown in Figure 2. In this soil failure, the till is what caused the failures, which left exposed bedrock. In no case was the tephra-rick organic soil found to be the cause for the 8 November failures, as based on extensive observations by the author during 8-22 July 1986.

Till and undifferentiated drift failures have also occurred in the past throughout Unalaska Island as based on geologic observations by the author (Figure 3) and on observations by local residents (Figure 4). Areas where geologic evidence exists for past soil failures have been identified on Plate H-1 and H-2 as regions of unstable soil slopes. Regions where tills and undifferentiated drift are known to exist but past failures have not been recognized or only very insignificant (small) failures have been recognized have been identified on Plate H-1 and H-2 as potentially unstable soil slopes. Such slopes could become unstable under natural conditions or more likely might fail if excavated for road and powerline installations.

The soil failures need not be necessarily triggered by just heavy rains. For example, till failures did occur at Atka Island during the 7 May 1986 Andreanof Islands earthquake and following aftershocks (unpublished data from author). Such failures also need not occur as a single event, especially if the failures are driven by groundwater springs as commonly found at failure sites in the Makushin (Broad Bay) Valley.

The "runout" zone for soil failures beyond the base of steep slopes appears to have never extended beyond 160 feet onto the floor of the Makushin (Broad Bay) Valley. Exceptions are possible, so a distance of 200 feet beyond the base of valley slopes that are considered unstable or potentially unstable would be appropriate for planning purposes.

The solifluction (seasonally unstable soil) constraint includes only regions of very pronounced solifluction lobes. Solifluction is the process of slow flowage of water saturated soil to lower altitudes and appears to be related to the seasonal freeze and thaw cycle. As such, it has been labelled on Plates H-1 and H-2 as seasonally unstable soils. Even though evidence of solifluction exists throughout the Unalaska Island region, only pronounced solifluction lobes are considered to be a constraint to the APA Unalaska geothermal development activity.

Regions of potential for subsidence due to man-caused loading, and potential and high potential for subsidence and fissuring due to earthquake loading have been identified as ground stability constraints on Plate H-1 and H-2. Such regions are found in valley basins that have had extensive alluvial, bay to saltwater lagoon, barrier bar, blackish-water and fresh lacustrine to marsh types of depositional environments (see transmission line and corridor section of this report). Although little is known about the subsurface geology of the low altitudes of the Makushin and Driftwood Valleys, such depositional environments are prime candidates for man caused or earthquake caused ground subsidence and fissuring.

More specifically, the moderately stratified nature of alluvial deposits mark them a prime canidate for differential earthquake subsidence and resulting fissuring due to soil consolidation and liquefaction. The stratified nature of the finer saltwater lagoon and bay deposits also would target such deposits as a prime candidate for differential earthquake subsidence and resulting fissuring. But, both types of deposits would be fair to good foundations, except during earthquakes, for man-caused loads with little long term subsidence. Barrier bars and active marine beaches due to their high-energy depositional environment actually would be less susceptible to subsidence and fissuring, although such potential would still exist. Lacustrine (blackish-water to fresh-water) and marsh deposits in contrast would be less likely to liquefy and consolidate during earthquake loading due to their fineness of materials, but would be likely to subside due to long term consolidation under man-caused surface loads. Such deposits were found to exist in the lower part of the Makushin (Broad Bay) Valley to depths of about 20 feet below the surface. Such organic-rick and water-saturated fine deposits were found in this investigation to be fairly easy to drill through with just a powered hand-held auger (see corridor section of this report).

The active fault zone constraint includes only faults that have a recognizable scarp, which is due to recent fault movements. Because of the erosive power of glaciers, most of the fault scarps have formed since the last great glaciation of Unalaska Island that ended about 11,000 years before present (Thorson and Hamilton, 1986). Two potential concerns arise with respect to these active faults: (1) horizontal or vertical movement of the ground surface either as slow creep or as instantaneous breaks, and (2) release of energy as earthquakes, which could impact the region. The Unalaska Island region has numerous active and nonactive faults (Reeder, 1986), and the possibility of the existence of additional active faults than indicated on Plate H-1 and H-2 is likely. For example, the Point Kadin rift zone has been active on its northwestern segment during the Holocene (unpublished data from author) and has just been shown to be active on its southeastern segment (Jacob and Boyd, 1985). This rift zone trends through plate 1 near the proposed APA geothermal powerplant site, yet it has not been indicated since the author as been unable to recognize any fault scarps along it at this location.

Rock glaciers were mapped as a constraint because they are or have been actively moving at an imperceptibly slow rate. Construction on or in front of such features could eventually be destroyed. Rock glaciers consist of coarse, angular boulder-size rubble that if active contain interstitial ice in the pore spaces. They normally occur as steep-fronted lobes or tongue-like rubble masses at the base of ciffs in mountainous terrain.

Glaciers and thick snow accumulations on slopes would naturally be an additional stability constraint, which has not been included on Plate H-1 and H-2 (see glacier hazards and snow avalance hazards sections of this report). Based on the glacial geology of the region, glacial advances occurred about 2,000 and more extensively about 5,000 years before present in the Makushin Volcano region (unpublished data from the author). In fact, Sugarloaf Cone is built on tills that were deposited from the 5,000 ybp advance, and this cone probably grew when the ice was still present, which would explain its phreatomagmatic products. Future advances are probable, but when and to what extent is presently a big unknown.

Potential nonvolcanic debris and mud flows are another constraint that exist in the Sugarloaf Cone region. Debris and the more fluid mud flows are a mass of water-lubricated debris that usually follows a stream course. The source of such flows in the Sugarloaf Cone region would be the landsliding of highly altered bedrock in the active fumarole areas. Such debris would then flow down the drainage system. The best and largest examples of debris flows are actually found in the upper reaches of the Glacier (Makushin Bay) Valley just below the largest fumarole field and its corresponding landslide. Debris flows have not been that common in the upper reaches of the Makushin (Broad Bay) Valley drainages, and such flows have been fairly small.

Lava flows, pyroclastic falls and flows, and lahars would also be an additional stability constraint, which has not been included on Plate H-1 and H-2 (see volcanic hazards section of this report), except for existing pyroclastic flow deposits over tills and existing lahars over alluvium. A lahar is a type of debris flow and results when pyroclastic materials resting on the flanks or on the top of a volcano become saturated with water and move downslope as a flow. Pyroclasts are clastic rocks that were formed by explosive volcanic eruptions. Pyroclastic flows are eruption clouds of hot pyroclasts and gases that are driven by gravity along the ground as a density current. The region has been impacted before the Holocene by base surge pyroclastic flows and then by extensive early Holocene phreatomagmatic block and ash (pyroclastic) flows from Makushin Volcano, as originally described by the author (1982). These flows were originally incorrectly identified as lahars by Drewes and others (1961). They are well exposed at the proposed power site. The only failures that the author has seen in these pyroclastic flow deposits have been due to till failures underneath them. These early Holocene pyroclastic flow deposits, which were emplaced about 8,000 ybp (Reeder, 1983), appear to be fairly stable and have not been included in the potentially unstable soil category of Plate H-1 unless their exposed bluffs overlie tills. The most recent phreatic (steam-blast) eruption of the volcano occurred 28 April 1986 (Reeder, 1986b), which resulted in a 20 mile plume. Yet, the threat of any large phreatomagmatic tephra falls or flows directly from the summit of Makushin Volcano, such as occurred in the early Holocene, is unlikely within the immediate future due to the size of the hydrothermal system within the Makushin caldera and its immediate volcanic complex (Reeder and others, 1985).

Tephra falls and lava flows from satellite vents such as the recent Sugarloaf Cone have been common during the Holocene from the southern, northeastern, northern, and northwestern flanks of Makushin Volcano. These Holocene tephra falls and lava flows are fairly stable, and should pose no serious problems for access routes to the proposed power site. Future satellite volcanic extrusions could cause some problems for the operation of any proposed geothermal power plant on the west flank of Makushin Volcano.

Lahars from Holocene phreatomagmatic tephra falls and flows have been recognized in the upper Makushin (Broad Bay) Valley near the canyon entrance and in the upper northwestern part of the Driftwood Bay Valley. Very small lahar deposits have also been found in the upper drainages, but these lahars are almost insignificant in comparison to the size of the older large block and ash (pyroclastic) flows that occurred in this region about 8,000 ybp. The larger low altitute lahars probably occurred shortly after the large pyroclastic flows were emplaced. The smaller higher altitude lahars are probably mid-Holocene in age. No lahars have been identified by the author as being late Holocene. The existing lahar deposits are fairly stable and should pose no serious problems for access routes to the proposed power site. One exception has been made for the large lahar deposit at the head of the Makushin (Broad Bay) Valley. Because this deposit is believed to overlie alluvial deposits, it has been placed into the high potential for subsidence and fissuring category (Plate H-1).

The Sugarloaf Cone and Makushin (Broad Bay) Valley region (Plate H-1 and H-2) is blanketed by a tephra-rick organic soil. Numerous stratigraphic sections of this soil were taken by the author in 1982. In the Sugarloaf Cone region it has been found to be up to 12 feet thick, but more typically it is about 8 feet or less in this region and normally about 2 to 6 feet thick in the Unalaska Bay region. The soils in general appear to be an acidic iron-rich soil that is fairly resistant to deformation and failure. Vertical cuts in this organic soil in drainage ravines or along roads do not fail unless underlain by a weak material such as till. Because of the strength of this tephra-rich organic soil, it has not been included on the enclosed Plate H-1 and H-2 constraint maps.

CONCLUSIONS AND RECOMMENDATIONS

Plates H-1 and H-2 are a good base for ground stability constraint considerations with respect to any serious feasibility and planning efforts for geothermal power development of the Makushin Volcano region. Naturally, any steep slope in the Makushin Volcano region would have some stability complications such as a possible falling rock "once-in-a-while". Only the significant constraints have been considered in Plates H-1 and H-2; excluding glaciers, snow avalances, lahars, lava flows, and pyroclastic falls and flows.

Probably the weakest aspect of Plate H-1 and H-2 is the lack of good regional subsurface information for the lower part of the Driftwood Bay Valley and for the lower part of the Makushin (Broad Bay) Valley. Additional geotechnical test drilling in these regions might be appropriate along the powerline corridor and access road routes before actual construction. It is also advised that a carefull examination for additional active faults than shown in Plate H-1 and H-2 be undertaken during the initial construction phase of the powerline corridor. This should be done so that appropriate design changes can be made if additional active faults are found.

REFERENCES CITED

Drewes, H., Fraser, G.D., Snyder, G.L., and Barnett, H.F., Jr., 1961, Geology of Unalaska Island and adjacent insular shelf, Aleutian Islands, Alaska, U. S. Geological Survey Bulletin 1028-S, p. 583-676.

Jacob, K.H., and Boyd, T.M., 1985, Analysis of data from a temporary seismic network on Unalaska Island, Alaska Division of Geological and Geophysical Surveys Public Data File 85-59, 47 p.

Reeder, J.W., 1982, Hydrothermal resources on the norhtern part of Unalaska Island, Alaska Division of Geological and Geophysical Surveys Open-file Report AOF-163, 17 p.

Reeder, J.W., 1983, Preliminary dating of the caldera forming Holocene volcanic events for the eastern Aleutian Islands, Geological Society America abstracts with programs, v. 15, no. 6, p. 688.

Reeder, J.W., 1986, An analysis of fault and volcanic dike orientations for the Makushin Volcano region of the Aleutian arc, in Reilly, W.I., and Storm, A., eds., Recent crustal movements of the Pacific region, Royal Society of New Zealand Bulletin No. 24, just published.

Reeder, J., 1986b, Makushin Volcano, in McClelland, L., Nielsen, E., Summers, M., and Wegert, E., eds, SEAN Bulletin, Smithsonian Institution, v. 11, no. 6, page 6.

Reeder, J.W., Denig-Chakroff, D., and Economides, M.J., 1985, The geology and geothermal resource of the Makushin Volcano region of Unalaska Island, Alaska, 1985 International Symposium on Geothermal Energy, Kailua-Kona, Hawaii, Geothermal Resource Council Transactions, v. 9, Part 1, p. 177-182.

Thorson, R.M., and Hamilton, T.D., 1986, Glacial geology of the Aleutian Islands, based on the contributions of Robert F. Black, in Hamilton, T.D., Reed, K.M., and Thorson, R.M., eds, Glaciation in Alaska, the geologic record, Alaska Geological Society, p. 171-191.

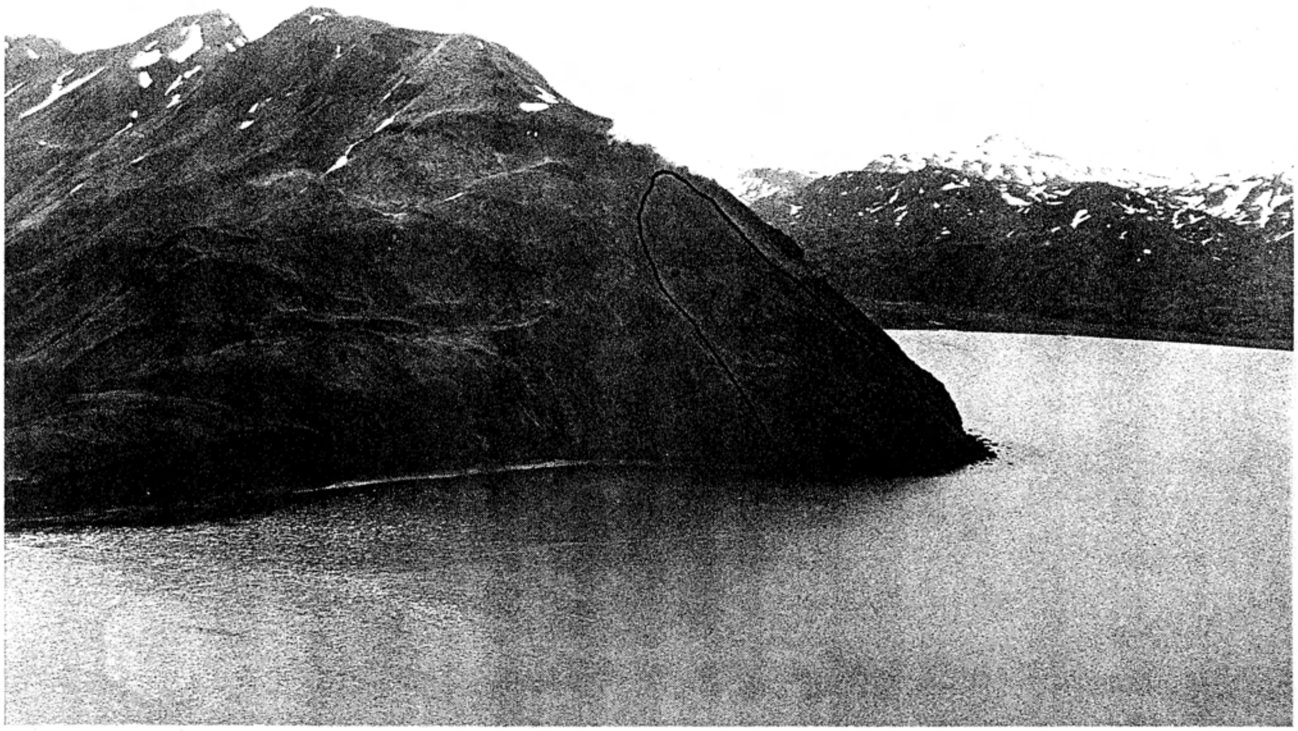


Figure 1. A view of the Devilfish Point landslide taken on 11 July 1986.
Nateekin Bay is in the background.

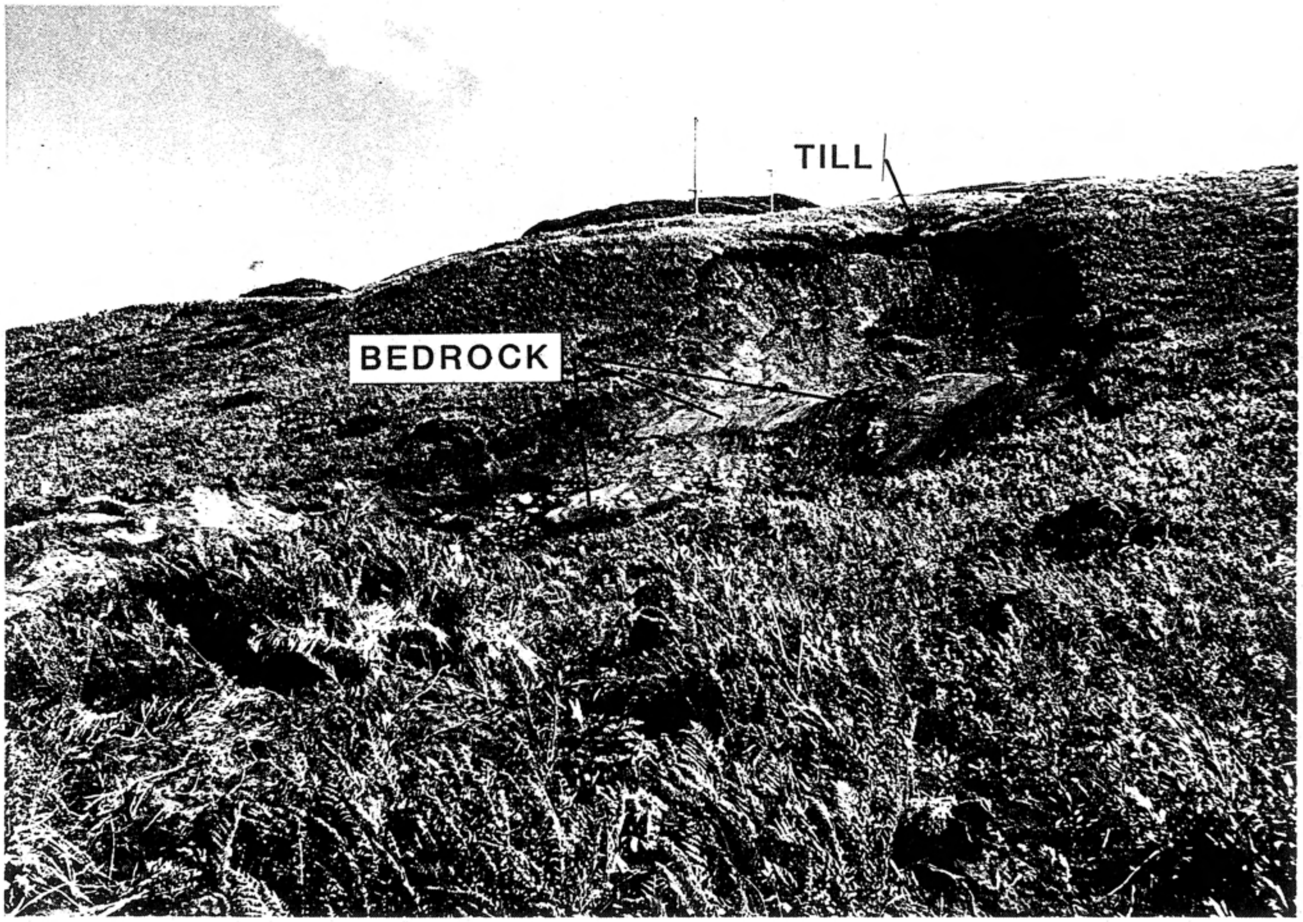


Figure 2. A view taken on 12 July 1986 of one of the many 8 November 1985 Unalaska landslides, which occurred during unusually heavy rains. This landslide is in the Unalaska Valley near Unalaska.1986.

Figure 3. Numerous till failures can be seen in this view, which is to the south from the upper part of the Makushin (Broad Bay) Valley near its canyon.

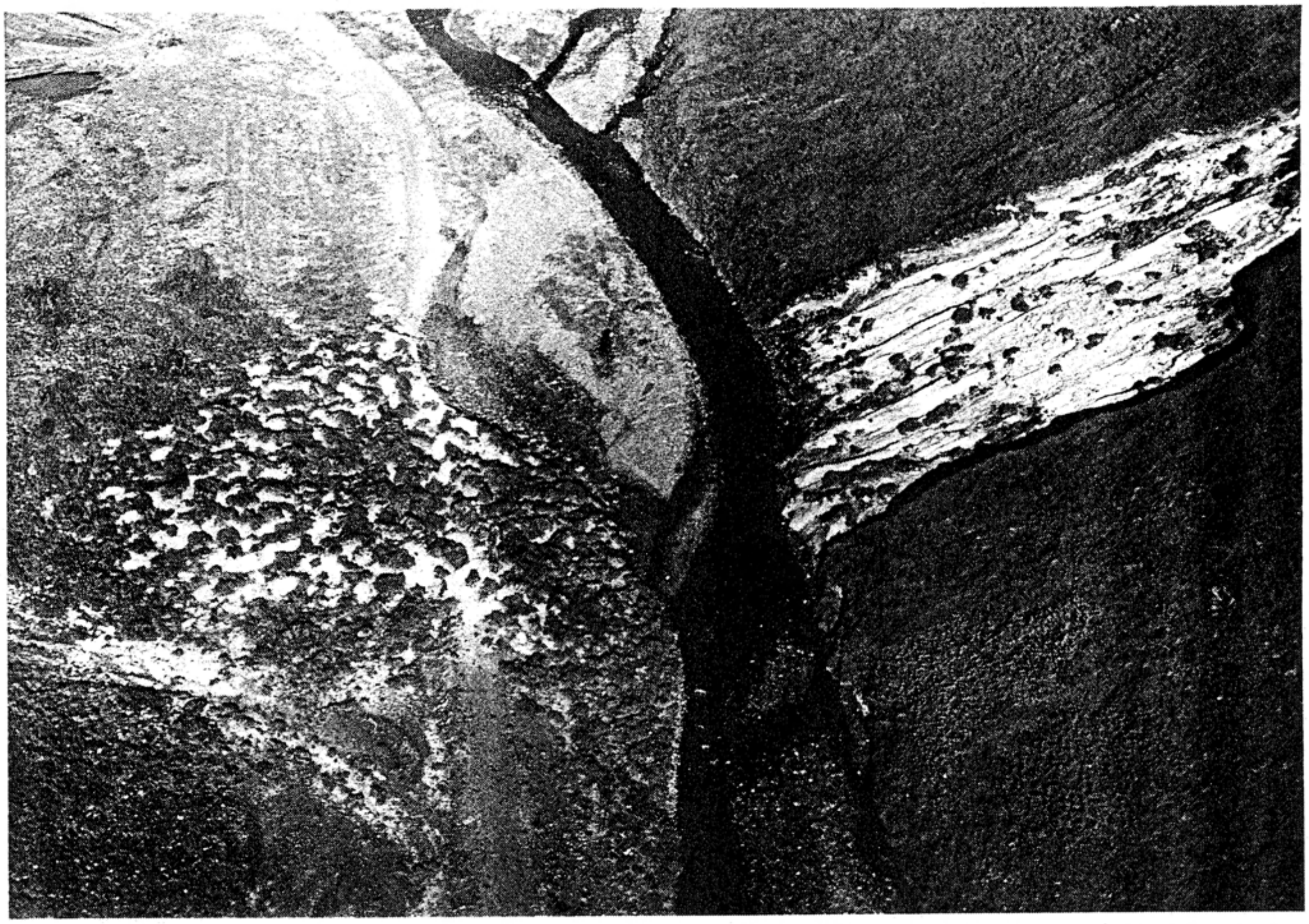


Figure 4. An aerial view taken July 1986 of a recent soil failure with exposed bedrock on the north side of the Makushin (Broad Bay) Valley. The road in this view was surveyed and engineered by Lee Goch (resident of Anchorage) in 1962-63. Abi Dickson (a resident of Unalaska) has hiked this region several times over the years and she observed this particular August 1979 landslide just after it had occurred.

HYDROLOGY

This section includes two subsections: Surface Water Hydrology and Water Quality. Streamflow, channel, and basin characteristics are discussed in the first section, Surface Water Hydrology, while water chemistry and geothermal wastewater dilution are the main topics of the Water Quality section. Three streams in the Makushin Valley River drainage basin were studied during July 14 - 18, 1986. None of these streams have been officially named, but for reference purposes the following names are used in this report: Makushin Valley River, Fox Canyon Creek, and Avalanche Creek (see Plate I-1). The Makushin Valley River drains and area of 33.1 square miles to the east of Makushin Volcano, including the geothermal well site.

SURFACE WATER HYDROLOGY

By Stan Carrick

SCOPE OF WORK

The purpose of the Surface Water Hydrology section is twofold: first, to describe and generally define streamflow of Makushin Valley River basin streams, especially those that could receive geothermal wastewater. Second, to assess the flow, channel, and basin characteristics of streams adjacent to potential road or transmission line corridors in the Makushin Valley. Streamflow information is necessary for power plant and facility siting, as well as for water quality analyses. Facility construction can have deleterious impacts on the natural streamflow; on the other hand, floodwaters can seriously damage buildings, road, and transmission line towers. In addition, streamflow magnitude data are critical for assessing potential water chemistry and dilution effects if geothermal wastewater is routed to the streams. Data gathered in the field along with empirical methods are used to present hydrologic information that should prove helpful in future feasibility and design work.

METHODS

Field work for this section was done on July 14, 16, 17, and 18, 1986, solely in the Makushin Valley River drainage basin. The field objectives were: (1) to establish two stream-stage monitoring instruments downstream of the geothermal well site, (2) measure discharge (where possible) on streams of interest, (3) survey channel morphology at selected sites, and (4) observe and note channel and basin characteristics. Field sites (Plates I-1 and I-2) were chosen based on the following criteria:

(1) accessibility and instrumentation potential
(2) discharge reach suitabilities
(3) sites downstream of potential geothermal waste fluid discharge
(4) representative flow and channel conditions

Site 1, Fox Canyon Creek, is immediately adjacent to and downstream of the geothermal test well area, and it is also upstream of its confluence with the Makushin Valley River. Discharge and water quality were measured at this site and a channel cross section was surveyed. A Kavlico stream-stage pressure transducer/water temperature probe was installed at site 1 and coupled to a Datapod 212 recording instrument. This unit will continuously record stream stage and temperature at regular intervals. Site 2 is on the Makushin Valley River upstream of its confluence with Fox Canyon Creek, yet still downstream of the test well site. Discharge and water quality were measured at this site, a channel survey on one side was done, and another Kavlico/Datapod unit was installed. Sites 1 and 2 are the closest sites to a potential geothermal wastewater discharge point.

Site 3, Avalanche Creek, was chosen because it is the largest tributary basin the the Makushin Valley River and it may have significant discharge and dilution effects on the main stem of the river. A discharge measurement was taken and water quality samples were obtained, but no instruments were installed. Site 4, downstream on the Makushin Valley River, was picked because it most nearly reflects basin conditions as a whole and it is below the major tributaries to the main stem. Water quality work was done at site 4, but the river couldn't be waded so a discharge measurement was not taken; no stage instrumentation was installed at this site either. Channel surveys were accomplished at three other locations on the Makushin Valley River (Plates I-1 and I-2). Because the river couldn't be waded the surveys were done on one side of the channel only, and elevations were recorded for various high water levels and for the channel longitudinal profile. Velocity measurements for stream discharge calculations were made with a Marsh McBirney Model 201 current meter, and a Sokkisha B2A automatic level was used for surveying.

Plates I-1 and I-2 show the mapping done for this section at a scale of 1:24,000 and a contour interval of 40 ft. The topographic map is based on photography from August 1, 1982, with both the photography and map production completed by North Pacific Aerial Surveys, Inc., in Anchorage. Flood discharge estimates are based on equations from Lamke's Flood Characteristics of Alaskan Streams (1979), and Rigg's Simplified Slope-Area Method for Estimating Flood Discharges in Natural Channels (1976). The National Weather Service, Reeve Aleutian Airways, Inc., and the Arctic Environmental Information and Data Center (AEIDC) were consulted about weather information and data was obtained from AEIDC.

RESULTS OF INVESTIGATION

The Makushin Valley River is a dynamic Aleutian Island, glacier-fed stream. Other than the Makushin Valley in the lower 7 mi of the river, all the basin's streams are steep and short. Three headwater tributaries drain two small glaciers on the east flank of Makushin Volcano, resulting in sustained flow from snow and glacier melt during the drier, warmer summer months. The lower 7 mi of the Makushin Valley River is rather atypical for an Aleutian stream because it is relatively broad (2,000 - 3,000 ft), flat, and long. Natural springs and seeps augment snow melt and surface flow. Volcanic material and glacial deposits dominate the headwaters area of the river, while volcanics, alluvium, and marshy lagoonal deposits are mostly found in the lower valley.

AEIDC (1974) gives a mean annual runoff of 4 cfs/sq mi for the Aleutians, with annual peak runoff rates reaching 25 cfs/sq mi. However, the Makushin Valley River basin is higher, steeper, and contains glaciers, so the runoff values should be higher. Mean annual runoff in the basin is probably closer to 6 - 8 cfs/sq mi, while annual peak runoff is near 35 cfs/sq mi.

Unalaska lies within the Maritime Climatic Zone characterized by moderate temperatures, moderate-to-high precipitation, and strong winds. No weather data exist for the Makushin Valley, but records do exist for Dutch Harbor (12 mi SE of the Valley) and Driftwood Bay (3 mi N of the Valley); both sites are near sea level. Table 1 presents a summary of all published weather data, as provided by AEIDC (1974, 1986).

Table 1. Unalaska Weather Summary

	Dutch Harbor	Driftwood Bay
Period of record	33 yrs (1922-1984)	10 yrs
Mean annual temperature	40.6°F	summer: 33°F to 55°F winter: 22°F to 39°F
Coldest month	FEB, 31.6°F	N.A.
Warmest month	AUG, 53.8°F	N.A.
Maximum recorded temperature	80°F	76°F
Minimum recorded temperature	2°F	3°F
Mean annual precipitation	59.8 in.	21 in.
Extreme daily precipitation	7.6 in.	N.A.
Annual snowfall total	72 in.	70 in.
Wettest month	OCT, 7.5 in.	N.A.
Driest month	JUL, 1.6 in.	N.A.
Average wind	SE 9.6 knots	NW 8.3 knots
Maximum wind	E 82 knots	WSW 55 knots

Precipitation in the Makushin Valley River basin is greater than Dutch Harbor because of orographic effects. The cooler, maritime climate and high percentage of cloud cover means that snow melt is more gradual in spring and summer. Consequently, spring peak streamflow is more prolonged and subdued, and most annual peak flows occur during late summer or fall rainstorms. Diurnal flow variations can also be great.

Table 2 presents streamflow characteristics from sites visited in the field, along with historical information on these sites in the basin taken from Peterson and Nichols (1983, 1984) and Dames and Moore (1982). Drainage areas and gradients were taken off the 1:24,000, 40 ft contour interval map. The flows are field measured and vary seasonally as well as in location. Fox Canyon Creek was measured twice and showed a range in flow of 36-60 cfs.

Table 2. Makushin Valley River basin streamflow characteristics.

Site, river mileage, elevation	Drainage area	Measured discharge and date	Gradient above site	Bankfull maximum depth	Bankfull width	Water surface slope	Channel type	Dominant channel bed composition
Site 1, Fox Canyon Creek, 9.6 mi, 720 ft	2.6 mi^2	60 cfs 7/14/86	552 ft/mi	4.33 ft	35 ft	0.0579	braided	gravel-boulders
Site 2, Makushin Valley River, 9.8 mi, 720 ft	5.5 mi^2	194 cfs 7/16/86	599 ft/mi	5 ft	40 ft	0.0324	braided & straight	cobbles-boulders
Site 3, Avalanche Creek, 6.6 mi, 290 ft	4.3 mi^2	162 cfs 7/16/86	528 ft/mi	4 ft[e]	48 ft[e]	0.0250[e]	braided	gravel-boulders
Site 4, Makushin Valley River, 2.0 mi, 20 ft	approx. 30 mi^2	750-850 cfs[e] 7/17/86	40 ft/mi below canyon	5 ft	150 ft	0.0037	meander	sand-cobbles
Survey Site 5, 3.9 mi, 70 ft	approx. 24 mi^2	650 cfs[e] 7/18/86	N.A.	4 ft	200 ft	0.0090	braided	gravel-cobbles
Survey Site 6, 7.3 mi, 320 ft	approx. 17 mi^2	500 cfs[e] 7/18/86	375 ft/mi	5 ft[e]	50 ft	0.0258	braided & straight	gravel-boulders
Historical[1] Site FCM Fox Canyon Creek 9.8 mi	2.6 mi^2	39 cfs 9/3/83	552 ft/mi	N.A.	N.A.	N.A.	braided	cobbles-boulders
Historical[1] Site MVB/BC Makushin Valley River, 10.0 mi	5.0 mi^2	7.9-130 cfs 5/18/82-8/10/84	599 ft/mi	N.A.	N.A.	N.A.	braided	cobbles boulders
Historical[1] Site MV Makushin Valley River, 7.3 mi	approx. 17 mi^2	58-400 cfs 5/19/82-8/10/84	375 ft/mi	N.A.	N.A.	N.A.	straight	gravel-boulders

[1] Peterson and Nichols, 1983 and 1984; Dames & Moore, 1983
[e] Estimated

Meanwhile, the upper Makushin Valley River sites had more measurements, ranging from 7.9 - 194 cfs. Downstream on the Makushin Valley River, below the canyon, flows were from 58 - 800 cfs, while one discharge measurement in July 1986 on Avalanche Creek yielded a flow of 162 cfs.

The smaller sub-basins have steep stream gradients, and only the main stem of the river below the canyon (approximately the lower 7.5 mi of the stream) has a gradient below 100 ft/mi. This is a dynamic hydrologic stream and changes in flow magnitude can be relatively rapid. Photos 1 and 2 depict typical stream reaches in the basin. Bankfull dimensions are given because bankfull stage corresponds to the discharge at which channel maintenance is most effective, and it is the discharge at which the stream's floodplain begins to receive streamflow.

Stream discharge is an important factor in water chemistry dilution. Fox Canyon Creek and the Makushin Valley River (site 2) are likely recipients of geothermal wastewater. Communications with the Alaska Power Authority indicate that wastewater discharge <u>may be</u> on the order of 5.0 cfs. Summer and fall flows in Fox Canyon creek and the upper Makushin Valley River (site 2) have ranged from 39 - 194 cfs, whereas the lowest flow measured in the entire basin was 7.9 cfs near site 2 (Historical Site BC) on May 18, 1982. Winter and spring flows in both creeks undoubtedly fall below 5-10 cfs for periods of time.

Downstream of these sites streamflow increases through the canyon. The lowest flow measured at Site 6 just below the canyon mouth was 58 cfs, but spring inflow, snowmelt, and rain at the lower elevation throughout the winter should maintain streamflow. Without additional low flow data and wastewater discharge information, specific dilution effects cannot be accurately predicted.

High streamflow will reduce or essentially negate any wastewater dilution problems, but floods can jeopardize facilities and construction work. No flood or bankfull discharges have been measured in the Makushin Valley River basin. Flooding here can occur from snowmelt, rain, volcanic activity (causing snowmelt), or possibly even glacial lake outburst floods (though no evidence suggests such outburst floods have occurred in the past or will occur in the future).

Flood flow calculations can be made based on field evidence and surveys, but time and unwadable streams precluded full surveys on all sites but one, Fox Canyon Creek. Using Rigg's (1976) slope-area method, bankfull discharge at Site 1 on Fox Canyon Creek equals 180 cfs, a reasonable figure based on measured flows and channel morphology. Lamke (1979) presents regression equations based on gaged streams for calculating flood flows of various recurrence intervals. The equations used physical characteristics of the basin such as drainage area and lake storage, as well as climatic factors like mean annual precipitation and temperature, to come up with a predicted flood discharge. Two basic regressions are given, one for the maritime coastal part of Alaska, and another for the rest of the state which includes the Aleutians.

Lamke's regressions were used for flood calculations at the lower Makushin Valley River site 4 only, because the significant climatic factors used in the equation could be taken from nearby Dutch Harbor data. The flows by recurrence interval are as follows: 5 yr - 1495 cfs, 10 yr - 1798 cfs, 25 yr - 2120 cfs, and 50 yr - 2623 cfs (standard of error is 68-78 percent). These figures may underestimate the flood flows based on discharge estimates obtained in the field. In July 1986, a conservative estimate of flow at site 4 was 800 cfs, at a water surface level nearly 2 ft below bankfull. It should be remembered that Lamke was only able to use three small low-elevation gaged basins on Amchitka Island for his regression analysis. The Makushin basin is unlike most basins in the Aleutians because it is large, high, and has glaciers; consequently, flood estimates for the basin (based on only Amchitka Island streams for the regression analysis) likely have high degrees of error. No gaged streams exist in southwest Alaska that approximate Makushin conditions, so comparisons of flow magnitude cannot be reliably attempted.

High flows in the basin are normally caused from heavy rains (which because of the moderate climate, can actually occur year round), or from combined rain and snow melt. Accelerated volcanic activity on the active Makushin Volcano could result in increased heat flow and snow melt, causing floods of a much higher magnitude than climatically induced floods. Also, various types of volcanic flows could possibly follow Makushin Valley River drainage paths.

Stream flooded areas would be relatively small upstream of mile 7.5 on the Makushin Valley River. The channels run in a narrow canyon and high flows are laterally confined. The streams are steep and active upstream, with high amounts of bed, bank, and canyon wall erosion taking place. Bed load movement in these streams is high, with gravel and cobbles in motion much of the time.

Downstream of mile 7.5, the valley opens up and the channel gradient decreases rapidly. The Makushin Valley River braids from mile 7.5 to about mile 3.0 where it begins to meander. The braided reaches are more unstable than meandering sections, and gravel bar erosion and deposition is constantly occurring. At the same time, one channel segment can rapidly be abandoned while the creation of another channel takes place some distance away. The meandering reaches tend towards greater stability as they move laterally by erosion along concave banks, with equal deposition on convex banks.

Floodwaters downstream would not be as confined as in the canyon. Plate I-2 shows areas outside of the 100-300 ft active floodplain that are subject to potential flooding by larger flows, based on photo interpretation (1"=2000') and field observation. Very high flows would inundate half the valley width at places, and whole sections of channels could be formed away from the present day channels. However, there is no evidence to indicate that a flow on the order of a 100-yr flood has taken place since 1963 when the road to Driftwood Bay was constructed, and most high water appears to have been mostly confined to the active channels and immediately adjacent areas.

The lower valley floor is relatively flat, poorly-drained in places, and criss-crossed by small tributaries and distributaries. During periods of heavy rain and high flows, much of the valley floor could be wet and boggy from surface water movement and a rising water table. Specific points of high erosion were not identified during field work in July 1986.

CONCLUSIONS AND RECOMMENDATIONS

1) Streamflow varies widely in the Makushin Valley River drainage basin, and varies seasonally and diurnally. Without additional low flow data and geothermal wastewater discharge information, predictions on effects to flow from wastewater discharge cannot be made. Low flows in a receiving stream, however, could be similar to wastewater discharge amounts. Fox Canyon Creek and the Makushin Valley River site 2 are being continuously monitored for stage and temperature now, and should provide adequate low flow data over the next 2-3 years. Additional geothermal wastewater discharge information is necessary for future feasibility work.

2) High-water effects on buildings, roads, and transmission line towers would be minimal or non-existent above mile 7.5 on the river, as long as any facilities are built away from the eroding canyon walls. Valley flooding and subsequent erosion/deposition could affect facilities on or near the active floodplain. The closer a facility is located to the active channel or floodplain, the greater the risk of high-water damage or increased maintenance costs. Facility corridors should be planned as far away from the active channel to decrease affects on water quality and fish habitat; stream crossings should be minimized. Additional data on streamflow in the lower Makushin Valley River is desirable, along with more detailed floodplain mapping or surveying where facilities are proposed. If human and equipment occupation of the basin, especially the upper basin, is planned and further data collection is undertaken, then a long-term weather station somewhere in the basin would provide very useful information. At the present time, one wind monitoring instrument is scheduled for installation near the test well site in September 1986.

REFERENCES CITED

AEIDC (Arctic Environmental Information and Data Center), 1986, Climate summaries for Dutch Harbor, Alaska: Personal commun., 12 p.

AEIDC, 1974, Alaska regional profiles, southwest region: L. Selkregg, Editor, University of Alaska, Fairbanks, pp. 4-115.

Dames & Moore Consulting Engineers, 1983, 1982 Environmental baseline data collection program, final report, Unalaska Geothermal Exploration Project: Dames & Moore, Anchorage, Alaska, pp. 1-20.

Lamke, R.D., 1979, Flood characteristics of Alaska streams: U.S. Geological Survey Water Resources Investigations 78-129, 61 p.

Peterson, L.A., and Nichols, G., 1983 and 1984, Unalaska geothermal exploration project, water quality and flow during geothermal well test: L.A. Peterson and Associates, Inc., Fairbanks, Alaska, 40 p.

Riggs, H.C., 1976, A simplified slope-area method for estimating flood discharges in natural channels: U.S. Geological Survey Journal of Research, V. 4 No. 3, p. 285-291.

WATER QUALITY

By Mary Maurer

SCOPE OF WORK

Water-quality protection is a concern in the development of the geothermal power facility because there is a pink salmon fishery in lower Makushin Valley River. The main water-quality impacts on the fishery that are associated with the development of a geothermal power facility in Makushin Valley are introduction of sediment and geothermal fluid into Makushin Valley River. Discharge of geothermal fluid into streams would raise concentrations of dissolved solids and trace elements. Sedimentation would result from road construction or erosion from the well site. Previous reports which contain baseline water-quality data are an environmental baseline study by Dames and Moore (1983), who also discuss potential impacts and mitigation measures, and test well monitoring studies by Peterson and Nichols (1983) and Peterson (1984).

The purpose of this report is to (1) supplement the existing database by comparing water-quality characteristics at four sites in Makushin Valley and (2) summarize selected water-quality variables at current and historic sites in upper Makushin Valley. Site selection was based on three considerations: obtain baseline information at continuous stream gaging stations in the upper watershed, document baseline conditions in a major tributary, and document baseline conditions in lower Makushin Valley River.

METHODS

Stream and site names used in this report are consistent with those of previous water-quality reports. Site 1 was located approximately 300 ft above the mouth of Fox Canyon Creek. Site 2 was located on the mainstem of Makushin Valley River approximately 500 ft above the Fox Canyon Creek confluence. Site 3 was located on an unnamed stream referred to in this report as Avalanche Creek which flows into Makushin Valley River at river mile 6.6. The site was located approximately 2 miles above the stream's confluence with Makushin Valley River. Site 4 was located on the mainstem of Makushin Valley River ¼ mile above the river's mouth. Site locations are shown on Plates I-1 and I-2.

Streamflow and water-quality variables were measured at each site during the week of July 14, 1986. Water temperature, dissolved oxygen, and conductivity were measured with a digital 4041 Hydrolab. Field pH was measured with an Orion digital pH meter. Alkalinity was measured in the field by titrating an untreated sample with 0.1600 N sulfuric acid, dispensed with a Hach digital titrator to an endpoint of pH 4.5. Grab samples were collected as near to the center of the stream as possible. Cross-sectional composite samples were not collected because high streamflow made wading difficult. However, streamflow was turbulent at site 1, 2, and 3 and waters appeared well-mixed at all sites. Major ion and trace metal samples were immediately filtered in the field through a 0.45 um membrane filter. Dissolved trace-metal samples were acidified with double-distilled 70 percent nitric acid immediately after collection.

Total suspended sediment samples were analyzed at the Alaska Division of Geological and Geophysical Surveys water-quality laboratory in Fairbanks, Alaska. Major ion and dissolved trace-metal samples were analyzed at the University of Utah Research Institute Earth Science Laboratory in Salt Lake City, Utah. All samples were analyzed in accordance with the methods of the U.S. Environmental Protection Agency (1983) or American Public Health Association (1980). Specific analytical methods and their detection limits are listed in Appendix A. The majority of trace elements were analyzed on an inductively coupled plasma spectrometer. Alternate analytical techniques were used for some elements to obtain lower detection limits. Arsenic was determined by the atomic absorption gaseous hydride method. Bromide was determined titrimetrically.

RESULTS OF INVESTIGATION

Water-Quality Characteristics

The water-quality variables that were measured in the field are shown in Table 3. Specific conductance was low and similar among sites, ranging from 48 to 70 umhos/cm. Water temperatures and dissolved oxygen concentrations were also similar, and percent saturation of dissolved oxygen exceeded 100 percent at each site. The water was slightly acidic at all sites, with site 2 having the lowest pH, 5.40. Alkalinity of water samples was low, but like specific conductance, values were slightly higher at sites 3 and 4 than at sites 1 and 2. Turbidity was low except at site 2, where a reading of 17 NTU was recorded. Turbidity levels and streamflow were noticeably higher on July 18 due to warmer air temperatures, although no field measurements were made on this date.

Total suspended sediment concentrations were variable among sites, ranging from 18.8 to 99.6 mg/L (Table 3). The highest concentration was measured at site 2 which also had the highest turbidity. Most of the sediment consisted of coarse sand particles and organic matter rather than silt and clay. These grain-sized particles were transported as suspended sediment because of highly turbulent streamflow.

Concentrations of major ions at each site were low (Table 3). Total dissolved solid concentrations ranged from 28 to 48 mg/l. Silica concentrations were also low, ranging from 5.6 mg/l at site 3 to 11.4 mg/l at site 1.

Major ion concentrations in milligrams per liter and ion percentages, based on milliequivalents per liter, are listed for each site in Table 3. Ionic concentrations in milliequivalents per liter and trilinear diagram coordinates are shown in Appendix A. Plotting these coordinates on a trilinear diagram shows that ionic composition was generally similar between sites (fig. 2). All sites had mixed-type waters because no cation or anion exceeds 50 percent of the total ionic composition. The only exception was site 3 which had calcium as the predominant cation. Although sites 1, 2, and 4 have similar cation percentages, anion percentages varied somewhat among sites. Chloride percentages were higher at sites 1 and 2 than at sites 3 and 4. Overall ionic composition was most similar between site 2 and 4, the two mainstem Makushin Valley River sites, and most dissimilar between sites 1 and 3, the two tributaries (fig. 2).

Table 3. Inorganic constituents and field variables at water-quality sites, Makushin Valley, July 14-17, 1986. Concentrations are in milligrams per liter (mg/L). Percent composition (%) is based on concentrations in milliequivalents per liter.

	SITE							
	1		2		3		4	
	JUL 14, 1986		JUL 14, 1986		JUL 16, 1986		JUL 17, 1986	
Constituent	mg/L	%	mg/L	%	mg/L	%	mg/L	%
Silica (SiO_2)	11.4		5.7		5.6		8.5	
Calcium (Ca)	3.53	37	3.51	43	6.60	61	5.90	50
Magnesium (Mg)	1.22	21	.93	19	.90	14	1.24	17
Sodium (Na)	4.53	42	3.50	38	3.12	25	4.39	33
Potassium (K)	N.D.[a]	-	N.D.[a]	-	N.D.[a]	-	N.D.[a]	-
Bicarbonate (HCO_3)	7.00	21	8.00	29	16.00	40	13.00	32
Sulfate (SO_4)	10.00	38	6.00	28	11.00	35	11.00	34
Chloride (Cl)	8.00	41	7.00	43	6.00	25	8.00	34
Fluoride (F)	.08	<1	.05	<1	.05	<1	.07	<1
Total suspended solids	18.8		99.6		19.2		37.1	
Dissolved solids:								
measured	38.00		28.00		30.00		48.00	
calculated	42.39		30.74		41.14		45.63	

	1	2	3	4
Field Variable	JUL 14 1986	JUL 14 1986	JUL 16 1986	JUL 17 1986
Time (hrs)	0935	1335	1300	0915
Streamflow (cubic feet per second)	59.7	194[b]	162	800[c]
Specific conductance (micromhos @ 25°C)	56	48	64	70
pH	6.35	5.40	6.50	6.55
Water temperature (°C)	4.2	4.5	4.4	4.2
Alkalinity (mg/L as $CaCO_3$)	6.2	7.5	13.7	12.9
Dissolved oxygen (mg/L)	14.1	13.2	14.4	14.5
Dissolved oxygen (percent saturation)	>100	>100	>100	>100
Turbidity (NTU)	3.2	17	3.7	7.5

[a] N.D. - not detected.
[b] Streamflow was measured 7-16-86, 1100 hrs.
[c] Estimate only, stream unwadable.

Almost all dissolved trace metal and minor element concentrations were below detection limits at the four sites (Appendix A). The only detected element was strontium at sites 3 and 4 where concentrations were 0.02 and 0.03 mg/l, respectively. Dissolved arsenic concentrations were less than 5 ug/l and bromide less than 0.2 mg/l at all four sites (Appendix A).

Baseline Water-quality in Upper Makushin Valley

In order to determine impacts of geothermal fluid on water quality in upper Makushin Valley River, it is necessary to determine baseline water-quality conditions in the upper river. Table 4 shows selected water-quality variables at sites in upper Makushin Valley. The location of these sites is shown on Plate I-1. The majority of the data were collected during the summer and autumn. The only low flow measurements were made at site BC during May. The data show that sites in upper Makushin Valley have relatively low specific conductances, low total dissolved-solids concentrations and low chloride concentrations during the summer. Concentrations do not vary significantly among sites. Specific conductance ranged from 43 to 72 umhos/cm among the sites during the summer. Total dissolved solid concentrations ranged from 9 to 52 mg/l and chloride concentrations ranged from 2.2 to 8.0 mg/l during the summer. The higher specific conductance and solute concentrations at site BC in May under low flow conditions suggests that solute concentrations at the other sites during the winter are considerably higher as well.

Table 4. Selected baseline water-quality data at specific sites in upper Makushin Valley.

Site [a]	Date	Discharge (cfs)	Specific conductance, (umhos/cm at 25°C)	Total dissolved solids (mg/L)	Chloride (mg/L)
Site 1	07-15-86	60	56	38	8.0
Site 2	07-15-86	194	48	28	7.0
MVB'	07-02-84	97	43	9	3.9
MVA	09-02-83	100	70	50	2.6
MVB	08-30-83	120	46	52	2.3
FCM	09-03-83	39	66	-	6.2
BC	09-02-82	65	72	34	2.2
BC	05-19-82	7.9	228	140	16.5

[a] Site location is shown on Plate I-1. Site 1 and site 2 are from the present study, site MVB' is from Peterson (1984), site MVA, MVB, and FCM are from Peterson and Nichols (1983), and site BC is from Dames and Moore (1983).

CONCLUSIONS AND RECOMMENDATIONS

The water quality at Makushin Valley River sites and two tributary sites was characterized by low temperatures, high dissolved oxygen concentrations, low dissolved ion and trace element concentrations, and variable suspended sediment concentrations. The main effect on water quality during the summer is snowmelt and precipitation which increase streamflow and dilute concentrations of dissolved ions and trace elements in the streams.

Although stream characteristics are now fairly well-defined during the summer, little water-quality data have been collected during the winter. The impact of geothermal fluid on stream water quality will be greatest during the winter because there will be less dilution by snowmelt and precipitation. Data on total dissolved solids, major ions, and trace elements should be collected to determine baseline water quality during the winter in upper Makushin Valley River. It is recommended that winter sampling be conducted at site 1 and site 2 because the sites are equipped with continuously recording streamflow equipment and they are below potential geothermal fluid discharge points. This will make it possible to relate water-quality variables to streamflow, particularly winter baseflow when it would otherwise be difficult to obtain a stream discharge measurement.

Once winter streamflow and water-quality characteristics are defined in the upper watershed, it will be possible to model dilution of geothermal fluid in Makushin Valley River. Although geothermal fluid discharge from a test well, monitored by Peterson and Nichols (1983) and Peterson (1984), showed that water-quality variables in Makushin Valley River met state water-quality criteria for the protection of freshwater aquatic life, tests were conducted in the summer during relatively high streamflow in Makushin Valley River. No tests of geothermal fluid dilution have been conducted during low streamflow periods. Therefore, it is recommended that dilution models be used to estimate water-quality variables as the result of discharging geothermal fluid into Makushin Valley River and Fox Canyon Creek during various streamflow conditions. Prior to the use of a dilution model the following must be determined: (1) the projected flow rate (in cubic feet per second) from the production well of the power facility, and (2) the stream site where regulatory agencies determine water-quality criteria are to be met during operation of the power facility. The dilution models can also be used by design engineers because the models will estimate the various volumes of geothermal fluid that can be discharged throughout the year and the volume which may require storage on-site.

If regulatory agencies choose a different stream site (rather than site 1 and 2) where water-quality criteria are to be applied, it will be necessary to obtain additional seasonal baseline streamflow and water-quality data at that site. This information could then be used in a dilution model to estimate water-quality variables at that site. It is recommended that a long-term monitoring site be established at that location to determine water-quality characteristics in Makushin Valley River during the operation of the power facility.

REFERENCES CITED

American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1980, Standard methods for examination of water and wastes (15th ed.): Washington, D.C., American Public Health Association, 1134 pp.

Dames and Moore, 1983, 1982 Environmental baseline data collection program final report: Prepared for Republic Geothermal, Inc. and Alaska Power Authority by Dames and Moore, Anchorage, Alaska, 55 pp. and appendices.

Peterson, L.A., 1984, Unalaska geothermal exploration project water quality and flow during test of geothermal well Makushin ST-1; July 5 to August 8, 1984, final report: Prepared for Dames and Moore and Republic Geothermal, Inc., by L.A. Peterson and Associates, Inc., Fairbanks, Alaska, 23 pp. and appendices.

Peterson, L.A., and Nichols, Gary, 1983, Unalaska geothermal project water quality and flow during geothermal well test: Prepared for Dames and Moore and Republic Geothermal, Inc., by L.A. Peterson and Associates, Inc., Fairbanks, Alaska, 23 pp. and appendices.

U.S. Environmental Protection Agency, 1983, Methods for chemical analysis of water and wastes: U.S. Environmental Protection Agency EPA-600/4-79-020.

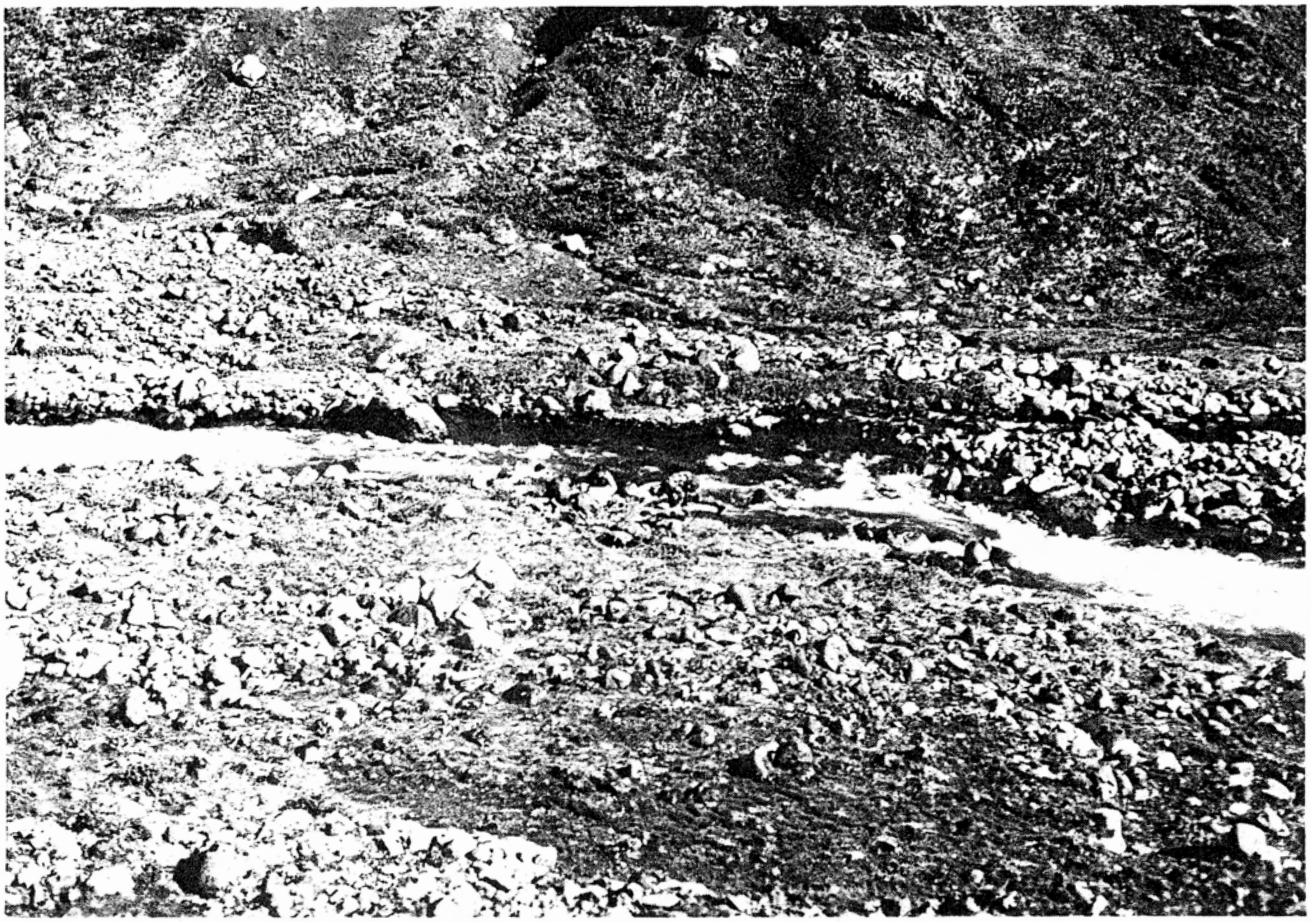
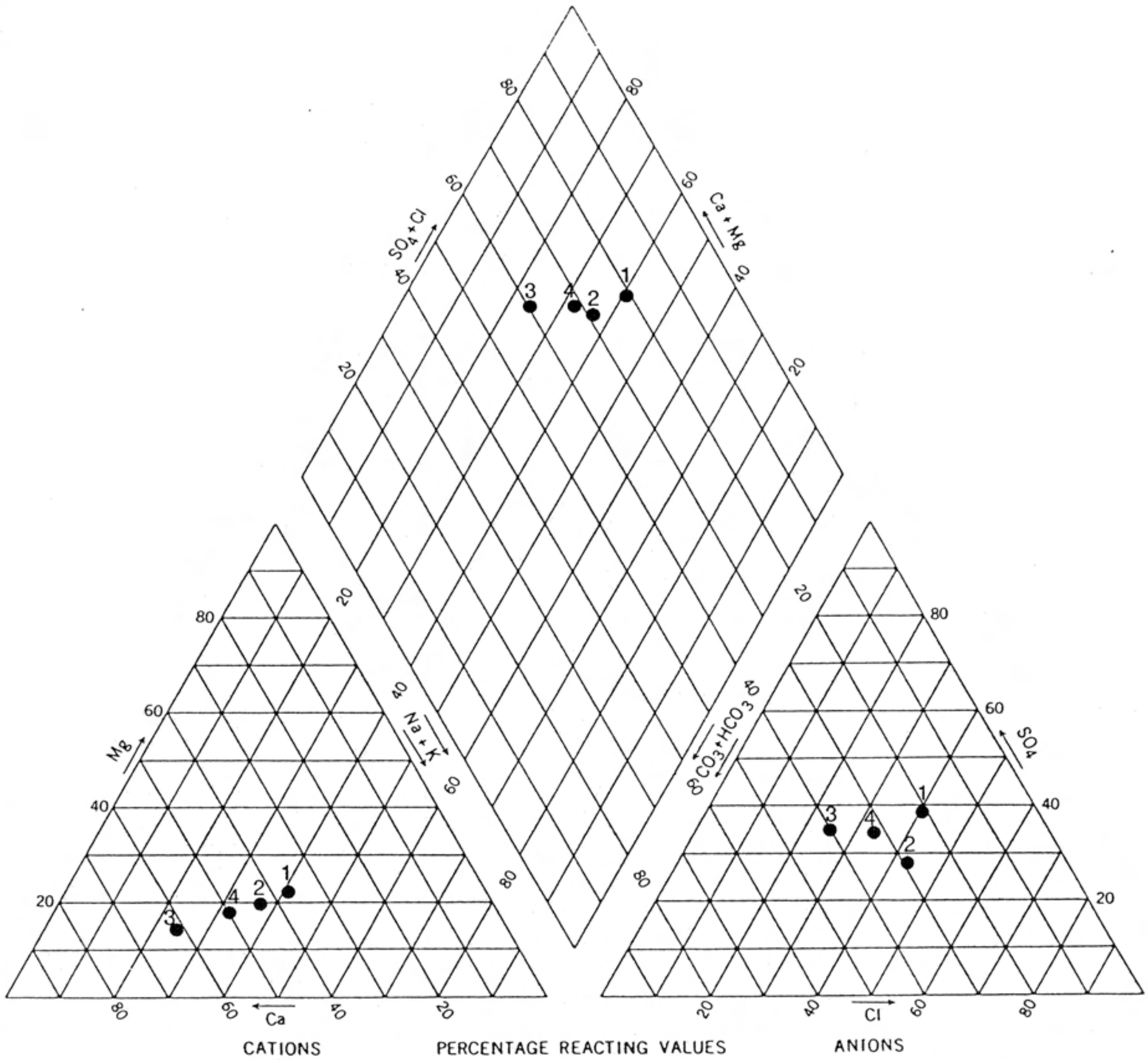


Figure 1a. Fox Canyon Creek (Site 1) at gage site near confluence with the upper Makushin Valley River, July 1986.

Figure 1b. Lower Makushin Valley River near mile 4.2, looking upstream, July 1986.



<u>Site Location</u>

Site 1 Makushin Valley River, above Fox Canyon Creek
Site 2 Fox Canyon Creek
Site 3 Avalanche Creek
Site 4 Makushin Valley River, near mouth

Figure 2. Trilinear diagram showing percentage of cation and anion compositions of streams in Makushin Valley, July 14 - 17, 1986. Number above circle indicates site number.

APPENDIX A

Laboratory water quality analyses of streams in Makushin Valley. These laboratory analyses were done by the University of Utah Research Institute, Salt Lake City, Utah.

UNIVERSITY OF UTAH RESEARCH INSTITUTE

UURI

EARTH SCIENCE LABORATORY
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108—1295
TELEPHONE 801-524-3422

July 29, 1986

State of Alaska
Department of Natural Resources
Division of Geological & Geophysical Surveys
P.O. Box 772116
Eagle River, Alaska 99577

Attention: Mary A. Maurer

REPORT

Sample	ppm Br	ppb As	ppm SiO_2
Pond 1	< 0.2	< 5	10.0
Pond 2	< 0.2	< 5	30.4
Pond 3	< 0.2	< 5	25.7
Pond 4	< 0.2	< 5	28.5
Pond 5	< 0.2	< 5	9.9
Site 1	< 0.2	< 5	11.4
Site 2	< 0.2	< 5	5.7
Site 3	< 0.2	< 5	5.6
Site 4	< 0.2	< 5	8.5

Ruth L. Kroneman

Ruth L. Kroneman
Chemist

RLK/cd

****

ALASKA
SITE 1

ID #: A:SITE1
DATE: 07-28-86

****

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)	CONCENTRATION (MOL/L)
Na	4.53	1	.61	.197E-03
K	N.D.	1	1.22	< .197E-04
Ca	3.53	1	.24	.881E-04
Mg	1.22	1	.49	.502E-04
Fe	N.D.	1	.02	< .000E+00
Al	N.D.	1	.61	< .371E-06
SiO2	11.59	1	.52	.193E-03
B	N.D.	1	.12	< .000E+00
Li	N.D.	1	.05	< .144E-05
Sr	N.D.	1	.01	< .114E-06
Zn	N.D.	1	.12	< .153E-06
Ag	N.D.	1	.05	< .927E-07
As	N.D.	1	.61	< .320E-05
Au	N.D.	1	.10	< .508E-07
Ba	N.D.	1	.61	< .655E-06
Be	N.D.	1	.00	< .000E+00
Bi	N.D.	1	2.44	< .579E-05
Cd	N.D.	1	.06	< .000E+00
Ce	N.D.	1	.24	< .285E-06
Co	N.D.	1	.02	< .000E+00
Cr	N.D.	1	.05	< .000E+00
Cu	N.D.	1	.06	< .157E-06
La	N.D.	1	.12	< .144E-06
Mn	N.D.	1	.24	< .000E+00
Mo	N.D.	1	1.22	< .834E-06
Ni	N.D.	1	.12	< .170E-06
Pb	N.D.	1	.24	< .000E+00
Sn	N.D.	1	.12	< .000E+00
Sb	N.D.	1	.73	< .000E+00
Te	N.D.	1	1.22	< .000E+00
Th	N.D.	1	2.44	< .388E-06
Ti	N.D.	1	.12	< .418E-06
U	N.D.	1	6.10	< .000E+00
V	N.D.	1	1.22	< .353E-05
W	N.D.	1	.12	< .326E-06
Zr	N.D.	1	.12	< .000E+00

ALASKA
SITE 1

ID #: A:SITE1
DATE: 07-28-86

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)	CONCENTRATION (MOL/L)
TOTAL ALKALINITY AS				
HCO3	7.00	2	1.00	.115E-03
CO3	N.D.	2	1.00	< .000E+00
Cl	8.00	2	1.00	.226E-03
F	.08	5	.05	.421E-05
SO4	10.00	4	1.00	.104E-03
Br	N.A.	2	1.00	< .000E+00
I	N.A.	2	.10	< .000E+00
NO3	N.A.	9	.10	< .000E+00
S	N.A.	2	1.00	< .000E+00
PO4	N.D.	1	1.84	< .000E+00

TOTAL DISSOLVED SOLIDS

MEASURED	38.00	4	4.00
CALCULATED	42.39	6	
100*MEAS/CALC	89.64		
pH	7.02	7	

****

ANALYTICAL METHODS:

1. INDUCTIVELY COUPLED PLASMA SPECTROMETER
2. TITRATION (LABORATORY)
3. TITRATION (FIELD)
4. GRAVIMETRIC
5. SPECIFIC ION ELECTRODE
6. METHOD OF HEM (1970, USGS Water Supply Paper 1473)
7. pH METER (LABORATORY)
8. pH METER (FIELD)
9. COLORIMETRIC
10. ATOMIC ABSORPTION
11. TURBIDIMETRIC

N.D. - NOT DETECTED
N.A. - NOT ANALYZED

****

ALASKA
SITE 1

ID #: A:SITE1
DATE: 07-28-86

	Milliequivalents/Liter
CATIONS	
Na	.19705
Ca	.17615
Mg	.10036
SUM OF CATIONS:	.47356
ANIONS	
HCO3	.11473
Cl	.22568
F	.00421
SO4	.20820
SUM OF ANIONS:	.55282
CATION-ANION BALANCE	-.07926
BALANCE DIFF. CATION + ANION	-7.72

****

TRILINEAR DIAGRAM COORDINATES

ALASKA
SITE 1

ID #: A:SITE1
DATE: 07-28-86

****

	Meq / L	Percent (Meq / L)
CATIONS		
Na	.19705	41.61148
K	.00000	.00000
Ca	.17615	37.19640
Mg	.10036	21.19211
TOTAL	.47356	100.00000
ANIONS		
HCO3	.11473	20.91285
CO3	.00000	.00000
SO4	.20820	37.95046
Cl	.22568	41.13669
TOTAL	.54861	100.00000

****

ALASKA
SITE 2

ID #: A:SITE2
DATE: 07-28-86

****

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)		CONCENTRATION (MOL/L)
Na	3.50	1	.61		.152E-03
K	N.D.	1	1.22	<	.156E-04
Ca	3.51	1	.24		.876E-04
Mg	.93	1	.49		.383E-04
Fe	N.D.	1	.02	<	.000E+00
Al	N.D.	1	.61	<	.000E+00
SiO2	5.82	1	.52		.969E-04
B	N.D.	1	.12	<	.000E+00
Li	N.D.	1	.05	<	.144E-05
Sr	N.D.	1	.01	<	.114E-06
Zn	N.D.	1	.12	<	.153E-06
Ag	N.D.	1	.05	<	.927E-07
As	N.D.	1	.61	<	.347E-05
Au	N.D.	1	.10	<	.508E-07
Ba	N.D.	1	.61	<	.583E-06
Be	N.D.	1	.00	<	.000E+00
Bi	N.D.	1	2.44	<	.110E-05
Cd	N.D.	1	.06	<	.000E+00
Ce	N.D.	1	.24	<	.500E-06
Co	N.D.	1	.02	<	.000E+00
Cr	N.D.	1	.05	<	.000E+00
Cu	N.D.	1	.06	<	.000E+00
La	N.D.	1	.12	<	.144E-06
Mn	N.D.	1	.24	<	.182E-06
Mo	N.D.	1	1.22	<	.730E-06
Ni	N.D.	1	.12	<	.000E+00
Pb	N.D.	1	.24	<	.000E+00
Sn	N.D.	1	.12	<	.000E+00
Sb	N.D.	1	.73	<	.000E+00
Te	N.D.	1	1.22	<	.000E+00
Th	N.D.	1	2.44	<	.733E-06
Ti	N.D.	1	.12	<	.209E-06
U	N.D.	1	6.10	<	.000E+00
V	N.D.	1	1.22	<	.294E-05
W	N.D.	1	.12	<	.435E-06
Zr	N.D.	1	.12	<	.000E+00

ALASKA
SITE 2

ID #: A:SITE2
DATE: 07-28-86

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)		CONCENTRATION (MOL/L)
TOTAL ALKALINITY AS					
HCO3	8.00	2	1.00		.131E-03
CO3	N.D.	2	1.00	<	.000E+00
Cl	7.00	2	1.00		.197E-03
F	.05	5	.05		.263E-05
SO4	6.00	4	1.00		.625E-04
Br	N.A.	2	1.00	<	.000E+00
I	N.A.	2	.10	<	.000E+00
NO3	N.A.	9	.10	<	.000E+00
S	N.A.	2	1.00	<	.000E+00
PO4	N.D.	1	1.84	<	.000E+00
TOTAL DISSOLVED SOLIDS					
MEASURED	28.00	4	4.00		
CALCULATED	30.74	6			
100*MEAS/CALC	91.08				
pH	7.08	7			

****

ANALYTICAL METHODS:

1. INDUCTIVELY COUPLED PLASMA SPECTROMETER
2. TITRATION (LABORATORY)
3. TITRATION (FIELD)
4. GRAVIMETRIC
5. SPECIFIC ION ELECTRODE
6. METHOD OF HEM (1970, USGS Water Supply Paper 1473)
7. pH METER (LABORATORY)
8. pH METER (FIELD)
9. COLORIMETRIC
10. ATOMIC ABSORPTION
11. TURBIDIMETRIC

N.D. - NOT DETECTED
N.A. - NOT ANALYZED

****

ALASKA
SITE 2

ID #: A:SITE2
DATE: 07-28-86

	Milliequivalents/Liter
CATIONS	
Na	.15225
Ca	.17515
Mg	.07650
SUM OF CATIONS:	.40390
ANIONS	
HCO3	.13112
Cl	.19747
F	.00263
SO4	.12492
SUM OF ANIONS:	.45614
CATION-ANION BALANCE	-.05224
BALANCE DIFF. CATION + ANION	-6.07

****

TRILINEAR DIAGRAM COORDINATES

ALASKA
SITE 2

ID #: A:SITE2
DATE: 07-28-86

****

	Meq / L	Percent (Meq / L)
CATIONS		
Na	.15225	37.69490
K	.00000	.00000
Ca	.17515	43.36436
Mg	.07650	18.94074
TOTAL	.40390	100.00000
ANIONS		
HCO3	.13112	28.91226
CO3	.00000	.00000
SO4	.12492	27.54515
Cl	.19747	43.54259
TOTAL	.45351	100.00000

****

[illegible]ASKA
SITE 3

ID #: A:SITE3
DATE: 07-28-86

****

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)	CONCENTRATION (MOL/L)
Na	3.12	1	.61	.136E-03
K	N.D.	1	1.22	< .130E-04
Ca	6.60	1	.24	.165E-03
Mg	.90	1	.49	.370E-04
Fe	N.D.	1	.02	< .000E+00
Al	N.D.	1	.61	< .000E+00
SiO2	5.57	1	.52	.927E-04
B	N.D.	1	.12	< .000E+00
Li	N.D.	1	.05	< .144E-05
Sr	.03	1	.01	.342E-06
Zn	N.D.	1	.12	< .153E-06
Ag	N.D.	1	.05	< .927E-07
As	N.D.	1	.61	< .467E-05
A[illegible]	N.D.	1	.10	< .508E-07
B[illegible]	N.D.	1	.61	< .102E-05
Be	N.D.	1	.00	< .000E+00
Bi	N.D.	1	2.44	< .000E+00
Cd	N.D.	1	.06	< .890E-07
Ce	N.D.	1	.24	< .500E-06
Co	N.D.	1	.02	< .170E-06
Cr	N.D.	1	.05	< .000E+00
Cu	N.D.	1	.06	< .000E+00
La	N.D.	1	.12	< .144E-06
Mn	N.D.	1	.24	< .000E+00
Mo	N.D.	1	1.22	< .104E-05
Ni	N.D.	1	.12	< .341E-06
Pb	N.D.	1	.24	< .000E+00
Sn	N.D.	1	.12	< .000E+00
Sb	N.D.	1	.73	< .986E-06
Te	N.D.	1	1.22	< .149E-05
Th	N.D.	1	2.44	< .474E-06
Ti	N.D.	1	.12	< .000E+00
U	N.D.	1	6.10	< .160E-05
V	N.D.	1	1.22	< .491E-05
W	N.D.	1	.12	< .000E+00
Zr	N.D.	1	.12	< .000E+00

ALASKA
SITE 3

ID #: A:SITE3
DATE: 07-28-86

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)	CONCENTRATION (MOL/L)
TOTAL ALKALINITY AS				
HCO3	16.00	2	1.00	.262E-03
CO3	N.D.	2	1.00	< .000E+00
Cl	6.00	2	1.00	.169E-03
F	.05	5	.05	.263E-05
SO4	11.00	4	1.00	.115E-03
Br	N.A.	2	1.00	< .000E+00
I	N.A.	2	.10	< .000E+00
NO3	N.A.	9	.10	< .000E+00
S	N.A.	2	1.00	< .000E+00
PO4	N.D.	1	1.84	< .000E+00
TOTAL DISSOLVED SOLIDS				
MEASURED	30.00	4	4.00	
CALCULATED	41.14	6		
100*MEAS/CALC	72.93			
pH	7.15	7		

****

ANALYTICAL METHODS:

1. INDUCTIVELY COUPLED PLASMA SPECTROMETER
2. TITRATION (LABORATORY)
3. TITRATION (FIELD)
4. GRAVIMETRIC
5. SPECIFIC ION ELECTRODE
6. METHOD OF HEM (1970, USGS Water Supply Paper 1473)
7. pH METER (LABORATORY)
8. pH METER (FIELD)
9. COLORIMETRIC
10. ATOMIC ABSORPTION
11. TURBIDIMETRIC

N.D. - NOT DETECTED
N.A. - NOT ANALYZED

****

ALASKA
SITE 3

ID #: A:SITE3
DATE: 07-28-86

	Milliequivalents/Liter
CATIONS	
Na	.13572
Ca	.32934
Mg	.07403
Sr	.00068
SUM OF CATIONS:	.53978
ANIONS	
HCO3	.26224
Cl	.16926
F	.00263
SO4	.22902
SUM OF ANIONS:	.66315
CATION-ANION BALANCE	-.12337
BALANCE DIFF. CATION + ANION	-10.26

****

TRILINEAR DIAGRAM COORDINATES

ALASKA
SITE 3

ID #: A:SITE3
DATE: 07-28-86

****

	Meq / L	Percent (Meq / L)
CATIONS		
Na	.13572	25.17557
K	.00000	.00000
Ca	.32934	61.09138
Mg	.07403	13.73304
TOTAL	.53909	99.99999
ANIONS		
HCO3	.26224	39.70205
CO3	.00000	.00000
SO4	.22902	34.67268
Cl	.16926	25.62527
TOTAL	.66052	100.00000

****

ASKA
SITE 4

ID #: A:SITE4
DATE: 07-28-86

****

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)	CONCENTRATION (MOL/L)
Na	4.39	1	.61	.191E-03
K	N.D.	1	1.22	< .179E-04
Ca	5.90	1	.24	.147E-03
Mg	1.24	1	.49	.510E-04
Fe	N.D.	1	.02	< .000E+00
Al	N.D.	1	.61	< .148E-05
SiO2	8.62	1	.52	.143E-03
B	N.D.	1	.12	< .000E+00
Li	N.D.	1	.05	< .144E-05
Sr	.02	1	.01	.228E-06
Zn	N.D.	1	.12	< .153E-06
Ag	N.D.	1	.05	< .185E-06
As	N.D.	1	.61	< .427E-05
Au	N.D.	1	.10	< .508E-07
B	N.D.	1	.61	< .655E-06
Be	N.D.	1	.00	< .000E+00
Bi	N.D.	1	2.44	< .536E-05
Cd	N.D.	1	.06	< .000E+00
Ce	N.D.	1	.24	< .500E-06
Co	N.D.	1	.02	< .170E-06
Cr	N.D.	1	.05	< .000E+00
Cu	N.D.	1	.06	< .157E-06
La	N.D.	1	.12	< .216E-06
Mn	N.D.	1	.24	< .000E+00
Mo	N.D.	1	1.22	< .104E-05
Ni	N.D.	1	.12	< .170E-06
Pb	N.D.	1	.24	< .000E+00
Sn	N.D.	1	.12	< .000E+00
Sb	N.D.	1	.73	< .107E-05
Te	N.D.	1	1.22	< .000E+00
Th	N.D.	1	2.44	< .388E-06
Ti	N.D.	1	.12	< .209E-06
U	N.D.	1	6.10	< .420E-07
V	N.D.	1	1.22	< .550E-05
W	N.D.	1	.12	< .490E-06
Zr	N.D.	1	.12	< .000E+00

ALASKA
SITE 4

ID #: A:SITE4
DATE: 07-28-86

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)	CONCENTRATION (MOL/L)
TOTAL ALKALINITY AS				
HCO3	13.00	2	1.00	.213E-03
CO3	N.D.	2	1.00	< .000E+00
Cl	8.00	2	1.00	.226E-03
F	.07	5	.05	.368E-05
SO4	11.00	4	1.00	.115E-03
Br	N.A.	2	1.00	< .000E+00
I	N.A.	2	.10	< .000E+00
NO3	N.A.	9	.10	< .000E+00
S	N.A.	2	1.00	< .000E+00
PO4	N.D.	1	1.84	< .000E+00
TOTAL DISSOLVED SOLIDS				
MEASURED	48.00	4	4.00	
CALCULATED	45.63	6		
100*MEAS/CALC	105.19			
pH	7.14	7		

****

ANALYTICAL METHODS:

1. INDUCTIVELY COUPLED PLASMA SPECTROMETER
2. TITRATION (LABORATORY)
3. TITRATION (FIELD)
4. GRAVIMETRIC
5. SPECIFIC ION ELECTRODE
6. METHOD OF HEM (1970, USGS Water Supply Paper 1473)
7. pH METER (LABORATORY)
8. pH METER (FIELD)
9. COLORIMETRIC
10. ATOMIC ABSORPTION
11. TURBIDIMETRIC

N.D. - NOT DETECTED
N.A. - NOT ANALYZED

****

ALASKA
SITE 4

ID #: A:SITE4
DATE: 07-28-86

	Milliequivalents/Liter
CATIONS	
Na	.19096
Ca	.29441
Mg	.10200
Sr	.00046
SUM OF CATIONS:	.58783
ANIONS	
HCO3	.21307
Cl	.22568
F	.00368
SO4	.22902
SUM OF ANIONS:	.67145
CATION-ANION BALANCE	-.08362
BALANCE DIFF. CATION + ANION	-6.64

****

TRILINEAR DIAGRAM COORDINATES

ALASKA
SITE 4

ID #: A:SITE4
DATE: 07-28-86

****

	Meq / L	Percent (Meq / L)
CATIONS		
Na	.19096	32.51146
K	.00000	.00000
Ca	.29441	50.12280
Mg	.10200	17.36573
TOTAL	.58738	100.00000
ANIONS		
HCO3	.21307	31.90769
CO3	.00000	.00000
SO4	.22902	34.29624
Cl	.22568	33.79607
TOTAL	.66777	100.00000

SPRINGWATER GEOTHERMAL RESOURCE ASSESSMENT OF THE MAKUSHIN (BROAD BAY) VALLEY

by John W. Reeder

SCOPE OF WORK

The Alaska Power Authority in cooperation with the Aleut Corporation and the Ounalaskha Corporation is presently pursuing a geothermal feasibility study, which addresses the potential for electrical power generation from the Makushin Volcano geothermal resource for the Unalaska/Dutch Harbor community. Interest has also been expressed from the local community in developing known geothermal resources at Summer Bay (Reeder, 1981) for recreational uses as well as possibly piping waste geothermal fluids to Broad Bay from the APA proposed power site. Such piped fluids could be used for direct utilization purposes such as agricultural greenhousing and aquacultural developments. Considering the importance of the local fishing industry as well as the fact that all fresh vegetable produce are transported from the lower 48 States, the basis of this concept is very justified. The economics might be another issue.

During the author's visit to Unalaska Island in the summer of 1980, it was reported by Henry Swanson (local long-time resident of Unalaska) that springs exist in the Makushin Valley that never freeze in the winter time. During the summer of 1980, the author conducted a quick investigation of the numerous springs in the valley and found no anomalous temperatures.

During an aerial reconnaissance of the Makushin Volcano region by the author in February of 1982, ponds devoid of ice and snow were found to exist along the northeastern and southern edges of the Makushin (Broad Bay) Valley (Reeder, 1982). At that time, the unfrozen ponds were interpreted as being due to just groundwater springs.

Preliminary estimates by the Alaska Power Authority indicate that it would be uneconomical to pipe geothermal fluids to Broad Bay for direct utilization from their proposed geothermal power site. The author was then asked to make an assessment of the geothermal resource potential of the Makushin (Broad Bay) Valley by chemical and physical property determinations of existing springs. The field examinations and water sampling were undertaken by Mary Maurer and by the author on the 15 and 16 July 1986. This report represents the results of this investigation.

METHODOLOGY

Aerial examinations of the Makushin (Broad Bay) Valley and of the Wide Bay valley were undertaken between 13 and 16 July 1986. The purpose of such examinations were to identify the distribution of groundwater and possible geothermal springs and ponds in these valleys. Five spring-fed ponds were selected in the Makushin Valley for direct examinations and for water sampling. This selection was such that a good regional distribution of springs would be sampled. This selection also included springs that appeared anomalous in appearance with respect to surrounding vegetation and with respect to their corresponding well defined deep pools and colorful mineral precipitates.

Water sampling procedures, which followed those described by Presser and Barnes (1974), were taken by Mary Maurer and author at about a two foot depth just off the edge of each of the selected water-sampling ponds. These samples were immediately filtered in the field, and the dissolved trace-metal sample for each site was then acidified with nitric acid. Water temperature, pH, alkalinity, and conductivity were also determined at every water-sampling site.

Major ion and dissolved trace-metal analyses were conducted on the samples by the University of Utah Research Institute in Salt Lake City, Utah. The samples were analyzed to the procedures and standards of the U. S. Environmental Protection Agency (1983). Most of the trace elements were analyzed on a ICP (inductively coupled plasma spectrometer), although other laboratory techniques were also used (See Appendix A).

RESULTS OF INVESTIGATION

Numerous groundwater spring-fed ponds are located along the northern and southern bottom edges of the Makushin (Broad Bay) Valley; all of the way from Broad Bay up to the Makushin Valley canyon just below Sugarloaf Cone. A few of these spring-fed ponds also occur on the main proper of the valley floor. All were found to have temperatures ranging between 5 to 15 °C. No ponds were found to exist in the Wide Bay valley, although cold (7°C) groundwater seeps were observed.

Five spring-fed ponds were selected for geochemical and physical properties investigations. These ponds are located:

(1) Pond site 1 at the southcentral edge of the valley;
(2) Pond site 2 at the northcentral edge of the valley;
(3) Pond site 3 at the southwest edge of the valley;
(4) Pond site 4 at the northwest edge of the valley; and
(5) Pond site 5 at the northeast edge of the valley.

The exact locations for these ponds are shown on Plate H-2 of the ground stability section.

These ponds ranged from just 7 to 8 foot deep 2.5 foot diameter features, as observed in the pond 1 region, up to 25 foot deep 150 foot diameter features, as observed in the pond 5 region. Usually several ponds would occur in close proximity, being fed by springs at their bottoms. On the edge of the Makushin Valley floor, several ponds were actually part of landslide depressions and were being feed by groundwater springs just upslope, as observed at ponds 2, 4, and 5. In these cases, either bedrock or tills were exposed at the site of the spring. Spring flows or upwelling appeared to be normally less than a liter per minute for individual springs. Any gas discharge, which is common for warm or hot springs, was absent in all Makushin Valley springs. Figure 1 is a view of pond 1, which is fed by three major groundwater springs at deep depressions in the pond. Figure 2 is a view of pond 4, which is fed by small springs from the hill to the right as well as by springs from the bottom of the pond.

The chemical composition and physical properties of the groundwater spring-fed ponds are given in Table 1. The specific conductances were found to be of medium values, ranging between 127 micromhos near the bay side of the valley to 500 micromhos near the head of the valley near the canyon. Temperatures increased from 5.8°C near the bay side to 15.0°C near the head of the valley. Dissolved solids increased from 76 mg/L near the bay side to 309 mg/L near the head of the valley. The pH also went from a slightly acid 6.7 pH water near the Bay to an acid 4.8 pH water near the head of the valley. In contrast, alkalinity decreased from 47 mg/L $CaCO_3$ near the bay of the valley down to 7 mg/L $CaCO_3$ near the head of the valley.

Table 1. Chemical composition and physical properties of groundwater springs in the Makushin (Broad Bay) Valley, Unalaska Island. Constituent concentrations are in milligrams per liter (mg/L). See Plate H-2 for pond locations.

Constituent	Pond 1	Pond 2	Pond 3	Pond 4	Pond 5
SiO_2	10.54	31.03	25.97	28.74	9.77
Al	N.D.	N.D.	N.D.	N.D.	N.D.
Fe	N.D.	N.D.	N.D.	N.D.	N.D.
Ca	23.39	14.49	61.81	48.47	15.70
Mg	1.99	3.54	4.81	4.71	1.70
Na	7.16	9.58	8.10	9.21	6.40
K	N.D.	N.D.	N.D.	N.D.	N.D.
Li	N.D.	N.D.	N.D.	N.D.	N.D.
HCO_3	58.00	15.00	2.00	7.00	52.00
SO_4	21.00	47.00	188.00	147.00	7.00
Cl	14.00	16.50	13.00	11.00	11.00
F	0.06	0.26	0.15	0.15	0.07
Br	<0.2	<0.2	<0.2	<0.2	<0.2
B	N.D.	N.D.	N.D.	N.D.	N.D.
H_2S	N.A.	N.A.	N.A.	N.A	N.A.
Sr	0.12	0.08	0.28	0.20	0.05
Temp. (°C)	8.5	8.5	15.0	13.0	5.8
pH, field	6.35	6.75	4.85	6.25	6.6
Dissolved solids:					
measured	108.00	124.00	309.00	262.00	76.00
calculated	106.78	129.86	303.10	252.92	77.26
Alkalinity: (mg/L $CaCO_3$)	49.9	16.0	7.3	12.0	47.1
Specific conductance (micromhos at 25°C)	228	204	500	401	127
Sample date	07/15/86	07/15/86	07/15/86	07/15/86	07/16/86

N.D. - not detected
N.A. - not analyzed

The concentration of major ions are about average for groundwaters, are low to comparable with respect to hotspring waters observed in the upper reaches of the Makushin Valley (Motyka and others, 1983), are high with respect to an observed coldwater spring in the upper reach of the Makushin Valley (Motyka and others, 1983), and high with respect to Makushin Valley surface waters (Dames and Moore, 1983; and the water quality section for surface water of this report). One major exception is that the Cl content of the ponds ranges between 200% to 300% of the Cl content of the hot springs in the upper reaches of the valley. For the "near the bay" ponds 1 and 5, the Si content is only about 5 to 10 per cent of what was found for the hot springs in the upper valley reaches. For the "head of the valley" ponds 3 and 4, the SO_4, Ca, and total dissolved solid contents are approximately the same as that found for the hot springs at the upper reaches of the valley, but the alkalinity is only about 2 per cent.

The percentages of cation and anion contents of the Makushin Valley pond waters are plotted on trilinear diagrams in Figure 3. These diagram plots are based on percentages of milliequivalents per liter, which are listed in Appendix A. These diagrams show that pronounced differences in ionic composition percentages exist between the waters of the ponds and that three groups of similar ionic composition percentages can be made: (1) ponds 1 and 5, (2) pond 2, and (3) ponds 3 and 4. These three groups reflect the bay region, the mid-valley region, and the head region, respectively, of the Makushin (Broad Bay) Valley. It is likely that these three groupings reflect distinct groundwater systems.

The hot springs found in the upper reaches of the Makushin Valley originated as local meteoric waters, as argued by Motyka and others (1983) because of the chemical characteristics of the fluids. These meteoric waters would have experienced rapid shallow circulation in fractured bedrock and would have been heated by rising steam and gases from a hotwater reservoir at depth. This hotwater reservoir has now been tapped by a State of Alaska APA exploratory well (Republic Geothermal, Inc. 1984). The size of this water-dominated reservoir is at least 0.7 cubic miles of equivalent fluid and it is directly related to the Makushin Volcano caldera complex (Reeder and others, 1985). These fluids were found to be very sodium and chloride rich at a temperature of about 192°C. These fluids consist of about 94 per cent Na + K with respect to Ca + Mg + Na + K, and of about 97 per cent Cl with respect to Cl + SO_4 + HCO_3 (Republic Geothermal, Inc., 1984). The ionic composition percentages plot of such a fluid on a trilinear diagram such as Figure 3 would be radically different from the hotspring plots for the springs investigated by Motyka and others (1983) and radically different from the Makushin Valley pond plots of Figure 3. There appears to be no direct relationship between the main Makushin geothermal reservoir with the Makushin (Broad Bay) Valley spring-fed ponds even though such ponds are high in Cl content compared to the hot springs. A similar but weaker ionic percentages argument can be made between the Motyka and others (1983) Makushin Volcano hotsprings and the Makushin (Broad Bay) Valley springs. This is supported by the lack of any gas discharge at the Makushin (Broad Bay) Valley ponds. Distinct hydrogeologic systems appear to exist.

The bedrock of the northern part of Unalaska Island is highly fractured (Reeder, 1986 and unpublished DGGS maps), and could host numerous groundwater fracture-flow systems. The high silt content of the Makushin (Broad Bay)

Valley subsurface probably would "rule-out" any large groundwater aquifers at least in the eastern part of the valley, which is believed to consist of marsh, lacustrine, salt-water lagoonal, and then till deposits with depth. This model for the eastern part of the valley is based on only two seismic refraction lines and two shallow drill holes, which were conducted as part of this investigation (see transmission line and corridor section). In addition, groundwater spring-fed ponds dominate on the edges of the valley where bedrock with its water filled fractures would exist at shallow depths. Field observations also identified spring-fed flows near some of the ponds as coming from bedrock. It does appear that the Makushin (Broad Bay) Valley springs are fed by groundwater fracture-flow systems, and that no large groundwater aquifer system probably exist within the eastern part of the unconsolidated deposits of the valley.

The slightly higher temperatures of ponds 3 and 4 do appear to be anomalous for groundwater spring-fed ponds. The average yearly air temperature for Unalaska Island is about 5°C with a summer mean of about 11°C and a winter mean of about -1°C (Drewes and others, 1961; and Selkregg, 1977). It is difficult to account for the solar heating effect on a pond, but groundwater springs should reflect the mean temperature of the region. Indeed, the mean temperatures of ponds 1, 2, and 5 are only slightly higher than the 5°C mean temperature. These slightly higher temperatures by up to 3.5°C are probably due to solar heating of the ponds. Yet, ponds 3 and 4 were found to be 10°C and 8°C higher than the mean temperature. This is probably due to deep circulation of their groundwater system(s) into hotter crust.

Results of applying SiO_2 and cation geothermometers to the Makushin (Broad Bay) Valley spring-fed pond waters are given in Table 2. The results for the different geothermometers for each pond are very inconsistent. In

Table 2. Silica and cation geothermometers applied to groundwater spring waters from the Makushin (Broad Bay) Valley. Temperature in °C. See Plate H-2 for pond locations.

	Pond 1	Pond 2	Pond 3	Pond 4	Pond 5
Temperature	8.5	8.5	15.0	13.0	5.8
Quartz conductive (no steam loss)	41	81	74	78	39
Quartz conductive (max. steam loss)	49	84	78	82	47
Chalcedony	8	50	42	46	6
Amorphous silica	-64	-32	-38	-34	-66
Na/K (Fournier)	154	157	179	184	153
Na/K (Truesdell)	112	115	141	147	110
Na-K-Ca (beta=1.33)	-14	0	-16	-9	-12
Cristobalite (alpha)	-7	31	24	28	-9
Cristobalite (beta)	-49	-14	-21	-17	-51

fact, the amorphous silica, Na-K-Ca, and Cristobalite geothermometers actual give temperatures lower than the pond temperature. The Chalcedony geothermometer gives a temperature for ponds 1 and 2 of about their own temperature, but suggest higher reservoir temperatures for the systems feeding ponds 2, 3, and 4. The Quartz conductive and Na/K geothermometers suggest even higher reservoir temperatures.

The geothermometers are of questionable value because of the ambiguities with the origin of the constituents of these waters. For example, secondary quartz and chalcedony are common in the bedrock, and such secondary bedrock minerals would have an effect on any groundwater or geothermal system. In fact, connate Na, Cl, and SO_4 rich waters (ocean water) probably existed in the originally marine metasediments and metavolcanics of the Unalaska Formation, which is exposed throughout the Makushin (Broad Bay) Valley. The dioritic intrusives, which are exposed throughout a good part of the upper reaches of the Makushin (Broad Bay) Valley, introduced sulfide mineralization into the Unalaska Formation. These factors could explain the high Na, Cl, and SO_4 contents of the ponds 3 and 4. The existence of such minerals would only complicate the results of any geothermometer analyses.

CONCLUSIONS AND RECOMMENDATIONS

There appears to be no warmwater or hotwater geothermal resource in the immediate Makushin (Broad Bay) Valley that might lend itself to direct utilization. The numerous spring-fed ponds in this valley appear to reflect groundwater fracture-flow systems. The system(s) in the western part of the valley floor might be slightly geothermal in nature, with possible relationships but no direct relationship to the Makushin Volcano geothermal system. With respect to potential direct utilization of geothermal fluids in the Broad Bay region, the author does not recommend any exploratory drilling for these fluids, especially since they appear to not exist.

REFERENCES CITED

Fournier, R.O., 1979, Geochemical and hydrologic considerations and the use of enthalpy-chloride diagrams in the prediction of underground conditions of hot-springs systems, Journal of Volcanology and Geothermal Research, v. 5, p. 1-16.

Fournier, R.O., 1981, Application of water chemistry to geothermal exploration and reservoir engineering, in Ryback, L., and Muffler, L.P.J.,eds., Geothermal systems: Principles and case histories, New York, Wiley and Sons, p. 109-144.

Fournier, R.O., and Truesdell, A.H., 1974, Geochemical indicators of subsurface temperature, Part 2: Estimation of temperature and fraction of hot water mixed with cold water, U. S. Geological Survey Journal of Research, v. 2, no. 3, p. 263-270.

Dames and Moore, 1983, 1982 environmental baseline data collection program final report, prepared for Republic Geothermal, Inc. and for Alaska Power Authority, 55 p. plus Appendices.

Motyka, R.J., Moorman, M.A., and Poreda, R., 1983, Progress report - thermal fluid investigations of the Makushin geothermal area, Alaska Division of Geological and Geophysical Surveys, Report of Investigation 83-15, 52 p.

Presser, T.S., and Barnes, I., 1974, Special techniques for determining chemical properties of geothermal water, U. S. Geological Survey, Water-Resources Investigations 22-74, 11 p.

Reeder, J.W., 1981, Initial assessment of the hydrothermal resources of the Summer Bay region on Unalaska Island, Alaska, Transactions Geothermal Resource Council, v. 5, p. 123-126.

Reeder, J.W., 1982, Hydrothermal resources of Makushin Volcano region of Unalaska Island, Alaska, in Watson, S.T., ed., Circum-Pacific Energy and Mineral Resources Conference, 3rd, Honolulu, American Association of Petroleum Geologist Circum-Pacific Series, p. 441-450.

Reeder, J.W., 1986, An analysis of fault and volcanic dike orientations for the Makushin Volcano region of the Aleutian arc, in Reilly, W.I., and Storm, A., eds., Recent crustal movements of the Pacific region, Royal Society of New Zealand Bulletin, No. 24, just published.

Reeder, J. W., Denig-Chakroff, D., and Economides, M.J., 1985, The geology and geothermal resource of the Makushin Volcano region of Unalaska Island, Alaska, 1985 International Symposium on Geothermal Energy, Kailua-Kona, Hawaii, Geothermal Resource Council Transactions, v. 9, Part 1, p. 177-182.

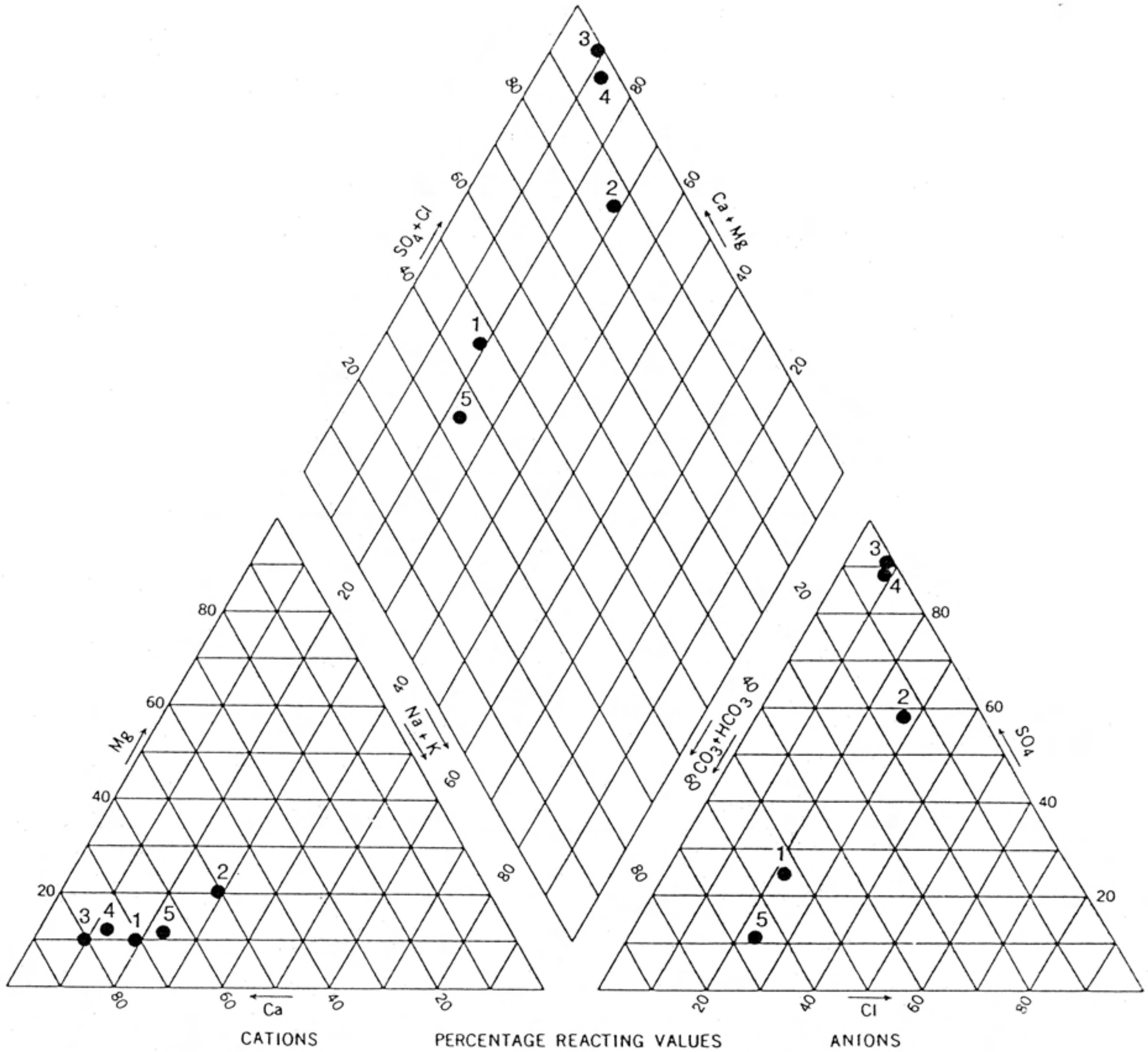
Republic Geothermal, Inc., 1984, The Unalaska geothermal exploration project, Phase 11 final report, prepared for Alaska Power Authority, page XII-26.

Selkregg, L.L., ed., Alaska regional profiles -- southwestern region, University of Alaska Arctic Environmental Information and Data Center, 313 p.

U. S. Environmental Protection Agency, 1983, Methods for chemical analysis of water and wastes, U. S. Environmental Protection Agency EPA-600/4-79-020.

Figure 1. A view taken 15 July 1986 of pond 1, which is about 25 feet long and about 20 feet wide. Mary Maurer is unpacking field water-sampling equipment on the south side of the pond. The bottom of the pond consist of organic rich muds, and has three 7 foot deep depressions that were formed by spring upwellings.

Figure 2. A view taken 15 July 1986 of pond 4 with Mary Maurer to the immediate left.



For exact site locations, see Plate 2 of ground stability section.

Figure 3. Trilinear diagram showing percentage of cation and anion compositions of ponds in the Makushin (Broad Bay) Valley, July 16-17, 1986. The number nearest the solid circle indicates pond number.

Appendix A

Laboratory water quality analyses of ponds in the Makushin (Broad Bay) Valley. These laboratory analyses were done by the University of Utah Research Institute, Salt Lake City, Utah

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
EARTH SCIENCE LABORATORY
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108—1295
TELEPHONE 801-524-3422

July 29, 1986

State of Alaska
Department of Natural Resources
Division of Geological & Geophysical Surveys
P.O. Box 772116
Eagle River, Alaska 99577

Attention: Mary A. Maurer

REPORT

Sample	ppm Br	ppb As	ppm SiO_2
Pond 1	< 0.2	< 5	10.0
Pond 2	< 0.2	< 5	30.4
Pond 3	< 0.2	< 5	25.7
Pond 4	< 0.2	< 5	28.5
Pond 5	< 0.2	< 5	9.9
Site 1	< 0.2	< 5	11.4
Site 2	< 0.2	< 5	5.7
Site 3	< 0.2	< 5	5.6
Site 4	< 0.2	< 5	8.5

Ruth L. Kroneman

Ruth L. Kroneman
Chemist

RLK/cd

****

ALASKA
POND 1

ID #: A:POND1
DATE: 07-28-86

****

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)		CONCENTRATION (MOL/L)
Na	7.16	1	.61		.311E-03
K	N.D.	1	1.22	<	.793E-05
Ca	23.39	1	.24		.584E-03
Mg	1.99	1	.49		.819E-04
Fe	N.D.	1	.02	<	.000E+00
Al	N.D.	1	.61	<	.000E+00
SiO2	10.54	1	.52		.175E-03
B	N.D.	1	.12	<	.000E+00
Li	N.D.	1	.05	<	.000E+00
Sr	.12	1	.01		.137E-05
Zn	N.D.	1	.12	<	.153E-06
Ag	N.D.	1	.05	<	.000E+00
As	N.D.	1	.61	<	.120E-05
Au	N.D.	1	.10	<	.000E+00
B[illegible]	N.D.	1	.61	<	.291E-06
B[illegible]	N.D.	1	.00	<	.000E+00
Bi	N.D.	1	2.44	<	.000E+00
Cd	N.D.	1	.06	<	.000E+00
Ce	N.D.	1	.24	<	.000E+00
Co	N.D.	1	.02	<	.000E+00
Cr	N.D.	1	.05	<	.000E+00
Cu	N.D.	1	.06	<	.000E+00
La	N.D.	1	.12	<	.000E+00
Mn	N.D.	1	.24	<	.000E+00
Mo	N.D.	1	1.22	<	.000E+00
Ni	N.D.	1	.12	<	.000E+00
Pb	N.D.	1	.24	<	.000E+00
Sn	N.D.	1	.12	<	.590E-06
Sb	N.D.	1	.73	<	.000E+00
Te	N.D.	1	1.22	<	.000E+00
Th	N.D.	1	2.44	<	.000E+00
Ti	N.D.	1	.12	<	.000E+00
U	N.D.	1	6.10	<	.676E-05
V	N.D.	1	1.22	<	.000E+00
W	N.D.	1	.12	<	.109E-06
Zr	N.D.	1	.12	<	.000E+00

ALASKA
POND 1

ID #: A:POND1
DATE: 07-28-86

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)	CONCENTRATION (MOL/L)
TOTAL ALKALINITY AS				
HCO3	58.00	2	1.00	.951E-03
CO3	N.D.	2	1.00	< .000E+00
Cl	14.00	2	1.00	.395E-03
F	.06	5	.05	.316E-05
SO4	21.00	4	1.00	.219E-03
Br	N.A.	2	1.00	< .000E+00
I	N.A.	2	.10	< .000E+00
NO3	N.A.	9	.10	< .000E+00
S	N.A.	2	1.00	< .000E+00
PO4	N.D.	1	1.84	< .000E+00

TOTAL DISSOLVED SOLIDS

MEASURED	108.00	4	4.00
CALCULATED	106.78	6	
100*MEAS/CALC	101.14		
pH	7.20	7	

****

ANALYTICAL METHODS:

1. INDUCTIVELY COUPLED PLASMA SPECTROMETER
2. TITRATION (LABORATORY)
3. TITRATION (FIELD)
4. GRAVIMETRIC
5. SPECIFIC ION ELECTRODE
6. METHOD OF HEM (1970, USGS Water Supply Paper 1473)
7. pH METER (LABORATORY)
8. pH METER (FIELD)
9. COLORIMETRIC
10. ATOMIC ABSORPTION
11. TURBIDIMETRIC

N.D. - NOT DETECTED
N.A. - NOT ANALYZED

****

ALASKA
POND 1

ID #: A:POND1
DATE: 07-28-86

	Milliequivalents/Liter
CATIONS	
Na	.31146
Ca	1.16716
Mg	.16370
Sr	.00274
SUM OF CATIONS:	1.64506
ANIONS	
HCO3	.95062
Cl	.39494
F	.00316
SO4	.43722
SUM OF ANIONS:	1.78594
CATION-ANION BALANCE	-.14088
BALANCE DIFF. CATION + ANION	-4.11

****

TRILINEAR DIAGRAM COORDINATES

ALASKA
POND 1

ID #: A:POND1
DATE: 07-28-86

****

	Meq / L	Percent (Meq / L)
CATIONS		
Na	.31146	18.96465
K	.00000	.00000
Ca	1.16716	71.06789
Mg	.16370	9.96746
TOTAL	1.64232	100.00000
ANIONS		
HCO3	.95062	53.32234
CO3	.00000	.00000
SO4	.43722	24.52462
Cl	.39494	22.15304
TOTAL	1.78278	99.99999

****

GEOTHERMOMETERS

ALASKA
POND 1

ID #: A:POND1
DATE: 07-28-86

****

Geothermometer	Temp (deg C)	Reference
Quartz (no steam loss)	41.	Fournier (1981)
Quartz (maximum steam loss)	49.	Fournier (1981)
Chalcedony	8.	Fournier (1981)
alpha-Cristobalite	-7.	Fournier (1981)
beta-Cristobalite	-49.	Fournier (1981)
Amorphous Silica	-64.	Fournier (1981)
Na/K (Fournier)	154.	Fournier (1979)
Na/K (Truesdell)	112.	Fournier (1981)
Na-K-Ca	-14. beta=1.33	Fournier and Truesdell(1974)

****

ALASKA
POND 2

ID #: A:POND2
DATE: 07-28-86

****

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)		CONCENTRATION (MOL/L)
Na	9.58	1	.61		.417E-03
K	N.D.	1	1.22	<	.110E-04
Ca	14.49	1	.24		.362E-03
Mg	3.54	1	.49		.146E-03
Fe	N.D.	1	.02	<	.000E+00
Al	N.D.	1	.61	<	.000E+00
SiO2	31.03	1	.52		.516E-03
B	N.D.	1	.12	<	.000E+00
Li	N.D.	1	.05	<	.000E+00
Sr	.08	1	.01		.913E-06
Zn	N.D.	1	.12	<	.153E-06
Ag	N.D.	1	.05	<	.000E+00
As	N.D.	1	.61	<	.120E-05
Au	N.D.	1	.10	<	.000E+00
Ba	N.D.	1	.61	<	.146E-06
Be	N.D.	1	.00	<	.000E+00
Bi	N.D.	1	2.44	<	.431E-06
Cd	N.D.	1	.06	<	.000E+00
Ce	N.D.	1	.24	<	.000E+00
Co	N.D.	1	.02	<	.000E+00
Cr	N.D.	1	.05	<	.000E+00
Cu	N.D.	1	.06	<	.000E+00
La	N.D.	1	.12	<	.000E+00
Mn	N.D.	1	.24	<	.000E+00
Mo	N.D.	1	1.22	<	.000E+00
Ni	N.D.	1	.12	<	.000E+00
Pb	N.D.	1	.24	<	.000E+00
Sn	N.D.	1	.12	<	.506E-06
Sb	N.D.	1	.73	<	.000E+00
Te	N.D.	1	1.22	<	.000E+00
Th	N.D.	1	2.44	<	.000E+00
Ti	N.D.	1	.12	<	.000E+00
U	N.D.	1	6.10	<	.118E-05
V	N.D.	1	1.22	<	.000E+00
W	N.D.	1	.12	<	.109E-06
Zr	N.D.	1	.12	<	.000E+00

ALASKA
POND 2

ID #: A:POND2
DATE: 07-28-86

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)	CONCENTRATION (MOL/L)
TOTAL ALKALINITY AS				
HCO3	15.00	2	1.00	.246E-03
CO3	N.D.	2	1.00	< .000E+00
Cl	16.50	2	1.00	.465E-03
F	.26	5	.05	.137E-04
SO4	47.00	4	1.00	.489E-03
Br	N.A.	2	1.00	< .000E+00
I	N.A.	2	.10	< .000E+00
NO3	N.A.	9	.10	< .000E+00
S	N.A.	2	1.00	< .000E+00
PO4	N.D.	1	1.84	< .000E+00

TOTAL DISSOLVED SOLIDS

MEASURED	124.00	4	4.00
CALCULATED	129.86	6	
100*MEAS/CALC	95.49		
pH	6.53	7	

****

ANALYTICAL METHODS:

1. INDUCTIVELY COUPLED PLASMA SPECTROMETER
2. TITRATION (LABORATORY)
3. TITRATION (FIELD)
4. GRAVIMETRIC
5. SPECIFIC ION ELECTRODE
6. METHOD OF HEM (1970, USGS Water Supply Paper 1473)
7. pH METER (LABORATORY)
8. pH METER (FIELD)
9. COLORIMETRIC
10. ATOMIC ABSORPTION
11. TURBIDIMETRIC

N.D. - NOT DETECTED
N.A. - NOT ANALYZED

****

ALASKA
POND 2

ID #: A:POND2
DATE: 07-28-86

	Milliequivalents/Liter
CATIONS	
Na	.41673
Ca	.72305
Mg	.29120
Sr	.00183
SUM OF CATIONS:	1.43281
ANIONS	
HCO3	.24585
Cl	.46546
F	.01369
SO4	.97854
SUM OF ANIONS:	1.70354
CATION-ANION BALANCE	-.27073
BALANCE DIFF. CATION + ANION	-8.63

****

TRILINEAR DIAGRAM COORDINATES

ALASKA
POND 2

ID #: A:POND2
DATE: 07-28-86

****

	Meq / L	Percent (Meq / L)
CATIONS		
Na	.41673	29.12197
K	.00000	.00000
Ca	.72305	50.52833
Mg	.29120	20.34970
TOTAL	1.43098	100.00000
ANIONS		
HCO3	.24585	14.54859
CO3	.00000	.00000
SO4	.97854	57.90675
Cl	.46546	27.54467
TOTAL	1.68985	100.00000

****

GEOTHERMOMETERS

ALASKA
POND 2

ID #: A:POND2
DATE: 07-28-86

****

Geothermometer	Temp (deg C)	Reference
Quartz (no steam loss)	81.	Fournier (1981)
Quartz (maximum steam loss)	84.	Fournier (1981)
Chalcedony	50.	Fournier (1981)
alpha-Cristobalite	31.	Fournier (1981)
beta-Cristobalite	-14.	Fournier (1981)
Amorphous Silica	-32.	Fournier (1981)
Na/K (Fournier)	157.	Fournier (1979)
Na/K (Truesdell)	115.	Fournier (1981)
Na-K-Ca	0. beta=1.33	Fournier and Truesdell(1974)

****

ALASKA
POND 3

ID #: A:POND3
DATE: 07-28-86

****

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)		CONCENTRATION (MOL/L)
Na	8.10	1	.61		.353E-03
K	N.D.	1	1.22	<	.129E-04
Ca	61.81	1	.24		.154E-02
Mg	4.81	1	.49		.198E-03
Fe	N.D.	1	.02	<	.000E+00
Al	N.D.	1	.61	<	.211E-04
SiO2	25.97	1	.52		.432E-03
B	N.D.	1	.12	<	.000E+00
Li	N.D.	1	.05	<	.451E-06
Sr	.28	1	.01		.321E-05
Zn	N.D.	1	.12	<	.313E-06
Ag	N.D.	1	.05	<	.681E-07
As	N.D.	1	.61	<	.110E-05
[illegible]	N.D.	1	.10	<	.155E-07
[illegible]	N.D.	1	.61	<	.309E-06
Be	N.D.	1	.00	<	.556E-07
Bi	N.D.	1	2.44	<	.341E-05
Cd	N.D.	1	.06	<	.000E+00
Ce	N.D.	1	.24	<	.226E-06
Co	N.D.	1	.02	<	.470E-07
Cr	N.D.	1	.05	<	.000E+00
Cu	N.D.	1	.06	<	.000E+00
La	N.D.	1	.12	<	.288E-06
Mn	N.D.	1	.24	<	.267E-05
Mo	N.D.	1	1.22	<	.425E-06
Ni	N.D.	1	.12	<	.000E+00
Pb	N.D.	1	.24	<	.000E+00
Sn	N.D.	1	.12	<	.803E-06
Sb	N.D.	1	.73	<	.000E+00
Te	N.D.	1	1.22	<	.000E+00
Th	N.D.	1	2.44	<	.233E-06
Ti	N.D.	1	.12	<	.652E-06
U	N.D.	1	6.10	<	.000E+00
V	N.D.	1	1.22	<	.222E-05
W	N.D.	1	.12	<	.000E+00
Zr	N.D.	1	.12	<	.387E-07

ALASKA
POND 3

ID #: A:POND3
DATE: 07-28-86

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)		CONCENTRATION (MOL/L)
TOTAL ALKALINITY AS					
HCO3	2.00	2	1.00		.328E-04
CO3	N.D.	2	1.00	<	.000E+00
Cl	13.00	2	1.00		.367E-03
F	.15	5	.05		.790E-05
SO4	188.00	11	1.00		.196E-02
Br	N.A.	2	1.00	<	.000E+00
I	N.A.	2	.10	<	.000E+00
NO3	N.A.	9	.10	<	.000E+00
S	N.A.	2	1.00	<	.000E+00
PO4	N.D.	1	1.84	<	.000E+00

TOTAL DISSOLVED SOLIDS

MEASURED	309.00	4	4.00
CALCULATED	303.10	6	
100*MEAS/CALC	101.95		
pH	4.98	7	

****

ANALYTICAL METHODS:

1. INDUCTIVELY COUPLED PLASMA SPECTROMETER
2. TITRATION (LABORATORY)
3. TITRATION (FIELD)
4. GRAVIMETRIC
5. SPECIFIC ION ELECTRODE
6. METHOD OF HEM (1970, USGS Water Supply Paper 1473)
7. pH METER (LABORATORY)
8. pH METER (FIELD)
9. COLORIMETRIC
10. ATOMIC ABSORPTION
11. TURBIDIMETRIC

N.D. - NOT DETECTED
N.A. - NOT ANALYZED

****

ALASKA
POND 3

ID #: A:POND3
DATE: 07-28-86

	Milliequivalents/Liter
CATIONS	
Na	.35254
Ca	3.08408
Mg	.39541
Sr	.00641
SUM OF CATIONS:	3.83845
ANIONS	
HCO3	.03278
Cl	.36673
F	.00790
SO4	3.91416
SUM OF ANIONS:	4.32157
CATION-ANION BALANCE	-.48312
BALANCE DIFF. CATION + ANION	-5.92

****

TRILINEAR DIAGRAM COORDINATES

ALASKA
POND 3

ID #: A:POND3
DATE: 07-28-86

****

	Meq / L	Percent (Meq / L)
CATIONS		
Na	.35254	9.19993
K	.00000	.00000
Ca	3.08408	80.48159
Mg	.39541	10.31848
TOTAL	3.83203	100.00000
ANIONS		
HCO3	.03278	.75991
CO3	.00000	.00000
SO4	3.91416	90.73852
Cl	.36673	8.50158
TOTAL	4.31367	100.00000

****

GEOTHERMOMETERS

ALASKA
POND 3

ID #: A:POND3
DATE: 07-28-86

****

Geothermometer	Temp (deg C)		Reference
Quartz (no steam loss)	74.		Fournier (1981)
Quartz (maximum steam loss)	78.		Fournier (1981)
Chalcedony	42.		Fournier (1981)
alpha-Cristobalite	24.		Fournier (1981)
beta-Cristobalite	-21.		Fournier (1981)
Amorphous Silica	-38.		Fournier (1981)
Na/K (Fournier)	179.		Fournier (1979)
Na/K (Truesdell)	141.		Fournier (1981)
Na-K-Ca	-16.	beta=1.33	Fournier and Truesdell(1974)
Na/Li	-10.		Fouillac and Michard(1981)

****

ASKA POND 4

ID #: A:POND4
DATE: 07-28-86

****

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)		CONCENTRATION (MOL/L)
Na	9.21	1	.61		.401E-03
K	N.D.	1	1.22	<	.156E-04
Ca	48.47	1	.24		.121E-02
Mg	4.71	1	.49		.194E-03
Fe	N.D.	1	.02	<	.000E+00
Al	N.D.	1	.61	<	.222E-05
SiO2	28.74	1	.52		.478E-03
B	N.D.	1	.12	<	.000E+00
Li	N.D.	1	.05	<	.000E+00
Sr	.20	1	.01		.228E-05
Zn	N.D.	1	.12	<	.153E-06
Ag	N.D.	1	.05	<	.927E-07
As	N.D.	1	.61	<	.200E-05
Au	N.D.	1	.10	<	.000E+00
B	N.D.	1	.61	<	.291E-06
Be	N.D.	1	.00	<	.000E+00
Bi	N.D.	1	2.44	<	.957E-07
Cd	N.D.	1	.06	<	.000E+00
Ce	N.D.	1	.24	<	.143E-06
Co	N.D.	1	.02	<	.000E+00
Cr	N.D.	1	.05	<	.000E+00
Cu	N.D.	1	.06	<	.000E+00
La	N.D.	1	.12	<	.216E-06
Mn	N.D.	1	.24	<	.182E-06
Mo	N.D.	1	1.22	<	.208E-06
Ni	N.D.	1	.12	<	.000E+00
Pb	N.D.	1	.24	<	.000E+00
Sn	N.D.	1	.12	<	.000E+00
Sb	N.D.	1	.73	<	.000E+00
Te	N.D.	1	1.22	<	.000E+00
Th	N.D.	1	2.44	<	.302E-06
Ti	N.D.	1	.12	<	.418E-06
U	N.D.	1	6.10	<	.139E-05
V	N.D.	1	1.22	<	.785E-06
W	N.D.	1	.12	<	.544E-07
Zr	N.D.	1	.12	<	.110E-06

ALASKA
POND 4

ID #: A:POND4
DATE: 07-28-86

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)	CONCENTRATION (MOL/L)
TOTAL ALKALINITY AS				
HCO3	7.00	2	1.00	.115E-03
CO3	N.D.	2	1.00	< .000E+00
Cl	11.00	2	1.00	.310E-03
F	.15	5	.05	.790E-05
SO4	147.00	4	1.00	.153E-02
Br	N.A.	2	1.00	< .000E+00
I	N.A.	2	.10	< .000E+00
NO3	N.A.	9	.10	< .000E+00
S	N.A.	2	1.00	< .000E+00
PO4	N.D.	1	1.84	< .000E+00

TOTAL DISSOLVED SOLIDS

MEASURED	262.00	4	4.00
CALCULATED	252.92	6	
100*MEAS/CALC	103.59		
pH	6.03	7	

****

ANALYTICAL METHODS:

1. INDUCTIVELY COUPLED PLASMA SPECTROMETER
2. TITRATION (LABORATORY)
3. TITRATION (FIELD)
4. GRAVIMETRIC
5. SPECIFIC ION ELECTRODE
6. METHOD OF HEM (1970, USGS Water Supply Paper 1473)
7. pH METER (LABORATORY)
8. pH METER (FIELD)
9. COLORIMETRIC
10. ATOMIC ABSORPTION
11. TURBIDIMETRIC

N.D. - NOT DETECTED
N.A. - NOT ANALYZED

****

ALASKA
POND 4

ID #: A:POND4
DATE: 07-28-86

	Milliequivalents/Liter
CATIONS	
Na	.40064
Ca	2.41865
Mg	.38744
Sr	.00457
SUM OF CATIONS:	3.21130
ANIONS	
HCO3	.11473
Cl	.31031
F	.00790
SO4	3.06054
SUM OF ANIONS:	3.49348
CATION-ANION BALANCE	-.28218
BALANCE DIFF. CATION + ANION	-4.21

****

TRILINEAR DIAGRAM COORDINATES

ALASKA
POND 4

ID #: A:POND4
DATE: 07-28-86

****

	Meq / L	Percent (Meq / L)
CATIONS		
Na	.40064	12.49356
K	.00000	.00000
Ca	2.41865	75.42422
Mg	.38744	12.08222
TOTAL	3.20673	100.00000
ANIONS		
HCO3	.11473	3.29156
CO3	.00000	.00000
SO4	3.06054	87.80576
Cl	.31031	8.90268
TOTAL	3.48558	100.00000

****

GEOTHERMOMETERS

LASKA
POND 4

ID #: A:POND4
DATE: 07-28-86

****

Geothermometer	Temp (deg C)	Reference
Quartz (no steam loss)	78.	Fournier (1981)
Quartz (maximum steam loss)	82.	Fournier (1981)
Chalcedony	46.	Fournier (1981)
alpha-Cristobalite	28.	Fournier (1981)
beta-Cristobalite	-17.	Fournier (1981)
Amorphous Silica	-34.	Fournier (1981)
Na/K (Fournier)	184.	Fournier (1979)
Na/K (Truesdell)	147.	Fournier (1981)
K-Ca	-9. beta=1.33	Fournier and Truesdell(1974)

****

ALASKA
POND 5

ID #: A:POND5
DATE: 07-28-86

****

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)		CONCENTRATION (MOL/L)
Na	6.40	1	.61		.278E-03
K	N.D.	1	1.22	<	.691E-05
Ca	15.70	1	.24		.392E-03
Mg	1.70	1	.49		.699E-04
Fe	N.D.	1	.02	<	.000E+00
Al	N.D.	1	.61	<	.000E+00
SiO2	9.77	1	.52		.163E-03
B	N.D.	1	.12	<	.000E+00
Li	N.D.	1	.05	<	.000E+00
Sr	.05	1	.01		.571E-06
Zn	N.D.	1	.12	<	.306E-06
Ag	N.D.	1	.05	<	.000E+00
As	N.D.	1	.61	<	.254E-05
Au	N.D.	1	.10	<	.000E+00
Ba	N.D.	1	.61	<	.218E-06
Be	N.D.	1	.00	<	.000E+00
Bi	N.D.	1	2.44	<	.000E+00
Cd	N.D.	1	.06	<	.000E+00
Ce	N.D.	1	.24	<	.000E+00
Co	N.D.	1	.02	<	.000E+00
Cr	N.D.	1	.05	<	.000E+00
Cu	N.D.	1	.06	<	.000E+00
La	N.D.	1	.12	<	.000E+00
Mn	N.D.	1	.24	<	.000E+00
Mo	N.D.	1	1.22	<	.000E+00
Ni	N.D.	1	.12	<	.170E-06
Pb	N.D.	1	.24	<	.000E+00
Sn	N.D.	1	.12	<	.000E+00
Sb	N.D.	1	.73	<	.000E+00
Te	N.D.	1	1.22	<	.470E-06
Th	N.D.	1	2.44	<	.000E+00
Ti	N.D.	1	.12	<	.000E+00
U	N.D.	1	6.10	<	.450E-05
V	N.D.	1	1.22	<	.000E+00
W	N.D.	1	.12	<	.544E-07
Zr	N.D.	1	.12	<	.000E+00

ALASKA
POND 5

ID #: A:POND5
DATE: 07-28-86

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS (ppm)	CONCENTRATION (MOL/L)
TOTAL ALKALINITY AS				
HCO3	52.00	2	1.00	.852E-03
CO3	N.D.	2	1.00	< .000E+00
Cl	11.00	2	1.00	.310E-03
F	.07	5	.05	.368E-05
SO4	7.00	4	1.00	.729E-04
Br	N.A.	2	1.00	< .000E+00
I	N.A.	2	.10	< .000E+00
NO3	N.A.	9	.10	< .000E+00
S	N.A.	2	1.00	< .000E+00
PO4	N.D.	1	1.84	< .000E+00
TOTAL DISSOLVED SOLIDS				
MEASURED	76.00	4	4.00	
CALCULATED	77.26	6		
100*MEAS/CALC	98.37			
pH	7.39	7		

****

ANALYTICAL METHODS:

1. INDUCTIVELY COUPLED PLASMA SPECTROMETER
2. TITRATION (LABORATORY)
3. TITRATION (FIELD)
4. GRAVIMETRIC
5. SPECIFIC ION ELECTRODE
6. METHOD OF HEM (1970, USGS Water Supply Paper 1473)
7. pH METER (LABORATORY)
8. pH METER (FIELD)
9. COLORIMETRIC
10. ATOMIC ABSORPTION
11. TURBIDIMETRIC

N.D. - NOT DETECTED
N.A. - NOT ANALYZED

****

ALASKA
POND 5

ID #: A:POND5
DATE: 07-28-86

	Milliequivalents/Liter
CATIONS	
Na	.27840
Ca	.78343
Mg	.13984
Sr	.00114
SUM OF CATIONS:	1.20281
ANIONS	
HCO3	.85228
Cl	.31031
F	.00368
SO4	.14574
SUM OF ANIONS:	1.31201
CATION-ANION BALANCE	-.10920
BALANCE DIFF. CATION + ANION	-4.34

****

TRILINEAR DIAGRAM COORDINATES

ALASKA
POND 5

ID #: A:PONDS
DATE: 07-28-86

****

	Meq / L	Percent (Meq / L)
CATIONS		
Na	.27840	23.16772
K	.00000	.00000
Ca	.78343	65.19499
Mg	.13984	11.63729
TOTAL	1.20167	99.99999
ANIONS		
HCO3	.85228	65.14259
CO3	.00000	.00000
SO4	.14574	11.13939
Cl	.31031	23.71802
TOTAL	1.30833	100.00000

****

GEOTHERMOMETERS

ALASKA
POND 5

ID #: A:POND5
DATE: 07-28-86

****

Geothermometer	Temp (deg C)	Reference
Quartz (no steam loss)	39.	Fournier (1981)
Quartz (maximum steam loss)	47.	Fournier (1981)
Chalcedony	6.	Fournier (1981)
alpha-Cristobalite	-9.	Fournier (1981)
beta-Cristobalite	-51.	Fournier (1981)
Amorphous Silica	-66.	Fournier (1981)
Na/K (Fournier)	153.	Fournier (1979)
Na/K (Truesdell)	110.	Fournier (1981)
Na-K-Ca	-12. beta=1.33	Fournier and Truesdell(1974)

CONSTRUCTION MATERIALS ASSESSMENT

By Randall G. Updike

SCOPE OF WORK

The construction of a geothermal power plant facility requires easy access to a variety of naturally-occurring construction materials that can be used in various phases of the development of the facility. This includes foundation and concrete aggregate at the site, sub-grade and road metal materials for access routes to the site, and large, angular rip-rap rock for port and bridge designs. Although at first impression these types of materials seem readily available anywhere, in fact quality resources are localized and may not be usable due to environmental constraints. This task is intended to provide an inventory of where the resources occur within the proposed project area, assess the relative quality of the resource, and identify constraints particular to that source area.

METHODOLOGY AND TECHNIQUES

Three general areas were considered during this investigation based upon potential construction in those areas: (1) Makushin Valley from Broad Bay to the Power Site, (2) Driftwood Valley from Driftwood Bay to the volcanic uplands, and (3) the volcanic uplands east of the power site. Aerial photography provided by North Pacific Aerial Surveys (8/1/82, 1:24,000 scale) was used prior to, during, and after the field investigation. Unpublished topographic maps prepared by North Pacific Aerial Surveys (1984, 1:24,000) were used as base maps for field work and to prepare the enclosed site location map (Plate K-1). Field investigations were supported by a Hughes 500-D helicopter. Several extended traverses on foot, e.g. down Driftwood Valley, across the highlands, and along segments of Makushin Valley, supplemented the aerial support. All field investigations utilized hand-dug pits and the collection of representative bag samples of material. Mechanical analyses of selected samples were performed by the Alaska Department of Transportation and Public Facilities Materials Laboratory in Fairbanks. Based upon field examination, selected sites were described for several attributes including overburden thickness, access, physical location, development constraints, and a qualitative rating as a resource site. Anticipating that the actual power site location and method of access would be selected from a number of alternatives, the field investigation for material sites was executed to provide data stations throughout the project area.

RESULTS OF INVESTIGATION

A total of 26 material sites were identified by this study task. These sites are identified by MS numbers on Plate K-1. A tabulated description of each of the sites is provided on the following pages. The primary considerations tabulated include (1) material type, (2) particle size range as general classes, (3) the most likely construction application for the material as it occurs naturally (this may be expanded by crushing and screening operations), (4) problems of access to the site, (5) thickness of overburden that would increase the extraction cost of the material, (6) drainage problems in terms of surface and ground water, (7) potential restrictions to site development inherent with the location of the site in terms of other geologic processes occurring in the surrounding area and potential environmental protection constraints that might be imposed, and (8) a qualitative rating of the site taking into consideration items (1) to (7), as well as alternative sources elsewhere in the same area of the project.

Selected particle size analyses are provided in figures 1 through 6. These should only be considered as representative and far more exhaustive analyses would be required prior to final material site selection. Figures 7 through 12 are a series of representative photographs of the physical expression of some of the materials sites.

CONCLUSIONS AND RECOMMENDATIONS

Both aggregate and building stone resources are to be found within the project area. However, readily available sources have restricted locations. Coarse aggregate is generally not available in Driftwood Valley or the volcanic uplands (except in the floodplain near Driftwood Bay, MS-1). Conversely, this resource is abundant in the floodplain of Makushin River and in alluvial fans bordering that valley. Unfortunately, most of this aggregate contains cobble or larger clasts so that in its natural state it is most suitable for sub-grade or primitive roads for heavy machinery. Supergrade-quality rock can be acquired in Makushin Valley either near the mouth of the river or by screening/crushing operations further upvalley. It should be noted that the lower half of Makushin Valley is believed to have several meters of organic sandy silt below the surface so that aggregate resources will be restricted to the exposed floodplain of the river and associated abandoned channels. For whatever road route is selected it might be well to consider the cost benefits of constructing temporary road access to coarse aggregate sites on the Makushin Valley side and fine aggregate sites on the Driftwood Valley side.

Three building stone sources were identified: (1) coarse angular volcanic blocks unearthed by prior excavation in Driftwood Valley (MS-7), (2) an exposure of dense andesite on the pre-existing switchback road at the head of Makushin Valley (MS-12), and (3) exposed andesite cliffs on the south buttress of Broad Bay (MS-26). In each case, large, dense, abrasion-resistant rock is available in close association with the existing road remnants.

This author recommends that once an access corridor is selected that the material sites identified on Plate K-1 which are in close proximity to the alignment be re-visited by trained personnel, additional samples be selected, and a field excavation work plan be developed for the site. Power auger testing is particularly recommended for material sites MS-2 to MS-10 because of the limited vertical dimensions of the pyroclastic beds providing the desired aggregate. Certain material sites in Makushin Valley will require engineered structures to mitigate environmental concerns of flow regime modification and ponding, including sites MS-14, MS-16, MS-17, MS-18, MS-19, MS-21, MS-23, and MS-25. Material site MS-1 is an excellent aggregate site but will require channels and culverts to divert ephemeral drainage through or around the site. Material sites MS-12 and MS-13 are located in a hazardous area of unstable slopes and avalanche potential which should be considered if long-term use of these sites is anticipated. MS-11 is the best location for fine aggregate (sand) in the project area but because of the very visible landform on which it occurs (Sugarloaf) the aesthetic factor of developing a quarry here should be considered. Although the site is identified on the north flank (because of ease of access), the visual concern might dictate that the west flank be utilized.

FIGURE 1.

GRAIN-SIZE ANALYSIS : MS-1
Unalaska Geothermal Project
Sample: UTFT #7

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67	84	12
1.5	38.1	-5.25	72	14
1.0	25.4	-4.67	58	11
0.75	19.1	-4.26	47	6
0.5	12.7	-3.67	41	4
0.375	9.5	-3.25	37	4
4	4.76	-2.25	33	3
10	2.00	-1.00	30	3
20	0.84	0.25	27	3
40	0.42	1.25	24	2
50	0.30	1.75	22	5
100	0.149	2.75	17	5
200	0.074	3.75	12	12

GRAVEL (#4-)	67
SAND (#4-, #200+)	21
SILT+CLAY (#200-)	12
ORGANICS (WT %)	8

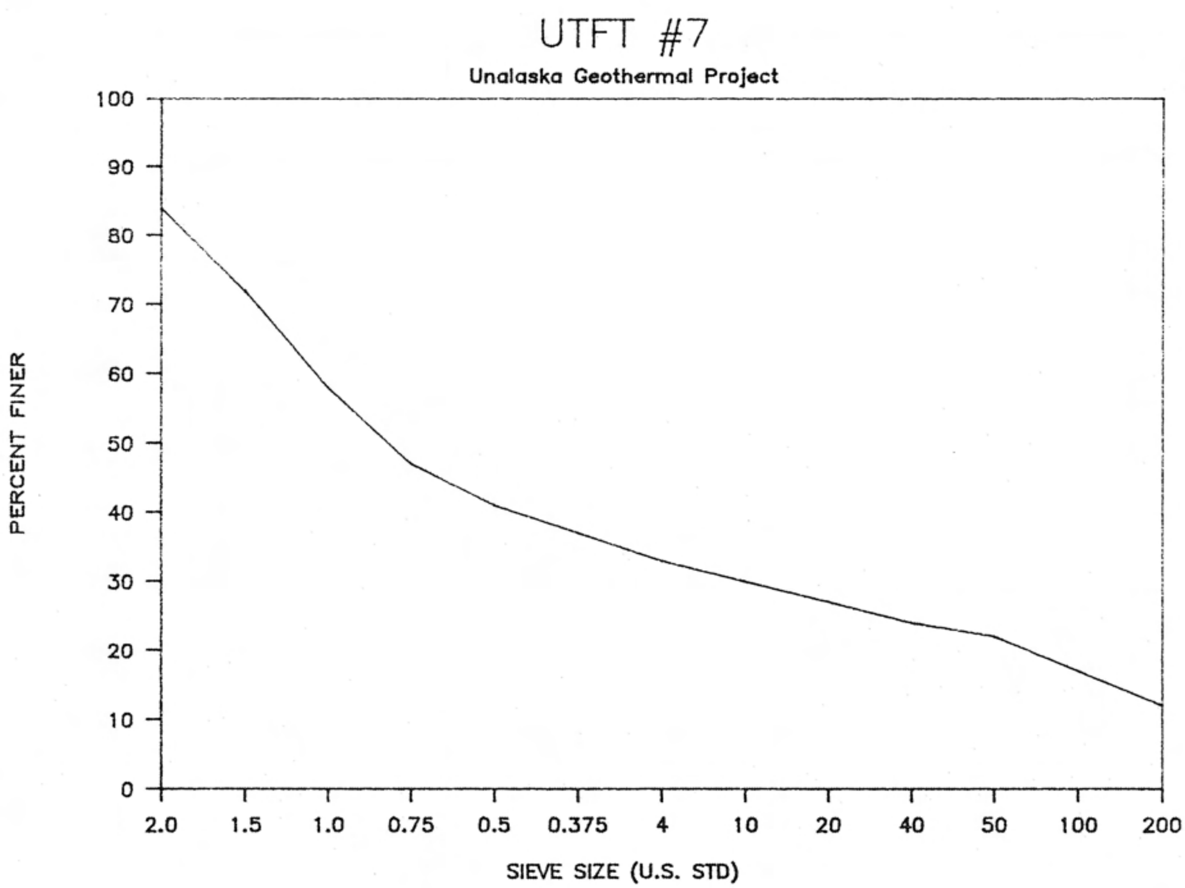


FIGURE 2.

GRAIN-SIZE ANALYSIS: MS-8
Unalaska Geothermal Project
Sample: UTFT #5

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25		
1.0	25.4	-4.67	100	7
0.75	19.1	-4.26	93	15
0.5	12.7	-3.67	78	13
0.375	9.5	-3.25	65	27
4	4.76	-2.25	38	15
10	2.00	-1.00	23	5
20	0.84	0.25	18	1
40	0.42	1.25	17	1
50	0.30	1.75	16	2
100	0.149	2.75	14	1
200	0.074	3.75	13	13

GRAVEL (#4+)	62
SAND (#4-, #200+)	25
SILT+CLAY (#200-)	13
ORGANICS (WT %)	<5

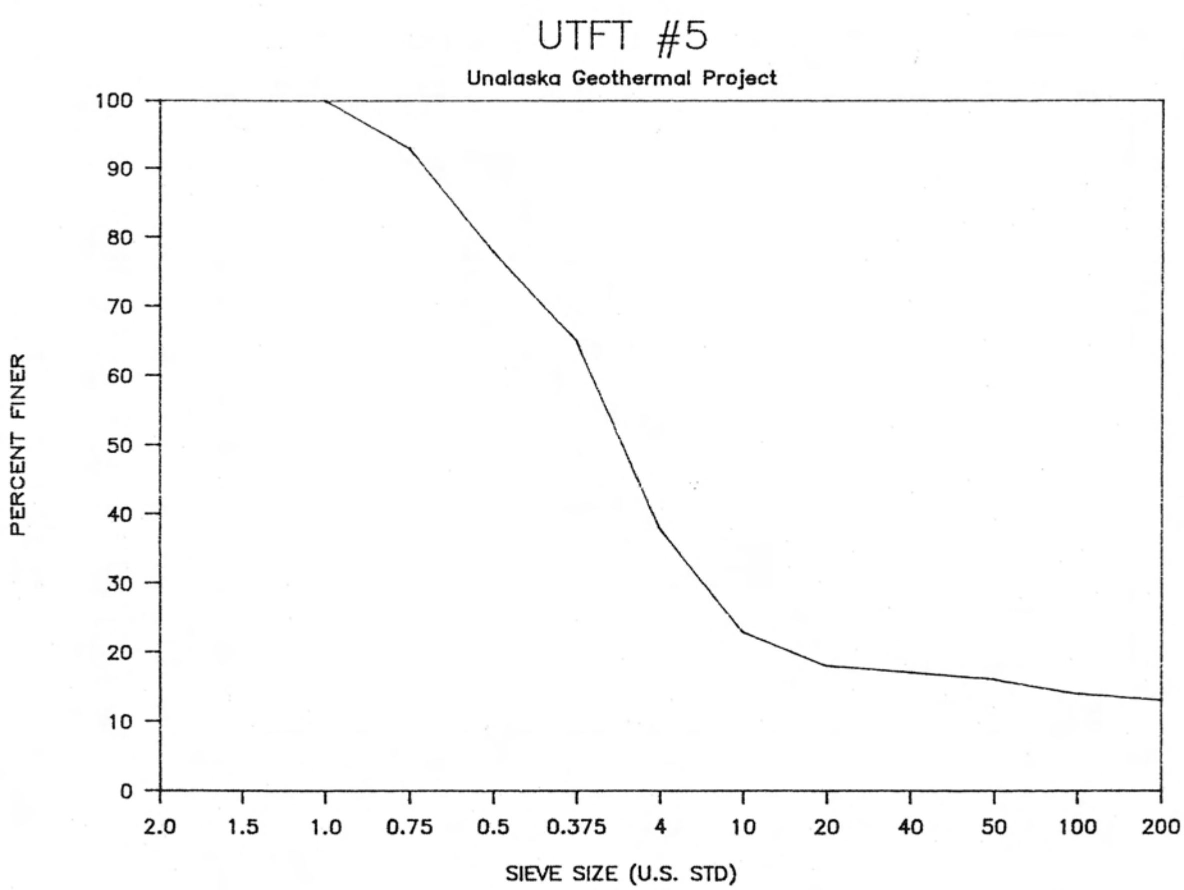


FIGURE 3.
GRAIN-SIZE ANALYSIS: MS-9
Unalaska Geothermal Project
Sample: UTFT #4

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25	100	8
1.0	25.4	-4.67	92	5
0.75	19.1	-4.26	87	10
0.5	12.7	-3.67	77	7
0.375	9.5	-3.25	70	11
4	4.76	-2.25	59	9
10	2.00	-1.00	50	6
20	0.84	0.25	44	3
40	0.42	1.25	41	2
50	0.30	1.75	39	6
100	0.149	2.75	33	7
200	0.074	3.75	26	26

GRAVEL (#4+)	41
SAND (#4-, #200+)	33
SILT+CLAY (#200-)	26
ORGANICS (WT %)	<5

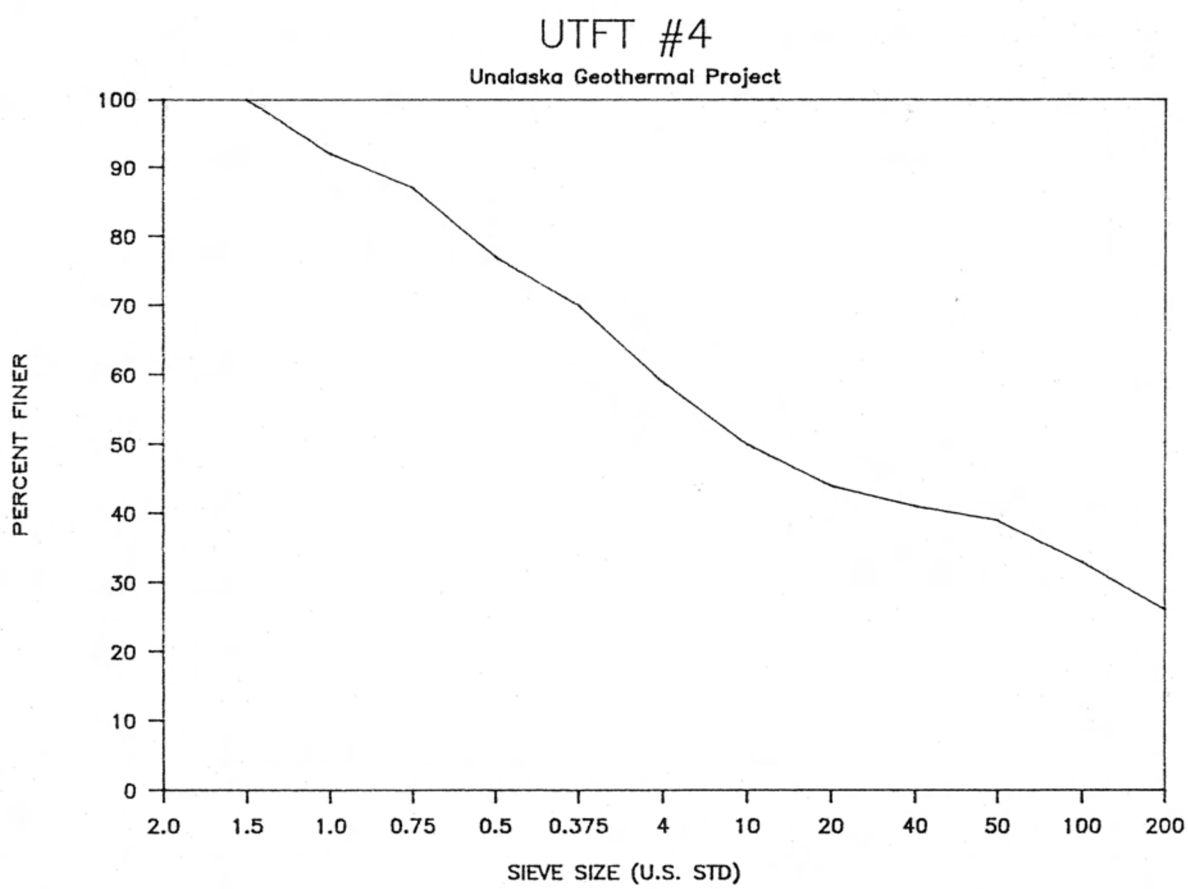


FIGURE 4.
GRAIN-SIZE ANALYSIS: MS-10.
Unalaska Geothermal Project
Sample: UTFT #3

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25	100	4
1.0	25.4	-4.67	96	7
0.75	19.1	-4.26	89	11
0.5	12.7	-3.67	78	7
0.375	9.5	-3.25	71	11
4	4.76	-2.25	60	10
10	2.00	-1.00	50	10
20	0.84	0.25	40	8
40	0.42	1.25	32	2
50	0.30	1.75	30	6
100	0.149	2.75	24	5
200	0.074	3.75	19	19

GRAVEL (#4+)	40
SAND (#4-, #200+)	41
SILT+CLAY (#200-)	19
ORGANICS (WT %)	<5

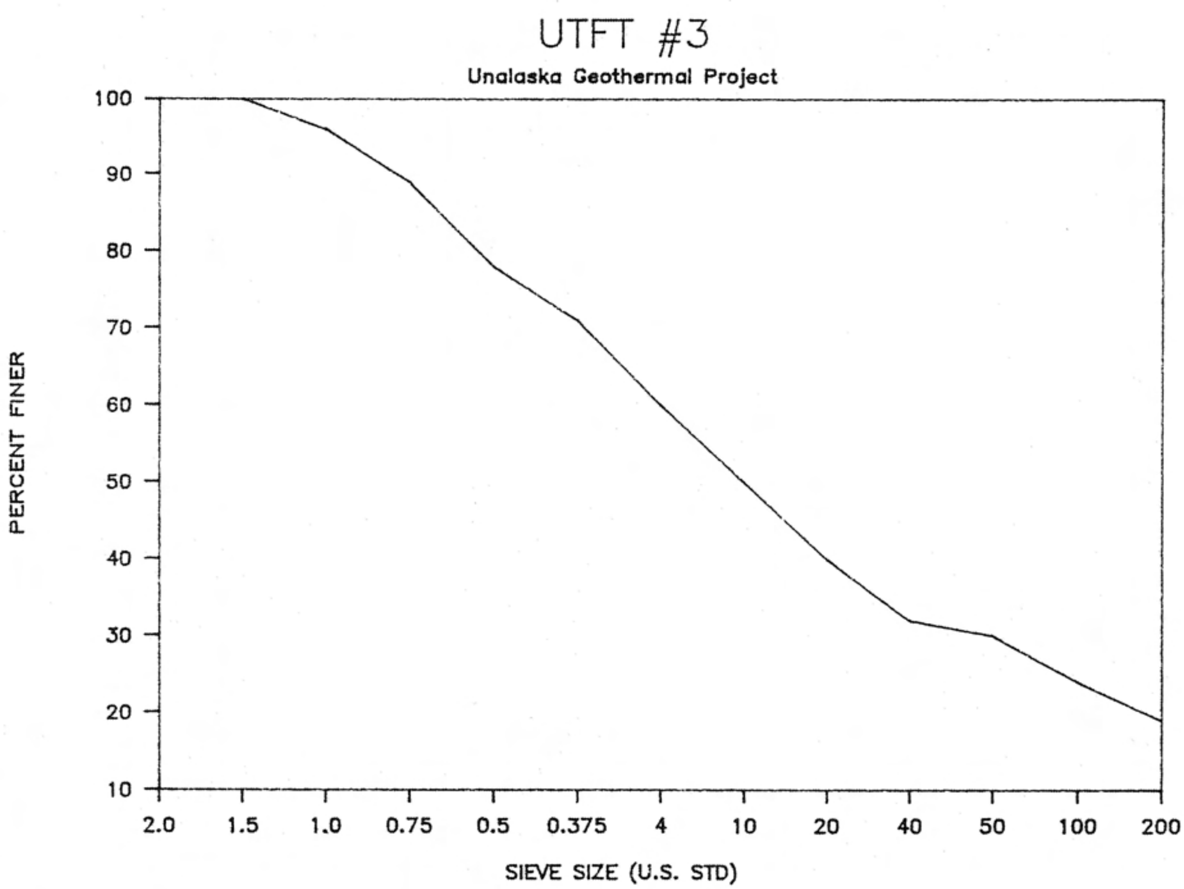


FIGURE 5.

GRAIN-SIZE ANALYSIS: MS-21.
Unalaska Geothermal Project
Sample: UTFT #11

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67	86	15
1.5	38.1	-5.25	71	18
1.0	25.4	-4.67	53	9
0.75	19.1	-4.26	44	9
0.5	12.7	-3.67	35	5
0.375	9.5	-3.25	30	7
4	4.76	-2.25	23	6
10	2.00	-1.00	17	5
20	0.84	0.25	12	5
40	0.42	1.25	7	2
50	0.30	1.75	5	3
100	0.149	2.75	2	1
200	0.074	3.75	1	1

GRAVEL (#4+)	77
SAND (#4-, #200+)	22
SILT+CLAY (#200-)	1
ORGANICS (WT %)	<5

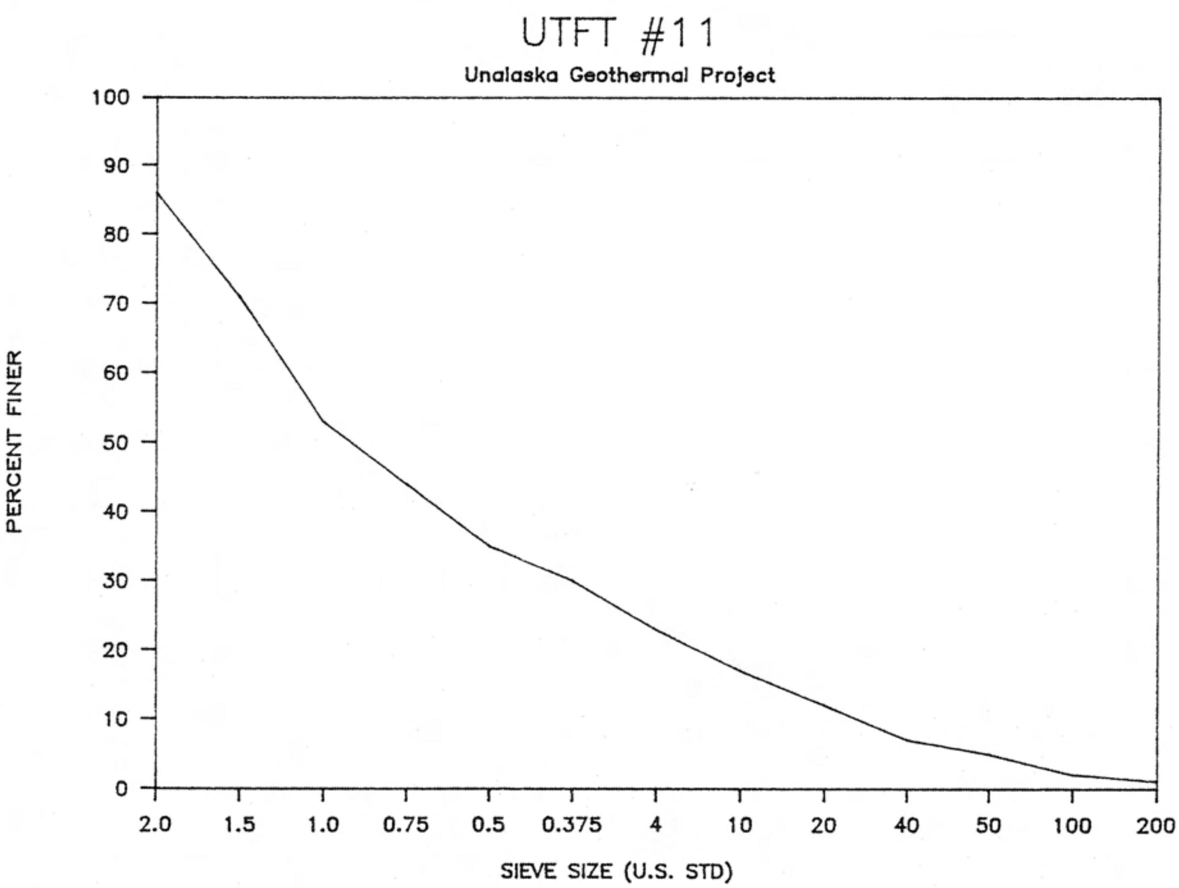


FIGURE 6.

GRAIN-SIZE ANALYSIS: MS-25.
Unalaska Geothermal Project
Sample: UTFT #10

SIEVE SIZE (U.S. STD)	(mm)	(phi)	CUMULATIVE % FINER	FRACTION % FINER
2.0	50.8	-5.67		
1.5	38.1	-5.25	100	1
1.0	25.4	-4.67	99	1
0.75	19.1	-4.26	98	11
0.5	12.7	-3.67	87	11
0.375	9.5	-3.25	76	27
4	4.76	-2.25	49	18
10	2.00	-1.00	31	13
20	0.84	0.25	18	6
40	0.42	1.25	12	1
50	0.30	1.75	11	4
100	0.149	2.75	7	4
200	0.074	3.75	3	3

GRAVEL (#4+)	51
SAND (#4-, #200+)	46
SILT+CLAY (#200-)	3
ORGANICS (WT %)	<5

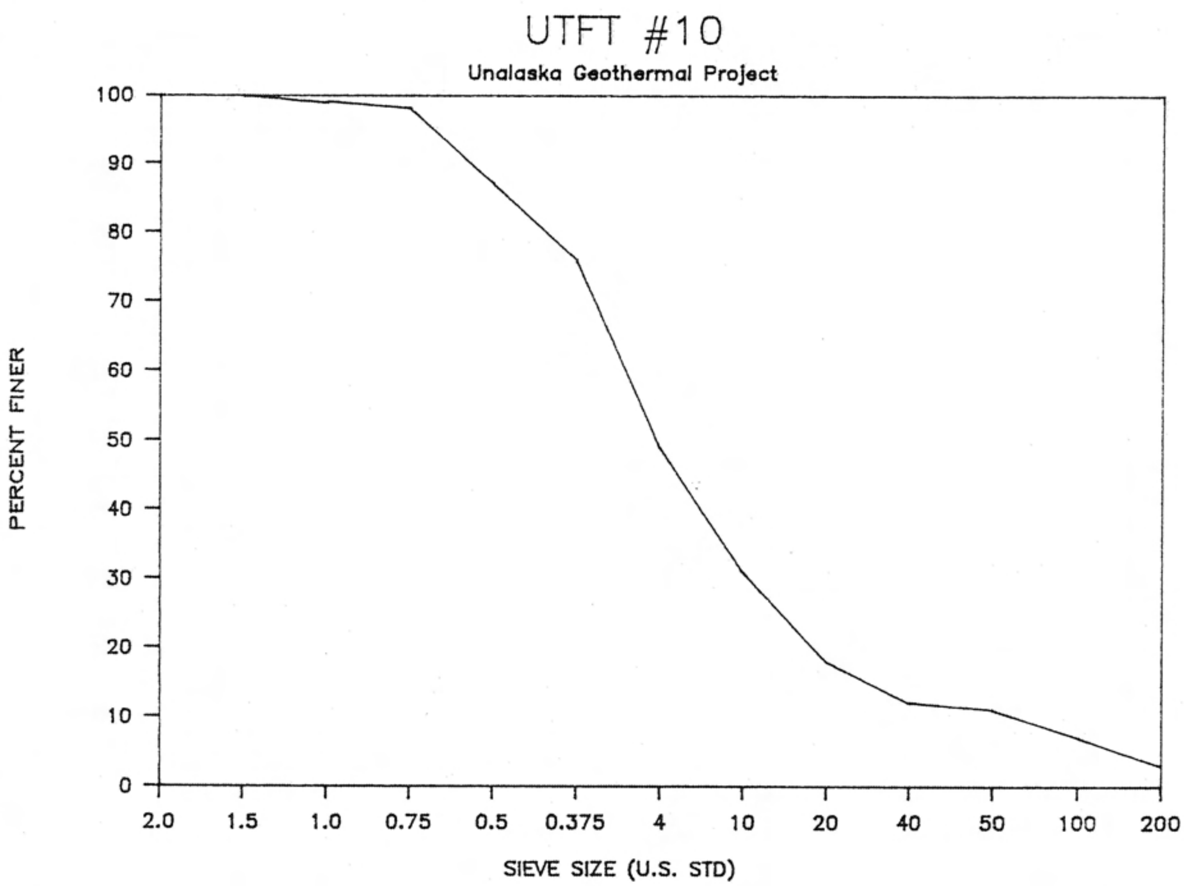


Figure 7. Typical stretch of the Makushin River valley floodplain, here near MS-17. Note backpack at right for scale.

Figure 8. Close-up view of typical Makushin River floodplain sandy gravel, here near MS-18. Pencil in foreground for scale.

Figure 9. Low altitude oblique aerial photograph of Driftwood Bay road (bottom) showing the distribution of upland pyroclastic deposits commonly containing lapilli (gravel). Also note the scattered distribution of loose volcanic boulders in the pyroclastic blanket, the larger ones being greater than 1 m diameter. Photo near MS-3.

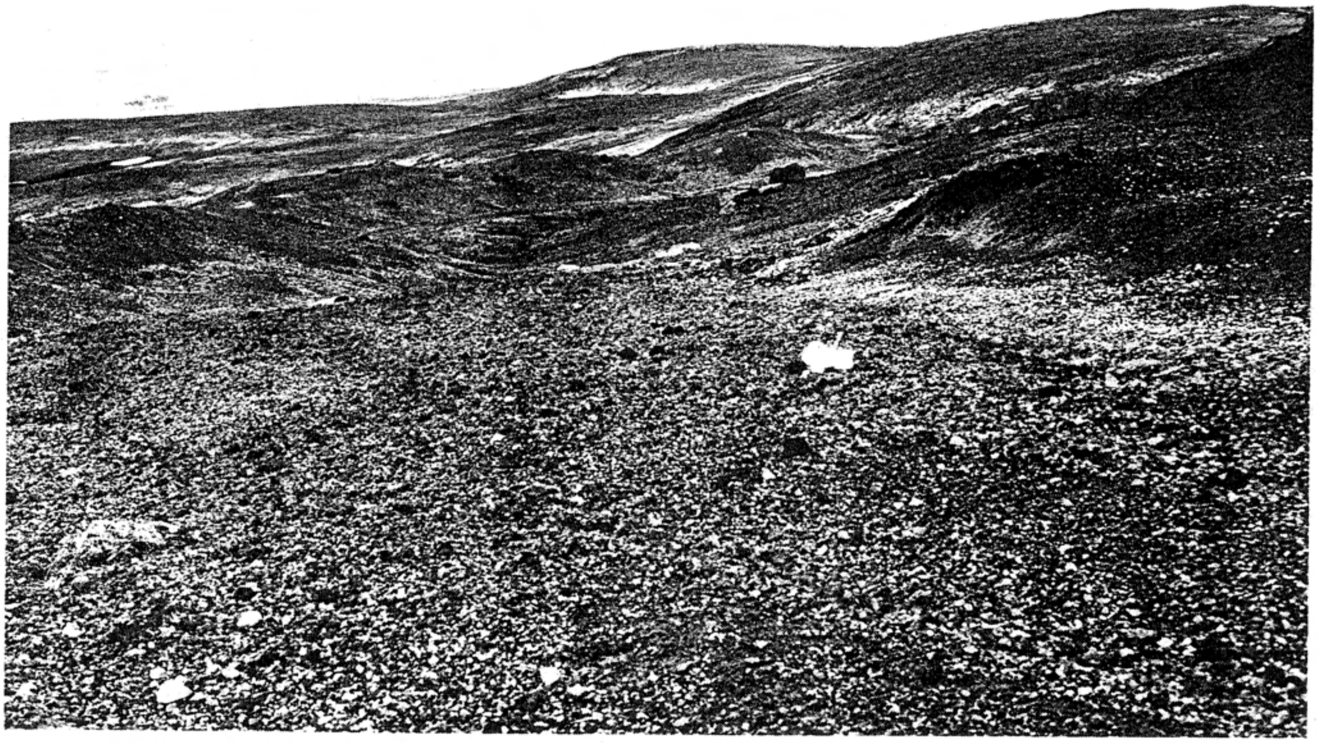


Figure 10. Photograph of partially excavated material site near MS-5. Much of the coarser aggregate is vessicular andesite and pumice in a finer aggregate of coarse to medium-fine sand (ash). Note hammer and sample bag for scale.

Figure 11. Andesite blocks being exhumed from pyroclastic lapilli-ash matrix at MS-7. These angular blocks occur immediately off of the existing road and could be easily loaded for use elsewhere as rip-rap. Note hammer on boulder for scale.

Figure 12. Exposure of blocky andesite at MS-12 suitable for rip-rap rock source. The exposure is on the existing Makushin-Driftwood road. The rock has a widely-spaced orthogonal joint system and textural uniformity ideal for construction stone quarry operations. Note hammer in foreground for scale.

MATERIAL SITE NUMBER: 1

MATERIAL TYPE:
[ ] Stone
[X] Coarse aggregate
[ ] Medium aggregate
[ ] Sand

SIZE RANGE:
[ ] Angular boulders
[ ] Boulders (to 1m) to sand
[X] Cobbles to silty sand
[ ] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref. UTFT-7

APPLICATION:
[ ] Rip-rap, buttress rock, blockfill
[X] Subgrade, coarse fill
[ ] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS:
[X] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN:
[ ] At surface
[X] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE:
[ ] Well-drained
[ ] Excavation will intercept shallow groundwater table
[X] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[ ] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[ ] Visual impact planning recommended
[X] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[X] Excellent for entire valley and upland
[ ] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 2

MATERIAL TYPE:
[ ] Stone
[ ] Coarse aggregate
[X] Medium aggregate
[ ] Sand

SIZE RANGE:
[ ] Angular boulders
[ ] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[X] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref.______________

APPLICATION:
[ ] Rip-rap, buttress rock, blockfill
[ ] Subgrade, coarse fill
[X] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS:
[X] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN:
[ ] At surface
[ ] Less than 0.5 m
[X] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE:
[X] Well-drained
[ ] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[X] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[X] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[X] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 3

MATERIAL TYPE:
[ ] Stone
[ ] Coarse aggregate
[X] Medium aggregate
[ ] Sand

SIZE RANGE:
[ ] Angular boulders
[ ] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[X] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref.____________

APPLICATION:
[ ] Rip-rap, buttress rock, blockfill
[ ] Subgrade, coarse fill
[X] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS:
[X] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN:
[ ] At surface
[ ] Less than 0.5 m
[X] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE:
[X] Well-drained
[ ] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[X] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[ ] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[X] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 4

MATERIAL TYPE:
[ ] Stone
[ ] Coarse aggregate
[X] Medium aggregate
[ ] Sand

SIZE RANGE:
[ ] Angular boulders
[ ] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[X] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref.____________

APPLICATION:
[ ] Rip-rap, buttress rock, blockfill
[ ] Subgrade, coarse fill
[X] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS:
[ ] On or adjacent to existing road
[X] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN:
[ ] At surface
[ ] Less than 0.5 m
[X] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE:
[X] Well-drained
[ ] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[X] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[ ] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[X] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 5

MATERIAL TYPE:
[ ] Stone
[ ] Coarse aggregate
[X] Medium aggregate
[ ] Sand

SIZE RANGE:
[ ] Angular boulders
[ ] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[X] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref. UTFT-5

APPLICATION:
[ ] Rip-rap, buttress rock, blockfill
[ ] Subgrade, coarse fill
[X] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS:
[X] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN:
[ ] At surface
[ ] Less than 0.5 m
[X] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE:
[X] Well-drained
[ ] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[X] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[ ] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[X] Excellent for entire valley and upland
[ ] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 6

MATERIAL TYPE:
[ ] Stone
[ ] Coarse aggregate
[X] Medium aggregate
[ ] Sand

SIZE RANGE:
[ ] Angular boulders
[ ] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[X] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref. UTFT-5

APPLICATION:
[ ] Rip-rap, buttress rock, blockfill
[ ] Subgrade, coarse fill
[X] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS:
[ ] On or adjacent to existing road
[X] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN:
[ ] At surface
[ ] Less than 0.5 m
[X] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE:
[X] Well-drained
[ ] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[X] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[ ] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[X] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 7

MATERIAL TYPE:
[X] Stone
[ ] Coarse aggregate
[ ] Medium aggregate
[ ] Sand

SIZE RANGE:
[X] Angular boulders
[ ] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[ ] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref.____________

APPLICATION:
[X] Rip-rap, buttress rock, blockfill
[ ] Subgrade, coarse fill
[ ] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS:
[X] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN:
[ ] At surface
[X] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE:
[X] Well-drained
[ ] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[X] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[ ] Visual impact planning recommended
[X] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[X] Excellent for entire valley and upland
[ ] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 8

MATERIAL TYPE: [ ] Stone
[ ] Coarse aggregate
[X] Medium aggregate
[ ] Sand

SIZE RANGE: [ ] Angular boulders
[ ] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[X] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref. UTFT-5

APPLICATION: [ ] Rip-rap, buttress rock, blockfill
[ ] Subgrade, coarse fill
[X] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS: [X] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN: [ ] At surface
[ ] Less than 0.5 m
[X] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE: [X] Well-drained
[ ] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[X] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[ ] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[X] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[X] Excellent for entire valley and upland
[ ] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 9

MATERIAL TYPE:
[ ] Stone
[ ] Coarse aggregate
[X] Medium aggregate
[ ] Sand

SIZE RANGE:
[ ] Angular boulders
[ ] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[X] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref. UTFT-4

APPLICATION:
[ ] Rip-rap, buttress rock, blockfill
[ ] Subgrade, coarse fill
[X] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS:
[X] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN:
[ ] At surface
[ ] Less than 0.5 m
[X] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE:
[X] Well-drained
[ ] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[X] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[ ] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[X] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[X] Excellent for entire valley and upland
[ ] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 10

MATERIAL TYPE:
[ ] Stone
[ ] Coarse aggregate
[X] Medium aggregate
[ ] Sand

SIZE RANGE:
[ ] Angular boulders
[ ] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[X] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref. UTFT-3

APPLICATION:
[ ] Rip-rap, buttress rock, blockfill
[ ] Subgrade, coarse fill
[X] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS:
[X] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN:
[ ] At surface
[ ] Less than 0.5 m
[X] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE:
[X] Well-drained
[ ] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[X] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[ ] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[X] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[X] Excellent for entire valley and upland
[ ] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 11

MATERIAL TYPE: [ ] Stone
[ ] Coarse aggregate
[ ] Medium aggregate
[X] Sand

SIZE RANGE: [ ] Angular boulders
[ ] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[ ] Gravel to silty sand
[X] Silty sand

Mechanical Analysis Ref.____________

APPLICATION: [ ] Rip-rap, buttress rock, blockfill
[ ] Subgrade, coarse fill
[ ] Supergrade, road metal
[X] Fine aggregate for use with binding agents

ACCESS: [ ] On or adjacent to existing road
[X] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN: [ ] At surface
[X] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE: [X] Well-drained
[ ] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[ ] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[X] Minor slope stability problem at site
[X] Visual impact planning recommended
[X] Long haulage distances to anticipated application
[X] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[X] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 12

MATERIAL TYPE:
[X] Stone
[ ] Coarse aggregate
[ ] Medium aggregate
[ ] Sand

SIZE RANGE:
[X] Angular boulders
[ ] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[ ] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref.____________

APPLICATION:
[X] Rip-rap, buttress rock, blockfill
[ ] Subgrade, coarse fill
[ ] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS:
[X] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN:
[X] At surface
[ ] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE:
[X] Well-drained
[ ] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[ ] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[X] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[X] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[X] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[X] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 13

MATERIAL TYPE:
[ ] Stone
[ ] Coarse aggregate
[X] Medium aggregate
[ ] Sand

SIZE RANGE:
[ ] Angular boulders
[ ] Boulders (to 1m) to sand
[X] Cobbles to silty sand
[ ] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref.______________

APPLICATION:
[ ] Rip-rap, buttress rock, blockfill
[ ] Subgrade, coarse fill
[X] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS:
[X] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN:
[ ] At surface
[X] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE:
[ ] Well-drained
[ ] Excavation will intercept shallow groundwater table
[X] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[ ] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[X] Minor slope stability problem at site
[ ] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[X] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 14

MATERIAL TYPE: [ ] Stone
[X] Coarse aggregate
[ ] Medium aggregate
[ ] Sand

SIZE RANGE: [ ] Angular boulders
[X] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[ ] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref.____________

APPLICATION: [ ] Rip-rap, buttress rock, blockfill
[X] Subgrade, coarse fill
[ ] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS: [ ] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[X] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN: [ ] At surface
[X] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE: [ ] Well-drained
[X] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[ ] Lateral and/or vertical extent of resource limited
[X] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[ ] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[ ] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[X] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 15

MATERIAL TYPE: [ ] Stone
[X] Coarse aggregate
[ ] Medium aggregate
[ ] Sand

SIZE RANGE: [ ] Angular boulders
[ ] Boulders (to 1m) to sand
[X] Cobbles to silty sand
[ ] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref.____________

APPLICATION: [ ] Rip-rap, buttress rock, blockfill
[X] Subgrade, coarse fill
[ ] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS: [ ] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[X] Valley margin, will require access road and drainage control

OVERBURDEN: [ ] At surface
[X] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE: [ ] Well-drained
[ ] Excavation will intercept shallow groundwater table
[X] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[ ] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[X] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[ ] Good for most of valley
[X] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 16

MATERIAL TYPE:
- [ ] Stone
- [X] Coarse aggregate
- [ ] Medium aggregate
- [ ] Sand

SIZE RANGE:
- [ ] Angular boulders
- [ ] Boulders (to 1m) to sand
- [X] Cobbles to silty sand
- [ ] Gravel to silty sand
- [ ] Silty sand

Mechanical Analysis Ref.____________

APPLICATION:
- [ ] Rip-rap, buttress rock, blockfill
- [X] Subgrade, coarse fill
- [ ] Supergrade, road metal
- [ ] Fine aggregate for use with binding agents

ACCESS:
- [ ] On or adjacent to existing road
- [ ] Near road or proposed road, requires some access construction
- [ ] On floodplain, may require temporary access road on fill
- [X] Valley margin, will require access road and drainage control

OVERBURDEN:
- [ ] At surface
- [X] Less than 0.5 m
- [ ] 0.5 to 2.0 m
- [ ] Greater than 2.0 m

DRAINAGE:
- [ ] Well-drained
- [ ] Excavation will intercept shallow groundwater table
- [X] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
- [ ] Lateral and/or vertical extent of resource limited
- [ ] Active floodplain, buffer structures will be necessary
- [ ] Serious slope stability problem in or adjacent to site
- [X] Minor slope stability problem at site
- [ ] Visual impact planning recommended
- [X] Long haulage distances to anticipated application
- [ ] High elevation suggests short seasonal availability
- [ ] Work site generally dangerous to operators

GENERAL RATING:
- [ ] Excellent for entire valley and upland
- [ ] Good for most of valley
- [ ] Good if setup for crush and screen, otherwise fair
- [X] Fair except for local use
- [ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 17

MATERIAL TYPE: [ ] Stone
[X] Coarse aggregate
[ ] Medium aggregate
[ ] Sand

SIZE RANGE: [ ] Angular boulders
[X] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[ ] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref.______________

APPLICATION: [ ] Rip-rap, buttress rock, blockfill
[X] Subgrade, coarse fill
[ ] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS: [ ] On or adjacent to existing road
[X] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN: [X] At surface
[ ] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE: [ ] Well-drained
[X] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[ ] Lateral and/or vertical extent of resource limited
[X] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[ ] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[ ] Good for most of valley
[X] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 18

MATERIAL TYPE:
[ ] Stone
[X] Coarse aggregate
[ ] Medium aggregate
[ ] Sand

SIZE RANGE:
[ ] Angular boulders
[X] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[ ] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref.____________

APPLICATION:
[ ] Rip-rap, buttress rock, blockfill
[X] Subgrade, coarse fill
[ ] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS:
[ ] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[X] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN:
[X] At surface
[ ] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE:
[ ] Well-drained
[X] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[ ] Lateral and/or vertical extent of resource limited
[X] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[ ] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[ ] Good for most of valley
[X] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 19

MATERIAL TYPE: [ ] Stone
[X] Coarse aggregate
[ ] Medium aggregate
[ ] Sand

SIZE RANGE: [ ] Angular boulders
[X] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[ ] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref.____________

APPLICATION: [ ] Rip-rap, buttress rock, blockfill
[X] Subgrade, coarse fill
[ ] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS: [ ] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[X] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN: [X] At surface
[ ] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE: [ ] Well-drained
[X] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[ ] Lateral and/or vertical extent of resource limited
[X] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[ ] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[X] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 20

MATERIAL TYPE: [ ] Stone
[X] Coarse aggregate
[ ] Medium aggregate
[ ] Sand

SIZE RANGE: [ ] Angular boulders
[ ] Boulders (to 1m) to sand
[X] Cobbles to silty sand
[ ] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref.____________

APPLICATION: [ ] Rip-rap, buttress rock, blockfill
[X] Subgrade, coarse fill
[ ] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS: [ ] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[X] Valley margin, will require access road and drainage control

OVERBURDEN: [ ] At surface
[X] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE: [ ] Well-drained
[ ] Excavation will intercept shallow groundwater table
[X] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[ ] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[X] Minor slope stability problem at site
[X] Visual impact planning recommended
[X] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[ ] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[X] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 21

MATERIAL TYPE: [ ] Stone
[X] Coarse aggregate
[ ] Medium aggregate
[ ] Sand

SIZE RANGE: [ ] Angular boulders
[ ] Boulders (to 1m) to sand
[X] Cobbles to silty sand
[ ] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref. UTFT-21

APPLICATION: [ ] Rip-rap, buttress rock, blockfill
[X] Subgrade, coarse fill
[X] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS: [ ] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[X] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN: [X] At surface
[ ] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE: [ ] Well-drained
[X] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[ ] Lateral and/or vertical extent of resource limited
[X] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[ ] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[X] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 22

MATERIAL TYPE:
[ ] Stone
[X] Coarse aggregate
[ ] Medium aggregate
[ ] Sand

SIZE RANGE:
[ ] Angular boulders
[ ] Boulders (to 1m) to sand
[X] Cobbles to silty sand
[ ] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref.____________

APPLICATION:
[ ] Rip-rap, buttress rock, blockfill
[X] Subgrade, coarse fill
[ ] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS:
[ ] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[X] Valley margin, will require access road and drainage control

OVERBURDEN:
[ ] At surface
[X] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE:
[ ] Well-drained
[ ] Excavation will intercept shallow groundwater table
[X] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[ ] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[X] Minor slope stability problem at site
[X] Visual impact planning recommended
[X] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[ ] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[X] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 23

MATERIAL TYPE:
[ ] Stone
[ ] Coarse aggregate
[X] Medium aggregate
[ ] Sand

SIZE RANGE:
[ ] Angular boulders
[ ] Boulders (to 1m) to sand
[X] Cobbles to silty sand
[ ] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref.____________

APPLICATION:
[ ] Rip-rap, buttress rock, blockfill
[X] Subgrade, coarse fill
[X] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS:
[ ] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[X] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN:
[ ] At surface
[X] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE:
[ ] Well-drained
[X] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[ ] Lateral and/or vertical extent of resource limited
[X] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[ ] Visual impact planning recommended
[X] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[ ] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[X] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 24

MATERIAL TYPE: [ ] Stone
[X] Coarse aggregate
[ ] Medium aggregate
[ ] Sand

SIZE RANGE: [ ] Angular boulders
[ ] Boulders (to 1m) to sand
[X] Cobbles to silty sand
[ ] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref._____________

APPLICATION: [ ] Rip-rap, buttress rock, blockfill
[X] Subgrade, coarse fill
[ ] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS: [ ] On or adjacent to existing road
[ ] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[X] Valley margin, will require access road and drainage control

OVERBURDEN: [ ] At surface
[X] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE: [ ] Well-drained
[ ] Excavation will intercept shallow groundwater table
[X] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[X] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[X] Minor slope stability problem at site
[X] Visual impact planning recommended
[X] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[ ] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[X] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 25

MATERIAL TYPE: [ ] Stone
[ ] Coarse aggregate
[X] Medium aggregate
[ ] Sand

SIZE RANGE: [ ] Angular boulders
[ ] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[X] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref. UTFT-10

APPLICATION: [ ] Rip-rap, buttress rock, blockfill
[ ] Subgrade, coarse fill
[X] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS: [ ] On or adjacent to existing road
[X] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN: [X] At surface
[ ] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE: [ ] Well-drained
[X] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[ ] Lateral and/or vertical extent of resource limited
[X] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[ ] Minor slope stability problem at site
[X] Visual impact planning recommended
[ ] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[ ] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[X] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

MATERIAL SITE NUMBER: 26

MATERIAL TYPE: [X] Stone
[ ] Coarse aggregate
[ ] Medium aggregate
[ ] Sand

SIZE RANGE: [X] Angular boulders
[ ] Boulders (to 1m) to sand
[ ] Cobbles to silty sand
[ ] Gravel to silty sand
[ ] Silty sand

Mechanical Analysis Ref.____________

APPLICATION: [X] Rip-rap, buttress rock, blockfill
[ ] Subgrade, coarse fill
[ ] Supergrade, road metal
[ ] Fine aggregate for use with binding agents

ACCESS: [ ] On or adjacent to existing road
[X] Near road or proposed road, requires some access construction
[ ] On floodplain, may require temporary access road on fill
[ ] Valley margin, will require access road and drainage control

OVERBURDEN: [X] At surface
[ ] Less than 0.5 m
[ ] 0.5 to 2.0 m
[ ] Greater than 2.0 m

DRAINAGE: [X] Well-drained
[ ] Excavation will intercept shallow groundwater table
[ ] Surface runoff will enter excavation unless controlled

RESTRICTIONS:
[ ] Lateral and/or vertical extent of resource limited
[ ] Active floodplain, buffer structures will be necessary
[ ] Serious slope stability problem in or adjacent to site
[X] Minor slope stability problem at site
[X] Visual impact planning recommended
[X] Long haulage distances to anticipated application
[ ] High elevation suggests short seasonal availability
[X] Work site generally dangerous to operators

GENERAL RATING:
[ ] Excellent for entire valley and upland
[X] Good for most of valley
[ ] Good if setup for crush and screen, otherwise fair
[ ] Fair except for local use
[ ] "Last Resort" site, likely not cost-effective

SEISMIC EXPOSURE OF THE MAKUSHIN SITE

John N. Davies, Lorraine W. Wolf and Charlotte Rowe

Introduction

The proposed site on the flanks of Makushin Volcano is exposed to a serious level of seismic hazard. This should not come as a surprise, given the setting of the site on an active volcano in one of the world's most active earthquake belts. We have evaluated this hazard in the standard way, essentially following the Cornell method and utilizing a set of computer programs developed by Woodward-Clyde Consultants under contract to NOAA during the Outer Continental Shelf Environmental Assessment Program.

This technique independently characterizes the seismicity on a suite of sources, specifies the attenuation of the ground motion from earthquakes on those sources to the site, and calculates the expected acceleration at the site due to the combination of all sources. This acceleration is given as a value which is not expected to be exceeded at a specified level of probability within a particular exposure period.

The best estimate of this value for the Makushin site is about 32% g, at a 90% probability of non-exceedence during a 50-year exposure period. By far, the most significant contributions to this exposure value come from earthquakes of magnitude six and seven in the crustal region nearby the site. Larger events on the main thrust zone contribute very little to the seismic hazard at the site unless relatively undamped structures with long (10's of seconds) natural periods are under consideration.

Seismotectonic Setting

The proposed site is on the flanks of Makushin Volcano in the Aleutian Arc (Figure 1). The volcanic hazards are considered elsewhere in this report. No special seismic hazard has been attributed to the volcano itself; we assume that large volcanogenic earthquakes are relatively rare in comparison to the crustal events surrounding Makushin.

The Aleutian Arc is one of the most active earthquake zones in the world with about 11% of the world's earthquakes occurring there. In the past 90 years three of the ten largest earthquakes in the world have occurred in the Aleutian Arc (Davies, 1986). One of these, the Andreanoff-Fox Islands earthquake of 1957, ruptured the plate boundary seaward of Makushin (Sykes, 1971). It is possible, however, that this event did not rupture the entire main thrust zone in the vicinity of Makushin and that a seismic gap exists here (House and others, 1981). If this is the case, then one the highest potentials for a great earthquake within the Aleutian Arc in the next 20 years could exist here (Jacob, 1984).

The seismicity of the Unalaska region recently has been described in detail by Boyd and Jacob (1986), Jacob and Boyd (1985), and Davison and Scholz (1985). A site, design and cost study for a runway extension at the Unalaska airport (Dames and Moore, 1980) includes a seismic hazard analysis by Neville Donovan. Other sources of earthquake data for this region are the various cataloges compiled and assembled by the National Earthquake Information Center (NEIC) and the lists of Abe and Noguchi compiled for Alaska by Davies (1986).

We have made use of each of the sources listed above and have compiled our own comprehensive listing of all earthquakes of magnitude greater than or equal to four within 300 km of Makushin. This file exists on tape at the Seismology Laboratory of the Geophysical Institute, University of Alaska, Fairbanks. A subset of those events greater than or equal to five is listed in the appendix to this section and is the basis for the seismic hazard analysis which follows.

A histogram illustrating the number of events greater than or equal to magnitude 5.0 per year from 1900 to 1986 is shown in Figure 2. Here we can see that this list is complete back to 1958; we exclude 1957 since it is contaminated with so many aftershocks of the Andreanoff-Fox Islands event. Therefore, we take the data from the period 1958-1986 as our instrumental seismicity catalog for the Makushin region.

The distribution of these earthquakes by magnitude is shown in Figure 3. The total number of events is 476. Both the raw number of events per half-magnitude window and the cumulative number larger than the lower limit for each window is plotted in the histogram. The b-value for the data between magnitudes 5.0 and 7.0 is 1.1; this value is identical to that obtained by Boyd and Jacob (1986).

Hazard Calculation

In calculating the seismic hazard at the Makushin site we have used the set of programs SEISMIC.EXPOSURE developed by Woodward-Clyde Consultants (1982) under the Outer Continental Shelf Environmental Assessment Program. While this analysis package allows the simulation of the time dependent hazard expected in a seismic gap environment, we have not made use of this feature. Our analysis, therefore, follows in broad terms the now standard procedure developed by Cornell (1968).

This procedure consists of four basic steps: (1) describing the geometry of the sources which may affect the site, (2) determining the recurrence rates for earthquakes of various magnitudes on each of those sources, (3) specifying the attenuation relations which describe the acceleration as a function of distance and magnitude from each earthquake, and (4) calculating the acceleration value which is expected to be the upper limit for the site at a specified level of probability within a particular exposure period. For all of our calculations we specify a 90% probability of non-exceedence and a 50-year exposure period.

We represent the earthquake sources by four zones, all of which are aligned along the strike of the arc (determined by the positions of the major volcanic centers) and centered on Makushin Volcano in respect to their position along the arc (Figure 1). The geometry of these zones in cross-section has been modeled using the hypocentral cross-section given in Figure 3 of Boyd and Jacob (1986).

The main thrust zone is represented by a plane 600 km long and 135 km wide, dipping approximately 12 degrees arcward from a depth of 5 km near the trench to 30 km at the downdip edge. These dimensions are chosen so that SEISMIC.EXPOSURE can accommodate an event as large as Mw = 9.5.

The Wadati-Benioff zone is represented by a plane 200 km long and 150 km wide, dipping approximately 49 degrees arcward from a depth of 40 km near the bottom of the main thrust zone to a depth of 150 km beneath the island arc. This plane is divided into a shallow zone and a deep zone at a depth of 95 km so that the intraplate seismicity can be separately specified to better match the actual distribution of hypocenters with depth. By far, most of the earthquakes of the Wadati-Benioff zone occur at depths less than 95 km.

The crustal seismicity (including the volcanogenic events) is projected onto a gently dipping plane 100 km long and 175 km wide which is 5 km deep near the trench and 15 km deep beneath the arc.

Thus, the four seismic source zones are: (1) the main thrust zone (MTZ), (2) the deep intraplate zone (DIZ), (3) the shallow intraplate zone (SIZ), and (4) the random crustal zone (RCZ).

The seismicity of the MTZ is modeled in two basic ways. The first is as a characteristic source; i.e., one which ruptures only in a given size earthquake with no events of different size. The second is as a Guttenberg-Richter source; i.e., one on which the distribution of magnitudes is governed by the Guttenberg-Richter relation:

$$\log N = A - bM. \qquad (1)$$

In the latter case the A-value is determined by assuming that there will be one characteristic earthquake during the average recurrence period associated with that event. This is a somewhat conservative assumption since the smaller events duplicate some of the events assigned to the RCZ. In our standard case we assume there will be one earthquake of magnitude 8.25 per 200 km of plate boundary per 50-year period. For the Guttenberg-Richter case we assume the b-value to be 1.1 (see also Figure 3). These values are taken from Boyd and Jacob (1986) and Davison and Scholz (1985).

We model the seismicity on the other three sources by pro-rating the events given in the appendix onto each zone according to depth (Table 1). The period 1958 to 1986 is selected since this data set appears complete for events of magnitude five and larger by inspection of Figure 2. We then have the number of events with magnitude greater than or equal to five over a 29-year period for each zone. Assuming a b-value of 1.1, the A-value can be calculated from equation (1) and then this relation can be used to specify the distribution of magnitudes on these source zones.

TABLE 1

Number of events of M > 5.0, 1958-1986

Seismic Zone	Depth Range(km)	Number of Events
RCZ	0-35	303
SIZ	35-95	173
DIZ	95-200	0
	total	476

The SEISMIC.EXPOSURE programs allow the use of two attenuation relations which are applied depending on the depth of the earthquake. We chose the OASES A and B relations (Figure 4) for the present calculation, as they are representative of the range of relations which have been used in Alaska (Wolf and Davies, ms in prep.). These relations are as follows:

type A $a = [191 \exp(0.823 M)] / [(R + C) \exp(1.56)]$ (2)

type B $a = [284 \exp(0.587 M)] / [(R + C) \exp(1.05)]$ (3)

where $C = 0.864 \exp(0.463 M)$, R = dist. to rupture (4)

We have made a "standard" calculation in which the values of all of the input variables are chosen to represent our best estimate of the actual seismic hazard at Makushin. Then we have made a great number of sensitivity calculations in which we have varied one or two of these values to test how sensitive the result is to the value of the input variable chosen. A selection of these results is presented in Table 2.

TABLE 2

Acceleration values for which there is a 90% probability of non-exceedence in 50 years at the Makushin site

Case	Description	Accel (%g)
1.	Standard/Char MTZ/A Atten	32
2.	2xSeis/Char MTZ/A Atten	37
3.	Standard/G-R MTZ/A Atten	32
4.	MM 6.5 RCZ/Char MTZ/A Atten	29
5.	7.5 km RCZ/Char MTZ/A Atten	41
6.	Standard/Char MTZ/B Atten	47-64
7.	b = .67/Char MTZ/A Atten	41
8.	9.5/290 MTZ/Char MTZ/A Atten	32
9.	9.5/50 MTZ/Char MTZ/A Atten	32

Definitions:

Standard - the source zones are as described above and as shown in Figure 1. The seismicity on the RCZ, SIZ, & DIZ are determined from Table 1, with a b-value of 1.1 and maximum magnitudes of 7.5, 7.5, & 7.0, respectively.

Char MTZ - Characteristic MTZ as defined above with one M = 8.25 event every 50 years per 200 km of plate boundary.

A Atten - OASES Attenuation relation A, mean plus three sigma.

2xSeis - the standard seismicity is doubled on all four zones.

G-R MTZ - Guttenberg-Richter MTZ as defined above with one M = 8.25 event every 50 years per 200 km of plate boundary and smaller events distributed according to magnitude by the Guttenberg-Richter relation.

MM 6.5 RCZ - the maximum magnitude on the RCZ is reduced from 7.5 to 6.5.

7.5 km RCZ - the maximum depth of the RCZ is reduced from 15 km to 7.5.

B Atten - OASES attenuation relation B, mean plus one and mean plus three sigma.

b = .67 - the b-value used to calculate the standard seismicity is reduced from 1.1 to 0.67.

9.5/290 MTZ - The characteristic earthquake on the MTZ is changed to one M = 9.5 event every 290 years per 600 km of plate boundary.

9.5/50 MTZ - The characteristic earthquake on the MTZ is changed to one M = 9.5 event every 50 years per 600 km of plate boundary.

Discussion

Case 1, which is our best estimate of the seismic hazard at Makushin yields an acceleration of 32% g. Recall that this acceleration is an estimated value which is not expected to be exceeded at the 90% probability level in an exposure period of 50 years. This case uses the source zone geometry described above and shown in Figure 1, with the RCZ at about 15km depth beneath the site. The seismicity is pro-rated by depth and projected onto the source zones as indicated in Table 1. By far the majority of the events are assigned to the RCZ. This factor combined with the proximity of the RCZ to the site, makes this zone the most important source of seismic exposure for the Makushin site. In fact, for accelerations of about 33% g the RCZ contributes about 99% of the ground motion; at about 10% g it contributes about 94% with the remainder more or less evenly divided among the other source zones.

The importance of the RCZ can also be seen in the results for cases 2, 4, 5 and 7. In case 2, doubling the total seismicity rate (which had its effect primarily through the increase on the RCZ) increased the acceleration expected from 32% to 37% g. Case 4 reduces the maximum magnitude allowed on the RCZ from M = 7.5 to M = 6.5 and the expected acceleration is correspondingly reduced from 32% to 29% g. Case 5 decreases the depth of the down-dip edge of the RCZ from 15 to 7.5 km and correspondingly increases the acceleration from 32% to 41% g. Case 7 is meant to test the sensitivity to the b-value, but what is actually done here is to increase (unrealistically, since the actual distribution of events with magnitude matches very closely the b-slope of 1.1; Figure 3) the number of larger magnitude events on the RCZ: the effect is about the same as halving the depth to the RCZ.

In contrast to these clear results, making large changes in the way in which the seismicity of the MTZ is characterized (cases 3, 8 and 9) had relatively little effect on the final acceleration values.

The most important variable of all is illustrated in case 6. The choice of attenuation function can cause a factor of two change in the expected acceleration, in this case increasing it from 32% to 64% g! This is an extreme result since we have applied the type b relation (eqn 3) at the 3-sigma level to all of the events regardless of depth, where as it was intended to apply only to Wadati-Benioff zone events deeper than some cut-off depth such as 20 km. The use of a cut-off depth which falls within the depth range of the RCZ results in an estimate of acceleration which falls correspondingly between 32% and 64% g.

In case 6 we have also changed the treatment of variance of the acceleration data from using the mean plus

3-sigma to the mean plus 1-sigma case; this results in decreasing the expected acceleration from 64% to 47% g.

Conclusions

The factors which affect the estimation acceleration at the Makushin site in decreasing order of importance are:

1.	the attenuation relation	32%
2.	the treatment of variance	17%
3.	the depth of the RCZ	9%
4.	doubling the seismicity on the RCZ	5%
5.	decreasing the max. mag. on the RCZ	3%

In our preferred solution we have made somewhat compensating assumptions regarding the problem of the choice of attenuation relation and the treatment of variance. The choice of the type a relation (eqn 2) tends to produce a low result while the choice of using the mean plus 3-sigma treatment tends to increase it. Similarly, we have made compensating assumptions in terms of the maximum magnitude earthquake and the depth of that event on the RCZ. The final result is not affected by reasonable choices of seismicity on the MTZ, DIZ and SIZ and little affected by that on the RCZ.

Therefore we recommend that the preferred solution of 32% g be used in the feasibility studies. This value is reasonably conservative for relatively short period structures. If any structures are contemplated which have a long (about 10 second) natural period, then the low accelerations from the larger events on the MTZ should be re-evaluated.

We have assumed that no large events will occur on the volcano. Given this assumption and for other reasons, it is strongly recommended that a small network of seismic stations be installed to monitor the activity of Makushin Volcano.

Acknowledgements

Hans Pulpan spent countless hours adapting the SEISMIC.EXPOSURE programs to the Geophysical Institute VAX and many more coaching us on their use and discussing our results; for all of which we are extremely grateful. Bruce Presgrave of NEIC ran several searches of their data bases and instructed us in the use of their HDS software for remote access to the hypocenter files for which we are most appreciative.

References

Boyd, T. M. and K. H. Jacob (1986). Seismicity of the Unalaska Region, Alaska, Bull. Seis. Soc. Am., 76, pp 463-481.

Cornell, C. A. (1968). Engineering Seismic Risk Analisis, Bull. Seis. Soc. Am., 58, pp 1583-1606.

Dames and Moore (1980). Site, Design and Cost Studies for feasibility Assessment of an Offshore Runway extension at Unalaska Airport, Alaska, report prepared for the Alaska Department of Transportation and Public Facilities, by Dames and Moore, 800 Cordova, Suite 101, Anchorage, Alaska 99501, Appendix E.

Davies, J. N. (1986). Seismicity, Seismic Gaps and Earthquake Potential in Alaska, in A Workshop on "Evaluation of Regional and Urban Earthquake Hazards and Risk in Alaska", W. W. Hays and P. L. Gori, editors, Proceedings of Conference XXXI, USGS Redbook Series, Open-File Report 86-79, pp 43-63.

Davison, C. D. and C. H. Scholz (1985). Frequency-moment Distribution of Earthquakes in the Aleutian Arc: A Test of the Characteristic Earthquake Model, Bull. Seis. Soc. Am., 75, pp 1349-1361.

House, L., L. Sykes, J. Davies, and K. Jacob (1981). Identification of a Possible Seismic Gap near Unalaska Island, Eastern Aleutians, Alaska, in Earthquake Prediction - An International Review, Maurice Ewing Series, 4, edited by D. W. Simpson and P. G. Richards, AGU Washington D.C., pp 81-92.

Jacob, K. H. (1984). Estimates of Long-term Probabiities for Future Great Earthquakes in the Aleutians, Geophys. Res. Lett., 11, pp 295-298.

Jacob, K. H. and T. M. Boyd (1985). Analysis of Data from a Temporary Seismic Network on Unalaska Island, final technical report to the Alaska Division of Geological and Geophysical Surveys, PDF85-59, 47p

Joyner, W. B. and D. M. Boore (1981). Peak Horizontal Acceleration and Velocity from Strong Motion Records inlcuding Records from the 1979 Imperial Balley, California, Earthquake, Bull. Seis. Soc. Am., 71, pp 2011-2038

OASES (1978). Offshore Alaska Seismic Exposure Study, Woodward-Clyde Consultants, San Francisco, CA.

Sykes, L. (1971). Aftershock Zones of Great Earthquakes, Seismicity Gaps, and Earthquake Prediction for Alaska and the Aleutians, Jour. Geophys. Res., 76, pp 8021 -8041.

Woodward-Clyde Consultants (1982). Development and Initial Application of Software for Seismic Exposure Evaluation, Vol. 1, Software Description, prepared for the National Oceanic and Atmospheric Administration by Woodward-Clyde Consultants, Three Embarcadero Center, Suite 700, San Francisco, CA 94111.

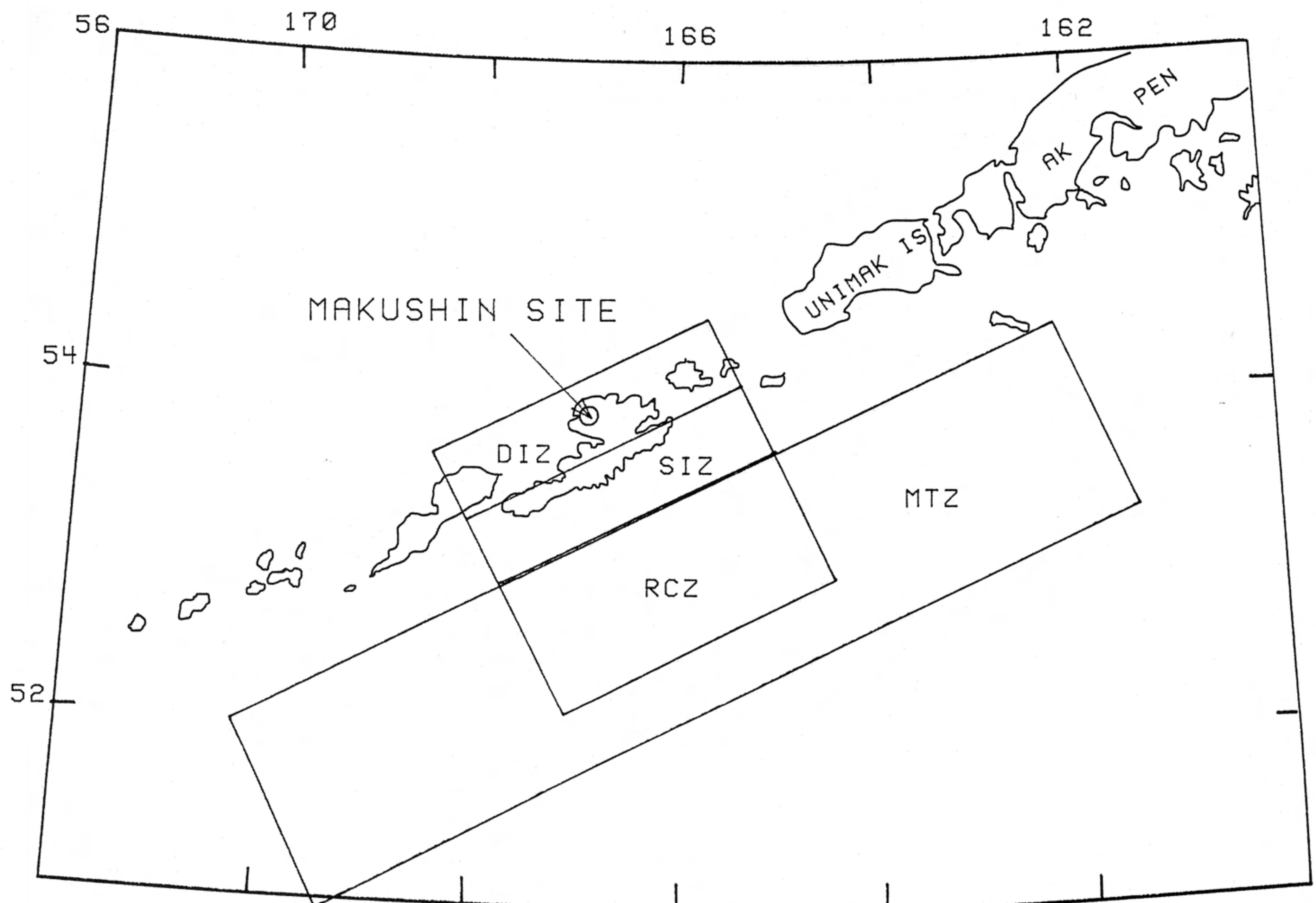
FIGURE CAPTIONS

Figure 1. Proposed Makushin site in Aleutian Arc. Outlined areas represent earthquake source zones: Main Thrust Zone (MTZ), Shallow Intraplate Zone (SIZ), Deep Intraplate Zone (DIZ), Random Crustal Zone (RCZ).

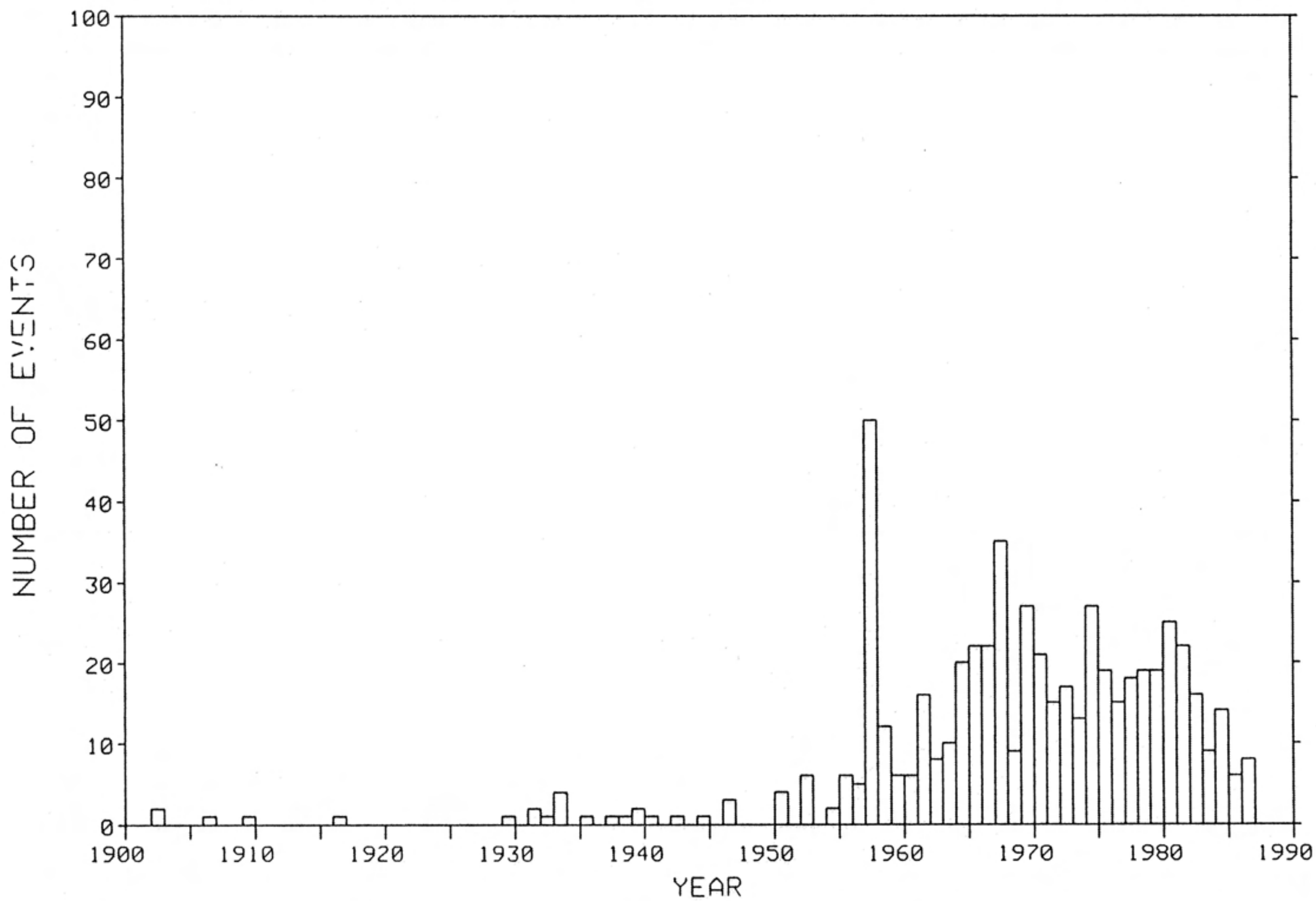
Figure 2. Yearly event count for earthquakes with $M \geq 5.0$ from 1900 to 1986 within 600 km of the Makushin site.

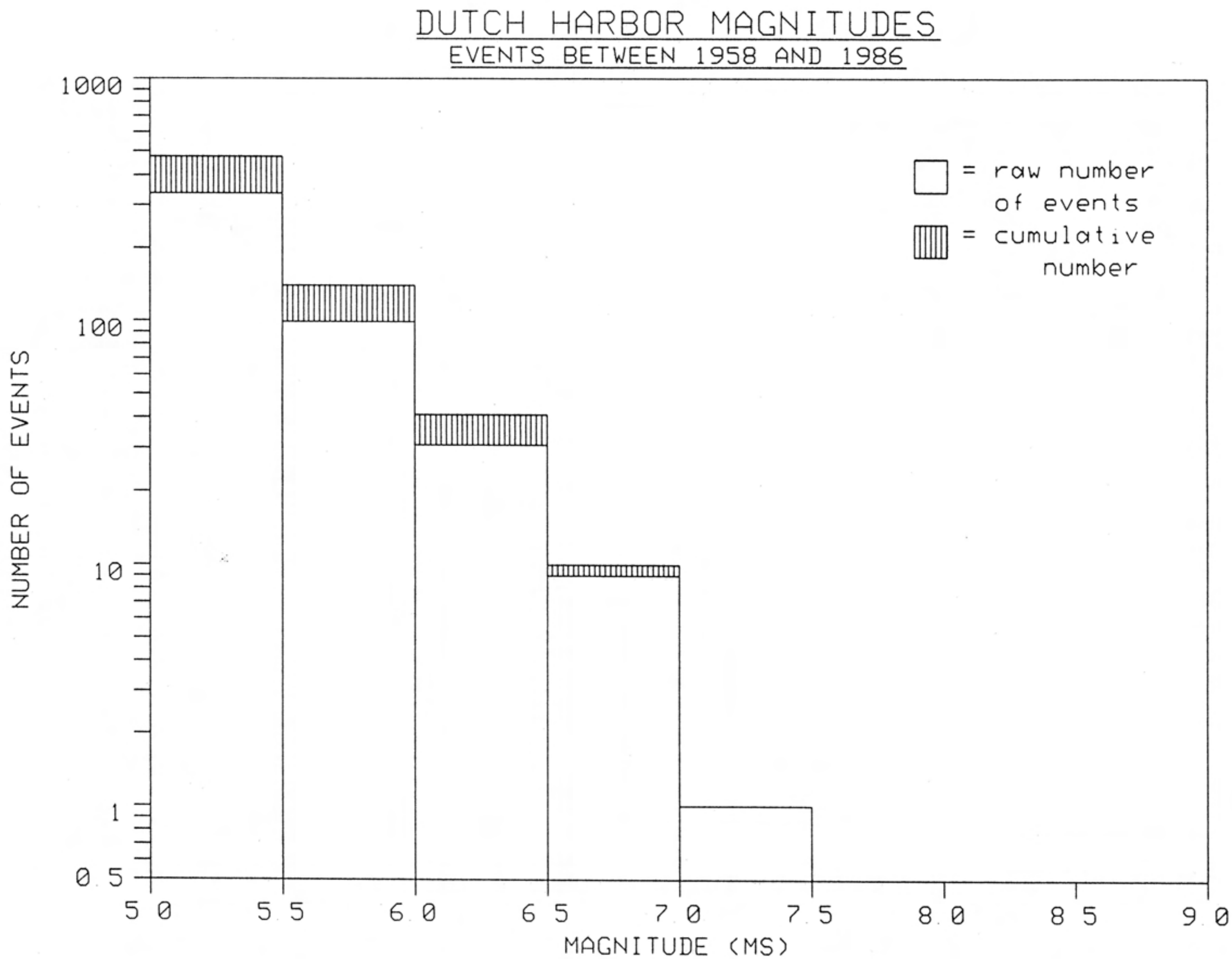
Figure 3. Number of events in Makushin region with $M \geq 5.0$ for the 29-year period (1958-1986) used in exposure calculations.

Figure 4. Comparison of attenuation curves for $M_s = 7.5$ using OASES types A and B (March, 1978) and Joyner and Boore (1981).

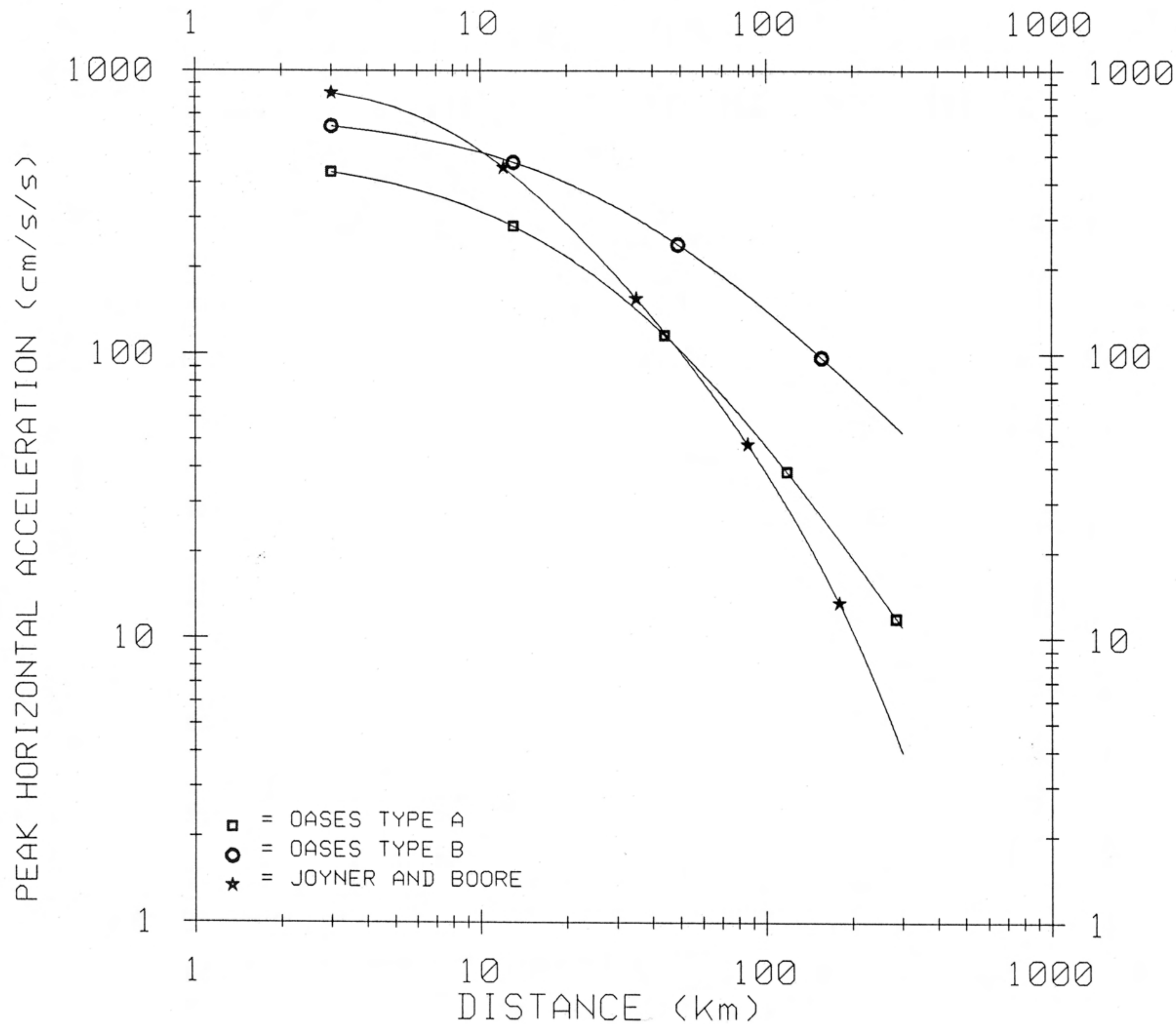

56
170
166
162
54
52
AK PEN
UNIMAK IS
MAKUSHIN SITE
DIZ
SIZ
RCZ
MTZ

YEARLY EVENT COUNTS
MAGNITUDES GREATER THAN OR EQUAL TO 5.0




DUTCH HARBOR MAGNITUDES
EVENTS BETWEEN 1958 AND 1986
1000
100
10
1
0.5
NUMBER OF EVENTS
= raw number of events
= cumulative number
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
MAGNITUDE (MS)

ATTENUATION CURVES FOR Ms = 7 5



APPENDIX

CHRONOLOGICAL EVENT LISTING
MAGNITUDES GREATER THAN OR EQUAL TO 5.00

Year	Mo	Dy	Time			Lat	Long	Depth	Mag
19 2	1	1	5	20	0.00	55N 0.00	165W 0.00	25.00	7.80
19 2	1	1	5	20	30.00	55N 0.00	165W 0.00	25.00	7.00
19 6	12	23	17	22	0.00	53N 0.00	165W 0.00	0.00	7.30
19 9	9	8	16	49	48.00	52N30.00	169W 0.00	90.00	7.40
1916	4	18	4	1	48.00	53N15.00	170W 0.00	170.00	7.50
1929	3	7	1	34	39.00	51N 0.00	170W 0.00	50.00	7.50
1931	3	29	17	24	58.00	51N 0.00	170W 0.00	25.00	6.00
1931	8	14	16	12	3.00	52N30.00	168W 0.00	25.00	6.00
1932	8	12	3	23	57.00	52N15.00	169W 0.00	25.00	6.75
1933	4	27	11	55	38.00	52N30.00	167W 0.00	25.00	6.00
1933	6	28	23	34	58.00	53N30.00	165W 0.00	25.00	6.00
1933	7	22	20	55	13.00	53N 0.00	169W30.00	25.00	6.75
1933	10	14	22	19	1.00	53N45.00	164W 0.00	25.00	6.25
1935	1	23	7	24	0.00	52N15.00	169W30.00	25.00	6.75
1937	7	18	1	1	15.00	54N 0.00	166W30.00	70.00	6.25
1938	7	24	13	12	13.00	53N30.00	167W 0.00	50.00	6.25
1939	2	24	14	15	45.00	53N 0.00	164W30.00	70.00	6.25
1939	8	20	7	17	26.00	54N 0.00	164W 0.00	75.00	6.25
1940	8	22	3	27	18.00	53N 0.00	165W30.00	25.00	7.00
1942	9	9	1	25	26.00	53N 0.00	164W30.00	80.00	7.00
1944	7	27	0	4	23.00	54N 0.00	165W30.00	70.00	7.10
1946	4	1	12	28	54.00	52N45.00	163W30.00	50.00	7.30
1946	7	12	21	56	27.00	53N30.00	169W 0.00	100.00	6.75
1946	10	30	7	47	34.00	54N15.00	164W 0.00	50.00	6.90
1950	7	12	11	9	10.00	52N30.00	167W30.00	0.00	6.25
1950	7	12	11	9	10.00	52N30.00	167W30.00	0.00	6.25
1950	9	2	2	47	13.00	52N30.00	170W 0.00	0.00	6.38
1950	9	2	2	47	13.00	52N30.00	170W 0.00	0.00	6.38
1952	1	12	20	11	37.00	52N30.00	167W30.00	0.00	6.50
1952	1	12	20	11	37.00	52N30.00	167W30.00	0.00	6.50
1952	1	21	3	42	55.00	52N30.00	167W30.00	0.00	6.75
1952	1	21	3	42	55.00	52N30.00	167W30.00	0.00	6.75
1952	7	7	2	52	59.00	54N12.00	164W30.00	0.00	6.25
1952	7	7	2	52	59.00	54N12.00	164W30.00	0.00	6.25
1954	12	30	11	32	28.00	53N 0.00	168W 0.00	60.00	6.63
1954	12	30	11	32	30.00	52N30.00	168W24.00	64.00	6.62
1955	1	13	2	3	43.00	53N12.00	167W24.00	0.00	6.90
1955	1	13	2	3	43.00	53N 0.00	167W30.00	0.00	6.90
1955	1	13	2	35	45.00	53N 0.00	167W30.00	0.00	6.50
1955	1	13	2	35	46.00	53N12.00	167W24.00	0.00	6.50
1955	7	17	21	58	23.00	54N24.00	168W18.00	0.00	5.88

1955	7	17	21	58	23.00	54N24.00	168W18.00	0.00	5.87
1956	6	4	7	9	19.00	52N 6.00	170W36.00	0.00	6.25
1956	6	4	7	9	19.00	52N 6.00	170W36.00	0.00	6.25
1956	8	30	4	24	26.00	53N48.00	164W 1.20	33.00	6.00
1956	8	30	4	24	26.00	53N48.00	164W 1.20	33.00	6.00
1956	12	3	7	20	6.00	52N38.40	168W36.60	0.00	6.63
1957	1	2	0	39	22.00	53N 0.00	168W30.00	0.00	6.63
1957	1	2	0	39	24.00	52N42.00	168W30.60	0.00	6.63
1957	1	2	2	17	35.00	52N30.00	168W 0.00	0.00	6.75
1957	1	2	2	17	39.00	52N27.60	168W24.60	0.00	6.75
1957	1	2	3	12	52.00	53N 0.00	168W 0.00	0.00	6.63
1957	1	2	3	12	54.00	52N38.40	168W13.80	0.00	6.63
1957	1	2	3	48	44.00	53N 0.00	168W 0.00	0.00	7.00
1957	1	2	3	48	50.00	52N43.20	168W 4.80	0.00	7.00
1957	1	2	4	3	30.00	52N45.60	168W45.00	0.00	6.50
1957	1	2	10	49	32.00	52N34.80	168W31.80	0.00	6.50
1957	1	9	7	52	56.00	52N39.60	167W30.00	0.00	6.50
1957	2	21	14	30	11.00	53N 1.20	171W16.20	126.00	6.75
1957	3	9	20	39	16.00	52N18.00	169W 0.00	0.00	7.10
1957	3	9	20	39	18.00	52N46.20	169W34.20	0.00	7.10
1957	3	11	9	58	44.00	52N44.40	168W24.60	0.00	6.88
1957	3	11	9	58	44.00	52N44.40	168W24.60	0.00	7.00
1957	3	15	2	52	8.00	53N 0.00	167W 0.00	0.00	6.75
1957	3	15	2	52	9.00	52N49.20	166W43.20	0.00	6.75
1957	3	17	22	44	44.00	54N 0.00	166W 0.00	0.00	6.50
1957	3	17	22	44	45.00	53N51.00	165W12.60	0.00	6.50
1957	3	18	2	24	39.00	52N30.00	171W 0.00	0.00	6.20
1957	3	18	2	25	36.00	52N16.20	170W53.40	76.00	6.20
1957	3	22	14	21	10.00	53N44.40	165W39.60	20.00	7.00
1957	3	22	14	21	10.00	53N44.40	165W39.60	20.00	7.00
1957	3	29	5	10	28.00	53N30.00	167W 0.00	0.00	6.50
1957	3	29	5	10	29.00	53N31.20	166W51.60	0.00	6.50
1957	3	29	22	49	51.00	52N45.60	168W29.40	0.00	6.13
1957	4	11	17	40	37.00	52N 0.00	168W30.00	0.00	5.25
1957	4	15	21	33	6.00	52N 4.20	167W 2.40	0.00	6.43
1957	4	19	15	44	53.00	51N30.00	168W30.00	0.00	6.70
1957	4	19	15	44	56.00	51N28.20	168W12.60	0.00	6.70
1957	4	19	22	19	26.00	52N 0.00	166W30.00	0.00	7.30
1957	4	19	22	19	30.00	52N12.00	166W16.80	4.00	6.50
1957	4	28	14	48	54.00	52N35.40	168W31.20	0.00	5.75
1957	4	29	4	30	6.00	52N24.00	168W48.00	0.00	5.50
1957	5	24	3	36	33.00	53N 0.00	167W30.00	0.00	6.13
1957	5	24	3	36	37.00	53N14.40	167W30.00	36.00	6.12
1957	6	15	18	18	20.00	52N 0.00	171W 0.00	0.00	6.00
1957	6	29	7	48	15.00	51N42.60	166W38.40	0.00	6.30
1957	9	2	14	20	13.00	51N30.00	168W 0.00	0.00	6.18
1957	9	2	14	20	14.00	51N41.40	168W 0.60	0.00	6.20
1957	10	10	18	53	59.00	54N 0.00	166W 0.00	0.00	5.75
1957	10	10	18	54	9.00	53N52.20	165W24.60	79.00	5.75

1957	10	23	5	56	56.00	52N31.80	169W41.40	38.00	6.25
1957	11	20	12	40	23.00	54N 0.00	165W 0.00	0.00	6.37
1957	11	20	12	40	27.00	53N47.40	164W42.60	0.00	6.37
1957	11	23	0	58	36.00	53N 0.00	167W30.00	0.00	6.15
1957	11	23	0	58	45.00	52N57.60	167W34.80	68.00	6.15
1957	12	1	19	5	35.00	52N30.00	170W 0.00	0.00	5.13
1957	12	1	19	5	35.00	52N30.00	170W 0.00	0.00	5.12
1958	5	12	5	38	18.00	52N12.60	169W32.40	0.00	6.40
1958	5	26	10	56	30.00	53N 0.00	169W30.00	0.00	6.13
1958	5	26	10	56	45.00	53N15.60	169W36.60	130.00	6.12
1958	5	30	18	4	53.00	52N43.80	168W37.20	0.00	6.13
1958	6	4	14	29	54.00	52N41.40	167W13.20	19.00	6.13
1958	6	8	0	38	52.00	53N 0.00	167W 0.00	0.00	6.63
1958	6	8	0	38	53.00	53N12.00	166W47.40	0.00	6.62
1958	6	9	15	59	6.00	52N57.00	167W13.20	0.00	6.10
1958	6	12	20	53	1.00	52N58.80	166W58.20	0.00	6.50
1958	7	24	13	8	5.00	52N44.40	169W46.20	0.00	5.75
1958	10	1	17	47	15.00	53N 0.00	165W30.00	0.00	6.25
1958	10	1	17	47	17.00	52N40.20	165W24.00	0.00	6.25
1959	4	22	10	55	5.00	54N 0.00	167W 0.00	0.00	6.00
1959	4	22	10	55	11.00	53N48.00	166W52.20	51.00	6.00
1959	6	3	5	43	28.00	52N59.40	169W49.80	0.00	5.38
1959	12	14	22	0	51.00	52N27.00	168W12.60	0.00	6.00
1959	12	14	22	0	51.00	52N27.00	168W12.60	0.00	6.00
1959	12	18	16	24	50.00	52N33.60	168W23.40	0.00	6.50
1960	6	29	17	6	57.00	52N41.40	168W 2.40	0.00	6.30
1960	6	29	17	7	0.00	53N 0.00	168W30.00	0.00	6.30
1960	11	6	22	10	3.00	52N41.40	168W 4.20	0.00	5.12
1960	11	6	22	10	6.40	52N54.00	168W 0.00	43.00	5.13
1960	11	13	9	20	31.00	51N24.60	168W51.60	0.00	6.70
1960	11	13	9	20	32.30	51N24.00	168W48.00	32.00	7.00
1961	1	11	11	59	52.00	51N58.80	170W52.20	0.00	5.88
1961	1	11	11	59	55.00	52N 0.00	171W 0.00	47.00	5.88
1961	1	14	16	38	54.00	54N 4.80	163W34.80	0.00	5.75
1961	1	14	16	38	54.80	53N54.00	163W24.00	38.00	5.75
1961	2	27	13	6	30.00	52N34.80	169W 1.80	0.00	6.10
1961	2	27	13	6	35.80	52N42.00	168W48.00	56.00	6.10
1961	8	29	14	51	14.20	52N24.00	170W48.00	41.00	5.13
1961	8	29	14	51	20.00	52N23.40	170W49.80	72.00	5.13
1961	9	2	0	26	3.00	52N10.80	171W 3.00	0.00	5.50
1961	9	2	0	26	6.20	52N12.00	170W54.00	39.00	5.50
1961	9	27	11	20	45.00	52N24.00	168W40.80	0.00	5.63
1961	9	27	11	20	46.80	52N30.00	168W42.00	27.00	5.63
1961	9	27	19	20	44.00	52N27.60	168W47.40	0.00	5.50
1961	9	27	19	20	48.60	52N42.00	168W42.00	42.00	5.50
1961	9	27	19	27	0.00	52N21.00	168W45.00	0.00	5.25
1961	9	27	19	27	0.70	52N24.00	168W42.00	22.00	5.25
1962	5	10	5	12	12.00	52N23.40	171W 1.80	0.00	5.50
1962	5	10	5	12	15.90	52N24.00	170W54.00	43.00	5.50

1962	12	1	1	50	15.00	52N27.60	170W12.60	0.00	5.38
1962	12	1	1	50	20.40	52N24.00	170W 6.00	38.00	5.38
1962	12	21	8	42	43.00	52N28.20	168W32.40	0.00	6.50
1962	12	21	8	42	48.30	52N24.00	168W30.00	33.00	6.50
1962	12	22	15	20	25.00	52N27.60	168W49.80	0.00	6.25
1962	12	22	15	20	31.00	52N30.00	168W48.00	47.00	6.25
1963	4	7	15	27	59.40	53N42.00	170W 0.00	174.00	6.00
1963	4	7	15	28	4.00	53N42.60	169W57.60	224.00	6.00
1963	5	22	16	25	32.00	52N 4.80	165W19.80	0.00	5.20
1963	5	22	16	25	37.20	52N 0.00	165W24.00	33.00	5.20
1963	6	24	16	17	11.00	52N20.40	171W13.20	0.00	5.40
1963	6	24	16	17	15.70	52N12.00	171W 6.00	36.00	5.40
1963	9	6	20	56	59.90	53N54.00	165W36.00	33.00	5.00
1963	9	6	20	56	59.90	53N54.00	165W36.00	33.00	5.00
1963	10	14	6	26	11.70	52N48.00	167W 6.00	80.00	5.10
1963	10	14	6	26	11.70	52N48.00	167W 6.00	80.00	5.10
1964	1	12	6	0	12.90	53N10.20	166W18.00	33.00	5.60
1964	1	12	6	0	13.20	53N12.00	166W18.00	33.00	5.50
1964	2	1	1	47	52.10	51N48.00	170W48.00	34.00	5.20
1964	4	16	13	43	8.80	52N 5.40	169W28.20	34.00	5.10
1964	5	8	23	40	44.10	52N12.00	169W30.00	20.00	5.20
1964	5	8	23	40	44.50	52N15.60	169W18.60	12.00	5.30
1964	5	9	2	2	28.80	52N12.00	169W36.00	25.00	5.10
1964	5	9	2	2	29.80	52N 8.40	169W30.60	28.00	5.30
1964	7	1	13	31	6.20	52N42.00	168W12.00	33.00	5.00
1964	7	15	7	26	1.40	52N 8.40	170W37.20	28.00	5.10
1964	7	15	7	26	1.40	52N 6.00	170W36.00	30.00	5.60
1964	8	31	23	20	19.40	52N24.00	170W42.00	33.00	5.20
1964	8	31	23	20	19.70	52N24.00	170W43.20	36.00	5.20
1964	9	23	4	59	47.40	53N36.00	163W54.00	29.00	5.50
1964	9	23	4	59	49.70	53N46.80	163W42.00	36.00	5.40
1964	9	25	17	24	44.90	53N36.00	163W54.00	33.00	5.10
1964	11	30	22	40	46.00	53N42.00	167W42.00	69.00	5.00
1964	12	2	13	18	29.00	53N48.00	165W24.00	35.00	5.00
1964	12	2	13	18	31.70	53N46.20	165W24.60	49.00	5.40
1964	12	15	22	34	7.70	51N 0.00	169W36.00	33.00	5.00
1965	3	30	16	9	2.40	53N42.00	165W36.00	30.00	5.10
1965	4	12	4	36	11.60	52N42.00	167W24.00	16.00	5.10
1965	4	12	4	43	10.00	52N42.00	167W30.00	22.00	5.30
1965	4	13	23	22	57.20	54N12.00	163W24.00	36.00	5.00
1965	5	27	12	56	51.40	53N54.00	164W54.00	33.00	5.00
1965	7	2	20	58	38.10	53N 1.80	167W33.00	40.00	6.70
1965	7	2	20	58	40.30	53N 6.00	167W36.00	60.00	6.70
1965	7	14	13	45	58.00	52N24.00	168W36.00	33.00	5.00
1965	7	14	17	55	51.40	52N36.00	168W42.00	6.00	5.30
1965	7	14	17	55	51.80	52N37.80	168W29.40	6.00	5.20
1965	7	14	18	1	30.10	52N30.00	168W36.00	22.00	5.10
1965	7	20	20	11	41.10	53N54.00	166W30.00	73.00	5.10
1965	9	4	7	48	43.60	52N10.20	170W32.40	17.00	5.10

1965	9	4	7	48	43.90	52N 0.00	170W24.00	28.00	5.30
1965	9	29	13	49	26.20	52N30.00	170W42.00	55.00	5.00
1965	10	3	10	46	16.50	52N30.00	170W36.00	22.00	5.40
1965	10	3	10	46	20.60	52N26.40	170W37.80	59.00	5.30
1965	10	7	14	6	8.70	52N12.00	169W30.00	19.00	5.00
1965	10	23	6	0	52.50	53N54.00	165W18.00	38.00	5.50
1965	10	23	6	0	52.50	53N51.00	165W18.00	39.00	5.40
1965	12	30	2	6	29.00	54N 6.00	164W18.00	13.00	5.70
1965	12	30	2	6	30.40	54N 5.40	164W16.80	19.00	5.50
1966	1	2	4	52	16.10	54N12.00	164W18.00	43.00	5.40
1966	1	2	4	52	16.50	54N12.60	164W22.80	45.00	5.10
1966	1	9	9	52	45.50	54N12.00	164W24.00	63.00	5.30
1966	1	20	16	32	19.20	52N24.00	169W36.00	14.00	5.30
1966	2	27	20	43	0.30	54N 0.00	164W 0.00	37.00	5.00
1966	5	19	7	6	24.40	54N 6.00	164W 6.00	9.00	5.10
1966	5	19	7	6	28.50	54N 2.40	164W 4.80	37.00	5.60
1966	6	11	11	21	58.20	53N30.00	167W30.00	57.00	5.00
1966	7	3	3	55	12.20	52N25.20	170W18.60	42.00	5.20
1966	7	3	3	55	13.70	52N24.00	170W18.00	55.00	5.00
1966	7	11	1	11	18.60	53N30.00	167W42.00	32.00	5.10
1966	7	11	1	11	19.00	53N27.60	167W39.00	32.00	5.00
1966	8	11	10	45	58.60	52N37.20	169W43.80	54.00	5.40
1966	8	11	10	45	59.10	52N42.00	169W42.00	56.00	5.30
1966	8	19	11	23	11.00	53N36.00	167W24.00	23.00	5.10
1966	8	19	11	23	12.00	53N35.40	167W19.20	24.00	5.10
1966	9	16	2	48	21.30	54N 0.00	163W24.00	32.00	5.20
1966	9	16	2	48	21.30	54N 1.20	163W25.80	32.00	5.20
1966	11	11	15	31	4.40	52N15.60	169W 4.20	37.00	5.50
1966	11	11	15	31	4.50	52N12.00	169W 6.00	40.00	5.40
1966	11	16	23	16	10.30	52N36.00	169W30.00	42.00	5.10
1966	11	16	23	16	11.40	52N34.80	169W31.80	53.00	5.00
1967	1	18	8	18	22.00	52N32.04	168W12.12	33.00	5.80
1967	1	18	8	18	22.30	52N33.00	168W14.40	33.00	5.70
1967	1	19	14	41	34.50	52N24.18	169W34.80	34.00	5.20
1967	1	19	14	41	34.60	52N22.20	169W34.20	34.00	5.20
1967	1	22	10	29	59.70	53N41.40	165W10.14	28.00	5.00
1967	1	22	10	30	0.00	53N33.00	165W10.20	30.00	5.00
1967	1	28	13	52	58.20	52N22.50	169W30.90	43.00	5.90
1967	1	28	13	52	58.30	52N24.00	169W32.40	42.00	6.00
1967	1	28	14	5	57.00	52N17.40	169W30.60	39.00	5.10
1967	1	28	14	5	57.10	52N18.06	169W29.28	45.00	5.00
1967	1	28	14	23	26.00	52N27.00	169W34.80	37.00	5.10
1967	1	28	14	23	26.10	52N22.56	169W24.90	41.00	5.10
1967	1	28	14	30	25.90	52N27.36	169W24.66	45.00	4.90
1967	1	28	16	31	21.60	52N19.20	169W19.80	32.00	5.30
1967	1	28	16	31	22.60	52N16.32	169W18.18	45.00	5.30
1967	1	28	17	19	32.50	52N16.20	169W30.00	36.00	5.00
1967	1	28	17	19	32.70	52N14.10	169W28.56	40.00	4.90
1967	1	28	17	26	34.40	52N20.94	169W23.40	45.00	4.70

1967	1	28	17	42	1.60	52N21.60	169W22.80	49.00	5.50
1967	1	28	17	42	1.80	52N24.06	169W23.16	50.00	5.60
1967	3	13	14	44	6.00	53N45.30	165W13.26	21.00	5.10
1967	3	13	14	44	7.00	53N41.40	165W15.00	31.00	5.10
1967	3	31	2	12	14.90	52N 3.36	169W42.12	7.00	5.30
1967	3	31	2	12	15.20	52N 4.80	169W42.00	7.00	5.20
1967	5	12	16	58	32.80	52N39.00	166W56.40	36.00	5.00
1967	6	1	3	36	18.00	53N36.00	165W38.40	49.00	5.70
1967	6	1	3	36	19.00	53N42.00	165W36.00	60.00	5.70
1967	6	19	17	7	45.40	52N42.00	166W54.00	33.00	5.70
1967	6	19	17	7	47.10	52N45.60	166W54.00	44.00	5.90
1967	6	20	7	38	44.90	52N48.00	167W 6.00	11.00	5.20
1967	6	20	7	38	50.00	52N47.40	167W 3.60	45.00	5.40
1967	7	6	13	42	22.50	52N36.00	168W12.00	14.00	5.90
1967	7	6	13	42	27.60	52N34.80	168W 7.80	49.00	5.90
1967	7	17	11	28	13.40	51N 6.00	169W18.00	33.00	5.00
1967	8	3	23	17	7.20	53N37.80	170W 4.80	184.00	5.00
1967	9	6	17	24	39.60	52N25.80	168W35.40	31.00	5.00
1967	9	28	3	0	30.50	52N12.00	171W 0.00	48.00	5.10
1967	9	28	3	0	31.00	52N10.80	171W 5.40	54.00	5.00
1968	1	14	12	40	48.50	52N48.00	171W24.00	44.00	5.60
1968	1	14	12	40	49.70	52N36.60	171W17.40	44.00	5.50
1968	1	14	17	43	6.00	52N39.00	171W15.00	3.00	5.40
1968	1	14	17	43	10.00	52N42.00	171W12.00	34.00	5.50
1968	3	5	0	30	58.20	53N49.80	163W14.40	34.00	5.10
1968	5	3	16	13	40.00	54N 9.60	163W15.60	17.00	5.00
1968	11	7	0	48	33.00	54N14.40	164W31.80	24.00	5.00
1968	11	7	0	48	33.60	54N18.00	164W36.00	37.00	5.10
1968	11	27	12	20	55.10	52N32.40	170W39.00	58.00	5.10
1969	2	13	1	35	50.00	52N 7.80	169W56.40	2.00	5.20
1969	2	13	1	35	52.40	52N 9.72	169W54.54	16.00	5.10
1969	6	7	22	47	14.00	52N28.20	169W 3.60	29.00	5.30
1969	6	7	22	47	15.40	52N29.10	169W 3.54	42.00	5.20
1969	6	18	23	44	11.20	52N37.62	167W53.58	18.00	5.40
1969	6	18	23	44	14.60	52N39.60	167W52.20	42.00	5.40
1969	6	19	20	24	59.60	54N12.00	164W 0.00	25.00	5.00
1969	6	19	20	25	1.30	54N10.80	164W12.60	39.00	5.00
1969	6	19	21	33	16.60	52N44.94	167W49.98	14.00	5.00
1969	7	25	12	54	27.30	53N16.80	167W 3.00	40.00	5.10
1969	7	25	12	54	27.60	53N18.06	167W 0.78	42.00	5.00
1969	7	31	11	23	1.20	53N 0.24	170W 6.66	37.00	5.30
1969	7	31	11	23	2.10	53N 2.40	170W 3.60	43.00	5.20
1969	9	3	6	13	9.20	52N58.80	169W53.40	52.00	5.00
1969	9	3	6	13	9.30	53N 3.42	169W54.90	52.00	5.00
1969	10	9	7	59	39.00	52N11.40	169W28.80	5.00	5.20
1969	10	9	7	59	41.30	52N18.96	169W30.78	22.00	5.10
1969	10	14	22	46	4.80	52N37.02	162W43.98	15.00	5.10
1969	10	14	22	46	5.40	52N44.40	162W37.80	15.00	5.00
1969	10	22	12	11	21.30	52N12.48	169W27.00	33.00	5.10

1969	10	22	12	11	22.90	52N16.20	169W22.20	39.00	5.20
1969	10	24	0	46	14.60	52N28.08	168W37.44	33.00	5.20
1969	10	24	0	46	15.00	52N27.00	168W38.40	34.00	5.30
1969	11	12	19	9	1.70	52N54.00	168W19.20	50.00	5.50
1969	11	12	19	9	2.00	52N58.50	168W16.56	53.00	5.40
1969	12	22	11	19	19.30	52N27.90	168W 8.58	33.00	5.20
1969	12	22	11	19	20.10	52N30.00	168W 7.20	37.00	5.30
1970	1	20	0	38	24.30	53N46.98	163W31.92	33.00	5.10
1970	1	20	0	38	25.00	53N50.40	163W36.00	33.00	5.10
1970	1	23	3	31	29.00	53N45.48	163W34.56	33.00	5.10
1970	1	23	3	31	29.30	53N43.20	163W36.60	36.00	5.20
1970	5	26	9	53	31.00	54N11.16	164W41.52	36.00	5.20
1970	5	26	9	53	33.60	54N13.80	164W36.60	56.00	5.30
1970	5	30	23	19	38.30	53N38.40	164W13.80	41.00	5.00
1970	7	28	19	28	13.60	54N 7.20	166W 1.20	89.00	5.00
1970	9	28	4	21	49.80	54N29.04	164W29.22	77.00	5.00
1970	9	28	4	21	50.30	54N25.20	164W27.00	78.00	5.00
1970	10	29	0	57	41.00	54N 7.80	164W38.40	14.00	5.20
1970	10	29	0	57	42.80	54N10.14	164W37.68	27.00	5.30
1970	12	1	19	29	16.60	52N25.08	169W 4.86	60.00	5.20
1970	12	1	19	29	17.30	52N35.40	169W 9.60	60.00	5.10
1970	12	10	10	15	6.90	52N55.80	169W42.00	44.00	5.50
1970	12	10	10	15	7.20	53N 5.76	169W50.94	48.00	5.50
1970	12	14	14	48	10.00	52N55.20	169W49.20	29.00	5.30
1970	12	14	14	48	11.80	53N 2.04	169W55.56	50.00	5.30
1970	12	14	21	11	36.00	52N51.00	169W51.60	20.00	5.10
1970	12	14	21	11	39.10	53N 0.54	170W 1.14	54.00	5.20
1970	12	29	10	24	31.40	51N14.28	168W26.22	9.00	5.00
1971	2	25	6	40	44.30	52N 7.98	169W29.64	32.00	5.30
1971	2	25	6	40	45.40	52N11.40	169W39.60	37.00	5.20
1971	4	5	9	4	42.30	53N15.60	170W31.80	150.00	5.80
1971	4	5	9	4	42.80	53N21.54	170W33.18	153.00	5.80
1971	4	10	0	36	44.40	52N 9.00	169W56.40	0.00	5.00
1971	5	10	0	1	16.30	52N 9.90	171W 0.30	48.00	5.30
1971	5	10	0	1	16.90	52N12.60	171W 4.20	48.00	5.20
1971	6	10	17	28	34.30	52N 7.80	170W33.00	26.00	5.30
1971	6	10	17	28	35.90	52N11.52	170W33.54	41.00	5.30
1971	6	27	17	15	38.80	51N57.00	170W27.00	0.00	5.20
1971	6	27	17	15	39.20	52N 0.48	170W27.06	18.00	5.20
1971	9	23	13	31	13.40	53N44.04	164W50.34	45.00	5.30
1971	9	23	13	31	13.90	53N48.60	164W45.60	45.00	5.30
1971	10	19	11	2	37.70	52N39.36	166W58.02	22.00	5.60
1971	10	19	11	2	38.90	52N40.20	166W57.00	0.00	5.60
1972	3	17	12	28	41.50	52N57.60	165W37.98	26.00	5.10
1972	3	17	12	28	42.00	53N 6.00	165W30.60	26.00	5.00
1972	4	21	1	28	8.20	53N57.00	166W49.20	91.00	5.80
1972	4	21	1	28	9.50	54N 0.42	166W51.18	103.00	5.80
1972	6	1	3	8	24.90	51N 0.60	169W29.40	0.00	5.00
1972	6	1	3	8	25.10	51N 2.76	169W34.02	33.00	5.00

1972	6	12	19	47	35.60	53N15.00	166W46.80	27.00	5.80
1972	6	12	19	47	37.20	53N21.00	166W47.10	44.00	5.80
1972	6	23	14	12	23.50	53N52.14	165W30.24	23.00	5.00
1972	8	12	12	34	20.40	53N48.36	164W47.46	33.00	5.00
1972	8	12	12	34	21.00	53N45.00	164W40.80	33.00	5.00
1972	10	13	4	46	11.00	52N53.40	162W58.80	0.00	6.00
1972	10	13	4	46	11.00	52N49.98	163W 3.84	38.00	5.90
1972	11	13	9	25	51.20	53N47.52	169W 2.58	129.00	5.10
1972	11	13	9	25	51.90	53N38.40	169W 0.60	136.00	5.00
1972	12	19	10	33	47.30	52N 5.40	169W36.60	25.00	5.10
1972	12	19	10	33	49.00	52N 2.34	169W39.24	44.00	5.00
1973	1	11	2	12	25.60	52N 2.40	169W33.60	14.00	5.40
1973	1	11	2	12	27.50	52N 6.06	169W36.30	30.00	5.40
1973	1	16	9	57	38.00	54N 3.00	165W28.80	75.00	5.20
1973	1	16	9	57	38.60	54N 7.20	165W32.58	81.00	5.30
1973	5	29	6	14	17.70	53N58.20	163W42.60	0.00	6.10
1973	5	29	6	14	22.30	54N 0.66	163W45.60	30.00	6.00
1973	6	18	10	17	26.30	52N10.56	164W52.02	15.00	5.40
1973	6	18	10	17	26.80	52N11.40	164W46.20	15.00	5.40
1973	8	3	3	57	6.10	53N12.00	169W43.20	115.00	5.10
1973	8	3	3	57	6.80	53N12.48	169W47.04	124.00	5.00
1973	12	2	22	9	54.50	52N16.98	168W44.10	40.00	5.60
1973	12	2	22	9	55.10	52N16.80	168W40.80	0.00	5.60
1973	12	21	15	28	18.20	52N19.80	169W29.40	36.00	5.00
1974	1	19	8	53	39.10	52N56.16	167W58.62	59.00	5.00
1974	1	19	8	53	39.20	52N58.80	167W57.60	52.00	5.00
1974	1	31	19	55	26.20	52N21.42	168W44.40	36.00	5.60
1974	1	31	19	55	27.40	52N22.80	168W41.40	0.00	5.60
1974	1	31	20	15	55.10	52N19.80	168W40.20	44.00	5.00
1974	2	6	4	4	7.20	53N47.94	164W40.32	2.00	5.90
1974	2	6	4	4	8.70	53N44.40	164W42.00	7.00	5.90
1974	2	28	19	19	17.30	52N54.00	166W45.60	3.00	5.10
1974	2	28	19	19	21.90	53N 0.60	166W39.84	33.00	5.00
1974	3	22	7	4	6.20	53N37.32	163W22.32	33.00	5.10
1974	3	22	7	4	6.60	53N40.20	163W27.00	0.00	5.00
1974	5	15	13	4	4.10	52N24.48	168W49.02	44.00	5.00
1974	5	15	13	4	4.70	52N25.20	168W46.20	0.00	5.20
1974	6	12	16	46	33.50	52N16.80	170W14.40	41.00	5.20
1974	6	12	16	46	34.30	52N26.46	170W12.12	46.00	5.20
1974	6	23	5	14	53.60	52N28.80	168W58.20	39.00	5.00
1974	6	23	5	14	53.80	52N32.22	169W 1.50	42.00	5.00
1974	8	24	10	41	11.20	52N24.42	168W16.38	41.00	5.70
1974	8	24	10	41	11.50	52N26.40	168W16.20	0.00	5.70
1974	8	24	22	18	55.10	52N18.60	168W17.40	0.00	5.30
1974	8	24	22	18	55.40	52N17.82	168W18.84	37.00	5.30
1974	11	20	0	9	11.90	53N34.20	165W 8.40	27.00	5.00
1974	11	20	0	9	15.00	53N36.00	165W15.18	57.00	5.00
1974	11	28	16	31	58.30	53N37.26	163W42.18	32.00	5.30
1974	11	28	16	31	59.20	53N41.40	163W42.00	0.00	5.20

1974	12	7	7	34	11.00	51N48.60	170W47.40	0.00	5.50
1974	12	7	7	34	11.00	51N51.42	170W47.70	33.00	5.50
1975	1	6	23	12	17.80	54N18.18	165W46.80	102.00	5.10
1975	1	6	23	12	18.70	54N14.40	165W48.00	113.00	5.10
1975	1	13	9	19	9.20	52N 6.00	171W 4.80	34.00	5.60
1975	1	13	9	19	10.30	52N13.20	171W 8.52	42.00	5.70
1975	4	8	20	32	24.90	51N57.00	166W11.40	0.00	5.30
1975	4	8	20	32	24.90	51N53.94	166W12.42	33.00	5.40
1975	4	11	10	47	15.00	54N 6.00	163W20.40	17.00	5.50
1975	4	11	10	47	15.30	54N 5.82	163W14.88	20.00	5.50
1975	5	1	18	47	53.70	52N40.20	167W 3.00	3.00	5.10
1975	5	1	18	47	56.00	52N42.54	167W 1.98	17.00	5.10
1975	5	16	7	57	46.80	54N 3.00	163W 9.00	5.00	5.30
1975	5	16	7	57	47.50	54N 5.34	163W 5.58	9.00	5.40
1975	6	26	7	59	27.00	52N21.60	168W43.80	35.00	5.10
1975	6	26	7	59	27.20	52N21.96	168W43.80	37.00	5.10
1975	11	1	0	48	23.40	53N39.30	163W21.96	25.00	5.70
1975	11	1	0	48	26.10	53N45.00	163W19.20	0.00	5.70
1975	11	30	20	30	17.00	52N36.60	167W 9.60	0.00	5.70
1975	11	30	20	30	17.00	52N35.94	167W11.04	24.00	5.70
1975	12	24	23	32	39.60	52N25.62	168W40.80	33.00	5.00
1976	1	4	8	44	10.70	52N51.60	166W45.60	32.00	5.30
1976	1	4	8	44	11.20	52N53.46	166W45.48	40.00	5.20
1976	2	19	22	1	27.10	53N28.26	164W30.00	33.00	5.00
1976	2	22	5	58	24.30	52N10.80	169W33.00	18.00	5.30
1976	2	22	5	58	27.70	52N14.58	169W30.48	44.00	5.30
1976	2	23	3	8	59.70	52N 2.88	169W28.68	26.00	5.00
1976	3	28	6	55	15.10	52N46.20	167W 7.80	0.00	5.10
1976	3	28	6	55	15.20	52N42.06	167W 9.18	36.00	5.20
1976	4	3	0	26	54.00	52N 9.00	169W36.84	22.00	5.00
1976	4	3	0	26	54.60	52N 7.80	169W42.60	23.00	5.00
1976	4	12	4	41	51.40	52N24.30	170W11.34	38.00	5.20
1976	4	12	4	41	51.80	52N19.80	170W12.60	44.00	5.20
1976	10	21	14	54	35.30	52N13.80	169W19.20	0.00	5.50
1976	10	21	14	54	35.60	52N13.74	169W23.40	36.00	5.40
1976	10	21	15	13	15.30	52N13.20	169W24.60	10.00	5.00
1977	3	26	4	36	14.70	52N17.70	168W15.42	38.00	5.70
1977	3	26	4	36	18.70	52N21.00	168W10.20	0.00	5.70
1977	5	15	15	50	47.10	52N26.76	168W 1.50	33.00	5.30
1977	5	15	15	50	48.20	52N32.40	167W58.80	0.00	5.30
1977	5	30	15	16	0.90	52N25.80	169W46.20	25.00	5.50
1977	5	30	15	16	1.60	52N25.68	169W42.42	33.00	5.60
1977	7	3	12	55	41.40	52N31.38	167W28.74	33.00	5.00
1977	7	3	12	55	42.70	52N32.40	167W28.20	0.00	5.00
1977	7	7	15	58	24.20	52N18.00	170W52.80	44.00	5.00
1977	7	7	15	58	24.80	52N18.24	170W53.34	52.00	5.00
1977	11	27	10	46	43.80	51N20.58	166W20.28	33.00	5.00
1977	11	27	10	46	43.90	51N22.80	166W20.40	33.00	5.00
1977	12	17	11	32	22.10	52N10.20	170W 8.40	26.00	5.00

1977	12	17	11	32	24.40	52N13.80	170W 5.82	44.00	5.00
1977	12	17	17	27	24.80	52N12.00	170W 5.40	20.00	5.30
1977	12	17	17	27	27.50	52N12.60	170W 1.50	40.00	5.30
1977	12	30	9	2	44.10	52N 8.88	169W35.16	38.00	5.00
1977	12	30	9	2	44.70	52N16.80	169W44.40	35.00	5.10
1978	1	25	21	43	3.60	52N 7.56	169W48.48	21.00	5.00
1978	1	25	21	43	5.01	52N10.80	169W52.80	26.00	5.00
1978	3	16	2	0	50.40	52N16.02	168W35.58	38.00	5.10
1978	3	16	2	0	52.10	52N31.80	168W40.80	40.00	5.20
1978	3	16	2	9	35.72	52N16.20	168W35.40	25.00	5.50
1978	3	16	2	9	38.40	52N17.70	168W37.32	49.00	5.50
1978	3	16	3	29	58.48	52N18.60	168W35.40	0.00	5.00
1978	3	16	3	29	59.60	52N18.84	168W34.86	33.00	5.00
1978	3	23	7	23	11.03	52N 0.60	169W30.60	5.00	5.60
1978	3	23	7	23	13.40	52N 0.60	169W27.90	23.00	5.60
1978	4	11	5	12	55.10	53N32.10	163W43.86	33.00	5.50
1978	4	11	5	12	55.53	53N36.00	163W42.60	0.00	5.50
1978	7	13	13	25	16.63	52N15.60	168W49.80	10.00	5.80
1978	7	13	13	25	19.70	52N14.52	168W48.96	33.00	5.80
1978	9	7	5	54	35.00	54N 2.40	164W 1.44	40.00	5.10
1978	9	7	5	54	35.16	54N 3.00	164W 0.60	39.00	5.10
1978	11	28	17	41	3.09	52N 1.80	170W 7.80	3.00	5.10
1978	11	28	17	41	4.10	52N 1.62	170W 6.54	11.00	5.20
1978	12	14	17	21	43.65	52N13.80	169W36.00	43.00	5.00
1979	1	16	7	13	27.98	52N31.20	167W53.40	18.00	5.50
1979	1	16	7	13	31.00	52N29.94	167W55.26	44.00	5.50
1979	5	8	12	56	14.80	52N50.10	168W18.00	39.00	5.10
1979	5	8	12	56	15.29	52N49.80	168W18.60	41.00	5.00
1979	5	25	16	45	27.30	52N36.66	167W 1.14	23.00	6.00
1979	5	25	16	45	30.54	52N40.80	166W58.20	0.00	6.00
1979	5	25	16	51	2.44	53N 1.20	167W12.00	33.00	5.20
1979	5	29	21	53	45.14	52N47.40	170W54.00	115.00	5.00
1979	7	15	5	50	19.26	51N58.80	170W34.20	21.00	5.40
1979	7	15	5	50	21.10	51N55.80	170W33.24	39.00	5.40
1979	8	10	7	25	10.00	52N 0.12	170W34.38	33.00	5.00
1979	8	10	7	25	11.10	52N 0.00	170W39.00	0.00	5.00
1979	9	1	5	27	16.09	53N58.20	165W13.20	55.00	5.80
1979	9	1	5	27	17.60	53N58.68	165W12.24	69.00	5.80
1979	12	4	12	1	19.46	53N46.20	164W 3.00	22.00	5.00
1979	12	4	12	1	21.20	53N42.36	164W 1.38	39.00	5.00
1979	12	9	22	25	50.70	52N59.76	170W14.28	102.00	5.40
1979	12	9	22	25	50.77	52N58.20	170W17.40	103.00	5.30
1979	12	17	23	7	34.62	52N42.00	168W43.20	37.00	5.00
1980	3	11	3	47	2.80	52N11.28	169W 1.80	20.00	5.20
1980	3	11	3	47	5.23	52N14.40	169W 7.20	0.00	5.10
1980	3	12	23	4	35.32	52N12.00	168W58.80	0.00	5.40
1980	3	12	23	4	35.40	52N 8.76	168W59.04	40.00	5.40
1980	3	24	3	59	50.32	52N56.40	167W42.00	24.00	6.10
1980	3	24	3	59	51.30	52N58.14	167W40.20	33.00	6.20

1980	3	24	4	2	19.30	52N36.00	167W27.18	33.00	6.10
1980	3	24	4	2	20.27	52N46.80	167W48.00	33.00	6.00
1980	3	24	4	41	59.10	52N53.16	167W42.84	33.00	5.00
1980	3	24	4	42	0.23	52N54.60	167W42.00	41.00	5.00
1980	7	26	16	19	50.23	54N19.80	165W15.60	0.00	5.00
1980	8	2	7	7	17.30	52N 6.72	169W21.90	33.00	5.30
1980	8	2	7	7	18.33	52N13.20	169W27.00	0.00	5.30
1980	8	3	7	11	43.00	51N59.94	169W17.04	33.00	4.80
1980	8	3	7	12	32.19	52N27.00	170W 1.20	39.00	5.20
1980	8	3	18	17	14.88	53N17.40	170W 4.80	0.00	5.20
1980	8	10	9	10	52.05	53N43.20	163W22.20	0.00	5.00
1980	8	10	9	12	14.40	54N29.40	163W44.40	0.00	5.20
1980	9	21	17	8	55.60	51N54.48	169W54.42	12.00	5.20
1980	9	21	17	8	55.87	51N58.20	169W58.20	12.00	5.20
1980	9	21	17	13	32.30	51N51.78	170W 1.80	14.00	5.40
1980	9	21	17	13	36.28	51N56.40	170W 7.80	0.00	5.40
1980	11	28	6	37	15.30	53N24.48	163W56.88	33.00	5.00
1980	11	28	6	37	15.35	53N24.00	163W59.40	32.00	5.30
1980	12	24	12	10	53.34	51N53.40	170W 9.60	0.00	5.20
1980	12	24	12	10	58.40	51N55.14	170W 2.58	33.00	5.00
1981	1	12	16	33	23.90	52N49.98	166W47.58	15.00	5.00
1981	1	12	16	33	24.81	52N49.80	166W49.20	20.00	5.00
1981	2	4	4	42	55.20	52N49.92	163W30.60	33.00	4.80
1981	2	28	13	10	58.66	52N16.20	168W26.40	0.00	5.00
1981	3	24	18	21	26.21	52N37.80	168W 4.20	20.00	5.50
1981	3	24	18	21	27.90	52N40.38	168W 2.22	33.00	5.50
1981	4	14	16	0	42.03	52N10.20	169W24.00	37.00	5.20
1981	6	5	7	9	19.15	52N16.86	165W11.94	33.00	5.50
1981	6	5	7	9	20.11	52N19.80	165W12.60	0.00	5.60
1981	6	7	17	52	33.90	53N49.98	165W 8.10	33.00	5.00
1981	6	13	13	21	14.76	53N38.04	163W31.74	23.00	5.00
1981	6	13	13	21	16.81	53N44.40	163W33.60	0.00	5.00
1981	7	11	8	58	7.57	52N23.40	170W36.00	48.00	5.00
1981	7	11	8	58	7.98	52N24.66	170W34.56	52.20	5.00
1981	7	12	17	3	25.40	52N28.80	169W10.80	36.00	5.30
1981	7	12	17	3	25.59	52N27.12	169W 6.90	39.20	5.20
1981	8	28	12	36	51.06	52N26.40	169W18.60	35.00	5.10
1981	8	28	12	36	51.39	52N25.44	169W16.86	39.40	5.10
1981	11	4	5	25	1.73	51N58.80	170W58.80	39.00	5.00
1981	11	9	16	45	5.97	53N13.26	165W44.82	33.00	5.50
1981	11	9	16	45	6.10	53N15.00	165W45.60	33.00	5.50
1981	11	14	0	43	2.36	54N 4.20	164W27.60	58.00	5.30
1981	11	14	0	43	3.30	54N 4.02	164W32.28	66.40	5.10
1982	1	25	5	29	33.52	53N13.32	165W43.14	60.00	6.10
1982	6	3	17	24	11.01	52N13.32	168W37.92	33.00	5.30
1982	6	6	1	13	59.53	52N11.76	168W36.72	33.00	5.20
1982	7	19	17	22	28.51	51N54.78	170W32.70	33.00	5.00
1982	7	20	14	26	38.69	52N15.54	168W46.08	33.00	5.00
1982	7	28	9	44	43.41	52N11.10	169W22.68	33.00	5.00

1982	8	19	14	46	27.93	52N12.06	169W30.60	33.00	5.20
1982	8	21	19	20	36.72	53N34.26	163W38.76	38.00	5.00
1982	8	24	4	9	15.63	53N38.70	165W26.22	33.00	5.30
1982	9	12	9	22	23.15	52N38.40	166W56.46	33.00	5.70
1982	9	12	9	28	39.54	53N 0.96	167W 6.24	33.00	5.10
1982	9	12	11	59	52.04	52N38.52	166W50.88	33.00	5.20
1982	9	12	16	50	37.76	52N49.14	167W 3.18	33.00	5.50
1982	9	16	6	46	7.98	52N57.18	167W 1.56	33.00	5.00
1982	10	27	14	32	24.78	52N20.34	168W25.68	33.00	5.10
1982	12	2	9	43	53.42	51N52.98	170W26.82	33.00	5.50
1983	3	12	7	0	15.18	52N13.50	170W10.32	33.00	5.20
1983	7	30	8	9	52.08	52N22.44	170W35.76	50.30	5.10
1983	8	31	22	20	7.49	53N30.30	163W36.30	33.00	5.10
1983	9	6	4	1	53.12	54N 5.16	164W 6.66	49.30	5.10
1983	9	11	13	50	59.78	52N11.22	170W41.10	33.00	5.00
1983	11	4	19	1	36.71	52N15.18	168W17.34	33.00	5.30
1983	11	11	22	47	53.76	52N29.46	170W38.34	59.10	5.10
1983	11	17	11	27	12.42	53N33.30	163W40.38	33.00	5.00
1983	12	27	23	5	57.96	54N11.46	164W 8.40	52.80	5.60
1984	1	23	22	6	6.59	53N17.22	169W38.34	102.60	5.30
1984	3	24	21	4	41.12	52N19.92	168W32.46	28.60	5.40
1984	3	24	22	43	37.66	52N22.26	168W27.36	33.00	5.10
1984	3	27	18	2	4.56	52N 0.66	169W42.48	35.40	5.00
1984	4	18	6	55	46.59	52N 2.76	169W45.18	33.00	5.00
1984	4	28	10	5	51.84	51N56.58	169W47.52	33.00	5.40
1984	6	4	17	19	59.21	52N 6.72	170W59.94	33.00	5.20
1984	6	12	11	9	15.47	53N38.88	165W13.08	43.10	5.30
1984	7	16	0	10	20.85	52N26.28	168W 9.06	33.00	5.10
1984	9	23	17	6	36.37	53N34.62	165W25.44	33.00	5.70
1984	10	13	18	42	58.83	53N35.28	163W35.76	33.00	5.00
1984	10	15	5	44	34.42	52N16.74	168W43.92	33.00	5.00
1984	10	20	15	41	45.16	52N 8.40	168W33.96	33.00	5.00
1984	11	8	13	2	0.13	52N10.86	170W59.94	33.00	5.40
1985	1	6	17	4	46.43	54N23.82	166W10.80	130.90	5.10
1985	4	13	16	46	3.76	54N51.24	163W52.32	33.00	5.00
1985	5	8	23	14	1.69	53N56.10	165W 0.12	41.80	4.60
1985	5	21	22	20	48.23	53N48.90	166W53.40	70.70	5.10
1985	7	26	7	4	27.40	52N46.56	166W37.20	33.00	5.10
1985	10	1	15	54	51.13	52N17.76	168W51.36	33.00	5.70
1985	10	2	7	49	52.81	52N20.94	168W46.98	33.00	4.80
1985	10	31	19	33	6.56	53N14.94	166W56.16	30.00	5.80
1986	3	4	8	47	14.85	51N35.58	166W56.88	33.00	5.60
1986	3	9	13	49	28.20	54N15.84	167W53.52	33.00	5.10
1986	3	20	19	40	8.72	54N10.92	168W 8.16	33.00	4.80
1986	4	11	17	22	20.60	54N 6.54	167W47.88	33.00	5.20
1986	6	9	2	17	38.39	54N 9.00	168W 5.82	33.00	5.00
1986	7	19	4	31	56.15	53N22.86	165W58.80	33.00	5.50
1986	7	19	5	4	8.41	53N21.84	165W55.50	33.00	5.10
1986	7	19	6	53	17.69	53N34.08	167W12.60	33.00	5.30

1986	7	19	11	31	7.67	53N36.90	167W24.18	33.00	4.80
1986	7	19	22	32	36.21	53N33.42	167W19.68	33.00	5.60
1986	7	20	1	59	9.12	53N37.08	167W17.58	33.00	4.80