GL02942 - 2 of 2

STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL AND GEOPHYSICAL SURVEYS
3001 Porcupine Drive
Anchorage, Alaska 99501

Preliminary Assessment of the Geothermal Resources of the Northern Part of Unalaska Island, Alaska

February 1981

John W. Reeder

TABLE OF CONTENTS

Appendix

LIST OF FIGURES

Introduction

Geological mapping at a scale of 1:50,000 complimented with some gravity measurements and warm-spring water sampling was undertaken in the northern part of Unalaska Island in the Aleutian Islands between July and September of 1980. The main objective of this work was to assess the hydrothermal resources of this region. This report presents the initial findings resulting from this work.

Most of the field work in the Unalaska Community region was carried out on foot and by Honda three-wheelers owned by Jeff and Gig Currier of Unalaska. Work in the Wide Bay - Tabletop Mountain region was also carried out by foot, where transport between the Wide Bay field camp and the Unalaska Community as well as transport along the coast of Unalaska Harbor for geological reconnaissance was done by means of an aluminum skiff owned and operated by Abi Dickson of Unalaska. Most of the work in the Makushin Volcano region was done by means of a Bell 206B Ranger helicopter operated by Ken Butters of Trans-Alaska Helicopters, Inc.

Participation

During the field work, I was continuously assisted by Kirk Swanson, a geology major undergraduate at Western State University and a "long-time" resident of Anchorage. The hot-spring atlas group of D.G.G.S. (Roman Motyka, Mary Moorman, Shirley Liss, and Malcome Robb) helped with water and gas sampling of the hot springs and fumaroles of the eastern and southeastern side of Makushin Volcano during approximately a one week visit. Shirley Liss also helped with obtaining water samples from the Summer Bay warm spring.

Participation in field work by local residents of Unalaska was not only allowed but encouraged. As a result, extensive help was received. Abi Dickson kindly helped with setting up and maintaining camp during most of the field operations at Wide Bay. The Currier family kindly shared their home during much of the field operations based near Unalaska. During many of the field traverses, I was accompanied by Abi Dickson, Kathy Grimnes, Jason Currier, Dianne Gay, Jim Dickson, and Susan Wahton to mention only a few. In general, the help from Kirk Swanson and the residents of Unalaska helped greatly with the field undertakings.

Special thanks is given to Jim Riehle, a volcanologist, who did most of the original air-photograph lineation recognition and air-photograph geologic interpretations for this project.

Background

Hydrothermal resources have been known to exist on Unalaska Island for some time. Dall (1897, see p. 472) stated, "In Unalaska, near Captain's

Harbor, a thermal spring exists, with a temperature of 94° Fahrenheit, containing sulphur in solution". After numerous attempts at locating this warm spring involving the Division of Power and Energy Development of the State of Alaska (Don Markle), Energy Systems, Inc. of Anchorage (John Deebee), Oregon Institute of Technology (Neil Basescu and Gene Culver), University of Utah Research Institute (Joe Moore), and local residents such as Kathy Grimnes and Abi Dickson, the spring was finally rediscovered in 1979 near Summer Bay (figure 1,2, and 3). Its temperature at the time of discovery was 91°F and its discharge was about one gallon per minute. The maximum temperature of the surface mud at the bottom of the spring was 95°F (Joe Moore, pers. comm., 1980).

Reports of hydrothermal activity are numerous for the Makushin Volcano region. An active fumarole field exists in a small crater located in the Makushin caldera. This fumarole field can be easily seen on the top of Makushin Volcano during rare clear days from such vantage points as the top of Amaknak Island near Dutch Harbor. The Makushin caldera is up to about 3km in diameter and is mostly filled with ice. Its presence has been used to argue for the existence of a shallow magma chamber within this volcanic complex (Tom Miller, U.S.G.S., pers. comm., 1980). Makushin Volcano has erupted 14 times since 1760 (Coats, 1950), where the last eruption occurred in 1938. As reported by Henry Swanson, a long-time resident of Unalaska, this 1938 eruption resulted in "muddy waters near Bishop's Point" just north of Makushin Volcano. Such turbid ocean waters were possibly due to the high influx of sediments from pyroclastic debris flows and/or turbid surface runoff resulting from a suspected flank eruption on the upper reaches of the north side of Makushin Volcano.

The site of the fumarole field on the top of Makushin Volcano has received a lot of attention because of its known sulfur deposits (Madden, 1919), which has resulted in numerous climbs of this mountain especially up its northeastern side. Such climbs should have resulted in some of the earliest observations of hot springs and fumaroles existing on the flanks of Makuskin Volcano. Unfortunately, I know of no written documentation of such observations during these early visits except for possibly one map (Maddren, 1919) which shows a creek on the southeastern flank of Makushin Volcano labeled as Hot Spring Creek. Based on my 1980 observations, this creek contains both hot springs and fumaroles, and is located near the base of the largest fumarole field that Kirk and I discovered during 1980 (figure 6).

During volcano investigations by the U.S. Geol. Survey in the Aleutian Islands - Alaska Peninsula, observation of fumaroles and hot springs were noted by Drewes et. al., (1961) on the south flank of Makushin Volcano. Tom Miller of the Alaska Branch of the U.S. Geol. Survey more recently observed these same fumaroles and hot springs (pers. comm., 1980).

Warm springs or at least springs that never freeze in the winter time were reported by Henry Swanson (pers. comm., 1980), a long-time resident of Unalaska, on the north side of Makuskin Valley near Broad Bay. This marks a region near geologically recent volcanic activity as represented by the Wide Bay cone and the Tabletop Mountain cone, adding suspicion to the possible existence of a hydrothermal system in this region.

These hydrothermal and potential hydrothermal resources are located near a large population center (i.e., Unalaska) which has a beautiful deep water harbor (i.e., Dutch Harbor) and which serves the largest Alaskan fishing fleet for the Bering - North Pacific region (Chandler, 1980). Such a situation probably prompted Markle (1979) to create a geothermal development scenario for Unalaska, and prompted myself to develop later an exploration plan including required budget for undertaking such a plan for Unalaska (Reeder et al., 1980).

The Division of Power and Energy Development of the State of Alaska was able to obtain grant money from the Department of Energy for geothermal planning work for Unalaska. As a result, D.G.G.S. received $15,000 in FY80 for initiating exploration work at Unalaska Island. Then for FY81, the D.G.G.S. received $73,000 from Alaska Power Authority through the Division of Energy and Power Development for actually undertaking exploration work at Unalaska, geared at assessing its geothermal resources. This combined State of Alaska and DOE funding in addition to my own research interest prompted this work at Unalaska.

Objectives

The general objectives of this investigation were not only to undertake 1:50,000 scale geologic mapping but to:

(1) identify any surface manifestations of any hydrothermal systems and take appropriate water samples of warm springs for standard geochemical determinations and geothermometry;

(2) determine the regional geologic structure potentially influencing hydrothermal systems and/or identify potential hydrothermal reservoir regions;

(3) identify rock potentially capping hydrothermal systems;

(4) identify shallow sources of heat potentially driving hydrothermal systems, including radiometric age dating and geochemical whole-rock analysis of igneous rocks; and

(5) identify geologic hazards in regions having potentially developable hydrothermal resources.

The region designated for regional investigation was the northern part of Unalaska Island. But, within this part of the island, priority was placed based on suspected or known hydrothermal potential on the immediate Summer Bay - Unalaska Community region, on the Wide Bay - Tabletop Mountain region, and on the Makushin Volcano region (figure 1).

Qualifying Statement

This report represents a conceptual hydrothermal and geological model for the northern part of Unalaska Island at this point in time. There is still a lot of work to be done as a result of the 1980 field work such as geochemical interpretations, petrographic thin-section examinations, and radiometric age dating determinations. In addition, there is justification for conducting further detailed field investigations. The main intent of any further work should be to substantiate, refine, and/or even disprove the proposed model in this report.

Geologic and Tectonic Setting of Unalaska Island

Unalaska Island is located in the eastern part of the Aleutian Island volcanic arc, a 1,100 mile archipelago extending from the Alaska Peninsula to the Kamchatka Peninsula. The Aleutian arc is actually part of a ridge-trench system associated with active volcanism and seismicity. With respect to the northern part of Unalaska Island, the Aleutian trench is located about 180 km to the south. Based on the theory of global tectonics, the floor of the Pacific Ocean (i.e., the Pacific Plate) is presently approaching relatively the Aleutian arc (i.e., the North Atlantic Plate) in a northwesterly direction at a rate of about 7 cm/year (Minster et al., 1974). Based on seismic models, the Pacific Plate dips about 30^{o} under the Aleutian arc until it reaches a depth of about 40 km where its dip increases abruptly to about 70^{o} (Jacob and Hamada, 1972); i.e., the Pacific Plate at the Aleutian trench is being underthrusted beneath the North American Plate. The history of tectonic plate-boundary interactions in this region such as presently occurring should have strong implications on the geologic evolution of Unalaska Island.

The rocks of Unalaska Island consist of an older group of altered sedimentary and volcanic rocks, a group of plutonic rocks intermediate in age, and a younger group of unaltered volcanic rocks. Such rock groups can be correlated with rock groups found throughout the eastern and central Aleutian Islands; i.e., an "early series" consisting mainly of a marine volcanic and sedimentary sequence that has been metamorphosed to a greenschist-grade, a "middle series" consisting mainly of plutonic rocks, and a "late series" consisting of an unaltered sequence of late Tertiary subaerial volcanic and sedimentary rocks (Marlow et al.,1973).

The "early series" is believed by Marlow et al. (1973), Scholl et al. (1975), and DeLong et al. (1977), to be Eocene to middle Miocene in age; i.e., 58 to 20 m.y.b.p., and to have been intruded by gabbro bodies dated about 30 m.y.b.p. The "middle series" or middle unit consists of epizonal plutons mainly of granodiorite composition that have intruded the "early series". These rocks have radiometric dates that fall betwen 10-15 m.y.b.p. (Marlow et al., 1973; DeLong et al., 1977). The "late series", consisting of interbedded andesitic magma rocks that unconformally overlies the "early and middle series", dates from the present back to probably at least 3 m.y.b.p. as based on radiometic age dates from andesitic magmas (Cameron and Stone, 1970). This date probably marks the time the modern volcanic arc began to form. In addition, an "initial series" has been proposed as making up the basement rock of the Aleutian ridge (Scholl et al., 1975), but no surface exposure of such rock as yet has been identified in the Aleutian Islands.

Unalaska Island consists mainly of rock exposures belonging to the older group of volcanic and sedimentary rocks designated the Unalaska Formation (Drewes et al., 1961). Drewes et al. divided the Unalaska Formation into three lithologically distict parts: "argillite southwest of Beaver Bay (southwest part of island), graywacke and conglomerate in the northern bulge area and south of Makuskin Bay, and coarse pyroclastic deposits in northeastern Unalaska Island, separated by wide transition zones...and intercalated with dacitic, andesitic, and basaltic flows and sills...and dikes of undetermined age...(where) all rocks were slightly altered".

Because of the lack of time and funds, the argillite and corresponding shallow intrusive rocks of the southern part of Unalaska Island were not examined in 1980. Pillowed lava and layered lava pods existing in this region were examined in detail by Snyder and Fraser (1963). The numerous sills of andesite and dacite and corresponding second-order structures such as pillowed lava were concluded by Snyder and Fraser to have been formed by magma intruding into unconsolidated to semi-consolidated marine muds deposited at non-shallow depths.

The graywackes and conglomerates in the northern bulge area of Unalaska Island were examined on several occasions during 1980. Such rocks were found to dominate the region of Glacier-Makuskin Valley, the upper part of Nateekin Valley, and the region north of Portage Bay (figure 1). In general, the beds were found to have a regional dip of about 10-20^{o} northeast and a strike to the northwest. Graywacke and conglomerate beds usually under 100 feet in thickness were at times separated by typical Unalaska Formation volcanic breccia and magma flows. No sills were found to exist in this region. The presence of channel deposits, graded bedding, and cross-stratification attest a proximal turbidite deposits of volcanically derived sedimentary rocks.

The coarse pyroclastic and magma flow deposits of the Unalaska Formation in the northeastern part of Unalaska Island were examined in the Summer Bay-Unalaska Community region, and were examined more casually throughout the Unalaska Bay region and in the southeastern area of the Makuskin Volcano region. Most of these volcanics are porphyritic with zoned plagioclase and subhedral angite with a groundmass of plagioclase, augite, and iron oxides. The "dacitic" rocks were usually found to be tuffacious ungraded breccia blows, whereas the andesites and basalts were represented by magma and/or poorly graded breccia flows. Only two sills were identified in this sequence of rock; one large sill exposed in the bluffs on the south side of Nateekan Bay and a small sill exposed at the soutwest end of Amaknak Island near the Unalaska Community. More sills are expected. These volcanic rocks are now

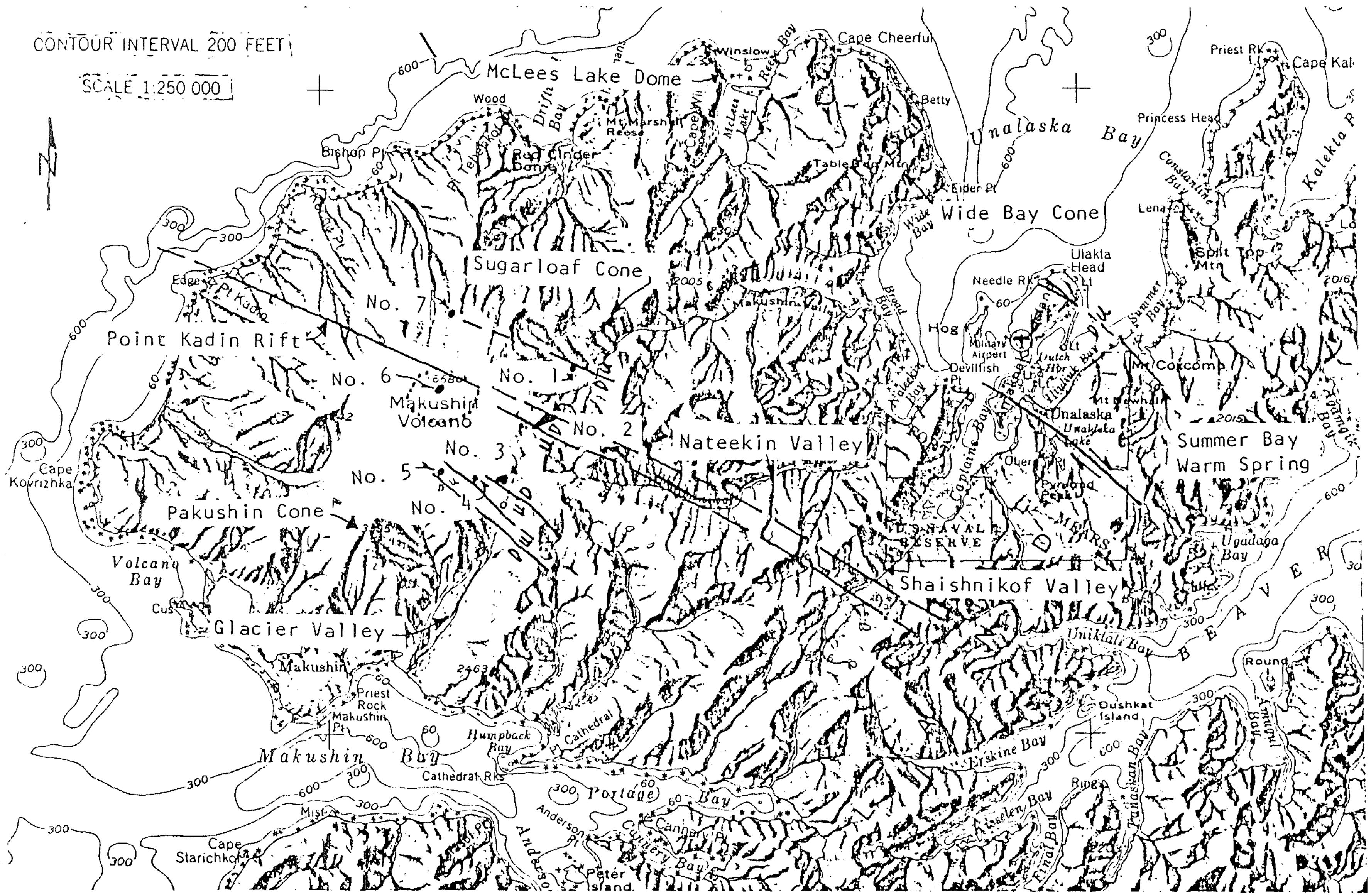

Figure 1 (a) Generalized hydrothermal map for the northern part of Unalaska Island. See figure 1 (b) for key to this map.

MAP SYMBOLS

Fault

Fault (location not exact)

Warm springs

Fumarole field with or without warm springs

Figure 1 (b) Key to figure 1 (a)

"greenstones", having been pervasively altered by albitization, chloritization, epidotization, silicification, and ziolitization. This sequence of rock was found to be extremely difficult to work with because of its degree of alteration and apparent lack of any obvious marker horizons.

The Unalaska Formation has been intruded by three well-exposed plutons and several smaller intrusive bodies (Drewes et al., 1961), having a wide spectrum of rock composition ranging from gabbro to felsic plutonic rocks. The Captain's Bay Pluton located just south and southwest of the Unalaska Community, one of the larger plutons, is zoned from a narrow rim of pyroxene gabbra and diorite to a heterogeneous central zone of hornblende-biotite granodiorite (Perfit, 1977). The other two plutons, the Shaler Pluton located south of Makushin Bay and the Beaver Inlet Pluton located south of Beaver Inlet, were not examined during the summer of 1980. The smaller intrusive bodies in the Unalaska Formation were found during 1980 to be more extensive than previously reported by Drewes et al. (1961) and by Perfit (1977). Although the ages of these smaller intrusive bodies have not been established, they have been considered to be approximately the same age as the larger plutonic bodies (Drewes et al., 1961; and Perfit, 1977). A Potasium - Argon age date of 11. 1 ± 3 m.y.b.p. for the Shaler Pluton has been determined (Marlow et al., 1973), and a Potasium - Argon age date of about 13 m.y.b.p. has been determined for the Captain's Bay Pluton (Lankford and Hill, 1979).

Unmetamorphosed "andesitic" volcanic rocks and volcanoclastics lie unconformably over the Unalaska Formation west of Unalaska Bay and north of Makushin Bay (Drewes et al., 1961). Nearly one-third of the summer of 1980 was spent examining these rocks. The Makushin Volcanics, which makes up most of these rocks, are mostly basalt with subordinate amounts of andesite and pyroclastics (Drewes et al., 1961). These volcanics typically contain 10 to 30 percent phenocrysts of plagioclase and augite with lesser amounts of olivine and scarce hyperstene (Drewes et al., 1961) in a trachytic groundmass comprising of plagioclase, granular augites and olivine. Locally these rocks are capped unconformably by "basaltic" flows and pyroclastic rocks originally mapped as the Eider Point Basalts (Drewes et al., 1961) that have similar mineralogies to the Makushin Volcanics but in addition have retained their constructional form.

Summer Bay - Unalaska Community Region

A better understanding of the Summer Bay warm spring and defining the potential of finding similar warm waters in the vicinity were the main objectives in mind during the geologic investigations in the Summer Bay - Unalaska Community region. In order to achieve these objectives, emphasis was initially placed on defining the geologic structure of the region, requiring the examinations of the Unalaska formation and plutonic bodies that have intruded it.

The Unalaska Formation was found to consist mainly of tuffaceous breccia and magma flows having a regional dip of about 10° north to slightly north-east and a regional strike of east-west to north west. The region northeast of Summer Bay was found to be dominated almost entirely by tuffaceous breccias, possibly explaining the smoother topographic expressions than typically found elsewhere. The massive nature of the igneous and pyroclastic members and the lack of any obvious key beds in the field have prohibited any subdivision yet of this formation. At several potential stratigraphic sections, extensive rock samples were taken specifically for detailed petrographic and geochemical analyses in hopes of detecting potential marker beds in the Unalaska Formation. These analyses have not yet been completed.

A few volcanically derived conglomerate-sandstone interbeds were observed in the Unalaska Formation between the Summer Bay and Ugadaga Bay. Unfortunately these interbeds were not traceable for large enough distances to serve as possible marker beds. Another sedimentary unit originally examined and described by Drewes et al.,(1961) and designated the Dutch Harbor Member by Lankford and Hill (1979) was mapped regionally during the summer of 1980. No other mappable sedimentary interbeds were found in the Unalaska Formation.

The type section for the Dutch Harbor Member was measured by Lankford and Hill (1979) just southeast of the Unalaska Community. At the type section, they found the Dutch Harbor Member to be 126 meters thick, and to consist dominantly of "greenish-gray, hard, indurated" sandstone and "rhythmically bedded" sandstone and conglomerate. The beds were found to dip between 20-23^o to the northeast with a strike of about N 30^o W. Lankford and Hill considered the Dutch Harbor Member as an interbed in the Unalaska Formation, being bound by an "upper volcanic sequence" and a "lower volcanic sequence".

A tuffaceous "andesitic" breccia containing clast over one-half meter in diameter was found immediately above Dutch Harbor Member near the type section. This same or a very similar breccia was found just below the Member, being separated from it by a normal fault dipping steeply to the southwest. Such faults, striking northwest, are numerous. Because of such faulting, the "upper volcanic sequence" appears to be exposed on both sides of the type section. The "lower volcanic sequence" if it exists either is not exposed or has not yet been recognized.

At the base of Pyramid Peak, a sequence of sedimentary rocks very similar to the Dutch Harbor Member was recognized. This body of rock, although chaotically faulted, was traced along a good part of the southeastern side of Captain's Bay and was traced across the Bay as part of an anticline. The axis of this anticline strikes about N70^o E with the beds to the south of this axis dipping up to 25^o but more typically at about 10^o to the south such as the pyroclastic and magma flow beds dip on the top of Pyramid Peak. To the north of this axis, beds dip as steeply as 40^o to the north. The anticline was not traced northeast beyond Pyramid Peak nor southwest beyond Captain's Bay.

With respect to the graywacke and conglomerate beds, and the volcanic breccia and magma flow beds exposed in the upper Nateekin Valley and in the region north of Portage Bay; it appears that the supposive Dutch Harbor

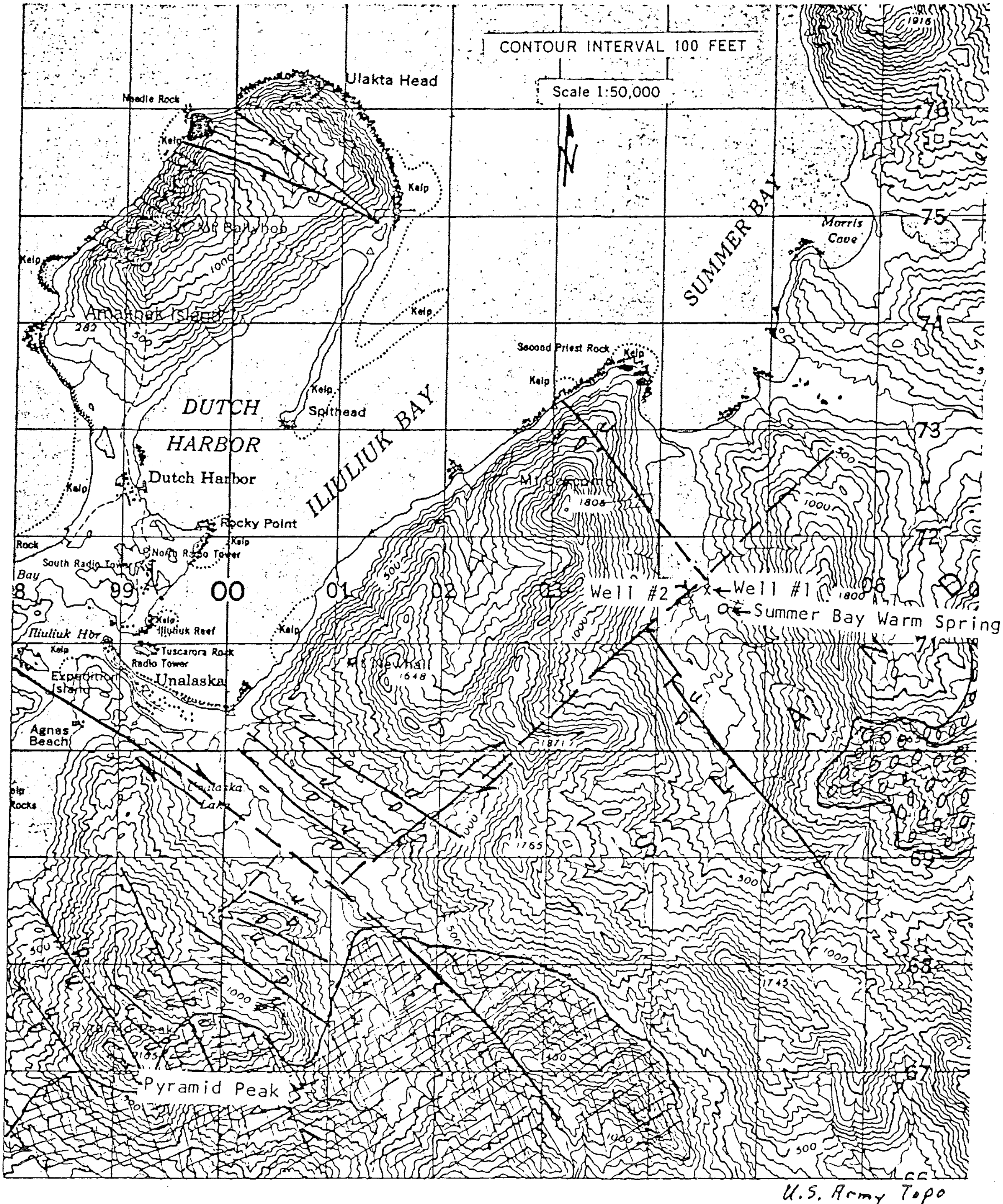

Figure 2 (a) Generalized geological map for the Summer Bay - Unalaska Community Region. See figure 2 (b) for key to this map.

EXPLANATION

Map Units

Unalaska Formation

Captains Bay Pluton

Plutonic bodies

Agamgik Formation

Map Symbols

Fault

Fault (location not exact)

Warm Spring

Hydrothermal well

Figure 2 (b) Key to figure 2 (a).

Member trends directly underneath or into these exposed rocks. In this case, the massive breccia and magma flow beds of the Unalaska Formation which are chacteristic of the Unalaska Bay region probably grade laterally in a southward direction into this sequence of graywackes and conglomerates. Because these sedimentary rocks dip northward, they have been considered relatively older than the rocks of the Unalaska Formation exposed at Unalaska Bay (Drewes et al., 1961). Based on the existence of northwest striking normal faults which could have vertically offset these beds, the rocks of the Unalaska Formation throughout the northern part of Unalaska Island are believed to be relatively of the same age.

The Unalaska Formation, at least in the northern part of Unalaska Island, is upper Oligocene to middle Miocene in age (i.e., about 20 to 30 m.y.b.p.) as based on bivalves, barnacle plates, burrow fillings, and a vertebra (Lankford and Hill, 1979), and based on bones and teeth of a desmostylid (Drewes et al., 1980) found in the Dutch Harbor Member just northeast of Unalaska Lake. Pelecypod molds of lower Miocene age were also found in volcanic breccias and sandstones in the Unalaska Formation southwest of Captain's Bay (Perfit, 1977) near Shaishnikof Lake.

Several small bodies of intrusive plutonic rock of intermediate composition were found to intrude the apparent Dutch Harbor Member sedimentary sequence on the southeast side of Captain's Bay, and bodies of plutonic rock of gabbro to intermediate composition were found exposed under this sedimentary sequence on the west side of Captain's Bay. One of these gabbro bodies was found to be connected directly to (most likely part of) the western exposure of the Captain's Bay Pluton. The other intrusive plutonic bodies are also believed to be related to the Captain's Bay Pluton which is exposed just to the southeast.

The lower exposure on the southeast side of Pyramid Peak are felsic to intermediate plutonic rocks of the Captain's Bay Pluton, where such rocks are suspected to underlie at shallow depths the rest of the mountain. Complex structure consisting dominantly of normal faults was found on the western and northern flanks of Pyramid Peak, where only the major recognized faults have been indicated in figure 2. Of these, several large normal faults exist on the northern side of Pyramid Peak dipping steeply to the north and striking in a northwest direction. The mapped Dutch Harbor Member, exposed on the flanks of Pyramid Peak, appears to have been uplifted relative to its type section in Unalaska Valley by nearly 1500 feet by these normal faults. Plutonic rocks related to the Captain's Bay Pluton are suspected to underlie the type section of the Dutch Harbor Member, and to underlie at shallow depths most of the western part of Unalaska Valley. The Captain's Bay Pluton is well exposed throughout the eastern part of this valley (Perfit, 1977).

Chaotic faulting of sedimentary rocks similar to if not the Dutch Harbor Member were also observed in the peaks at the head of Unalaska Valley; i.e., between the Unalaska Community and Ugadaga Bay. Many of these faults are a series of nearly parallel normal faults striking roughly to the northeast and dipping steeply to the west. Perfit (1977) and Perfit and Lawrence (1979) also recognized the country rock near the Captain's Bay Pluton as having been domed, faulted, and chaotically fractured. They observed the intrusive contacts as being characterized by: (1) inequigranular to porphyritic plutonic rocks that exhibit irregular and indistinct contacts with the surrounding rock; (2) locally abundant zenoliths and schlieren; (3) extensive brecciation, shearing, and fracturing; (4) secondary mineralization (such as quartz, pyrite, and calcopyrite); (5) vein pegmatite development; and (6) hydrothermal alteration of wall rock". Such contacts are characteristic of forceful plutonic intrusions.

The Unalaska Formation at Amaknak has apparently been domed and fractured by the intrusion of two small plutonic bodies of gabbro to intermediate plutonic rocks (Pefit, 1977). Three more similar instrusive bodies were found during 1980 in the Summer Bay region along the coast. These Summer Bay plutonic bodies have "dike-like" configurations up to 20 feet in thickness, being nearly vertical and striking approximately N 45° W.

A large normal fault striking about N 45° W and dipping 60 to 75° south, marking the southwest limit of these five small intrusive bodies, is well exposed along the coast just south of Summer Bay (figure 2). This fault is suspected to be genetically related to the "forceful" intrusion of these plutonic bodies. An unusual amount of secondary silica, free sulfur irons oxides, and some pyrite was visually observed on the exposed fault surface which, if extended across the Summer Bay Lake, extends directly through the Summer Bay warm spring. Unfortunately, extensive bedrock examination immediately at the spring did not indicate the presence of this fault, although joints striking about N 45° W are highly suspected as controlling the source waters for the spring, and accounting for the alignment in this direction of a smaller nearby spring to the main spring.

The Summer Bay warm spring occurs near the base of exposed Unalaska Formation in a boggy swamp located south of Summer Bay Lake (figure 3). Extensive talus, glacial till, allumium, and/or beach deposits were suspected to exist underneath this swampy region; i.e., material that could easily contain aquifers of warm water. Water samples were taken during the summer by Shirley Liss and myself at the main spring, having a temperature of 35°C and a discharge of approximately 1 gallon per minute. Quartz adiabatic geothermometry of this water indicates a reservoir source temperature of about 60° C (Motyka, D.G.G.S., pers. comm., 1981), where these results are still preliminary since complete chemical analyses have not as yet been completed by D.G.G.S. (Appendix A).

During the summer of 1980, I was informed by Don Markle of the State of Alaska Division of Energy and Power Development that a contract had been given to Dames and Moore for the drilling of two one-hundred feet geothermal wells in the Unalaska Community. Unfortunately, such well depths are not deep enough to establish good bedrock temperature gradients (White et al., 1975). Although the Unalaska Community area is highly fractured, no hot springs have been reported in this region nor did I observe fractures such as the one normal fault near Summer Bay containing the large quantities of

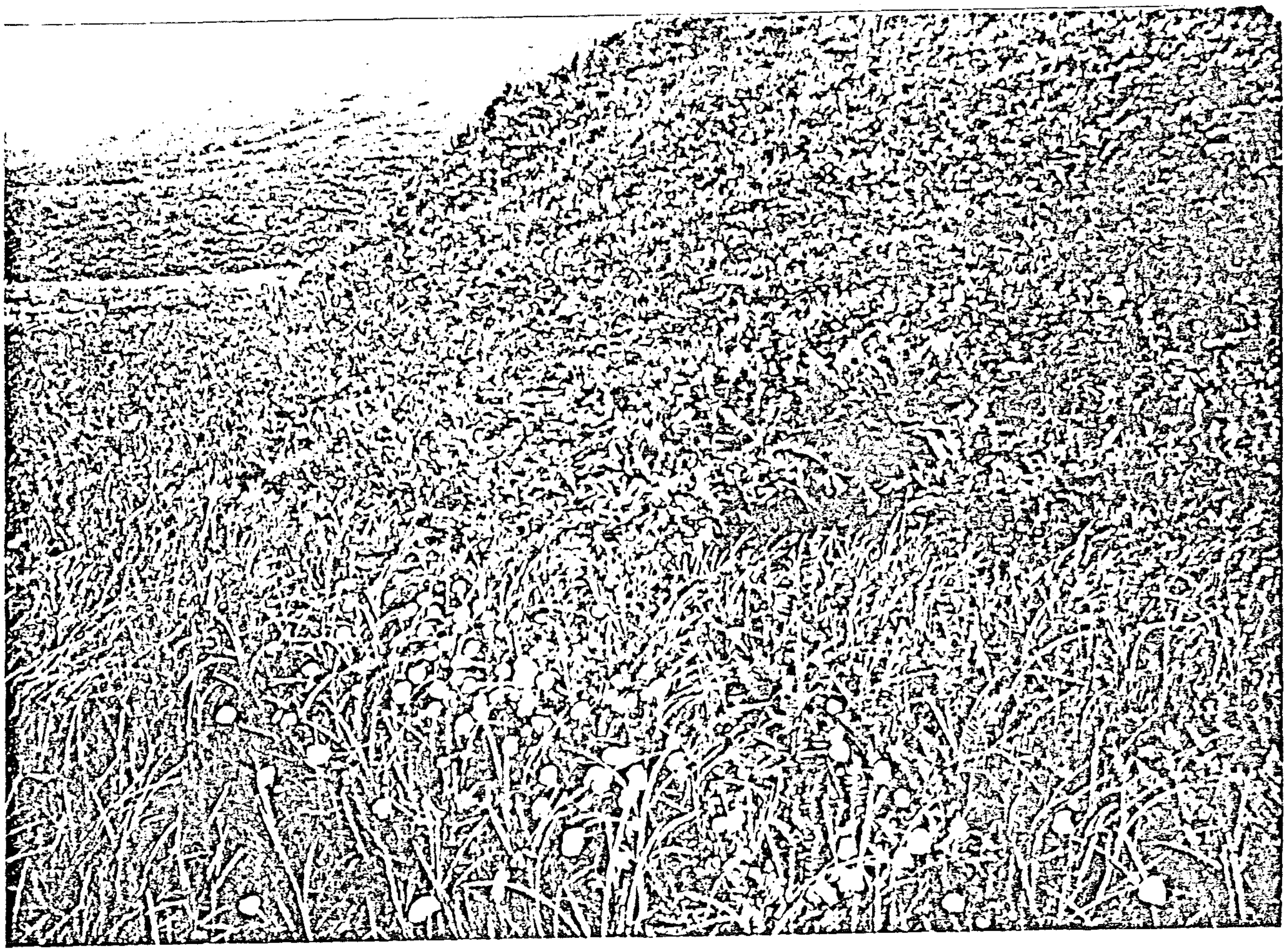

Figure 3 A view of the Summer Bay warm spring taken in June, 1980.

secondary minerals potentially related to hydrothermal activity. Unconsolidated deposits existing south of Unalaska Lake could contain aquifers of warm water tapped from potential fractured-bedrock sources. But two city wells penetrate this material and even though the well logs for these wells have been lost, it is suspected that if warm-water aquifers had been penetrated, it would have been well known by the community. So I could not recommend to Don Markle any hydrothermal drilling sites within the immediate Unalaska Community region. After I informed Don that I could and would recommend hydrothermal drilling sites at Summer Bay, he had the contract changed so the wells could be drilled in the Summer Bay region.

Two wells were drilled and later abandoned at sites I had selected in the Summer Bay region in the fall of 1980 (Dames and Moore, 1980). The first drilling site was located on the south shore of Summer Bay Lake directly in line with the normal fault which appeared to trend directly toward the warm spring. The site was marked by cold-water seeps, most likely seeping from the nearby swamp, and by iron-stained sediments. Actually, such iron deposits and cold-water seeps had no influence on the selection of this site.

The first well, being located just above the elevation of the water level of Summer Bay Lake, passed through medium to coarse volcanic black sands down to a depth of 34 feet where a fine chalky clay containing small shell fragments was encountered. The volcanic black sands were penetrated again at a depth of 37 feet. Bedrock typical of the meta-volcanics of the Unalaska Formation was encountered at a depth of 54 feet.

The well penetrated a warm-water artesian aquifer at a depth of 42 feet, having thickness of under three feet. After the well was initially drilled on September 25, the well was flowing at the ground surface under natural artesian pressure at a rate of about 48 gallons per minute through a four inch diameter well casing, and at a temperature of 49.5° Celsius. The well was allowed to flow overnight, and was flowing naturally at a rate of 50 gallons per minute and a temperature of about 50.0° Celsius by 9 A.M. (figure 4). The pressure head was found to be six feet above the ground surface or approximately six feet above the existing lake level.

The second well was sited about 200 yards along the lake west of the first well for the main purpose of determing whether the warm water aquifer extends west beneath the meadow. The well being located about three feet above the elevation of the water level of Summer Bay Lake passed through about 15 feet of alluvium containing similar volcanic black alluvium sand as found in well no. 1. Below 15 feet, the well penetrated only the volcanic black sands down to a depth of about 52 feet. From 52 to 57 feet, a layer of chalky silt and clay with small shell fragments were encountered; bedrock being penetrated at 57 feet.

A warm water artesian aquifer was again encountered by well no. 2 at a depth of about 44 feet. On the morning of September 27, the well was

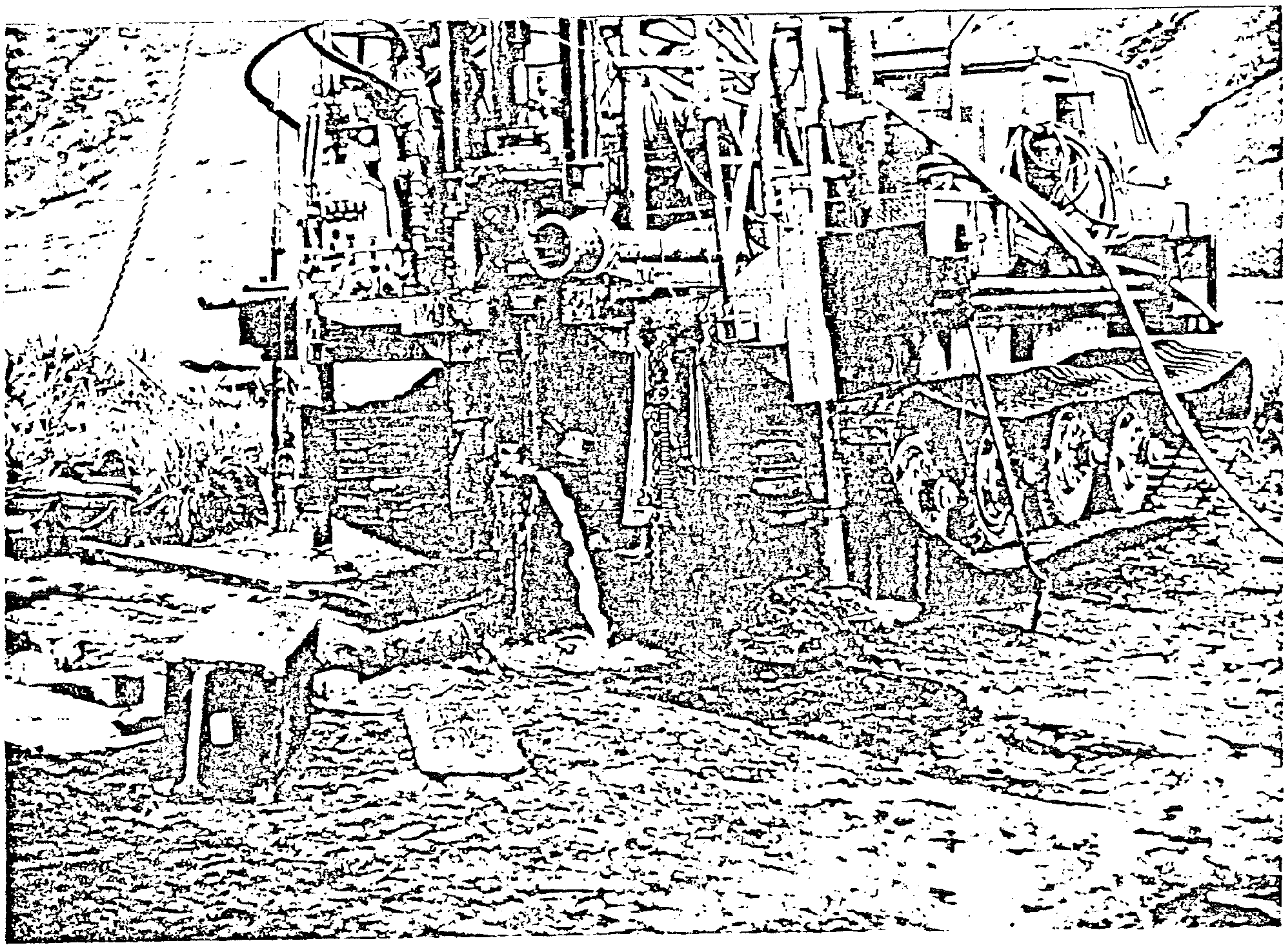

Figure 4 A view of the first Summer Bay hydrothermal well, flowing naturally under artesian pressure.

allowed to flow naturally. By noon, the well was flowing at 7.2 gallons per minute from a 4 inch diameter casing and at a temperature of about 43.5° Celsius. The pressure head was found to be three feet above the ground surface or approximately six feet above the existing lake level.

The black volcanic sand has been initially examined petrographically and has been found to consist mainly of scoraceous glass grains containing recognizable bytownite and hyperstene phenocryst typical of the Eider Point Basalts from the Makushin Volcano and Eider Point Region. In addition, lithic fragments most likely derived from the Unalaska Formation were observed. Although the source or sources of this volcanic material are presently unknown, this ash is suspected to have resulted, mainly because of its large grain size, from a fairly large eruption of Makushin Volcano since the last glacial maximum of about 11,500 y.b.p. Other sources could have been Tabletop Mountain and the Wide Bay cone near Eider Point on Unalaska Island, Okmok caldera on Umnak Island (Byers, Jr, 1959; Laughlin, 1975; and Black, 1976), Akutan Island (Byers and Barth, 1953), and Fisher caldera on Unimak Island (Miller and Smith, 1977). Further petrographic examinations including glass refraction index determinations of this material and with material from the Makushin Volcano region need to still be completed.

A chunk of plutonic rock was caught in the drilling bit at the bottom of the second well. If this plutonic rock is from a piece of float, it is probably from a nearby source in the poorly rock-exposed valley floor since no plutonic bodies have been recognized in the Summer Bay valley except for the small outcrops found near the coast. The rock is a quartz diorite, being an intermediate plutonic rock similar to the other small intrusive bodies at Summer Bay. It shows similar signs of alteration as occurred with the surrounding Unalaska Formation except extensive silica secondary mineralization and extensive shearing was observed. The discovery of plutonic rock at this second well was not initially expected, which prompted further field examinations. Apparently, the normal fault striking N 45° W originally recognized to trend toward the warm spring is offset to the southwest by another fault (figure 2). If the N 45° W fault is actually genetically related to the small intrusive bodies at Summer Bay and the northern part of Amaknak Island, these small intrusive bodies based on the relative ages of faults are older than the Captain's Bay Pluton. In part, this might explain their more intense alteration.

Chemical analyses of water samples from the Summer Bay wells (Appendix B) in comparison to analyses of water samples from the warm spring (Appendix A) indicate anomalously higher amounts of every constituent for the artesian warm waters with respect to the warm spring waters. Results from our Fairbanks laboratory indicate values as high as 522 mg/l for SO_4 and 10.3 mg/l for Mg in the artesian warm waters as an example (Motyka, D.G.G.S., pers. comm., 1981). Although the D.G.G.S. chemical analyses of these well waters are still incomplete, Quartz adiabatic geothermometry indicate reservoir source temperatures of as high as 86° Celsius.

The actual nature of the warm water aquifer system is not known, but its source is probably from highly fractured Unalaska Formation and intruded plutonic bodies. The aquifer of warm artesian water is suspected of being actually confined by an impermeable layer consisting of mineral precipitates from the warm waters. Such a cap may have required an extensive amount of time to be formed; i.e., hundreds of years if not longer. Drilling through such caps should only be done with proper care, where any wells should be properly completed and/or abandoned; i.e., definitely not the way the 1980 wells were drilled and abandoned (Dames and Moore, 1980).

Porphyritic "basaltic" to "dacitic" dikes, striking between N 70° W to N 40° W directions and dipping southwest, cut parts of the Unalaska Formation throughout the northern part of the island (Drewes et al., 1961). Such dikes are found to be quite numerous in the central part of Amaknak Island and in the Summer Bay region, making up in some places over 50 percent of the rock. Most of these dikes contain noticeable amounts of pyrite and iron-oxides, and have been altered like most of the rocks found in the Unalaska Formation. Such a concentration of dikes represents what was originally a volcanic rift zone, where these dikes would have been feeder dikes supplying most of the materials making up the Unalaska Formation. Thus, such dikes would be approximately the same age as the Unalaska Formation.

A few porphyritic dikes have also been found cutting the Captain's Bay Pluton. Such dikes are geologically significant since they are younger than 13 m.y.b.p.; i.e., younger than or about the same age as the Captain's Bay Pluton. Such dikes, showing signs of alteration similar to the alteration found in the older dikes, also strike about N 50° W.

Of interest was the discovery in 1980 of about 800 feet in thickness of "basaltic" magma and breccia flows containing numerous conglomerate to sandstone interbeds. This sequence of rock located between Agamgik Bay and Summer Bay is only moderately altered with secondary silicification and zeolitization being common. This unit, dipping to the southeast at angles as great as 25° and striking east to northeast, unconformably overlies the Unalaska Formation. A type section was measured, but more detailed description of this section will need to await geochemical and petrographic thin-section analyses. Although no correlations to surrounding dikes have yet been made with this sequence, this unit is suspected to be roughly the same age as the Captain's Bay Pluton; i.e. much younger than the underlying Unalaska Formation. These rocks probably represent the old remains of a volcanic complex similar to what presently exists in the Wide Bay - Tabletop Mountain region. This unit is designated here as the Agamgik Formation since it was found to be a distinct mappable unit.

One "basaltic" dike discovered between Morris Cove and Summer Bay Lake is only slightly altered. This dike, striking roughly N 45° W, is suspected to be much younger than the Captain's Bay Pluton. Age-dating samples were taken in hopes of obtaining a good radiometric age date. Although most dikes of the region appear to have occurred during the formation of the Unalaska Formation, several have been recognized or are suspected to have occurred more recently.

A major right-lateral strike-slip fault has been recognized in the immediate Unalaska Community area. A recent road-cut exposes this fault, where the soil horizon over the fault, examined at a distance of about ten feet, appears disturbed. Such soil disruptions could have been easily caused by recent fault movements, activities of man, and/or natural surficial processes. Although the initial examinations of this fault are only preliminary, the fault could presently be active. The right lateral strike-slip direction of displacement would result in a relative clockwise rotation of the part of Unalaska Island between Beaver Inlet and Unalaska Bay away from the volcanically active northwestern region of Makushin Volcano and Wide Bay. Land displacements of up to 700 meters are suspected, possibly offsetting the Iliuliuk Bay topographic feature from the Captain's Bay topographic feature where both were originally suspected of being aligned.

Such a suspected land mass rotation, as previously suggested, would result in crustal spreading and in the formation of "graben-like" structural basins. Such a basin is strongly suspected to exist presently in Unalaska Bay between Amaknak Island and Wide Bay. This basin, if it exists, would be expected to be bound by normal faults striking approximately N 50° E to N 70° E. Although no such faults have been recognized in this region, air-photo linears striking approximately in this direction have been. Graben controlled basins have been recognized throughout the Aleutian ridge (Scholl et al., 1975), their formation in part being correlated to extensive nearly volcanic extrusions and tectonism.

The Wide Bay - Tabletop Mountain Region

The Wide Bay - Tabletop Mountain region consists of exposures of the Unalaska Formation throughout the Broad Bay - Makushin Valley region, and exposures of Makushin Volcanics to the north. In addition, two small geologically recent cones and one geologically recent dome have been recognized in the region (Drewes et al., 1961). These are the Wide Bay cone near Eider Point commonly called the "extinct volcano", Tabletop Mountain cone and related domes and magma flows, and a dome and corresponding magma flow near the west end of McLees Lake. All three volcanic bodies have compositions similar to the Eider Point Basalts.

The Wide Bay cone is a symmetrical unglaciated composite cone. Individual lava flows traced from the crater of this cone to the valley in the west show signs of glaciation at their toes, as indicated by the presence of glacial striations. The Tabletop Mountain cone in contrast appears to have been eroded by glacial processes where glacial striations are quite common on the surfaces of the flows issued from this cone and/or nearby domes. The small dome west of McLees Lake appears to have been extensively eroded, although one flow from this dome, partly extending down a bluff toward the lake, still has retained some of its "levee-like" flow features. Relatively, extrusive volcanic activity has progressed from the McLees Lake dome in a S 55° E to S 60° E direction as represented by Tabletop Mountain and its domes immediately to its northeast, and then by the Wide Bay cone. The Wide Bay cone probably is no older than 11,400 years, the time of the last glacial maximum (Black,1976). The crater on top of Wide Bay cone has been breached on two opposite sides. These two breaks are aligned in about a N 45° W direction; the strike of a suspected feeder dike. Further geochemical analyses should help better establish any further links between volcanic activity in this region.

Numerous small water springs were noted throughout the region between the Wide Bay cone and Tabletop Mountain, but none of these were found at above normal surface-water temperatures (i.e., about 10° Celsius). Most of these springs issue from the conformal contacts between magma flows and more porous pyroclastic flows.

Along the north side of Makushin Valley just west of Broad Bay about half a dozen large springs occur, being represented by large deep ponds. The actual discharge from these springs is unknown, but their temperature is about 8° Celsius. These springs probably represent the suspected warm springs reported by local residents of Unalaska (Henry Swanson, pers. comm., 1980). The source for these springs may be fracture zones within the Unalaska Formation and/or large aquifer systems under artesian pressure in the unconsolidated deposits filling the Makushin - Broad Bay Valley. This valley could contain some of the largest groundwater resources in the northern region of Unalaska Island.

The region south of the Makushin - Broad Bay Valley but north of Nateekin Valley was never examined during 1980. The upper part of of Makushin Valley below 800 feet elevation was also never examined, although several helicopter passes were made. No hydrothermal surface manifestations were recognized.

The Makushin Volcano Region

Several impressive fumarole fields and warm springs were examined in this region during the summer of 1980. One of these fumarole fields, fumarole field no. 1, is located just east of Makushin Volcano in the upper reaches of Makushin Valley at an elevation of about 1400 feet above sea level (figures 1 and 5). The largest fumarole field observed, fumarole field no 2, being about one-half mile long and about one-quarter mile wide is located further up this valley at elevations between 2,000 and 2,600 feet (figures 1 and 6). Two other fumarole fields were examined southeast of Makushin Volcano in the upper reaches of the Makus in - Glacier Valley at elevations of about 2,000 feet for fumarole field no. 3 and at elevations of about 2200 feet for fumarole field no. 4 (figures 1 and 7). A fumarole field, fumarole field no. 5, at about 2600 feet was also examined on the south side of Makushin Volcano. The fumarole field on the top of Makushin Volcano, fumarole field no. 6, was never examined in any detail during 1980 mainly because of logistical and weather problems. In addition, a fumarole field, fumarole field no. 7, was visited by Dr. Ross Schaff and Dr. Bill Long (D.G.G.S., pers. comm., 1980) during a 1968 visit to the region. This particular fumarole field was not visited during 1980. In all cases except for fumarole fields no. 6 and no. 7, warm water springs were found in the fields or at lower elevations near the fields.

The region to the southeast consists mainly of rock exposures belonging to the Unalaska Formation, whereas Makushin Volcanics make up the Makushin Volcano and most of the rock exposures to the northwest of an imaginary boundary striking about N 60° E as marked by Pakushin cone, Sugar Loaf cone, and Tabletop Mountain cone (figure 1). All of these geologically recent cones, consisting of Eider Point Basalts, have been, except for Pakushin cone, subject to fairly intense glacial erosion. Pakushin cone, like the Wide Bay cone, is suspected to date within the last 11,400 years.

To the southeast of Makushin Volcano, the Makushin Volcanics form a highly eroded cap only on the highest peaks nearest the volcano. The rocks to the southeast appear to have been uplifted relative to the rocks to the northwest of the Pakushin - Tabletop Mountain demarkation. It is suspected that the Unalaska Formation has actually been "down dropped" relative to the rocks to the southeast because of the large volume of volcanic extrusion as only partly represented by the existing Makushin Volcanics and the Eider Point Basalts. A N 60° E rift zone is expected in the region of the Pakushin - Tabletop Mountain demarkation. Numerous linear features have been recognized on air photographs in the northern Unalaska Island as striking approximately N 60° E, but no faults striking in this direction have been verified in the Makushin Volcano region. One of the objectives of any future work should be to detect the suspected N 60° E rift zone.

Several faults striking between N 40° W to N 70° W were found in the field near the vicinity of the fumarole fields (figure 1). Two of these faults which strike about N 60° W extend nearly the entire length of the

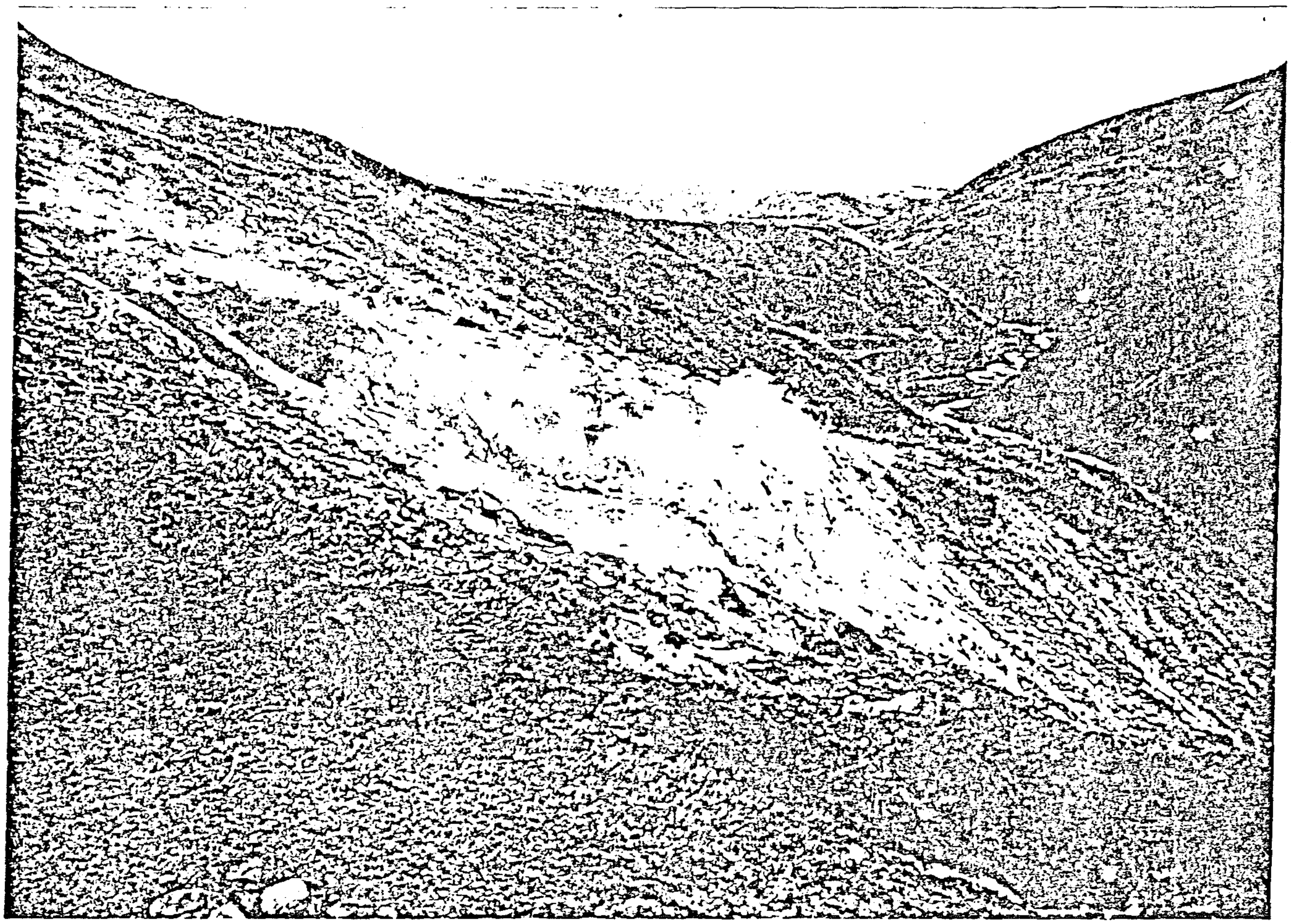

Figure 5 A view of fumarole field No. 1.

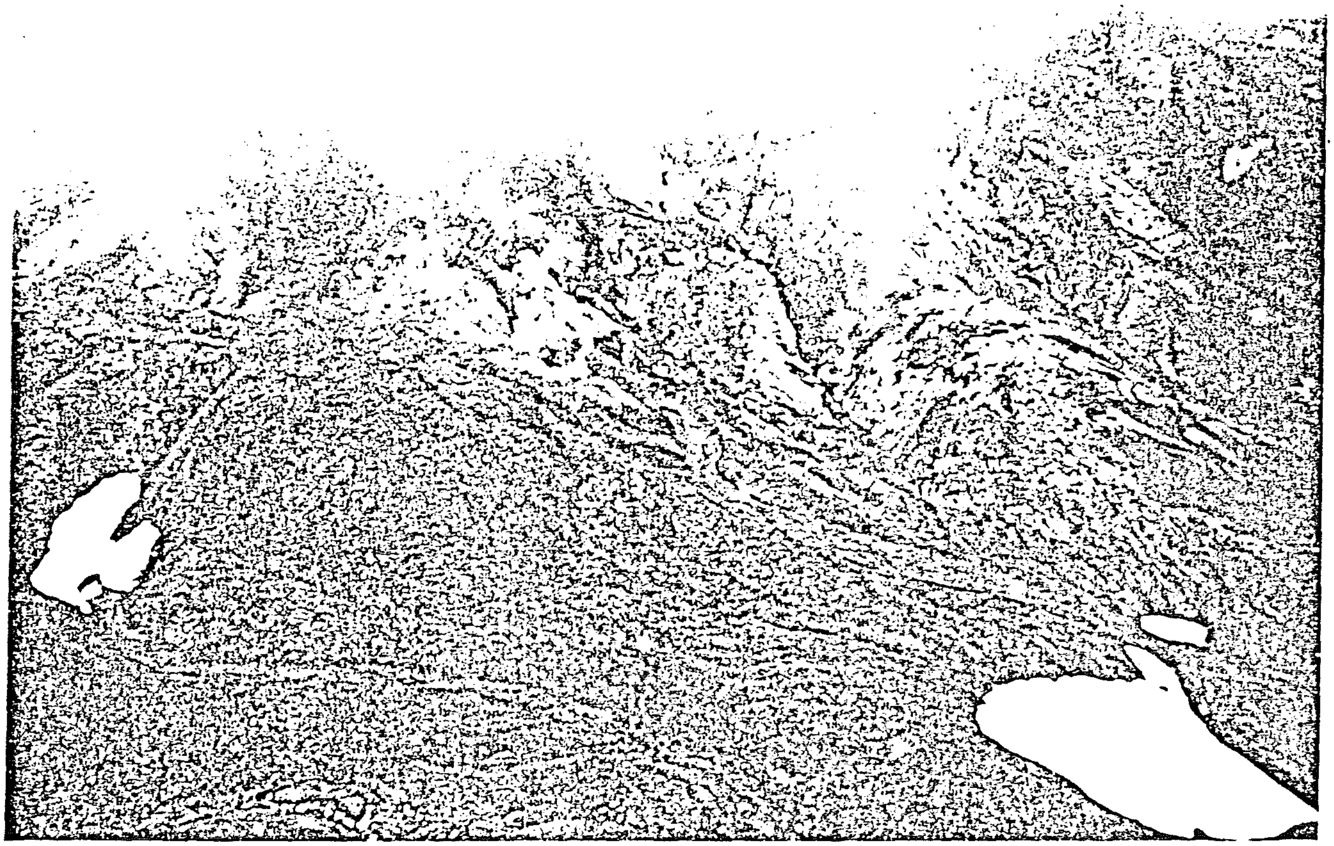

Figure 6 A view of fumarole field no. 2.

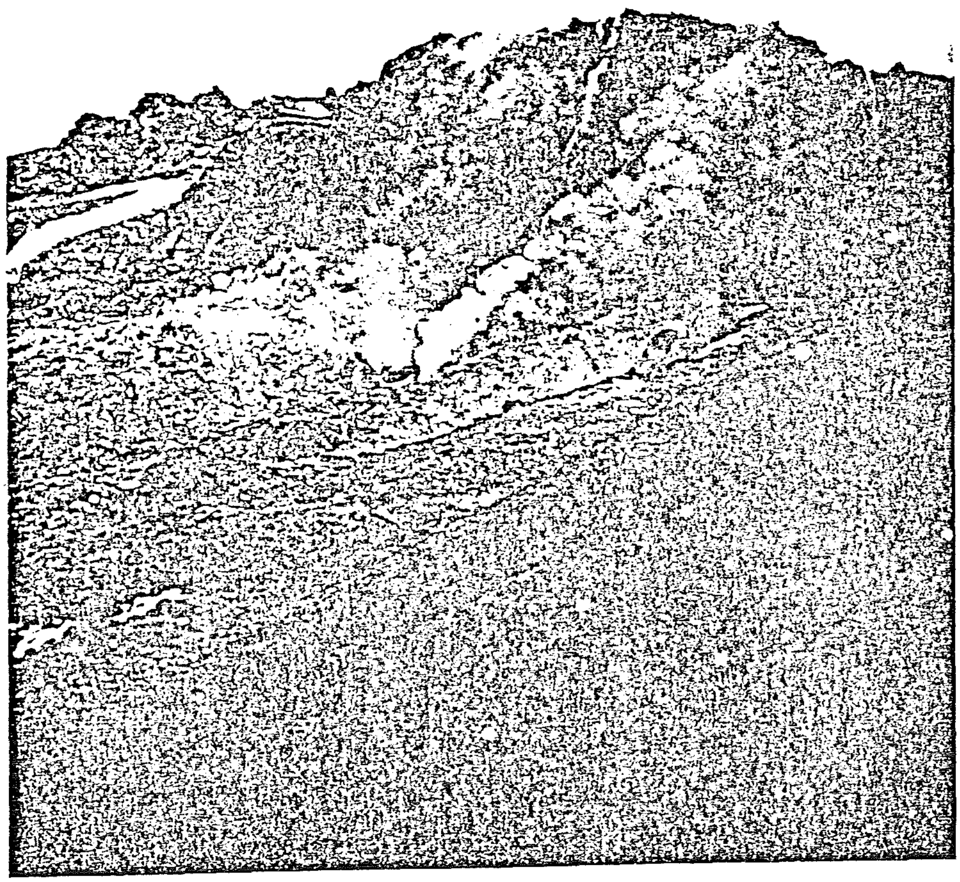

Figure 7 A view of fumarole field no. 3.

northern part of Unalaska Island, a distance of over 20 miles. These particular faults are considered to be presently active, where both visually disrupt soil horizons in the Shaisnikof Valley. Both faults were traced on air phtographs through the upper reach of the Nateekin Valley where they parallel the upper reach of this valley. These faults border both sides of the fumarole field no. 2, where the northern fault parallels a dike of undetermined age striking N 56° W and dipping steeply south. The fumarole field appears to be bound within a small "graben-like" structure. By following the trend of these faults, one will pass through the northeastern end of the Makushin caldera complex and then will pass along the "Point Kadin fissure line" which, as described originally by Drewes et al., (1961), strikes N 75° W through several recent explosion craters. Based on the lack of glacial erosion on the extruded flows and on the degree of development of a submarine bench, Drewes, et. al., claimed this fissure line and extruded lavas as dating within the last several thousand years. Based on the large lichens I observed on the surfaces of some of the scoraceous "basaltic" rocks exposed on the largest of these explosion craters, these craters must be at least several hundred years in age.

A small fault trending in approximately a N 70° W direction was observed near fumarole field no. 1, cutting pyroclastic flow deposits believed to be less than 11,400 years in age (figure 5). If this fault is extended in a N 60° W direction, it would pass directly through the reported fumarole field no. 7. Other faults striking between N 40° W to N 65° W were also observed near the fumarole fields no. 3, no. 4, and no. 5 (figure 1).

A lineation was recognized on air photographs cutting across the Makushin - Glacier Valley at about a N 60° W direction, trending directly toward the center of Makushin cone. Unfortunately, by the time helicopter transport was available (not until August), vegetation had become so thick on the valley floor that this suspected fault break could not be found.

Due to the underthrusting of a plate under another, such as is presently occurring at the Aleutian trench, compressional stresses in the direction of plate convergence will exist in the arc region of the upper plate (Nakamura, 1977). Since dikes trend to propagate in a direction normal to the minimum principle stress, their general orientation should reflect the direction of maximum horizontal compression. Nakamura et al., (1977) determined the direction of the principal tectonic stress based on the orientation of flank eruptions on volcanoes for the Aleutian volcanic arc. His findings roughly correlate with the relative motion between the Pacific and North American Plates (Nakamura et al, 1980) based on the known boundaries and rotation centers of the two plates. For Makushin Volcano, Nakamura et al.,(1977) determined a maximum stress orientation of N 60° W where the expected azimuth was about N 45° W. My findings indicate a N 60° W as tne actual field azimuth.

The faults recognized near the fumarole fields are suspected to have been caused by active tectonic processes. Such faults probably penetrate deep into the crust, where they may contain magma. In the case of the Point Kadin rift, the magma did reach the surface, resulting in extensive volcanic extrusions and formation of at least one dike. In the case of the fumarole region, the magma is probably at shallow depths, i.e., less than 2 km, and probably serves as the heat source driving the hydrothermal system and/or systems.

The Unalaska Formation in the region of fumarole fields no. 1, no. 2, and no. 3 has been intruded by small plutonic bodies of gabbro and/or intermediate plutonic rocks. These intrusive bodies and the surrounding Unalaska Formation are severely jointed and/or fractured expecially along contact boundaries. In one small gabbro body just northeast of the fumarole field no. 2, the following joints were measured at just one location:

N 32° E with a 83° dip to the south;
N 57° W with a 74 ° dip to the south (orientation of maximum compressional stress);
N 80° W with a 30° dip to the north; and
N 28° W with a 83° dip to the south.

Such joints in the plutonic bodies and the Unalaska Formation as well as the regional faults trending N 60° W serve as good reservoirs for the hydrothermal systems and/or help allow surface-water recharge to such systems. In addition, the Makushin Volcanics can serve as an impermeable cap to reservoirs such as manifested by fumarole fields no. 2, 3, 4, 5, and 7. Recent lava flows related to Sugar Loaf (Eider Point Basalts) caps the region near fumarole field no. 1, and may serve as an impermeable cap as well.

The hydrothermal systems are expected to extend throughout a much larger area than actually indicated by the observed hydrothermal manifestations. But on the other extreme, not all (and possibly none) of the fields observed in 1980 are believed to be connected. For example, the fumarole field no. 1 and no. 2 are separated by a large plutonic quartz diorite body that shows very little hydrothermal alteration. Hopefully, rocks collected from this pluton will yield a good radiometric age date. Most of the hydrothermal systems are expected to have an approximate N 60° W orientation in regional extent, extending under regions of higher topography from their surface exposures.

The hillsides throughout the region southeast of Makushin Volcano contain numerous areas of highly altered country rock, which is a relic of past hydrothermal activity. Yet, there are no signs of recent volcanic extrusion from any point in this region except for Sugar Loaf cone to the northeast, Pakushin cone to the southwest, and naturally Makushin Volcano to the northwest.

Just northeast of the fumarole field no. 2 and in the vicinity of fumarole field no. 1, is a sequence of pyroclastic flow deposits positioned on top of glacial tills (figure 5). Although the thickness of this sequence of recent pyroclastic deposits varies throughout the valley, its surface is fairly smooth, sloping away from Makushin Volcano. At the vicinity of fumarole field no. 1, the base of the sequence consists of a welded breccia flow about 4 to 8 feet thick containing chunks of black "dacitic" glass as large as 20 cm in diameter, dark "andesitic" scoria, and pumice. The unit above consists of pumice and scoria chunks as large as 15 cm in diameter in a matrix of lithic fragments and ash, and contains a few blocks as large as 10 feet in diameter derived from the lower unit. This unit has some crude layering, believed to be flow structures, and is about 30 to 80 feet in thickness. This ash-flow unit is the surface unit.

A similar but much thinner sequence of pyroclastic deposits was found between fumarole fields no. 2 and 3 on the south side of Makushin volcano. Drewes et al., (1961) also reported a large body of pyroclastic deposits in the Bishop Point region on the north side of Makushin Volcano. Unfortunately, these deposits were not visited during 1980.

At present, these pyroclastic deposits are suspected to be related to a large eruption event of Makushin Volcano occurring since the last glacial maximum of 11,400 y.b.p., where such an event may be related to the formation of the existing 3 km diameter Makushin caldera. Geochemical and petrographic analyses should clarify if there are any such correlations throughout this region, including the determination of any correlation with the black sands from the wells drilled at Summer Bay.

The fumarole field no. 1 and no. 3 were sampled (gas samples from fumaroles and water samples from the low-chloride hot springs) and fumarole field no. 2 and 4 were quickly examined by the D.G.G.S hot spring atlas group (Motyka, Robb, Liss, and Moorman) during a one-week helicopter supported visit. The analyses of these samples have not been made available to me. The measurement of temperatures at the surface of up to 100° Celsius were not uncommon in these fumarole fields. The hydrothermal systems are probably shallow vapor-dominated systems overlying separate heat sources.

Conclusions

The fumarole fields and hot springs found in the Makushin Volcano region appear to be related to active volcanic-tectonic processes; reflected by N 60^{o} W rift zones which may not only allow for surface-water recharge and contain ideal reservoir rock, but may also allow the upward movement to shallow depths of magma. In addition, what also makes these hydrothermal resources so appealing is that they also occur (or at least most of them) in highly jointed and fractured Unalaska Formation and corresponding plutonic bodies which are in part ideal for allowing recharge and for containing hydrothermal reservoirs, and which are in part capped by less permeable young volcanic materials. These factors collectively result in one of the most ideal hydrothermal situations possible.

The volcanic manifestations in the Wide Bay - Tabletop Mountain region although similar to the rocks exposed in the Makushin Volcano region actually represents a distinct volcanic complex. This complex is probably related to a rift zone trending roughly N 60^{o} W. Such a rift zone if extended across Unalaska Bay would underlie the Summer Bay region.

The Summer Bay warm spring was originally thought to be related to deep joints in the Captain's Bay Pluton which was originally suspected to underlie the region. The small intrusive plutonic bodies existing near or at Summer Bay are now suspected to be the upper part of a larger plutonic body distinct from and older than the Captain's Bay Pluton. Most springs in Alaska have been noted by Waring (1917) and by Miller and Barnes (1976) to occur along the fractured and faulted margins of granitic plutons. Although this is probably the case for the Summer Bay region, anomalously high heat flows are now suspected to exist in this region due to the existence of shallow "dike-like" magma bodies which would be oriented about N 50^{o} W; i.e., in the direction of maximum horizontal stress as originally determined by Nakamura, et. al. (1977) for this region.

Because most dikes in the Unalaska Formation are oriented in a N 45^{o} W to N 75^{o} W direction, a similar maximum stress orientation for this region is interpreted to have existed in this range during and since the creation of the Unalaska Formation. Because most of these dikes occur in the eastern Unalaska Bay region, the main center of volcanic extrusion has shifted with time from the eastern Unalaska Bay region to the present Makushin - Wide Bay region.

Only a few sedimentary interbeds have been observed in the Unalaska Formation in the Unalasia Bay region. Either this formation was formed over a geologically short period of time, not allowing extensive sedimentary interbeds to form between the volcanic flows as they were extruded, and/or most of these flows were extruded subaerially like most of the volcanics are presently being deposited in the Makushin - Wide Bay region. Unlike the Makushin Volcanics and Eider Point Basalts, dips radiating from supposive point sources were never observed in the Unalaska Formation.

The Unalaska Formation supposedly was formed during the subduction of the Kula Plate, where uplift and a shutdown of arc magmatism occurred throughout the arc during the subduction of the Kula spreading ridge about 30 m.y.b.p. (late Oligocene to early Miocene; DeLong et al., 1978). Subduction of the Kula spreading ridge may actually represent the time of extensive volcanic extrusions as reflected by the Unalaska Formation in the Unalaska Bay region. Higher than normal heat flows during the subduction of the Kula spreading ridge probably caused regional low-grade thermal metamorphism (albitization) as suspected by Drewes et al.,(1961) and DeLong et al., (1978). But, most of the alteration in the Unalaska Formation is most likely due to hydrothermal activity related to plutonic magmatism (Drewes et al., 1961; and Perfit, 1977). Subduction related magmatism such as represented by Captain's Bay Pluton probably did not re-initiate until after the subduction of the Kula spreading ridge; i.e., about 20 m.y.b.p.

Hydrothermal Development Potential

Although the fumarole field no. 2 is the most impressive, and larger hydrothermal systems are suspected to exist throughout the region between field no. 2 and 5; logistics will rule out any immediate development in these areas. In contrast, fumarole field no. 1 is at a reasonable elevation and is only about six and one-half miles from the Driftwood Bay airfield and only about two and one-half miles from an old World War II road leading to this airfield. Infact, the region between field no. 1 and the road (i.e., the region between fumarole field no. 1 and the Sugar Loaf cone) consists of Eider Point Basalts capping either Unalaska Formation and/or corresponding plutonic bodies. This region could contain hydrothermal systems similar to the one manifested at field no. 1. Any initial attempts at tapping hydrothermal systems, as a recommendation, should be done just N 60^{o} W of the fumarole field no. 1 on top of the ridge at an elevation of about 1800 feet.

A potential problem for any development of hydrothermal resources in the Makushin Volcano region is volcanic and/or other natural earth hazards. Any major volcanic eruption in this region could destroy any hydrothermal power facility. From a safety point of view, during the operation in this region of any hydrothermal power facility, a seismic, gravity, and tiltmeter "volcanic eruption warning" network should be continuously operated. An additional problem could be ground stability. For example, fumarole field no. 2 is dominated at the surface by solifluction and other related mass-gravity movements (figure 6).

With respect to the Summer Bay region, the aquifer tapped by the two exploration wells probably extends underneath Summer Bay Lake, to the warm spring, and to the hills toward the west. Water flowage in the aquifer is probably in a near "due north" direction as based on the measured piezometric heads in the two exploration wells. The possibility of tapping warm waters directly from highly fractured rock is possible farther up the Summer Bay Valley in the region northeast of the suspected normal fault (figure 2), as well as under the meadow near the warm spring and exploration wells.

High heat gradients are suspected within the Captain's Bay Pluton in such locations as in the Shaishnikof Valley near Shaishnikof Lake; the site of active faulting. But, the rock in this region is expected not to yield enough warm waters required to be considered of useable quantities.

Work To Be Completed

By the first of July, I would like to have completed a "Hydrothermal Resource Map of the Northern Part of Unalaska Island". This map will indicate areas of known hydrothermal activity as well as show the regional geology. In addition, I would like to have by this date a paper completed on my gravity work. Eventually, I would like to see a D.G.G.S. open-file report entitled, "Assessment of the Geothermal Resources of the Northern Part of Unalaska Island", which will contain a lineation map, extent of hydrothermal alteration map, and a geologic map. Petrographic thin-section examinations, geochemical whole-rock analyses, and air-photo re-examination, and gravity modeling all need to be addressed within the next several months. Following the first of July, I hope there will be enough funds to pay for some radiometric age date determinations.

Recommendations for Future Work

There is need for undertaking detailed geologic mapping (possibly at a 1:12,5000 scale) in the immediate hydrothermal areas near Makushin Volcano. If any development is going to occur in this region, it will be most likely near fumarole field no. 1. I would suggest any initial detailed mapping be done in the upper Makushin - Broad Bay Valley in the vicinity of this fumarole. Such work can be done by foot, but such work in other Makushin fumarole fields will probably require helicopter support. To supplement this mapping, I would suggest a few soil-trench surveys and soil-geochemical surveys (Hg) across suspected active faults in known or suspected hydrothermal regions.

I would also recommend passive seismic studies in the Makushin Volcano region in an attempt to delineate any magma and/or highly altered zones by attenuation studies, and to better define the active faulting mechanisms of the region. Further gravity surveys might also be helpful, but I am not going to make any definite recommendations until I have worked further with the gravity data collected last summer.

One of the biggest problems in conducting any geological and/or geophysical surveys in the Makushin region is the lack of good topographic maps and the lack of good air-photograph coverage. I highly recommend having NASA fly, with their WB57 or with their U2, this island with the intent of obtaining good black and white, and color high altitude air photographs along with multi-channel thermal scanning and radar imagery. In addition to these airborne remote-sensing surveys, the possibilities of obtaining aeromagnetic and INPUT data for this region should be seriously considered. Such "air-borne" geophysical surveys eliminate the problems topography and logistics cause with conducting standard "land bound" geophysical exploration surveys.

Any well drilling in the Makushin region should be undertaken with the proper safety measures normally required in drilling vapor-dominated hydrothermal reservoirs. Also, such wells should be designed to obtain the proper hydrothermal reservoir properties required to determine the production potential of the reservoir (Prof. M. Economides, Univ. of Alaska, pers. comm., 1981).

With respect to the Summer Bay region, seismic refraction surveys could help define the dimensions of the unconsolidated body penetrated by the two hydrothermal wells. Conductivity (EM) and/or direct electrical resistivity surveys might also help define the extent of the hydrothermal resources in the valley. Unfortunately, large topographic relief and the nearness of salt water could seriously interfere with these proposed electrical surveys. A geochemical soil survey (Hg) up the Valley from the swampy meadow at the warm spring could help define the extent of the bedrock sources. I will make no further recommendations with respect to gravity until I have worked with the gravity data collected last summer.

Very little is known about the hydraulic properties of the aquifer containing the warm artesian waters at Summer Bay. If any future drilling is to be conducted at this site, it should be designed such as these properties can be determined.

REFERENCES

Black, R.F., 1976, "Geology of Umnak Island eastern Aleutians as related to the Aleuts", Arctic and Alpine Research, v. 8, no. 1, p. 7-35.

Byers, F.M., Jr. 1959, "Geology of Umnak and Bogoslos Islands, Aleutian Islands, Alaska", U.S. Geol. Survey Bulletin, 1028-L, p. 267-369.

Byers, F.M., Jr., and Barth, T.F., 1953, "Volcanic activity on Akun and Akutan Islands", Pacific Sci. Cong, 7th, 1949, New Zealand, Proc., v. 2, p. 382-397.

Cameron, C.P. and Stone, D.B., 1970, "Outline geology of the Aleutian Islands with peleomagnetic data from Shenya and Adak Islands", Alaska Univ. Geophys. Inst., UAG R-213, 152 p.

Chandler,A.D., 1980, " 'Fresh' or frozen: Bottom fish of the Bering Sea bring changes to the fisherman", Oceans, v. 13, no. 6, p. 22-31.

Coats, R.R., 1950, "Volcanic activity in the Aleutian Arc", U.S. Geol. Survey Bull. 974-B, p. 35-49.

Dall, W.H., 1897, Alaska and its resources, Boston, Lee and Shepard, Publishers, p. 627.

Dames & Moore, 1980, Final report: "Geothermal drilling studies near Unalaska, Alaska" , prepared for the Division of Energy and Power Development, State of Alaska, p. 5.

DeLong, S.E., Fox, P.J., and McDowell, F.W., 1978, "Subduction of the Kula Ridge at the Aleutian Trench", Geological Soc. of America Bull., v. 89, p. 83-95.

Drewes, H., Fraser, G.D., Snyder, G.L., and Barnett, H.F., 1961, "Geology of Unalaska Island and adjacent insular shelf, Aleutian Islands, Alaska", U.S. Geol. Survey Bull. 1028-S, p. 5583-5676.

Jacob, K., and Hamada, K., 1972, "The upper mantle beneath the Aleutian Island arc from pure-path Rayleigh-ware dispersion data", Bull. of Seismal. Soc. America, v. 62, p. 1439-1453.

Lankford, S.M., and Hill, J.M., 1979, "Stratigraphy and depositional environment of the Dutch Harbor Member of the Unalaska Formation, Unalaska, Alaska", U.S. Geol. Survey Bull. 1457-B, p. B1-B14.

Laughlin, W.S., 1975, "Aleuts: Ecosystem, Holocene history, and Siberian origins", Science, v. 189, p. 507-515.

Maddren, A.G., 1919, "Sulphur on Unalaska and Akun Islands and near Stepovak Bay, ALaska", U.S. Geol. Survey Bull. 692, p. 283-298.

Markle, D., 1979, Geothermal energy in Alaska: Site Data Base and Development Status, Oregon Institute of Technology, Geo-Heat Utilization Center, 572 p.

Marlow, M.S., Scholl, D.W., Buffington, E.C., and Alpha, Tau Rho, 1973, "Tectonic history of the central Aleutian Arc", Geol. Soc. America Bull., v. 84, p. 1555.

Miller, T.P. and Barnes, I., 1976, "Potential for geothermal-energy development in Alaska: Summary", Circum-Pacific Energy and Mineral Resources: American Assoc. of Petroleum Geologist, Halbouty, M.T., Maher, J.C., and Harold, M.L., eds., Memoir 25, p. 149-153.

Miller, T.P. and Smith, R.L., 1977, "Spectacular mobility of ash flows around Aniakchak and Fisher Calderas, Alaska", Geology, v. 5, no. 3, p. 173-176.

Minster, J.B., Jordan. T.H., Molnar, P., and Haines, E., 1974, "Numerial modelling of instantaneous plate tectonics", Geophy. Jour. Royal Astr. Soc., v. 36, p. 541-576.

Nakamura, K., 1977, "Volcanoes as possible indicators of tectonic stress orientation - principle and proposal", Jour. Volcanology and Geothermal Res., v. 2, p. 1-16.

Nakamura, K., Jacob, K.H., and Davies, J.N., 1977, "Volcanoes as possible indicators of tectonic stress orientation - Aleutians and Alaska", Pageoph, v. 115, p. 87-112.

Nakamura, K., Plasker, G., Jacob, K.H., and Davies, J.N., 1980, "A tectonic stress projectory map of Alaska using information from Volcanoes and faults", Bull. Earthquake Research Institute, v. 55.

Perfit, M.R., 1977, The Petrochemistry of Igneous Rocks from the Cazman Trench and the Captain's Bay Pluton, Unalaska Island: Their relation to Tectonic Processes, Ph. D. Dissertation, Columbia University, p. 375.

Perfit, M.R., and Lawrence, J.R., 1979, "Oxygen isotopic evidence for meteoric water interaction with the Captain's Bay pluton, Aleutian Islands", Earth and Planetary Scie. Letters, v. 45, p. 16-22.

Reeder, J.W., Coonrod, P.L., Bragg, N.J., Denig-Chakroff, D., and Markle, D.R., 1980, Draft: Alaska Geothermal Implementation Plan, Dept. of Energy Contract No. DE-FG51-79 R000074, p. 108.

Reeder, J.W., Motyka, R.J., and Wiltse, M.A., 1980, "The State of Alaska Geothermal Program", Geothermal Res. Council, Trans., v. 4, p. 823-826.

Scheidegger, K.F., and Kulm, L.D., 1975, "Late Cenozoic volcanism in the Aleutian Arc: Information from ash layers in the Northeastern Gulf of Alaska", Bull. Geol. Soc. Am., v. 86, p. 1407-1412.

Scholl, D.W., Duffington, E.C., and Marlow, M.S., 1975, "Plate Tectonics and the structural evolution of the Aleutian-Bering Sea Region", The Geophysics and Geology of the Bering Sea Region: Geol. Soc. America Spec. Paper 151, p. 1-31.

Scholl, D.W., Marlow, M.S., and Buffington, E.C., 1975, "Summit basins of Aleutian Ridge, North Pacific", Am. Assoc. Petroleum Geologist Bull., v. 59. p. 799-816.

Snyder, G.L. and Fraser, G.D., 1963, "Pillowed lavas: Instrusive layered lava pods and pillowed lavas, Unalaska Island, Alaska" U.S. Geol. Survey Bull. 454-B, p. B1-B23.

Waring, G.A., 1917, "Mineral springs of Alaska", U.S. Geol. Survey Water Supply Paper 418, 114 p.

Workman, W.B., 1979, The Significance of Volcanism in the Prehistory of Subarctic Northwest North American in Sheets, P.D., and Grayson, D.K., eds., Volcanic Activity and Human Ecology, New York, Academic Press, 644 p.

White, D.E., Fournier, R.O., Muffler, L.J.P., and Truesdell, A.H., 1975, "Physical results of research drilling in thermal areas of Yellowstone National Park, Wyoming", U.S. Geol. Survey Prof. Paper 892, p. 70.

APPENDIX A

Summer Bay Warm Spring Water
Sample Analysis

(H)

CODE RM 80 SB	IDENTIFICATION Summer Bay		Unalaska Is.
COLLECTED BY Shirley Liss	DATE 7/18/80	FILTERATION 0.45	
TEMP 35 °C	pH 6.98	SPECIFIC CONDUCTANCE: FIELD —	LAB
RESIDUE (180°C)	TDS(CALC)	DENSITY	

MAJOR CONSTITUENT ANALYSIS

CATIONS	mg/l	mg/l	meq/l	METH.	ANAL.	ANIONS	mg/l	mg/l	meq/l	METH.	ANAL.
H						HCO_3	73				
Li	0.03					CO_3					
Na	150				TB + MM	OH					
K	3.0				TB + MM	SO_4	245.4				
Rb						$NO_2(N)$					
Cs						$NO_3(N)$					
$NH_4(N)$	not run					o-PO_4					
Mg	1.0				TB + MM	F	0.22				TB
Ca	200				TB + MM	Cl	404				TB
Sr	0.94					Br					
Ba						I					
TOTAL						TOTAL					

BALANCE (C − A) ÷ ((C + A)/2) X 100 =

SiO_2	H_2S	B
18 ppm MM		0.5 ppm MM

TRACE ANALYSIS

	ppm (~~µg/l~~)	METHOD	µg/l	METHOD	µg/l	METHOD
As						
Sb						
Ag						
Al						
Au						
Be						
Cd						
Co						
Cu						
Fe	0.09					
Hg						
Mn						
Mo						
Ni						
Pb						
V						
Zn						

Geothermometry

Na-K	109
Na-K-Ca 1/3	92
Na-K-Ca 4/3	24
Qz Ad	60
Qz (m)	60
Chal	37
Cris	11
OPAL	-49

APPENDIX B

Summer Bay Hydrothermal Well No. 1
Water Sample Analysis

B

CHEMICAL & GEOLOGICAL LABORATORIES OF ALASKA, INC.

TELEPHONE (907)-279-4014
274-3364

ANCHORAGE INDUSTRIAL CENTER
5633 B Street

ANALYTICAL REPORT

CUSTOMER Ak. Geological & Geophysical Survey SAMPLE LOCATION: Summer Bay

DATE COLLECTED 9-25-80 TIME COLLECTED: ---

SAMPLED BY --- SOURCE Well No. 1

REMARKS Filtered, Acidified

FOR LAB USE ONLY

RECVD. BY SE LAB # 5367-1

DATE RECEIVED 10-14-80

DATE COMPLETED 11-21-80

DATE REPORTED 11-24-80

SIGNED Archie L. Green

	mg/l		mg/l		mg/l
[ ]Ag, Silver	<0.1	[ ]P, Phosphorous	<0.1	[ ]Cyanide	
[ ]Al, Aluminum	<0.1	[ ]Pb, Lead	<0.1	[ ]Sulfate	385
[ ]As, Arsenic	<1.0	[ ]Pt, Platinum	<0.1	[ ]Phenol	
[ ]Au, Gold	<0.1	[ ]Sb, Antimony	<0.1	[ ]Total Dissolved Solids	
[ ]B, Boron	0.8	[ ]Se, Selenium	<1.0	[ ]Total Volatile Solids	
[ ]Ba, Barium	0.06	[ ]Si, Silicon	16.4 (ICAP)	[ ]Suspended Solids	
[ ]Bi, Bismuth	<0.1	[ ]Sn, Tin	<0.1	[ ]Volatile Suspended Solids	
[ ]Ca, Calcium	410 (AA)	[ ]Sr, Strontium	2.9	[ ]Hardness as $CaCO_3$	
[ ]Cd, Cadmium	<0.1	[ ]Ti, Titanium	<0.1	[ ]Alkalinity as $CaCO_3$	
[ ]Co, Cobalt	<0.1	[ ]W, Tungsten	<1.0	[ ]	
[ ]Cr, Chromium	<0.1	[ ]V, Vanadium	<0.1	[ ]	
[ ]Cu, Copper	<0.1	[ ]Zn, Zinc	<0.1	[ ]	
[ ]Fe, Iron	<0.05	[ ]Zr, Zirconium	<0.1	[ ]	
				* * * * * *	
[ ]Hg, Mercury	<1.0	[ ]Ammonia Nitrogen-N		[ ]mmhos Conductivity	
[ ]K, Potassium	10 (AA)	[ ]Kjedahl Nitrogen-N		[ ]pH Units	
[ ]Mg, Magnesium	1.5	[ ]Nitrate-N		[ ]Turbidity NTU	
[ ]Mn, Manganese	<0.05	[ ]Nitrite-N		[ ]Color Units	
[ ]Mo, Molybdenum	<0.1	[ ]Phosphorus (Ortho)-P		[ ]T. Coliform/100ml	
[ ]Na, Sodium	330 (AA)	[ ]Chloride		[ ]	
[ ]Ni, Nickel	<0.1	[ ]Fluoride	1.0	[ ]	