DOE/ET/27034--T2

GEOTHERMAL ENERGY RESOURCE ASSESSMENT OF PARTS OF ALASKA

DOE/ET/27034--T2

DE83 000140

by

Eugene M. Wescott and Donald L. Turner

Final Report to:

The Division of Geothermal Energy of the U.S. Department of Energy
Under Cooperative Agreement DE-FC07-79-ET-27034

Principal Investigators:

Eugene M. Wescott
Donald L. Turner
Juergen Kienle

August 1982

DISCLAIMER

TABLE OF CONTENTS

Table of Contents Cont'd

LIST OF FIGURES

Table of Contents Cont'd

SUMMARY

Under the sponsorship of the U.S. Department of Energy, the Geophysical Institute in cooperation with the Alaska Division of Geological and Geophysical Surveys has investigated the geothermal energy potential of several areas in Alaska. This report primarily summarizes the effort of the Geophysical Institute although other personnel and agencies participated in some of the work.

Detailed site-specific geologic, geophysical and geochemical surveys were carried out in the vicinity of Pilgrim Springs, Alaska in 1979 and 1980. Preliminary test drilling by the State of Alaska confirmed the existence of a near surface reservoir 50 m thick and about 1 km^2 in area with artesian flow at a temperature of 90°C and up to 400 gallons per minute from six inch diameter wells. A state funded exploratory drilling program is now in progress.

In 1980 a reconnaissance survey of the central Seward Peninsula revealed evidence of extensive tensional tectonic features suggestive of an incipient rift system. Although no new geothermal resource areas were discovered, the proposed rift model should be useful for future more detailed geothermal studies.

In the interior of Alaska, hot springs are typically associated with fracture systems near the margins of granitic plutons. Two areas have been studied in detail: Chena Hot Springs about 96 km east of Fairbanks and Manley Hot Springs 145 km west of Fairbanks. Both areas show helium and mercury anomalies. Privately funded drilling is scheduled at Manley Hot Springs for the summer of 1982.

In 1981 an extensive helium soil gas sampling program and a gravity survey were carried out in the lower Susitna Basin where several wildcat

wells were found to have anomalously high temperatures at accessible depths. The results indicate the presence of discontinuous geothermal reservoirs of about 40 square miles in area in the Willow-Big Lake area, perhaps at depths accessible to water well drilling rigs.

Geophysical and geochemical surveys were also carried out in 1981 on Unalaska and Akutan Islands in the Aleutian Islands jointly with the Alaska Division of Geological and Geophysical Surveys. At Summer Bay on Unalaska Island a suite of geophysical and soil sampling techniques have outlined a near surface reservoir of warm water. At Akutan these techniques discovered a much hotter and more extensive reservoir. Scientific reports on this work will be published under the auspices of the Alaska D.G.G.S. later this year.

The scientific reports and papers produced under this program and other Alaskan geothermal studies are listed in Appendices A and B.

Geothermal Investigation of Pilgrim Springs, Alaska

INTRODUCTION

Pilgrim Springs, Alaska was the subject of an intensive geophysical and geological survey during June-August, 1979. The springs are located on the Seward Peninsula, about 75 km north of Nome (Figure 1). Earlier studies, including a reconnaissance geological and geophysical survey by Forbes, et al. (1975), and geochemical studies of Pilgrim Springs water by the U.S. Geological Survey (Waring, 1917; Miller, et al., 1975) had indicated that Pilgrim Springs might be an important geothermal target.

Geophysical Institute personnel were responsible for project management, bedrock mapping, geophysical surveying, analysis and integration of field data, and preparation of the final report. Alaska Division of Geological and Geophysical Surveys (A.D.G.G.S.) personnel were responsible for surficial mapping, geological supervision and logging of test drill holes, geochemical analyses, and preparation of the sections of a report covering these areas (Turner and Forbes, 1980).

Base camp was established at Pilgrim Springs, Alaska on June 16, 1979. The field program was initiated with the thermal gradient measurements which were accomplished with driven probes on a 100 meter grid. Helicopter supported mapping produced a 1:63,360 scale geologic map of the surrounding area. A surficial geologic map of the area was prepared at a scale of 1:63,630 by the A.D.G.G.S. (Klein, 1982). Mapping, temperature measurement and electrical conductivity work was completed by July 15, 1979. Seismic, resistivity, and gravity studies were completed on July 29, 1979, and the camp was closed on July 31, 1979.

A preliminary report to the Alaska Division of Energy and Power Development (A.D.E.P.D.) with analysis of field data and drilling

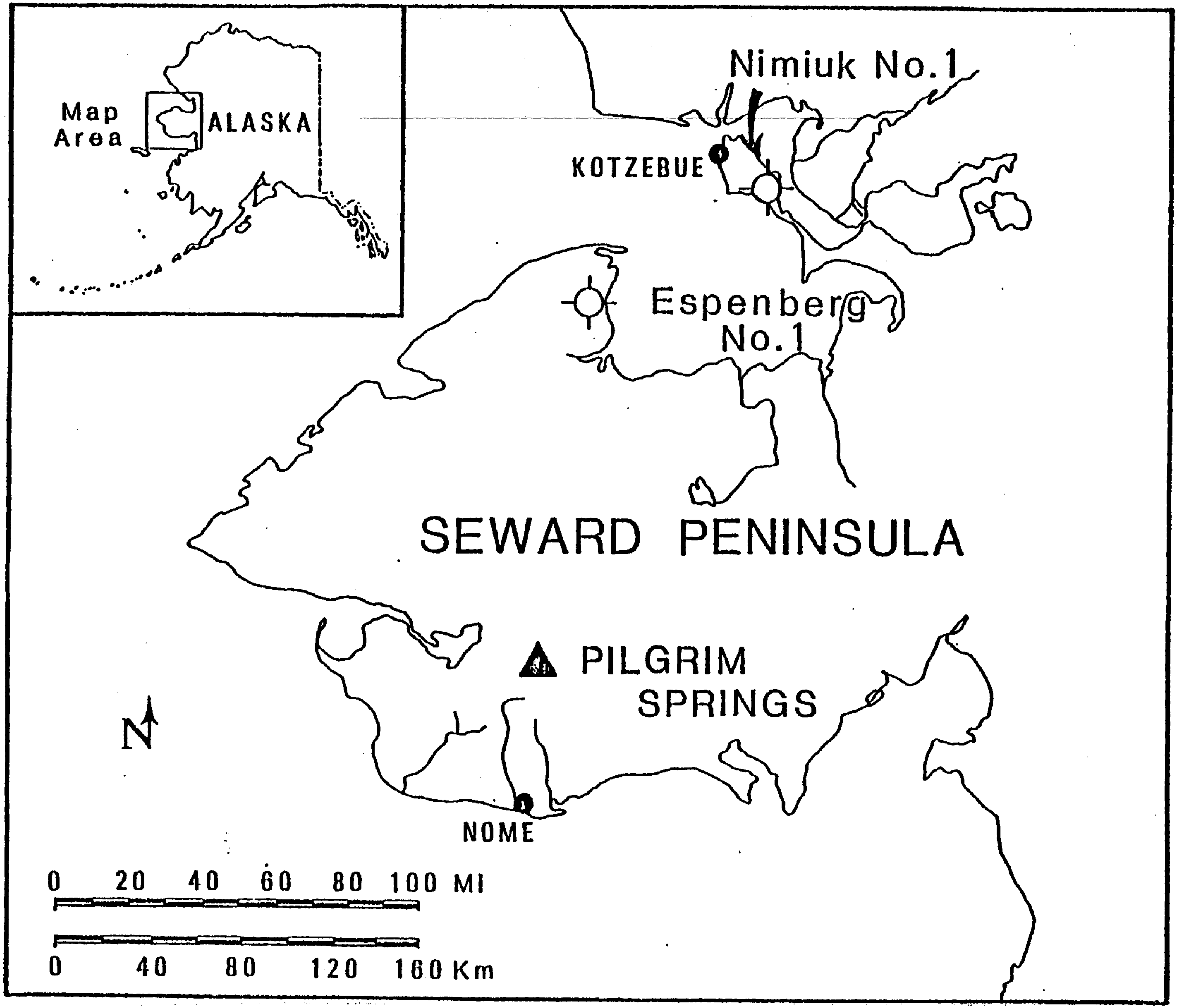

Figure 1. Location of Pilgrim Springs.

recommendations was completed in late August, 1979 (Forbes, et al., 1979). Based on the recommendations of the report, the A.D.E.P.D. contracted for two 15-ft test drill holes which were drilled in November, 1979, with geologic supervision and logging by the A.D.G.G.S.

Our final project report (Turner and Forbes, 1980) contains a more extensive analysis of the results of the geological and geophysical surveys than was presented in the preliminary report. It also provides a preliminary discussion of the recent initial exploratory drilling results and recommendations for phase-two geophysical surveys, hydrologic studies, exploratory drilling and geochemical studies, as summarized in the following section.

The Geophysical Institute part of the Pilgrim Springs study was supported by funding from the U.S. Department of Energy, Division of Geothermal Energy ($97,000); State of Alaska Division of Energy and Power Development ($56,000); Comprehensive Employment Training Act ($20,000); and National Science Foundation, Division of Polar Programs, Polar Earth Sciences Section, NSF Grant DPP77-20462 ($15,000).

SUMMARY

The Pilgrim Springs geothermal area, located about 75 km north of Nome, was the subject of an intensive, reconnaissance-level geophysical and geological study during a 90-day period in the summer of 1979. The thermal springs are located in a northeast-oriented, oval area of thawed ground approximately 1.5 km^2 in size, bordered on the north by the Pilgrim River. A second, much smaller, thermal anomaly was discoverd about 3 km northeast of the main thawed area. Continuous permafrost in the surrounding region is on the order of 100 m thick.

Present surface thermal spring discharge is ≈ 4.2 x 10^{-3} m^3 s^{-1} (67 gallons/minute) of alkali-chloride-type water at a temperature of 81°C. The reason for its high salinity is not yet understood because of conflicting evidence for seawater vs. other possible water sources. Preliminary Na-K-Ca geothermometry suggests deep reservoir temperatures approaching 150°C, but interpretation of these results is difficult because of their dependence on an unknown water mixing history. Based on these estimates, and present surface and drill hole water temperatures, Pilgrim Springs would be classified as an intermediate-temperature, liquid-dominated geothermal system.

The springs are located in the Pilgrim River Valley, a fault-bounded tectonic depression, or graben, flanked on the north and south by mountains composed of highly-deformed, upper amphibolite facies metamorphic rocks of probable Precambrian age, cut by discordant granitic plutons of probable Mesozoic age. Seismic, gravity and resistivity surveys indicate that the crystalline basement of the valley floor is at least 200 m beneath Pilgrim Springs, much deeper than was previously believed. The gravity data also suggest that Pilgrim Springs is near the intersection of two inferred fault zones forming the corner of a deep, downdropped basement block.

The seismicity of the area indicates currently active normal faulting. Mapped north-south trending faults in the Kigluaik Mountains south of Pilgrim Springs may extend through the downdropped crystalline basement under the Pilgrim River Valley. One or more of these faults could possibly provide a deep conduit for the geothermal system. Surficial geologic mapping indicates considerable subsidence of the Pilgrim River Valley during Quaternary time. A north-south trending Quaternary fault extends across the valley and appears to coincide with the western boundary of the main thawed area. Resistivity studies confirm the presence of this fault but do not suggest that it is presently serving as a hot water conduit in the vicinity of our resistivity profile.

Geologic evidence suggests that the low-lying region extending from the Imuruk Basin through the Kusitrin Valley to the Imuruk lava fields may represent an incipient rift through the Seward Peninsula. We therefore propose that the manifestations of anomalous heat flow (young volcanism and alkali-chloride hot springs) in this region may be associated with tensional tectonics and active rifting.

Resistivity surveys have located a shallow, 50 m-thick, pancake-shaped reservoir of hot, saline water about 1 km^2 in area under Pilgrim Springs (Figure 2a-b). Shallow ground electromagnetic surveys (used here for the first time in a geothermal area), ground temperature surveys and modelling of convection cells have been used in conjunction with deep resistivity surveys to determine drilling targets within the area of this reservoir. Thermal, hydrologic and geologic models of the total geothermal system suggest that hotter reservoirs could be present at greater depths. Computer modelling of resistivity data does not rule out this possibility.

Two 50 m exploratory test holes, separated by 100 meters, were drilled in November, 1979, in the area of the primary drilling target recommended in our preliminary report. Artesian aquifers were encountered in a 20-30 m depth interval. Flow rates were estimated at 200 and 300-400 gallons per minute, respectively, at a temperature of 90°C.

Preliminary hydrologic studies involving a Pilgrim River temperature survey and ground water flow estimates calculated from temperature profiles have resulted in a proposed water balance model and power estimates for

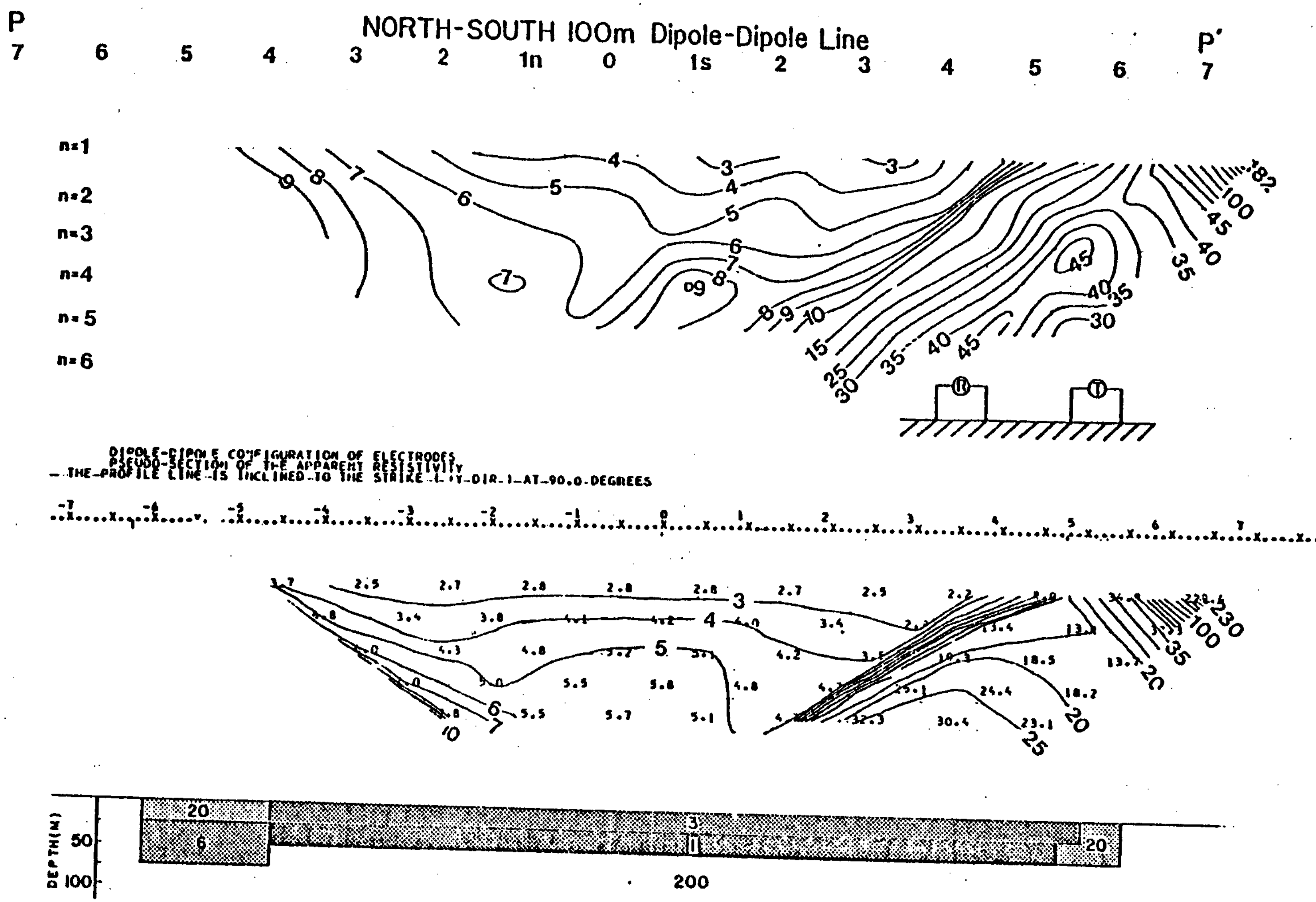

Figure 2a. Field data, N-S 100 m dipole-dipole pseudosection. Station numbers in hundreds of meters (e.g., 1S = 100 m south of origin).

Figure 2b. Two dimensional computer model of the basic shallow reservoir structure underlain by rocks of greater resistivity. All values in Ω-m.

the geothermal system. This analysis suggests that the power presently being dissipated from the upper 50 m of the system is a minimum of 350 megawatts (MW), with more than 300 MW of this amount in subsurface groundwater discharge beneath the Pilgrim River (Osterkamp et al., 1980; Gosink et al., 1980). The accessible resource base for the upper 50 m of the system referenced to 0°C is estimated at 500 MW. The beneficial power available for direct (nonelectric) use is estimated at 30 MW. Referencing these estimates to 15°C would reduce them to 2/3-3/4 of the above values. Quantitative estimates of the electrical power potential will depend on engineering and reservoir parameters which are presently unknown. It is clear, however, that the electrical power potential will probably be a small fraction of the 30 MW beneficial power estimate.

We emphasize that many hydrologic measurements are preliminary, based on reconnaissance-level studies, and that our preliminary power estimates should be viewed with caution until they can be tested by more extensive field measurements and analysis.

CONCLUSIONS

Our reconnaissance-level studies suggest that the Pilgrim Springs area is underlain by an intermediate-temperature, liquid-dominated geothermal system (Muffler, 1979) of substantial magnitude. Initial exploratory drilling has confirmed the presence of the shallow, ≈ 1-1.5 km^2 hot water reservoir delineated by our geophysical surveys. Large artesian flow rates of 200 and 300-400 gallons/minute of 90°C water indicate that at least one good aquifer is present at shallow depths within this reservoir. Resistivity surveys suggest that the shallow reservoir is approximately 50 m thick. Deeper hot water reservoirs may also be contained in the thick sedimentary section identified by the seismic and gravity surveys, but they have not as yet been located by our initial resistivity surveys.

Our analysis indicates that the power presently being dissipated from the upper 50 m of this geothermal system is a minimum of 350 megawatts (MW), with more than 300 MW of this amount in subsurface groundwater discharge beneath the Pilgrim River. The accessible resource base (Muffler, 1979) for the upper 50 m of the system referenced to 0°C is estimated at 500 MW. The beneficial power (Muffler, 1979) available for direct (nonelectric) use is estimated at 30 MW.

These power estimates are referenced to 0°C, the approximate mean annual ground temperature in the unthawed region surrounding Pilgrim Springs, and a value close to the mean annual air temperature (-3.5°C at Nome). Referencing these estimates to 15°C would reduce them to 2/3-3/4 of the above values.

The available evidence indicates that the geothermal system at Pilgrim Springs is not likely to have steam temperatures at depth which are adequate for economic production of electricity using conventional steam turbine generation technology. Pilgrim Springs does appear to have excellent potential for the production of hot water for direct heat applications and, perhaps, an as yet undetermined quantity of relatively low-temperature steam. Such a system is capable of generating moderate amounts of electricity for local community use, particularly if Rankin-cycle turbines are used. These turbines utilize an organic working fluid, such as isobutane, which flashes to vapor at a temperature well below the boiling point of water. The organic fluid is heated by passing through a heat exchanger coupled to the geothermal system.

Estimation of the electrical power potential of Pilgrim Springs must depend on engineering parameters associated with this special technology, as well as ultimate reservoir temperatures and production parameters which are presently unknown. It is therefore premature to attempt a quantitative estimate of electrical power potential at this time, except to state that it will probably be a small fraction of the 30 MW beneficial power (non-electric) estimate.

Further discussion of engineering applications is beyond the scope of this report. Engineering, developmental, and economic studies should be initiated as soon as the next phase of geophysics, hydrology, and exploratory drilling, and geochemistry are completed and the extent and magnitude of the hydrological and thermal regimes in the geothermal resource have been delineated.

REFERENCES

Forbes, R. B., L. Gedney, D. VanWormer and J. Hook, (1975) A geophysical reconnaissance of Pilgrim Springs, Alaska; Technical report, Geophysical Institute, University of Alaska.

Forbes, R. B., E. M. Wescott, D. L. Turner, J. Kienle, T. Osterkamp, D. B. Hawkins, J. T. Kline, S. Swanson, R. D. Reger and W. Harrison, 1979, A geological and geophysical assessment of the geothermal potential of Pilgrim Springs, Alaska, Geophysical Institute, University of Alaska and Alaska Division of Geological and Geophysical Surveys Preliminary Rept., 39 pp., 1 plate.

Gosink, J. P., T. E. Osterkamp, A. Lockhart and V. Gruol, 1980, A preliminary investigation of the possible existence of a hot water acquifer under the Pilgrim River, Geophys. Inst., Univ. of Alaska Rept. to AK Div. of Energy and Power Development, 12 p.

Klein, J. T., Surficial geology of the lower Pilgrim Valley and vicinity, western Seward Peninsula, Alaska, two plates scale 1:63,360, Alaska DGGS Report AOF 140.

Miller, Thomas P., Ivan Barnes and William W. Patton, Jr., (1975) Geologic setting and chemical characteristics of hot springs in west-central Alaska; J. Research U.S. Geological Survey, V. 3, No. 2, March-April 1975, p. 149-162.

Muffler, L. J. P., editor, 1979, Assessment of geothermal resources of the United States--1978, U.S. Geol. Survey Circular 790, 163 pp.

Osterkamp, T., J. Gosink, R. Forbes, R. Gaffi, J. Hanscom, M. Kane, C. Stephens and J. Kline, A reconnaissance study of the hydrothermal characteristics and accessible power of Pilgrim Springs, Alaska, in: Turner, D. L. and Robert B. Forbes, Editors, "A Geological and Geophysical Study of the Geothermal Energy Potential of Pilgrim Springs, Alaska, Rept. UAG R-271, Geophys. Inst., University of Alaska, Prepared for Div. of Geothermal Energy, U.S. Dept. of Energy and State of Alaska, Div. of Energy and Power Development, 165 pp., 1 pl., 1980.

Turner, D. L.and R. B. Forbes, Editors, A geological and geophysical study of the geothermal energy potential of Pilgrim Springs, Alaska, Rept. UAG-271, Geophys. Inst., University of Alaska, Prepared for Div. of Geothermal Energy, U.S. Dept. of Energy and State of Alaska, Div. of Energy and Power Development, 165 pp., 1 pl., 1980.

Waring, G. A., (1917) Mineral springs of Alaska; U.S. Geological Survey Water Supply Paper 492.

Geothermal Reconnaissance of the Central Seward Peninsula

INTRODUCTION

This was the third of a series of reports on the geothermal energy resources of the Seward Peninsula. Our two previous reports focused on Pilgrim Springs (Figure 1) and gave the results of geological, geophysical, geochemical and hydrologic studies, accessible power estimates and recommendations for follow-on studies and exploratory drilling targets (Forbes et al., 1979; Turner and Forbes, 1980).

During our 1979 investigations at Pilgrim Springs we developed the hypothesis that these hot springs were associated with tensional tectonics and active rifting. We also proposed that the low-lying region extending from the Imuruk Basin through the Kuzitrin Valley to the Imuruk lava field (Figure 3) represents an incipient rift through the Seward Peninsula (Turner and Forbes, 1980)

In July 1980, we conducted a helicopter-supported geological and geophysical reconnaissance survey of the central Seward Peninsula, designed to test the rift hypothesis and to provide information on the regional geothermal energy potential of the area. The results of this work, together with our previous studies have provided evidence for a tectonic model of active rifting extending 250 km across the central Seward Peninsula and offshore into the Bering Sea. This rift model should be useful as a working hypothesis and an exploration model for future, more detailed geothermal studies on the Seward Peninsula.

In order to increase scientific yield as well as cost effectiveness, we operated a combined field camp with our NASA-supported project designed to test the effectiveness of remote-sensing (synthetic aperture radar and thermal infrared) techniques in the exploration and assessment of geothermal

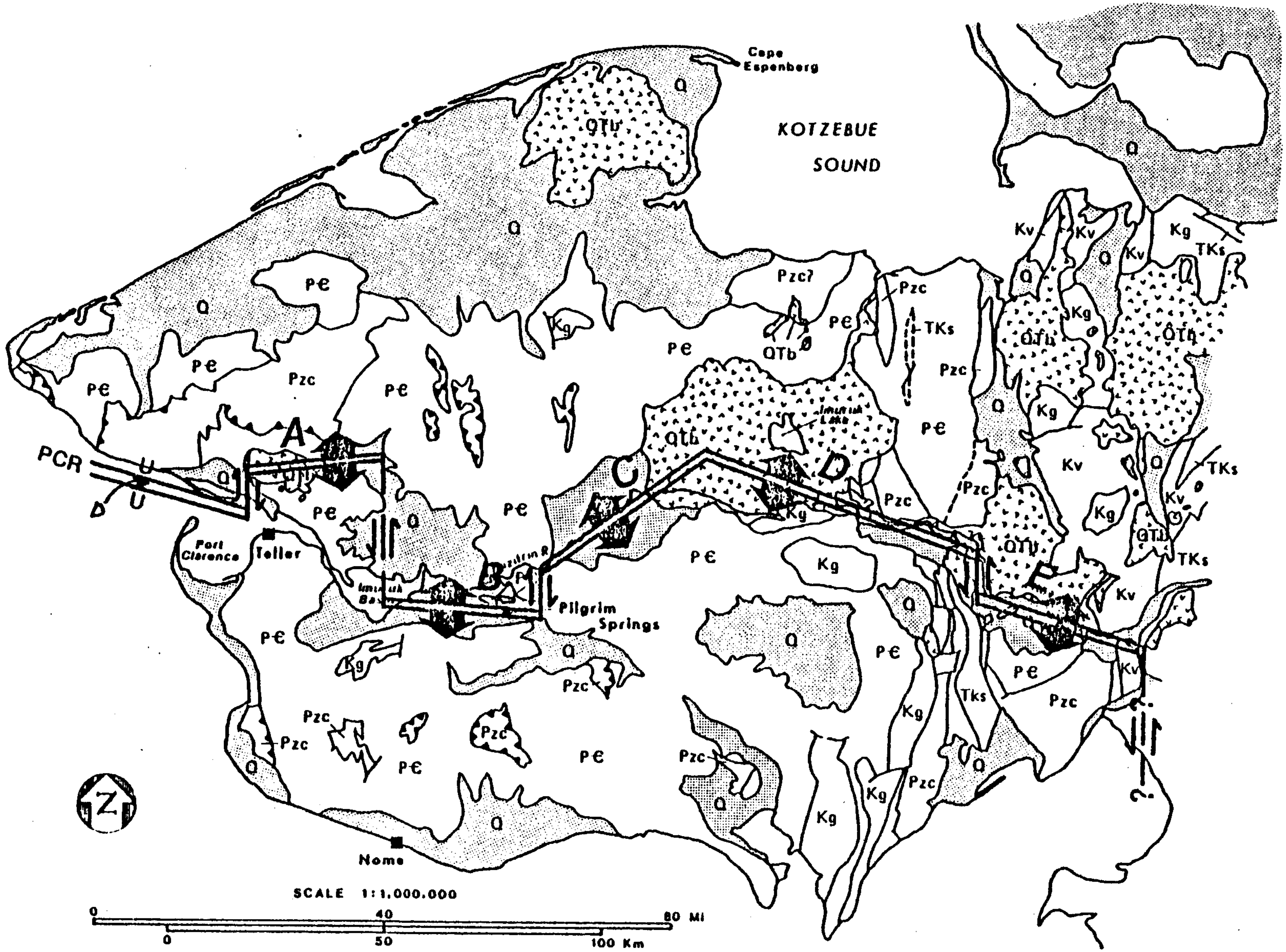

Figure 3. Diagram of proposed rift model for the central Seward Peninsula. The graben structure offshore (PCR) is the Port Clarence Rift (Hopkins et al., 1974). Geology generalized from Hudson (1977) and Hopkins et al. (1974).

energy resources. The Pilgrim Springs area was utilized as a known geothermal target for this study. The results of the remote sensing study are included in this report and integrated with our geological and geophysical work.

SUMMARY

The central Seward Peninsula was the subject of a geological, geophysical and geochemical reconnaissance survey during a 30-day period in the summer of 1980. The survey was designed to investigate the geothermal energy resource potential of this region of Alaska. Based upon our previous work (Turner and Forbes, 1980) and the 1980 survey, we have proposed a continental rift system model to explain many of the Late Tertiary-to-Quaternary topographic, structural, volcanic and geothermal features of the region. Geologic evidence for the model includes normal faults, extensive fields of young alkalic basalts, alignment of volcanic vents, graben valleys and other features consistent with a rift system active from late Miocene time to the present. Rift systems in many parts of the world are known for their abnormal heat flow and significant geothermal potential.

Five traverses crossing segments of the proposed rift system were run to look for evidence of structure and geothermal resources not evident from surface manifestations. Gravity, helium and mercury soil concentrations were measured along the traverses. Both helium and mercury soil concentrations have been shown elsewhere to be useful indicators of geothermal resources. We found that mercury soil content varied widely along the traverses and cannot be used to identify areas of interest in the environment of the central Seward Peninsula. Helium in soil gas, however,

offers great promise as a geothermal exploration tool. Our surveys found numerous He anomalies that tend to support the rift model. With the exception of two sampling sites, all helium anomalies were found near proposed rift segments. Several areas of significant helium soil gas concentration warrant closer study in any further detailed exploration for geothermal resources.

Gravity profiles across the proposed rift segments generally show features consistent with a rift system. One traverse, the Noxapaga, has been interpreted by a two-dimensional model, and can be explained by low density sediments filling a valley 1.25 km deep and 32 km wide. Geologic evidence indicates that this valley is a structural feature (graben). Gravity profiling across the Pilgrim River Valley also appears to agree with a graben structure, as supported by geologic evidence.

A long-spaced seismic refraction line was run in the Pilgrim River Valley at Pilgrim Springs to determine the depth to crystalline bedrock. Despite some intrumental problems a depth of 425 m was obtained. Previous depth estimates were much shallower (> 200 m; Turner and Forbes, 1980). The revised depth estimate suggests that deeper geothermal reservoirs may be present and that the reservoir potential of the Pilgrim Springs geothermal resource area may be even greater than was previously estimated (Turner and Forbes, 1980).

We also carried out deep resistivity and VLF studies in the Pilgrim River Valley to further our understanding of the nature of the geothermal resources at and outside of the hot springs area. Three-dimensional modelling of galvanic resistivity generally agrees with a shallow reservoir as determined by drilling but does not rule out deeper significant reservoirs in the 425 m of valley fill. VLF and galvanic resistivity measurements confirm the existence of low resistivity (presumably hot saline water) under a zone along the Pilgrim River and under a small thawed area 4 km northeast of Pilgrim Springs. We found that the VLF EM-16R technique agreed well with galvanic resistivity measurements and could be very useful as a regional exploration tool.

A National Aeronautics and Space Administration study of remote sensing techniques in the Central Seward Peninsula was also carried out in 1980, centered on Pilgrim Springs. Radar measurements proved to be useful in locating linear features under the vegetation which are useful in structural mapping and geothermal resource exploration. Thermal infrared imagery disclosed three warm ground zones in the Pilgrim Springs vicinity under less than ideal conditions. However, the interpretation of infrared imagery appears to be too difficult and expensive to be useful in regional studies of significantly larger areas.

We did not discover any new geothermal resource areas in our 1980 work. However, we have established that the central Seward Peninsula may contain a continental rift system with some areas of abnormal helium soil gas concentrations and likely abnormal heat flow, suggesting that the geothermal energy potential of the area is high, and that Pilgrim Springs may only be the "tip of the iceberg".

REFERENCES

Forbes, R. B., E. M. Wescott, D. L. Turner, J. Kienle, T. Osterkamp, D. B. Hawkins, J. T. Kline, S. Swanson, R. D. Reger and W. Harrison, 1979, A geological and geophysical assessment of the geothermal potential of Pilgrim Springs, Alaska, Geophysical Institute, University of Alaska and Alaska Division of Geological and Geophysical Surveys Preliminary Rept., 39 pp., 1 pl.

Hopkins, D. M., R. W. Roland, R. E. Echols and P. C. Valentine, 1974, An anvilian (Early Pleistocene) marine fauna from western Seward Peninsula, Alaska, Quaternary Research, V. 4, p. 441-470.

Hudson, T., (compiler) 1977, Geologic map of Seward Peninsula, Alaska, U.S. Geol. Survey Open File Report 77-796A, Scale 1:1,000,000.

Turner, D. L. and R. B. Forbes, (Eds.) 1980, A geological and geophysical study of the geothermal energy potential of Pilgrim Springs, Alaska, University of Alaska, Geophysical Institute Report UAG R-271, 165 pp., 1 pl.

Geothermal Investigations of Chena Hot Springs, Alaska

INTRODUCTION

Chena Hot Springs are located about 96 km east of Fairbanks, Alaska on a good, all-weather road (see Figure 4). The springs were known from the gold rush days and are currently owned by the "Chena Hot Springs Group", a limited partnership. Extensive resort development is now well underway. Guidance for future drilling to expand production from the geothermal reservoir is desired.

The Springs flow from alluvial fill in the Valley of Monument Creek. The valley fill is underlain by quartz monzonite of the Chena Pluton, which was emplaced about 58 m.y. ago.

The Chena Hot Springs area was the subject of a Masters thesis project in 1973-74 by Norma Biggar under the direction of Dr. R. B. Forbes. This project marked the beginning of geothermal assessment and resource definition studies by the Geophysical Institute of the University of Alaska. The first half of the report edited by Wescott and Turner, (1981) is an abridged and updated version of Biggar's thesis.

A ground temperature survey at 0.5 m depth defined a narrow, southeast-trending anomaly pattern with a maximum temperature of 48°C (Figure 5). The elongated orientation of this anomaly parallels a dominant set of shear zones and faults in the granitic pluton. Analysis of 1979 U-2 aerial photography indicates the presence of a bedrock fault adjacent to the temperature anomaly surrounding the springs and probably contiguous with it, suggesting that the thermal waters are rising along the fault system into the valley fill.

In August and September, 1979 geophysical crews from the Geophysical Institute conducted preliminary surveys at the Springs area to extend the earlier work and to explore to greater depths. In summer 1980 the

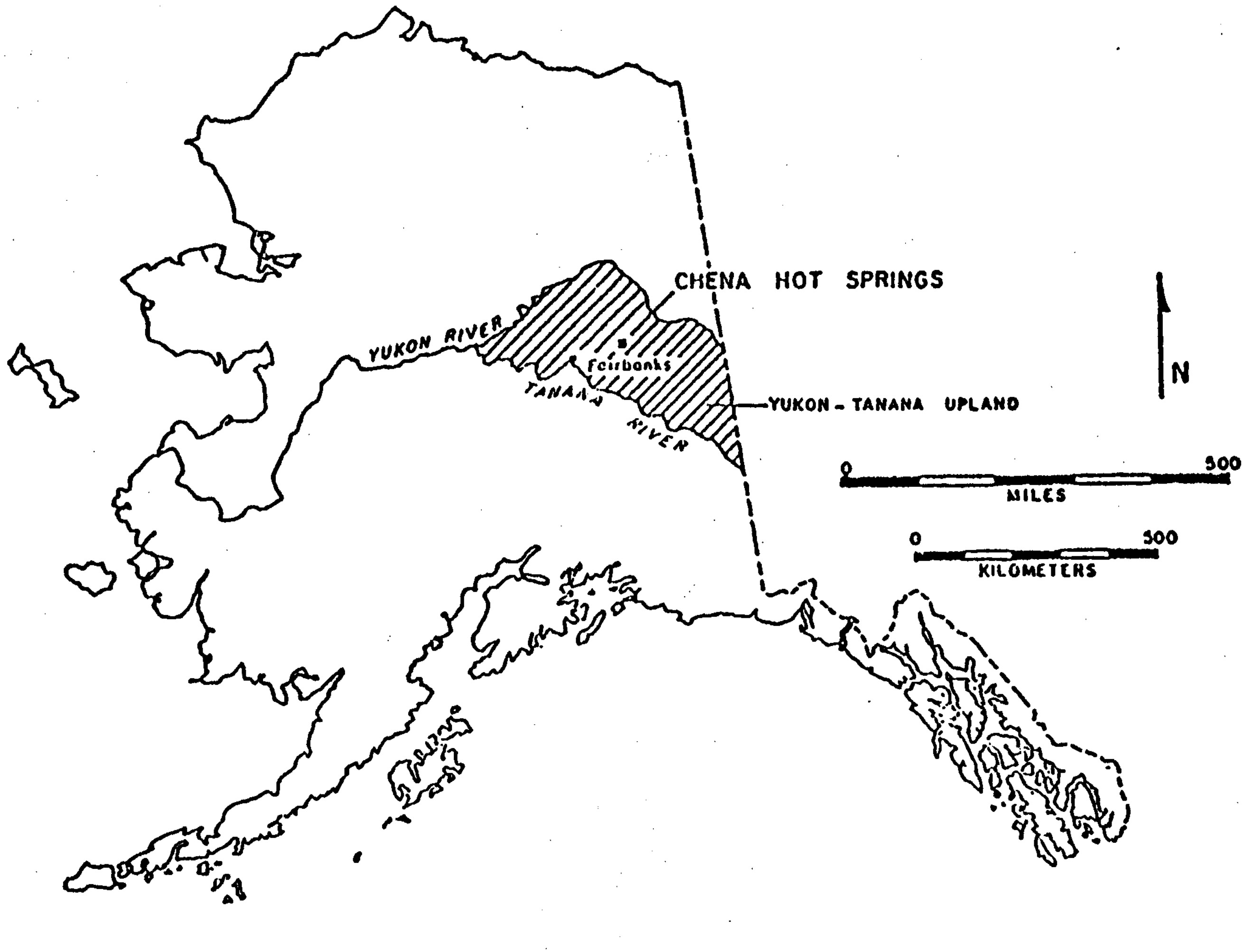

Figure 4. Map of Alaska, showing the Yukon-Tanana Upland and the location of the study area.

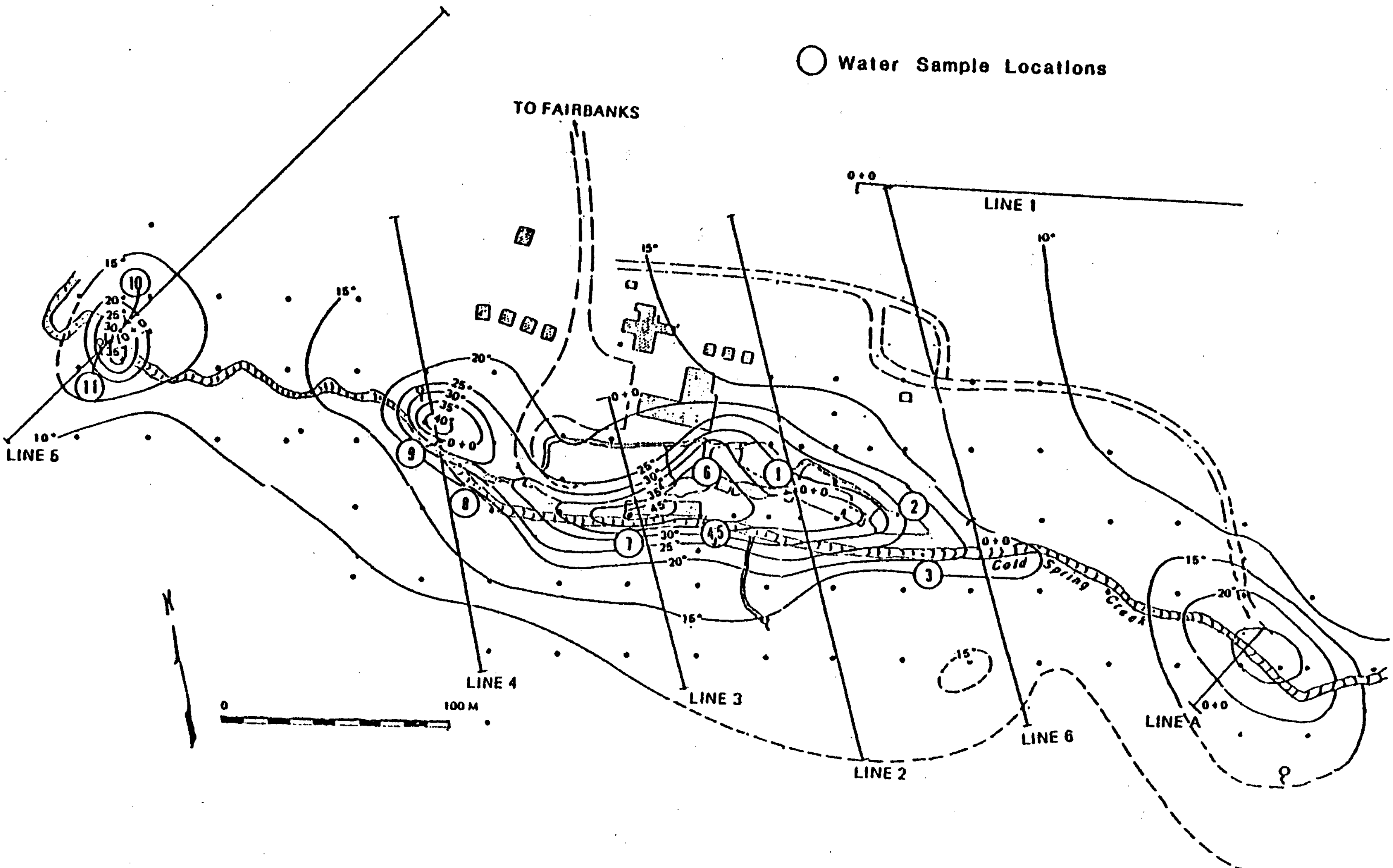

Figure 5. Shallow (0.5 m) isotherms, conductivity survey lines and water conductivity sample locations at Chena Hot Springs.

work was continued with geological mapping, helium and mercury soil sampling and further electromagnetic profiling.

SUMMARY

In August and September 1979 geophysical surveys were carried out. An electromagnetic survey was used to investigate the near-surface (~ 10 m) conductivity (Figure 5). In general, the zones of good conductivity were broader than the 0.5 m-depth temperature anomalies but confirmed the narrow, SE-trending thermal source.

Deeper galvanic resistivity measurements using the Schlumberger depth profiling method revealed that the quartz monzonite basement rocks under the alluvial fill are fractured and water-saturated to considerable depths. A resistivity contrast of 20:1 was found between the cold water and hot water-filled rocks.

A seismic refraction survey also indicates that the granitic "bedrock" reported in water well logs is fractured and water-saturated. Massive granitic rock was inferred to be present at a depth of about 40 m.

A pipe was driven to emplace a plastic tube for temperature and groundwater flow measurements. An impenetrable layer was encountered at 7.7 m, which is assumed to be the top of the granitic rubble zone. A downhole temperature maximum of 58.8°C was measured at 5.5 meters.

In summer 1980 helium and mercury soil sampling was carried out in the vicinity of the mapped thermal anomaly to establish the usefulness of these techniques in the area. Samples were also obtained in a much larger area of the Chena Pluton and towards Fairbanks. More shallow electromagnetic surveys were carried out in the vicinity of the thermal anomalies. Further geological mapping has defined the Chena Pluton contacts,

petrological relationships and faults which seem to control the geothermal resource. No evidence for geothermal reservoirs other than below the known hot springs was found. Significant helium and mercury anomalies along the fault are recommended as drilling targets for expanded utilization of the resource.

CONCLUSIONS

Chena Hot Springs seems to be a classic example of hot springs formed by deep ground water percolating through a fracture system near the margin of a granitic pluton. Near-surface EM-31 conductivity surveys, helium and mercury soil sampling, and near-surface temperature measurements are all consistent with Biggar's hypothesis that the source of Chena Hot Springs is a southeast-trending fault in the quartz-monzonite of the Chena Pluton. The surface expression of this fault has been found on U-2 photographs and by ground geologic mapping in 1980.

Seismic and galvanic resistivity surveys penetrated into the bedrock underlying the sediments of Monument Creek Valley. Both methods indicate that the bedrock is fractured and water-filled to depths of about 40 m or more. Neither method found solid bedrock underneath the springs area, but the narrow, elongate nature of the thermal anomaly makes it difficult to explore with methods we employed.

Helium surveys in the vicinity of the hot springs proved to be very useful in delineating the regions of possible conduits for hot water. Helium brought near the surface by water rising up the fault will tend to be released and rise straight to the surface as pressure and temperature decrease. The significant helium anomalies are confined to a very narrow zone, presumably the trace of the fault. A very large helium anomaly at the northwestern end of the thermal anomaly is an attractive target for drilling into the conduit. Significant helium anomalies near the southeastern end of the thermal anomaly may also indicate that additional hot water could be reached by shallow drilling. Mercury soil values tend to correlate with near surface temperatures in the hot springs vicinity, but show large statistical fluctuations at sites in the greater Chena Pluton area probably not related to geothermal causes.

Our limited helium and mercury surveys in the Chena Pluton vicinity did not disclose any other geothermal prospects, but much more extensive surveys would be required to rule out other resources in the Fairbanks-Chena area. The U.S.G.S. Water Resources Division which measures stream flow in the Chena River reports that several stretches of the river between Fairbanks and Chena Hot Springs typically remain unfrozen during the winter (personal communication, 1980). Investigation of these areas to determine if warm springs are present is recommended for future work.

REFERENCES

Wescott, E. M., and D. L. Turner, 1981, A geological and geophysical study of the Chena Hot Springs geothermal area, Alaska, Geophysical Institute Report UAG R-283, to Division of Geothermal Energy, USDOE under Cooperative Agreement DE-FC07-79-ET27034.

Biggar, N. E., 1974, A geological and geophysical study of Chena Hot Springs, Alaska, Master Thesis, U of Alaska.

Geothermal Investigations at Manley Hot Springs, Alaska

INTRODUCTION

Manley Hot Springs lies within the Yukon-Tanana upland physiographic province of the Interior of Alaska, near the junction of the Tanana A-2 and Kantishna River D-2 quadrangles, latitude 65° 00' N, longitude 150° 38' W (Fig. 6). By air, Manley is 145 km west of Fairbanks and 71 km east of the village of Tanana. State Highway 2, known as the Elliott Highway, connects Manley Hot Springs with Eureka, Livengood and Fairbanks along a 260 km gravel-surfaced road. From Manley Hot Springs, a road continues 21 km northeast to Tofty, an old placer mining district. Manley Hot Springs is also connected by a 5 km road to a barge landing on the Tanana River. The village of Manley Hot Springs is situated on the northern margin of the Tanana Valley along Hot Springs Slough, a 13 km long, shallow waterway which drains into the Tanana River. Elevations in the Manley Hot Springs area range from less than 260 feet for the Tanana Valley floor, to 2650 feet for the summit of Hot Springs Dome located to the northwest. The dome is the highest part of a narrow, 43 km-long, northeast-trending ridge known as Bean Ridge, which separates the Tanana Valley from a parallel valley occupied by Patterson and Baker Creeks.

The Manley Hot Springs area lies within the zone of discontinuous permafrost. Normal vegetation consists of thick brush on the upper slopes, and white spruce, black spruce, birch, aspen, poplar and scattered brush on the lower slopes. Trees are up to 0.6 m in diameter. The poorly drained portions of the lowlands consist of black spruce and muskeg-type vegetation. The climate is typical of the Yukon River valley; long, cold winters and short, warm summers with a possible range of

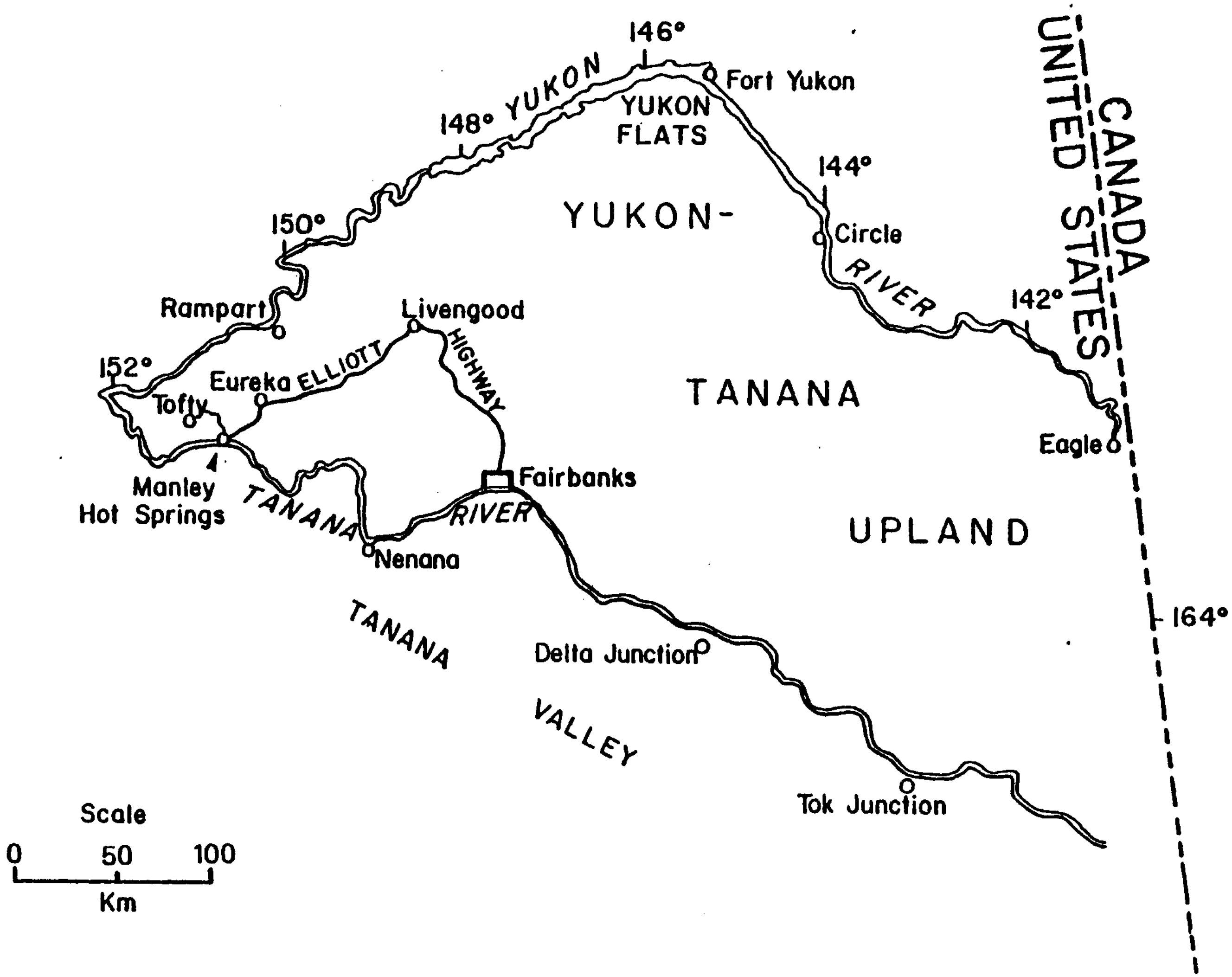

Figure 6. The Yukon-Tanana Upland physiographic province showing the location of Manley Hot Springs.

temperatures from 70° F below zero to 98° F above zero. The annual precipitation is 25 to 30 cm, most of which falls as rain through the summer months. The town has an airstrip, post office, store, lodge and elementary school. Power is supplied by diesel generator with a 40 kw capacity.

The main hot springs are 0.75 km north of the central part of town, and several occurrences of warm seeps are found within a 0.8 km radius of the main springs. In general, the warm springs and seeps occur near the base of east-facing slopes of Bean Ridge near the edge of the Tanana Valley. However, they are localized only along a 1.4 km long portion of these slopes between Ohio Creek and the highway road to Tofty. Charles and Gladys Dart own the hot springs and the surrounding 236 acres. They utilize the thermal water for space heating of their home and the operation of a 30 by 45 m greenhouse and a small public bath house. The hot springs also serve as the community's principle water source for drinking, washing, and other uses. The greenhouse is located next to the main springs and is used primarily for raising tomatoes. The tomatoes are sold locally and have also been shipped into Fairbanks where there is always a ready market. Other greenhouse vegetables which are sold locally include cucumbers, eggplants and melons. A few wells have been drilled adjacent to the Dart's land, and one of these has warm (29° C) water. However no wells have been drilled close to the hot springs. Water is piped and used as it flows from the spring mouths. Since the thermal water is mixing to some extent with ground water and/or water from Karshner Creek, drilling could result in hotter water with higher rates of flow. One of the main purposes of this study was to help delineate targets for drilling of a geothermal well to be drilled in the summer of 1982.

SUMMARY AND CONCLUSIONS

The Manley Hot Springs Dome stock is characteristically massive and well-jointed. Drilling done by the Bureau of Mines near the summit of Hot Springs Dome discovered almost complete oxidation of rock to a depth of 136 meters which was the deepest hole drilled. This suggests that the fracture permeability of the granite allows for migration of ground water to substantial depth from the dome summit, and quite possibly, the slopes of the dome. Hopkins and Taber (1962) show the margin of the Hot Springs Dome Stock as dipping moderately to gently underneath the "Boulder Ridge Formation" in the Manley Hot Springs area. The intersection of the granite-metasediment contact with the surface is approximately 0.6-0.8 km upslope of the hot springs. Hornfelsed sediments which include recrystallized, thin-bedded quartzite and "knotted" slates overlie granitic rocks in the Manley Hot Springs area. Contact metamorphism may have increased fracturing within these rocks, or water may be migrating along bedding planes in thin-bedded quartzite.

All of the springs and seeps appear to be issuing from surficial deposits of either loess or alluvium which overlies loess. The loess is composed of massive, homogeneous silt and may be fairly impermeable unless fractures are present. Cliff exposures of loess 10-30 meters in thickness are observed in the Manley Hot Springs area, however it is not believed that loess deposits attain thicknesses much greater than this. Gravel alluvium is found along the floor of Karshner valley. The valley conspicuously widens near the main hot springs, and two low knolls flank either side of the valley. The knolls are composed of highly permeable sand and gravel alluvium, and several hot springs flow near the base of one of the knolls. Other springs and seeps appear to issue from loess or at the base of loess cliffs. In general, the springs and the shallow, thermally disturbed ground are distributed over a 1.2 km long, northeast trending belt as shown in Figure 7. Variations in elevation of the springs suggest that they may be structurally and not topographically controlled.

Based on the above evidence, the following model is proposed for the low temperature geothermal system present at Manley Hot Springs: Ground water along the southeast slopes of Bean Ridge enters joints and fractures in granitic rocks of the Manley Hot Springs Dome stock. The water migrates deeply enough in the granite to be heated by a normal geothermal gradient of 30-50°C/km. Given a reservoir temperature of 137°C, derived from the cation geothermometers, this would imply migration to depth of about 2.5-4.5 km. As water is heated, it circulates towards the surface, eventually rising along bedding planes or fractures in hornfelsed "Boulder Ridge Formation" metasedimentary rocks. The overlying loess apparently acts as a caprock, allowing the hot water to migrate along the loess-metasediment interface. Areas of fracturing in the loess allow for final escape of thermal water to the surface, expressed as hot springs and seeps. Another method of escape of thermal water apparently involves sub-surface migration downslope to the main valley. This may be the case for some of the springs and one temperature anomaly.

The conspicuous widening of Karshner Valley near the main springs, as well as the differences in elevations of the spring sites suggests structural control for the springs. No faults were detected, but exposures are poor.

Future analysis of the water chemistry will aid in interpretation of sub-surface water-rock reactions, as well as the extent of mixing of thermal water with ground water. A seismic survey would aid in delineating the depth to basement in Karshner Valley, as well as possible faulting.

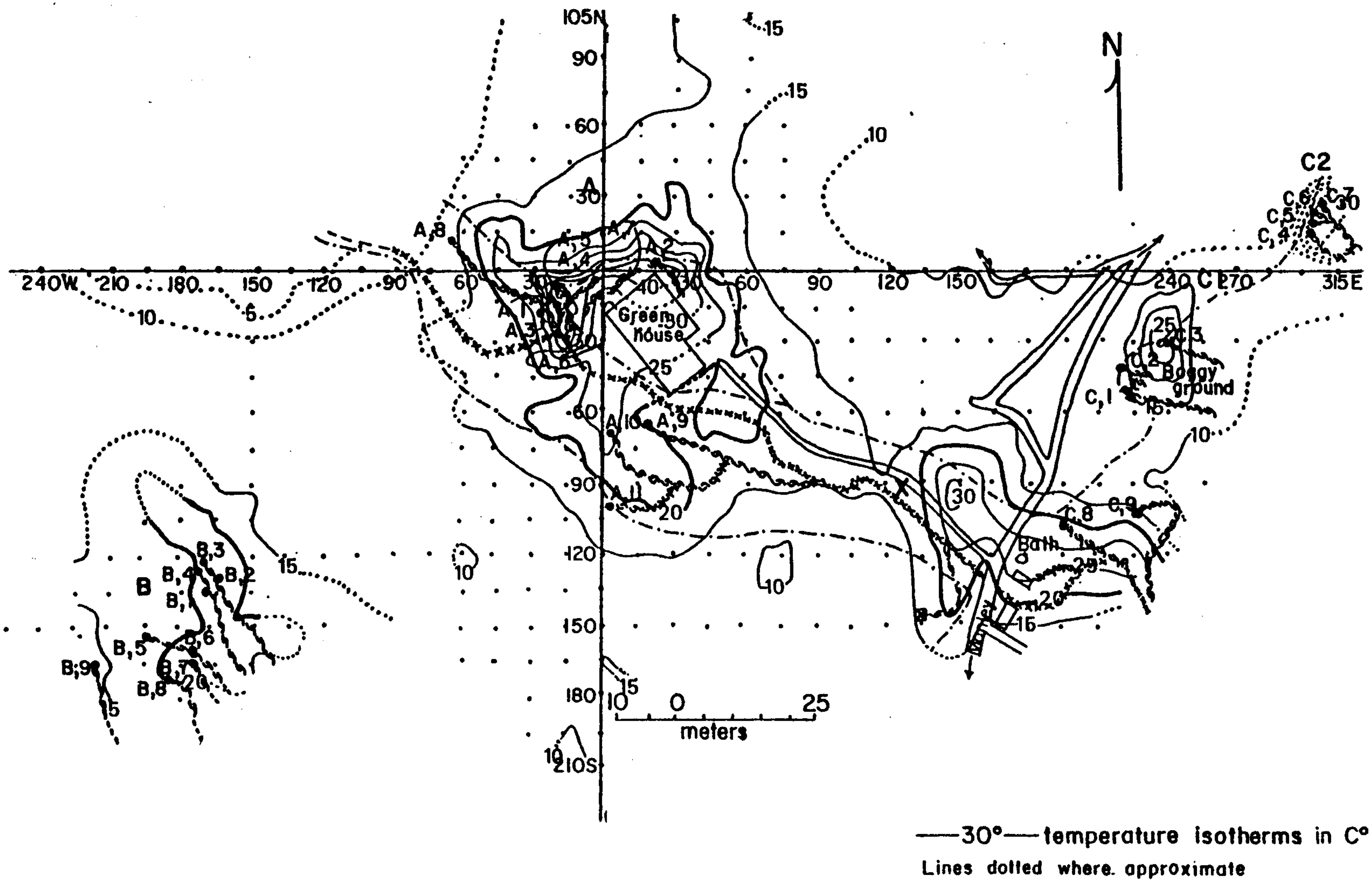

Figure 7. Shallow (0.5 m) isotherms and thermal spring locations at Manley Hot Springs.

More extensive helium surveys could be useful in defining areas of hot water migration and detection of the fault or fracture system which may control the Manley Hot Springs geothermal area.

Based on findings from the helium, temperature, mercury, and resistivity surveys, three localities at Manley Hot Springs were chosen as likely sites for a geothermal well (Figure 8). The first and most promising site is the area just north to northwest of the greenhouse, referred to as site 1. The area is an obvious choice, since the hottest springs are located here. Helium soil gas values are anomalously high, as are shallow ground temperature and shallow resistivity values. Site 2 is the second most likely site based on anomalous helium values. It is located on the floor of Karshner Valley near the intersection of drainages of several springs. Site 3, the third most likely drilling site, is located near a temperature anomaly just west of the main road on the north side of Karshner Creek Valley. It is characterized by anomalous temperature and resistivity values and anomalous mercury values occur several meters upslope. Helium soil gas values, however, are not anomalously high.

The thermal water of Manley Hot Springs has probably been mixed with cooler ground water and/or water of Karshner Creek. Drilling to an adequate depth could result in substantially hotter water, allowing for geothermal energy utilization on a much larger scale than at present.

The low-temperature geothermal resource present at Manley Hot Springs is a highly viable energy source, especially in light of its location near a small population center in the interior of Alaska. The work of Karshner and Manley in the early part of the century attests to the fact that Manley Hot Springs as well as other hot springs of the Interior, can be utilized on a much larger scale than they are presently. Agricultural

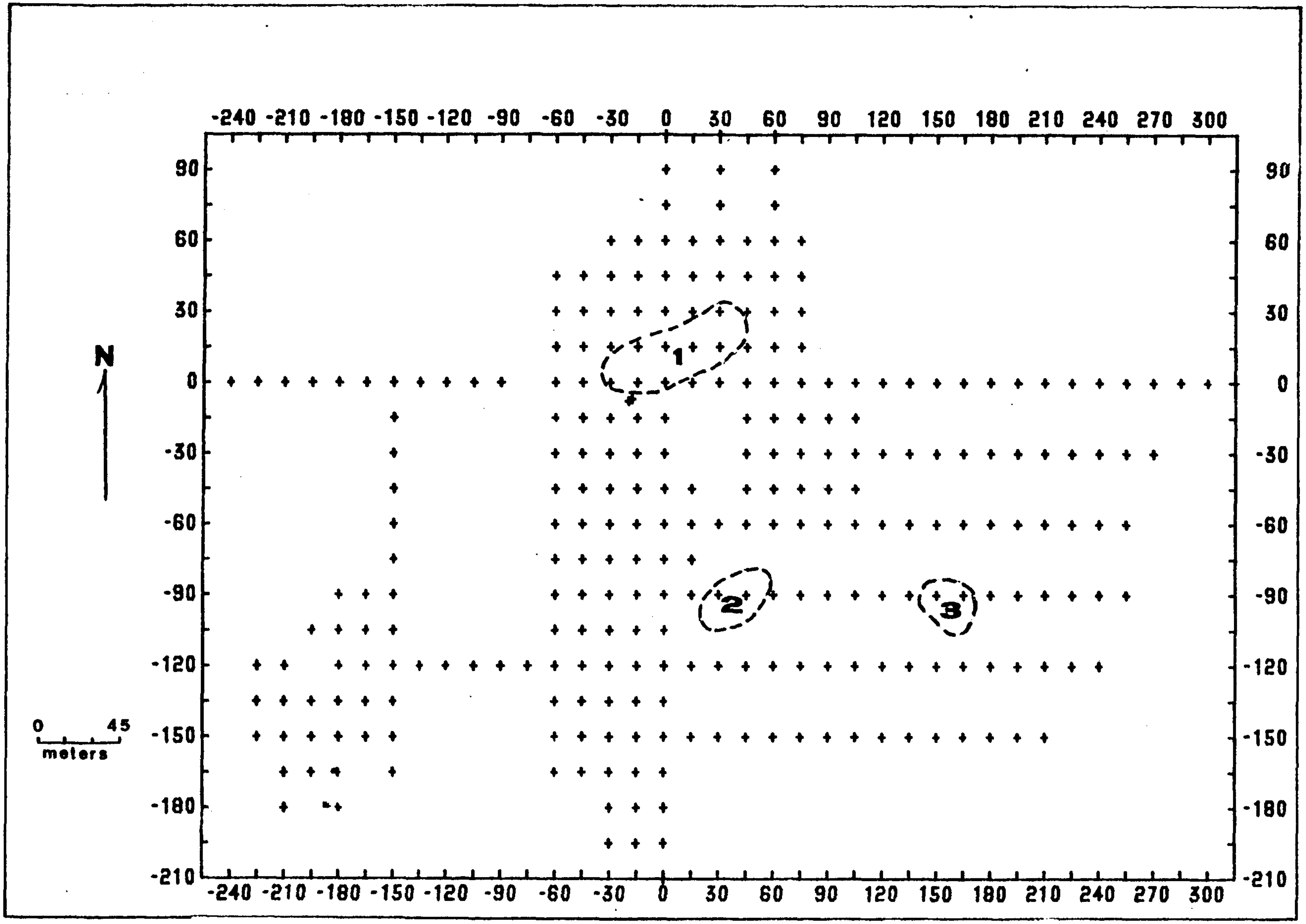

Figure 8. Proposed geothermal well sites.

production, spaceheating and even the generation of small amounts of electricity by geothermal means could be highly beneficial to surrounding communities.

A Preliminary Investigation of the Geothermal Energy Resources of the Lower Susitna Basin

INTRODUCTION

Four dry wildcat wells drilled in the lower Susitna basin have encountered anomalously high temperatures, suggesting that low temperature geothermal resources might be present which could be used for space heating and agriculture. There are no known surface manifestations of a geothermal resource in the area but a water well driller has recently encountered a warm saline reservoir at 40 ft depth. North of the Castle Mtn. Fault the basin contains about 2,000 ft. of coal-bearing Tertiary sediments overlain by glacial drift and underlain by a granitic basement. South of the fault the basin has been down dropped and contains a much thicker sedimentary section.

SUMMARY AND PRELIMINARY CONCLUSIONS

A helium soil gas and water survey was conducted with an approximately one mile grid spacing in order to explore for hot water reservoirs at depth. The helium data corroborate the temperature anomalies in the three hot wells studied and suggest that discontinuous hot water reservoirs totalling at least 40 square miles may be present in the Willow-Big Lake area (Figure 9). The helium anomalies extend to within six miles of Wasilla, where our preliminary survey ended. It is possible that this anomaly trend may extend as far east as Wasilla, or even possibly farther to the east.

There is a strong suggestion of elongate trends in the helium anomaly patterns of Figure 9, suggesting that these patterns could be controlled by Tertiary faults which are covered by the glacial drift that mantles the region.

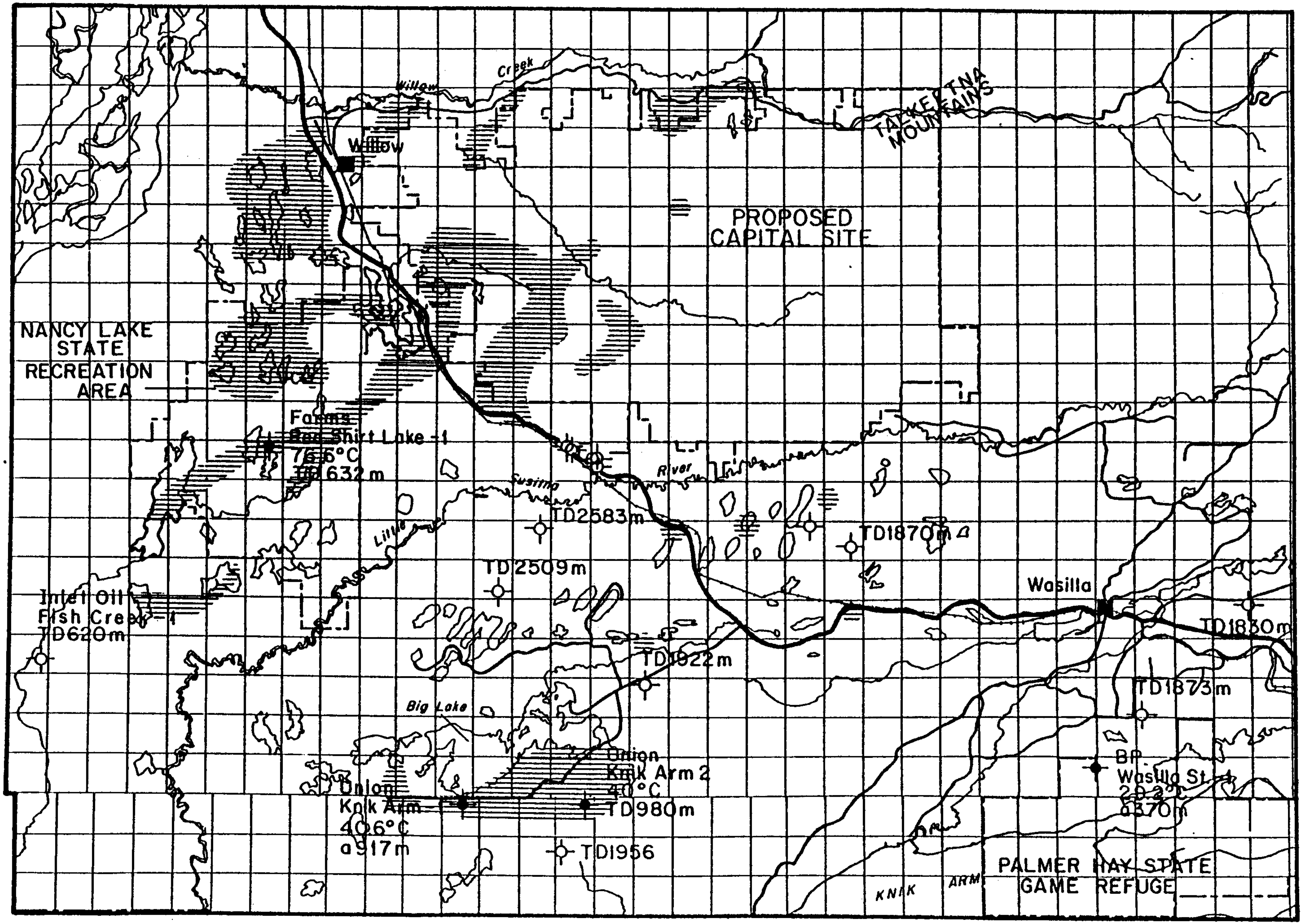

Figure 9. Map of the lower Susitna basin showing estimated areas of high helium concentrations (shaded areas).

A gravity survey of the area indicates that two basement ridges are present (Figure 10). The Tertiary sedimentary section containing good aquifers is inferred to be thinner over these ridges than in adjacent areas and is believed to be accessible by normal water well drilling techniques. Helium anomalies are present over both basement ridges (Figure 10). Geothermal aquifers are therefore likely to be encountered at shallower depths over these ridges than in adjacent areas studied.

We have postulated two models - radiogenic heating of aquifers by U and Th-rich basement pegmatites and fault-controlled hydrothermal convection to account for the geothermal system in the area studied. The very large extent and apparent elongate orientation of most helium anomaly patterns appear to favor the fault model (Figure 9).

Our initial study appears to indicate that a substantial geothermal resource may be present in the Willow-Big Lake area. However, very large gaps exist in the preliminary data base we have used to delineate this resource, and the nature of the geothermal system supplying the reservoirs is not understood. Reservoir depths and thicknesses are presently unknown. We have also been unable to determine the lateral extent of the suspected reservoir system, and, in particular, whether or not it extends to the rapidly growing population center of Wasilla.

We strongly recommend the follow-on work discussed below which will focus on providing a much better definition of the nature of the geothermal system and the lateral and vertical distribution of geothermal reservoirs, as well as detailed recommendations for exploratory drilling. Indirect evidence from our helium survey is very encouraging, but the actual confirmation of the suspected geothermal resource will require exploratory drilling and well testing. Drilling should be relatively inexpensive

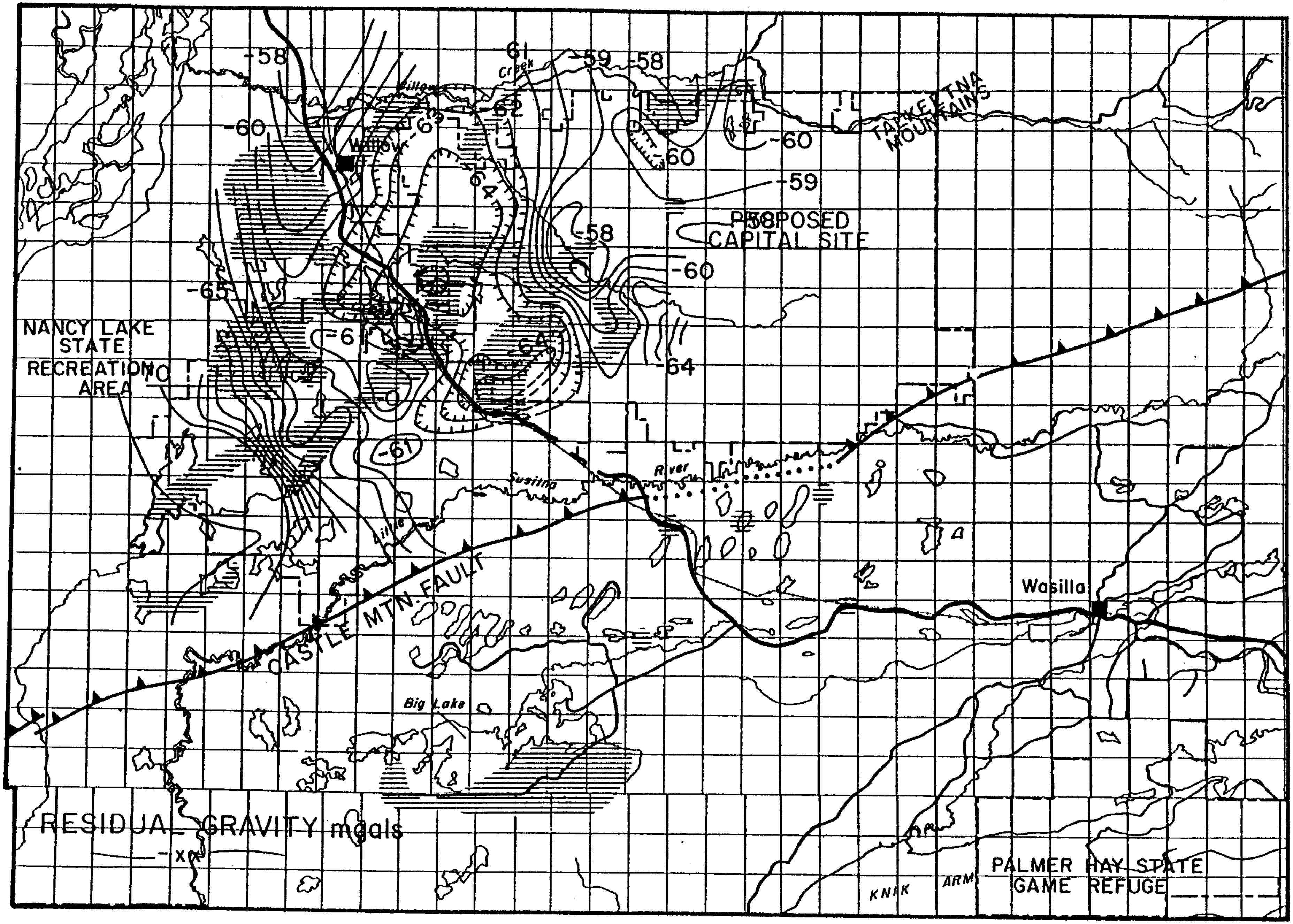

Figure 10. Residual gravity anomaly map of the lower Susitna basin. Estimated areas of anomalously high helium concentrations from Figure 9 are shaded.

due to the shallow depths to suspected reservoirs inferred from the gravity survey.

RECOMMENDED FOLLOW-ON WORK

The specific phases of a proposed follow-on work plan are as follows:

1. Completion of the 1/sq. mi. grid of the helium soil gas survey. Gaps in the existing data base should be filled in to allow a better definition of the distribution of areas believed to be underlain by hot water. A helicopter-supported survey should focus on the central and eastern areas shown in Figures 9 and 10, and include the area around Wasilla. A finer (0.5 mile) grid spacing should also be used in critical areas if available helicopter time permits.
2. A wider-spaced helium reconnaissance survey extended to the Palmer area to investigate the remote possibility that geothermal anomalies might extend that far to the east. This survey should utilize a 5 mile spacing along existing road systems and will not require helicopter support. The additional cost will be low and we believe that the large population and potential energy market of the Palmer area justifies checking the possibility out.
3. A helicopter-supported gravity survey designed to fill in gaps in the existing gravity data base and to extend its detailed coverage to the south and east. This survey will provide better regional control for estimates of depth to granitic basement for the purpose of siting geothermal exploration wells.

4. A seismic refraction survey along the basement ridges inferred from the present gravity survey. This survey should provide accurate estimates of basement depths in these critical areas.
6. Deep resistivity surveying in selected areas of large helium anomalies. Resistivity results should be correlated with available well logs in the area to help determine the depths and thicknesses of geothermal reservoirs.
6. Continued research on helium soil gas surveying and on various electrical resistivity surveying techniques as geothermal exploration tools, both in site-specific and regional applications under Alaskan conditions and geologic settings. We have accumulated a considerable amount of information on this subject from our geothermal studies of Pilgrim, Chena and Manley Hot Springs, and from our regional work on the Seward Peninsula.

EXPLORATORY DRILLING AND RESERVOIR TESTING

We hope to generate interest in a cooperative program of exploratory drilling and reservoir testing based on the results of this report and the recommended follow-on study. We think it is possible that the State Park System might find it desirable to plan for use of hot water for park facilities in the Nancy Lake State Recreation Area (Figure 9).

A future program of drilling might involve the State or local government, the Division of Parks, with geologic and geophysical well logging by the Geophysical Institute and Alaska Division of Geological and Geophysical Surveys; and with flow testing to estimate reservoir characteristics and energy potential by the University of Alaska Petroleum Engineering Department.

Preliminary Drilling Recommendations

We recommend the following exploratory drilling, based on the results of the present study. First, Red Shirt Lake #1 should be redrilled to 2000 ft depth. A detailed temperature log should be run, together with appropriate flow tests to evaluate the reservoir parameters of zones producing hot water. Geochemical studies to determine water quality and geothermometry should also be made. Water quality data will be critical to the design of appropriate heat exchangers (e.g. scaling and corrosion problems) and to the question of whether or not the water should be reinjected after use vs. surface disposal.

Several shallow wells should be drilled to granitic basement southwest of Willow, in the area of the superposed basement ridge and helium anomaly pattern shown in Figure 10. Depth to basement is inferred to be approximately 200-500 ft. in this area from analysis of the gravity data. Specific siting of these wells within the designated area should be determined by local considerations (logistics, land status, etc.) and by the results of a detailed helium soil gas survey to be done prior to final site selection. Temperature, self potential, resistivity and lithologic logs should be run in these wells. Flow testing and water chemistry should also be done as discussed above.

Note: The following sections on Unalaska and Akutan Islands have not yet been made available to the public. They will be incorporated in future reports to be published by the Alaska Division of Geological and Geophysical Surveys. Because this work has not been reported previously, the results are given in more detail than the previous sections which summarize previously published work.

Geophysical Surveys of Summer Bay Warm Springs, Unalaska Island, Alaska

INTRODUCTION

In the summer of 1980 two wells were drilled near the Summer Bay warm springs at the southern shore of Summer Lake on Unalaska Island (Reeder, 1981). In well #1 50°C artesian water was encountered at 42 ft depth, and in well #2, 43.5°C artesian water was produced at 44 ft depth. In the summer of 1981 we carried out a suite of geophysical and geochemical surveys in the area of Summer Lake and the warm springs to determine the nature and extent of the geothermal reservoir, and to make recommendations for possible future drilling.

The geophysical survey included a seismic refraction line, EM-31 near-surface apparent electromagnetic conductivity measurements, Schlumberger vertical electric soundings, dipole-dipole galvanic resistivity measurements beneath Summer Lake, and a gravity profile. Helium concentrations in water from the warm springs, in soil gas and soil were sampled in a grid system south of Summer Lake to locate sources of upwelling hot water. Mercury soil concentrations were also sampled. The helium and mercury survey results are also summarized in this report.

A coherent model of the near surface warm water reservoir can be derived from the geophysical measurements.

SUMMARY

The integrated geophysical survey carried out in the Summer Bay warm springs area has revealed a shallow (20-40 m base) geothermal reservoir confined to the northeast end of the valley at the southern end of Summer Lake. EM-31 conductivity measurements indicate the presence of saline water within 6 m of the surface (Figure 11). Deeper galvanic resistivity

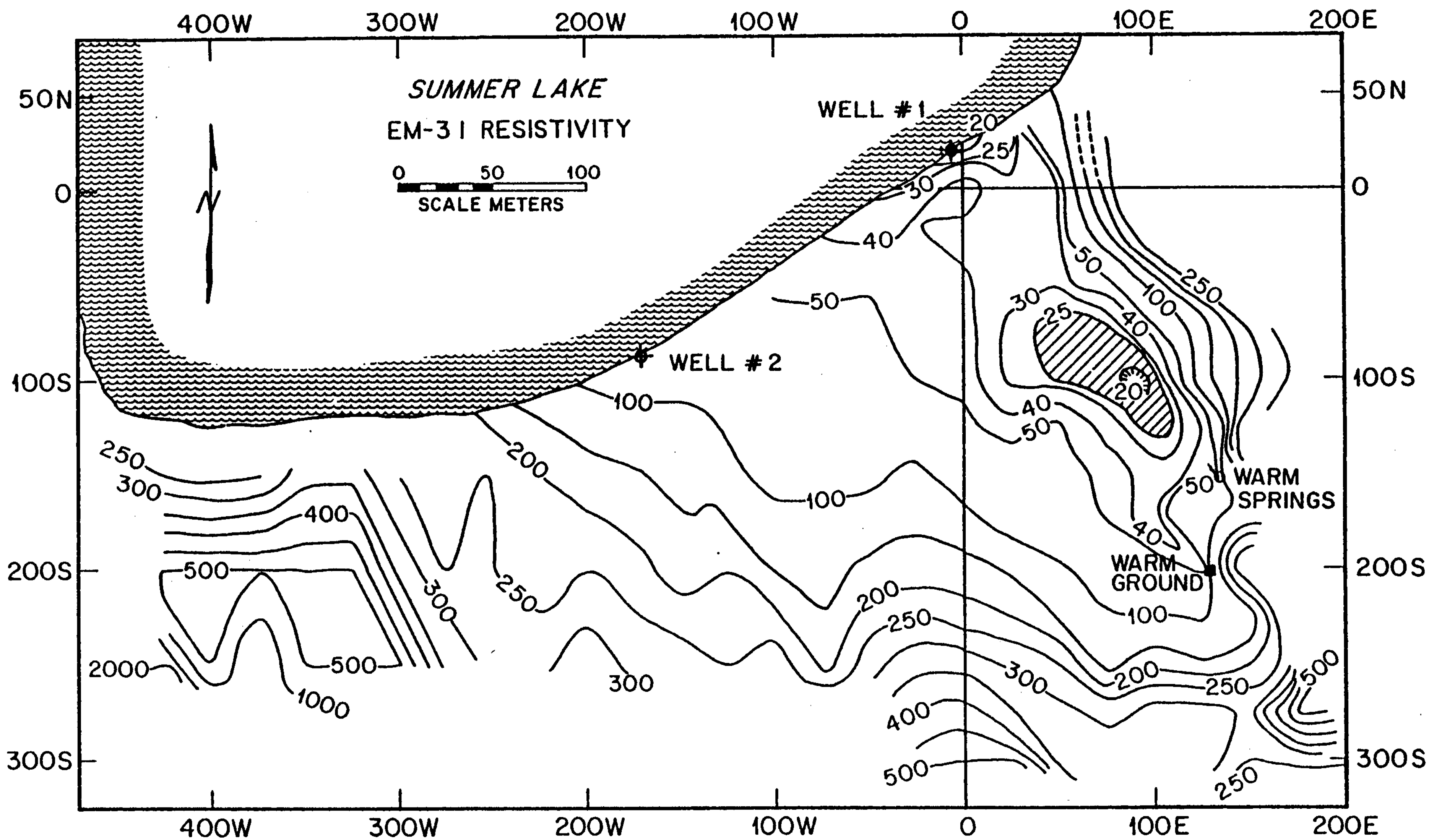

Figure 11. Contour map of EM-31 apparent resistivity in Ω-m with transmitter and receiver coils horizontal, at the southern end of Summer Lake, Unalaska Island. The locations of the warm springs, an area of warm ground, and two test wells which produced artesian flow are shown.

vertical-electric soundings verify that a low resistivity zone exists. This zone is confined to the northeast end of the valley and has a base between 20-40 m in depth. Seismic refraction and gravity profiles along the N-S baseline have shown that the basement slopes to the north and have produced evidence of a fault with about 15 m throw, near the south end of Summer Lake. Reeder (1981) has mapped an east-northeast trending fault extending through this locality. The fault may serve as a conduit for warm water and may form a boundary of the near surface reservoir. Deep dipole-dipole resistivity measurements spanning Summer Lake suggest deeper geothermal reservoirs may be present under the northern end of the lake.

Drilling Recommendations

The results of the geophysical surveys have shown the existence of a near-surface reservoir of limited extent. From the resistivity and seismic data it may be 30 m deep and 750 m^2 in area. The two test wells produced water of 50°C maximum temperature and maximum flow rate of 50 gallons per minute at a depth of 42 ft. It is possible that somewhat hotter water might be obtained nearer the center of the resistivity anomaly. Any future drilling should verify the fault offset, and probable deeper reservoir base southeast of drill hole #1.

The temperature and size of the reservoir suggest that it cannot be used for electric power generation, or for direct heat applications in Unalaska or Dutch Harbor. The resource might, however, be utilized to develop a spa resort area with a pool, cabins etc. in the Summer Lake area.

REFERENCE

Reeder, J. W., 1981, Preliminary assessment of the geothermal resources of the northern part of Unalaska Island, Alaska, Preliminary report, State of Alaska, Division of Geological and Geophysical Surveys.

Helium and Mercury Surveys of Parts of Unalaska Island

INTRODUCTION

The concentrations of helium and mercury in soil, and of helium in water have been shown to be useful indicators of geothermal resources [Roberts, et al., (1975); Bergquist, (1980); Matlick and Buseck, (1975)]. In Alaska, helium and mercury surveys in the Chena Hot Springs area (Wescott and Turner, 1981a), at Pilgrim Springs (Wescott and Turner, 1981b), at Summer Bay Warm Springs, Unalaska Island (Wescott, et al., 1982) and at Manley Hot Springs (East, 1982) have shown excellent correlations with areas of upwelling of geothermal waters. More recently an extensive helium survey in the lower Susitna basin has revealed extensive areas of helium anomalies probably associated with geothermal resources (Turner and Wescott, 1982).

The radioactive decay of uranium and thorium is the source of helium in the earth. The solubility of helium in water increases with temperature above 30°C, so geothermal waters are efficient scavengers of helium produced at depths in the rocks (Mazor, 1972). As the geothermal waters rise towards the surface, helium is released due to cooling and de-pressurization. Aleutian volcanic rocks contain much less uranium and thorium than the more acidic igneous and metamorphic rocks of the Chena Hot Springs and Pilgrim Springs areas and thus we would expect Aleutian helium anomalies to be less pronounced. The average atmospheric concentration of helium is 5.24 ppm. Allowing for uncertainties in the collection and analysis procedure, we have assumed that any soil concentration of helium greater than 5.40 ppm is a significant anomaly. The results of the helium survey are shown in in Figure 12.

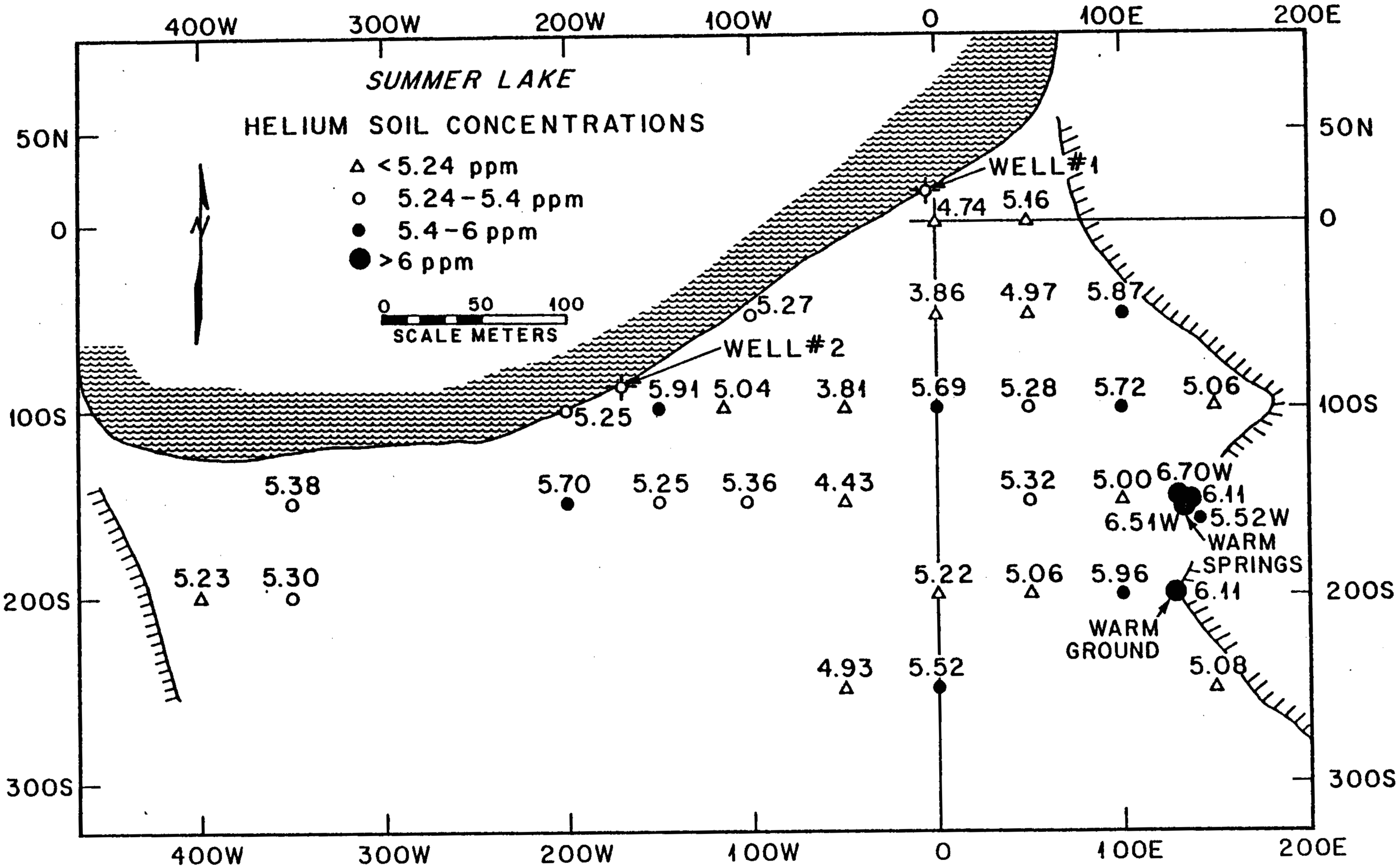

Figure 12. Map of the warm springs area at the southern end of Summer Lake, Unalaska Island, showing helium soil concentrations in ppm. Anomalously high values are shown by solid circles. Anomalously low values which are probably due to gas dilution are shown by open triangles. Three water samples are suffixed W.

CONCLUSIONS

Although the helium and mercury sampling surveys were limited, the results of these surveys have been very encouraging. Because the helium production rate in Aleutian basic volcanic rocks is lower than in continental granitic rocks, the helium anomalies were smaller than those found at Pilgrim Springs, Chena Hot Springs and Manley Hot Springs.

Fewer mercury samples were collected and analyzed than helium samples, so the mercury anomaly patterns are not as clear, although the Summer Bay anomalous mercury values are in the same general area as the helium anomalies. In spite of low helium production rates and the limited He and Hg sampling distribution in the areas studied, we find that the helium and mercury anomalies have effectively defined areas of geothermal interest. We recommend that detailed helium and mercury surveys be included in future exploration programs on Unalaska.

REFERENCES

Bergquist, L. E., 1980, Helium: An exploration tool for geothermal sites, Geothermal Resources Council Transactions, v. 3, 59-60.

Matlick, J. S., III, and P. R. Buseck, 1975, Exploration for geothermal areas using mercury: a new geochemical technique, In: Proceedings Second United Nations Symposium on the Development and Use of Geothermal Resources, v. 1, 785-792.

Mazor, E., 1972, Paleotemperatures and other hydrological parameters deduced from noble gases dissolved in groundwaters; Jordan Rift Valley, Israel, Geochimica et Cosmochimica Acta, v. 36, 1321-1326.

Wescott, E. M. and D. Turner, 1981a, A geological and geophysical study of the Chena Hot Springs geothermal area, Alaska, University of Alaska, Geophysical Institute Report UAG R-283.

White, D. E., 1967, Mercury and base-metal deposits with associated thermal and mineral waters, In: Barnes, H. L. Ed., Geochemistry of hydrothermal ore deposits, New York, Holt, Rinehart, and Winston, 575, 631.

A GEOPHYSICAL SURVEY OF HOT SPRINGS BAY VALLEY, AKUTAN ISLAND, ALASKA

INTRODUCTION

A series of hot springs occur along a 1.5 km distance at the NW edge of Hot Springs Bay Valley, Akutan Island, Alaska. The island has an active volcano - Akutan. Motyka et al. (1982) have reported that the geothermometry gives an estimated reservoir temperature range of 160°-190°C. The heat loss by the springs is estimated at 1.6 MW (Motyka et al., 1981). In the summer of 1981 geologic mapping and geophysical surveys were carried out in the valley to locate and evaluate geothermal energy resources. Geophysical techniques included near surface conductivity profiling, seismic refraction profiling, Schlumberger vertical electrical soundings, and dipole-dipole resistivity profiling.

GEOLOGY

The Hot Springs Bay Valley has steep side walls composed of an upper section of lava flows and minor mudflows of 1.4 m.y. age lying unconformably on a thick section of well indurated volcanic mudflows cut by abundant fine-grained dikes.

The valleys on the island appear to have been scoured to U shapes by glaciers. Hot Springs Bay Valley has a flat floor formed by volcanic debris flows. The uppermost unit is a lahar which is nonporous and impermeable where exposed.

GEOPHYSICAL SURVEYS

Electrical resistivities of the waters from two of the springs with temperatures of 84 and 59°C are 2.39 and 8.03 Ω-m respectively. The resistivities of the valley sediments are generally much higher, so the near surface resistivity should be well correlated with temperature anomalies where hot water is closest to the surface. We used a Geonics EM-31 electromagnetic conductivity meter to measure the near surface (6 m depth) resistivity over a 1.26 square km area. The contoured data are shown in Figure 13. The low resistivity zones form a narrow sinuous pattern along the NW side of the valley. No other low resistivity zones were located. The pattern suggests that an ancient buried stream channel forms a permeable zone through the lahar. The near surface resistivity is about 100 Ω-m over the rest of the valley except for two sand dune areas where it is 500 Ω-m.

Four Schlumberger vertical electrical soundings were made: one 900 m inland parallel to the valley and 200 m from the NW side, a second parallel to it on a terraced debris flow, a third between hot springs C and D and a fourth near hot springs A (Figure 13). The data were interpreted by an automatic curve fitting program (Zhody, 1974). Figure 14 shows the vertical electric sounding (VES) curve and interpretation run about 150 m from the NW edge of the valley on a lahar terrace. All appear to indicate a geothermal reservoir of 2.2 to 12 Ω-m resistivity, 23 to 42.5 m thickness and a depth of 13 m near the NW edge of the valley to 52 m towards the center.

Three 100 m dipole-dipole pseudo sections were run along and perpendicular to the valley. The results are plotted in Figure 15 to show where they intersect. They all suggest a cap rock, presumably an impermeable lahar, of thickness 40-70 m underlain by a reservoir thicker towards the center of the valley and towards the NE. The SE-NW dipole-dipole no. 1 section was modeled using a two-dimensional program. The result suggests a basement rock of 1500 Ω-m perhaps 150 m deep towards the valley center. Archie's law suggests a porosity of 45-82% for the reservoir and 4-7% for the basement rocks (Archie, 1942).

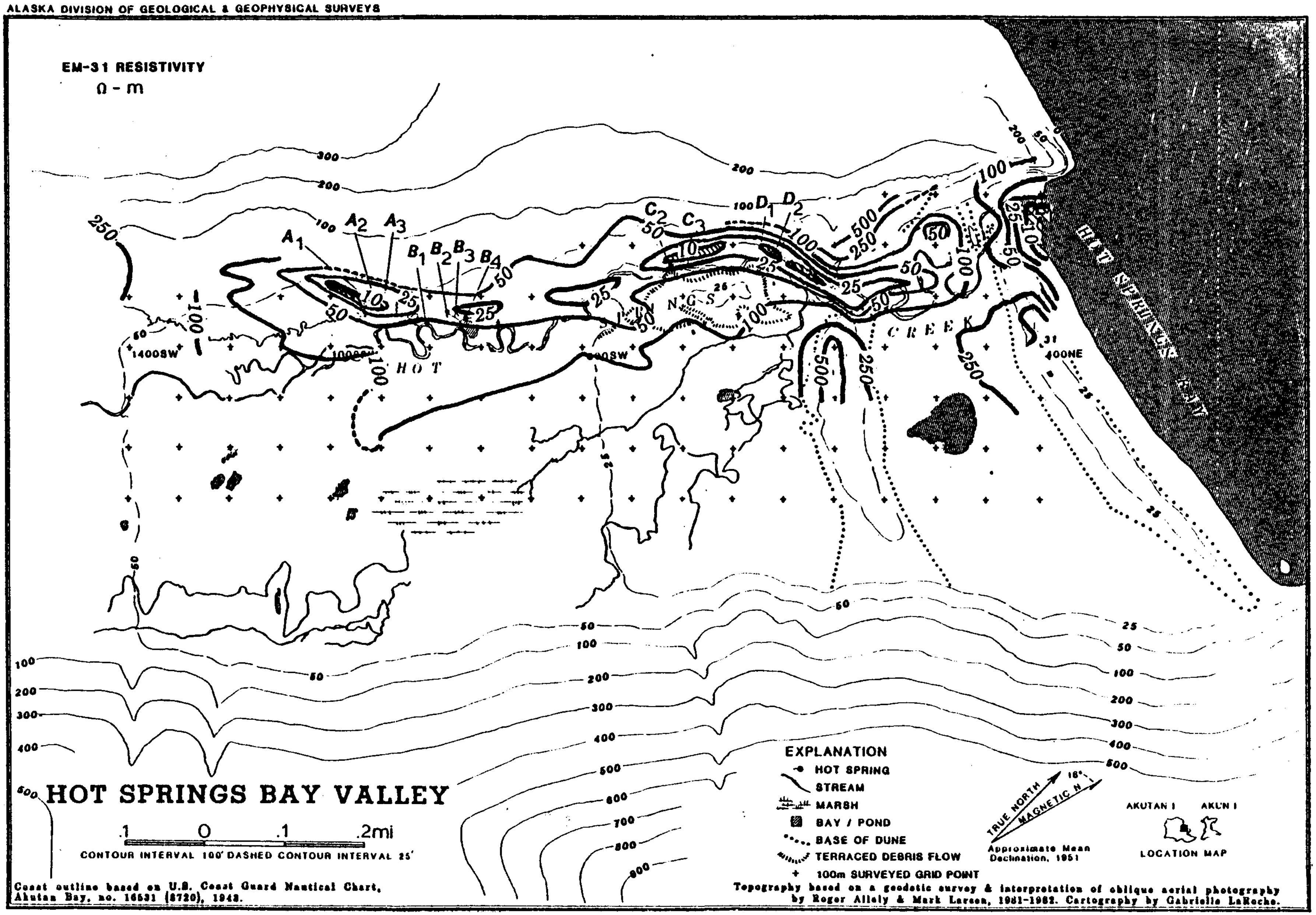

Figure 13. Map of Hot Springs Bay Valley, Akutan Island, Alaska, with superposed near-surface (6 m) electrical resistivity contours from a Geonics EM-31 survey. The resistivity values appear to be inversely related to anomalously high ground temperatures.

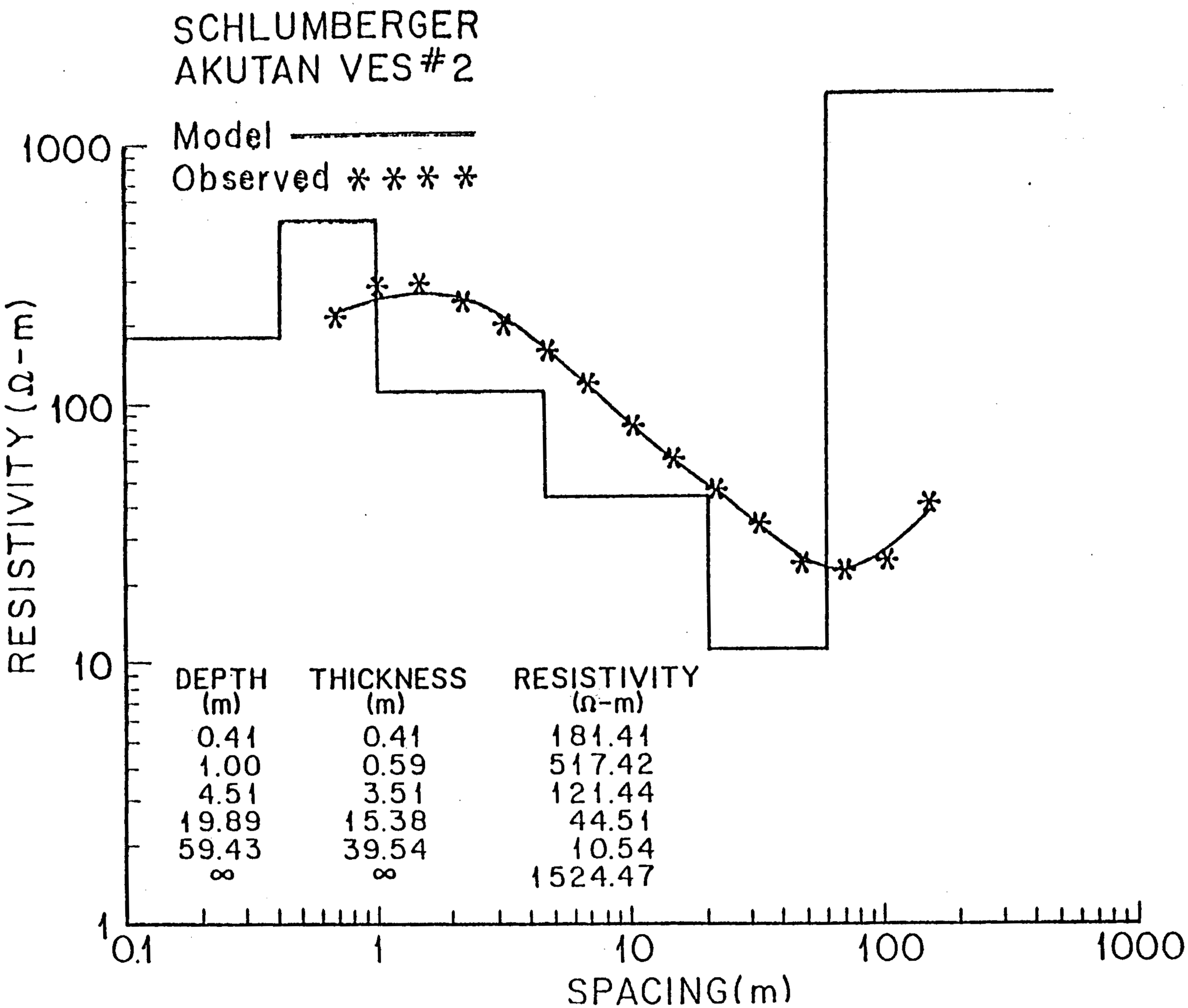

Figure 14. Plot of vertical electric sounding #2 on a lahar terrace 100 SE of the C springs (see Figure 1). True resistivity vs. depth of the model is also plotted. The lowest resistivity layer is interpreted as a geothermal reservoir of porosity 45-82%.

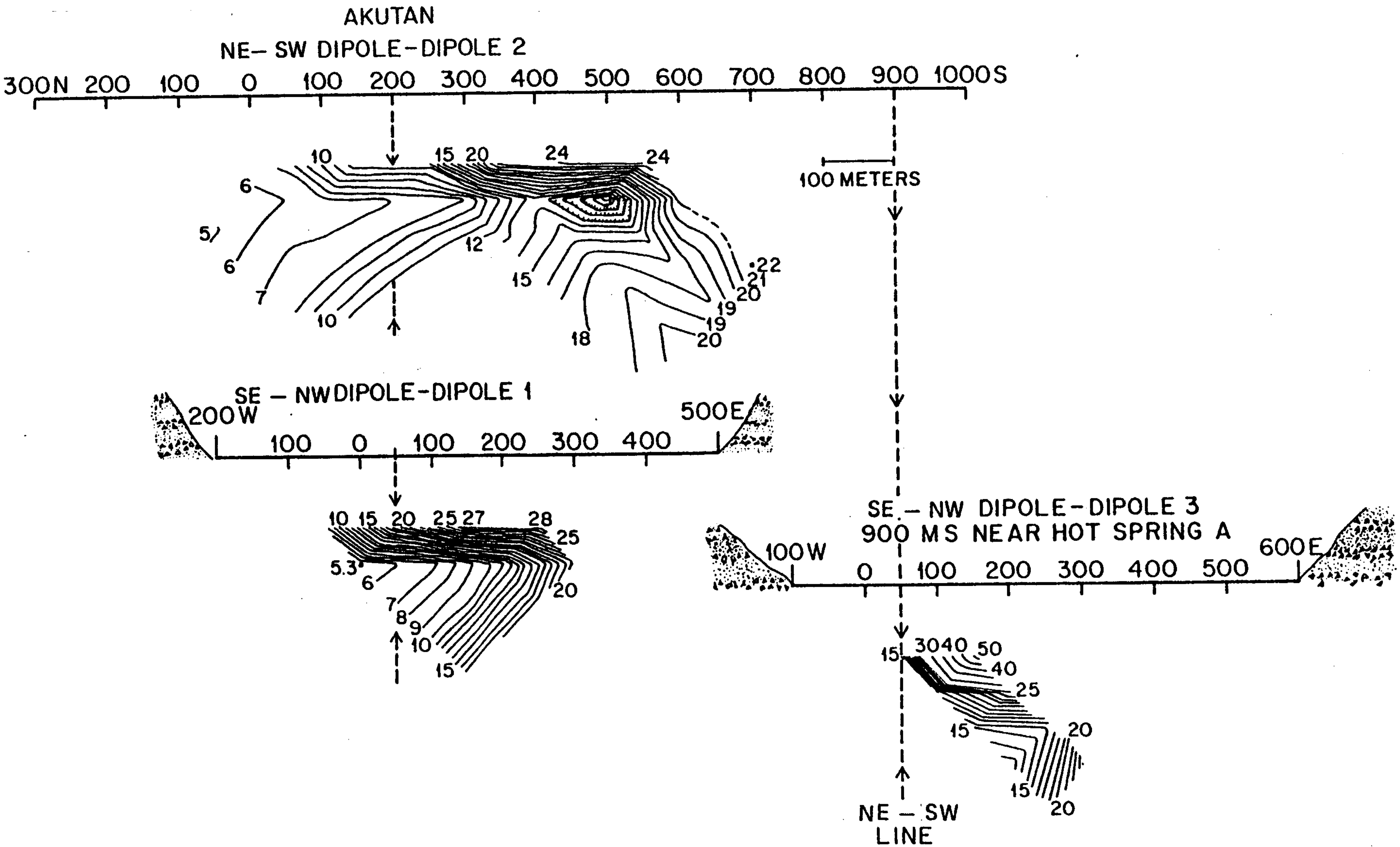

Figure 15. 100 m dipole-dipole resistivity pseudo-sections plotted to show where the NW-SE sections intersect the NE-SW section contours in Ω-m. The sections generally show a medium resistivity cap layer 40-70 m thick overlying a geothermal reservoir layer 40-75 m thick underlain by high resistivity bedrock.

Seismic profiling results agree with the resistivity data. There are three basic units: the top or lahar unit has a velocity ranging between 1630-1960 m/sec and a thickness of 30-75 m; the geothermal reservoir unit has a velocity of 3240-3505 m/s, a thickness of 40-75 m and a base which slopes steeply towards the center of the valley and down the valley towards the ocean. The basement rocks have a velocity of 4900 m/s, and probably correspond to the indurated volcanic mudflows that form the valley walls, although they could also be lava flows, intrusives, or hydrothermally cemented sediments. Figure 16 shows the seismic profile parallel to the valley. The reservoir apparently coincides with the medium velocity layer.

CONCLUSION

Geophysical surveys have located a probable geothermal reservoir at least 1.5 x 0.5 km^2 in area with a thickness ranging between 40-75 m. Figure 17 shows a composite profile parallel to the valley about 200 m from the NW side. The reservoir probably extends further to the NE as evidenced by hot spring E (Figure 13) at the ocean shoreline. It may be thicker toward the NE end of the valley which was not fully explored. Deep resistivity and seismic profiling agree on the general shape of the reservoir which probably rests on a glaciated volcanic bedrock surface. The resource outlined is sufficient to supply hot water and power to the town of Akutan and to an expanded fish processing industry 5 km distant.

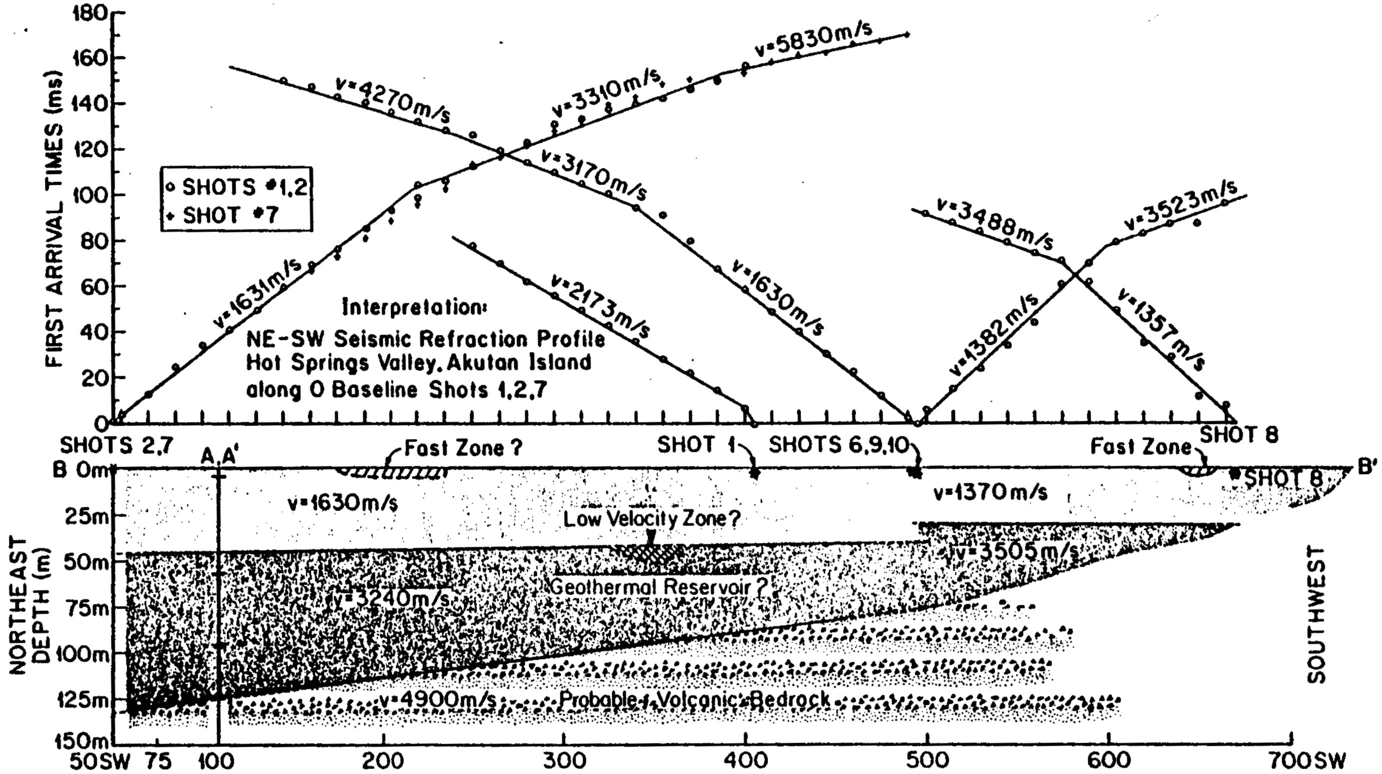

Figure 16. First arrival seismic travel time curves for profile parallel to valley. Bottom interpreted cross section. The interface where dashed indicates zones of no seismic information.

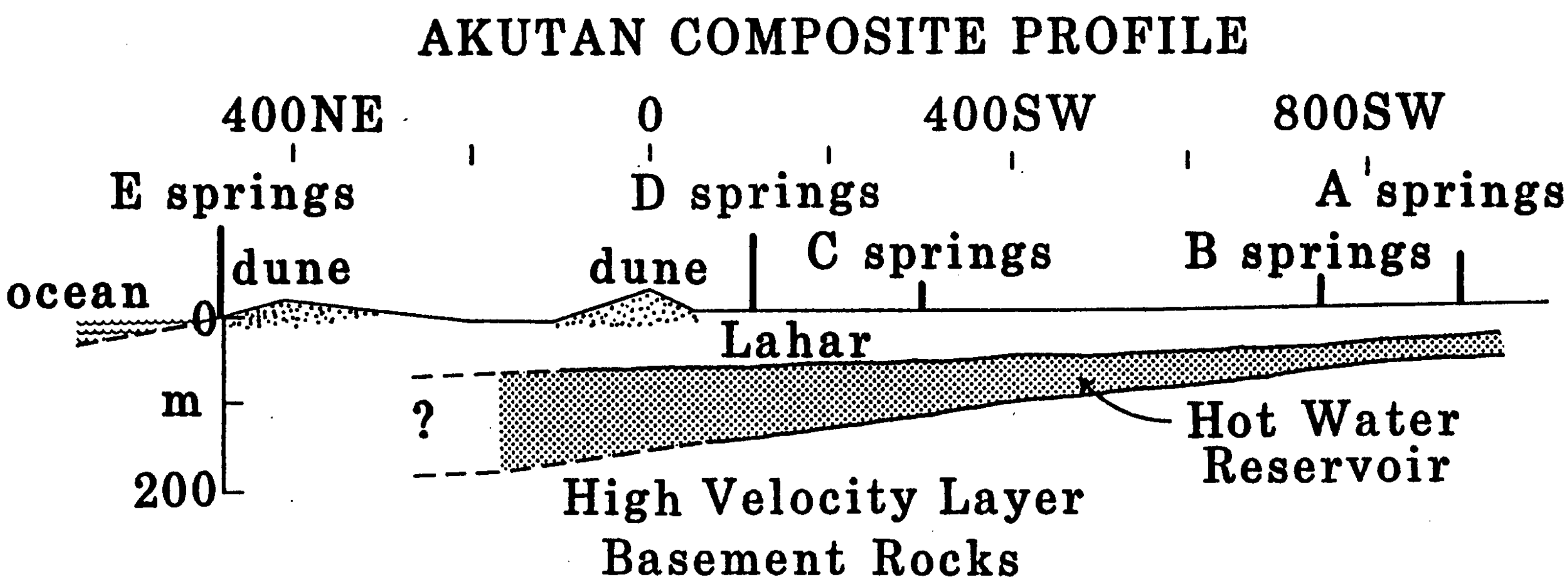

Figure 17. Composite cross section of lower Akutan Hot Springs Bay Valley taken parallel to axis of valley.

RERERENCES

Archie, G. E., 1942, The electrical resistivity log as an aid in determining some reservoir characteristics, Trans. AIME 146 p. 54-62.

Motyka, R. J., Moorman, M. A. and Liss, S. A., 1981, Assessment of thermal spring sides, Aleutian Islands, Atka Is. to Beckerof Lake: Preliminary results and evaluation, Alaska Div. of Geol. and Geoph. Surv. Open File Report 1A4, 175p.

Motyka, R. J., Moorman, M. A. and Poreda, R., 1982, Fluid geochemistry of Hot Springs Bay Valley, Akutan Island, Alaska, Geothermal Resources Council Transactions, 1982 Annual Meeting.

Zhody, A. R., 1974, A computer program for the automatic interpretation of Schlumberger sounding curves over horizontally stratified media, U.S. Geol. Sur. Report, GD-74-017.

Helium and Mercury Soil Surveys of Hot Springs Bay Valley, Akutan Island, Alaska

Introduction

The concentrations of helium and mercury in soil, and of helium in water have been shown to be useful indicators of geothermal resources [Roberts, et al., (1975); Bergquist, (1980); Matlick and Buseck, (1975)]. In Alaska, helium and mercury surveys in the Chena Hot Springs area (Wescott and Turner, 1981a), at Pilgrim Springs (Wescott and Turner, 1981b), at Summer Bay Warm Springs, Unalaska Island (Wescott, et al., 1982) and at Manley Hot Springs, (East, 1982) have shown excellent correlations with areas of upwelling of geothermal waters. More recently an extensive helium survey in the lower Susitna basin has revealed extensive areas of helium anomalies probably associated with geothermal resources (Turner and Wescott, 1982).

The radioactive decay of uranium and thorium is the source of helium in the earth. The solubility of helium in water increases with temperature above 30°C, so geothermal waters are efficient scavengers of helium produced at depths in the rocks Mazor (1972). As the geothermal waters rise towards the surface, helium is released due to cooling and de-pressurization. The Aleutian volcanic rocks contain much less uranium and thorium than the more acidic igneous and metamorphic rocks of the Chena Hot Springs and Pilgrim Springs areas and thus we would expect Aleutian helium anomalies to be less pronounced. The average atmospheric concentration of helium is 5.24 ppm. Allowing for uncertainties in the collection and analysis procedure, we have assumed that any soil concentration of helium greater than 5.40 ppm is a significant anomaly.

Helium Survey

He samples were collected in the area of the Hot Springs Bay Valley by one of three methods: 1. Driving a hollow collection tube about 75 cm into the ground and drawing off a gas sample in a syringe. The gas was then introduced into a small evacuated steel "CO_2" cartridge and sealed. 2. Augering a soil core sampler about 75 cm into the ground, placing the bottom soil core in a steel can and sealing it. 3. Water samples were collected in a sample bottle with a known volume of air. The bottle was shaken for 30 seconds to allow the helium in the water to equilibrate with the air, then a gas sample was drawn off by syringe and inserted into an evacuated steel cartridge as in the soil gas sampling technique.

The helium analysis was done at Western Systems Inc., Morrison, Colorado, by mass spectrometry with a precision of 10 ppb. There are 43 soil or soil gas sample localities and 4 hot springs water samples. The hot springs water samples are about 22% above the atmospheric background: 6.56, 6.41, 6.57 and 6.05 ppm. In comparison, water samples from Manley Hot Springs at 30 ppm are 573% above background, consistent with the higher He production rate in the acidic plutonic and metamorphic rocks of that area (East, 1982). Of the 43 soil sample locations, 27 show anomalously high helium values. The two largest He values of 6.12 ppm are at 150 NW, 300 NE and 150 NW, 200 SW; somewhat removed from the sinuous pattern of anomalously conductive ground found with the EM-31. In general the helium anomalies extend farther out into the valley than the near surface conductivity anomaly.

The pattern of helium anomalies is probably distorted by the production of other gases in the organic-rich marsh. There are 3 samples which are below the atmospheric concentration of 5.24 ppm, one as low as 4.84 ppm. Friedman (personal communication, 1981) has found similar anomalously low helium values in other surveys, and has ascribed this phenomenon to dilution of the helium content of the soil gas by other gases such as methane and CO_2. Thus, since we know some sample sites show anomalously low values below the atmospheric value of 5.24, others which are above 5.24 may have also been lowered by this effect. Since we did not sample for other gases, we cannot correct for this effect.

Mercury Survey

Mercury content in soils has also been reported as a possible indicator of geothermal resources (Matlick and Buseck, 1975). They confirmed a strong association of Hg with geothermal activity in three of four areas tested (Long Valley, California; Summer Lake and Klamath Falls, Oregon). Mercury deposits often occur in regions containing evidence of hydrothermal activity, such as hot springs (White, 1967).

Mercury is highly volatile. Its high vapor pressure makes it extremely mobile, and the elevated temperatures near a geothermal reservoir tend to increase this mobility. The Hg migrates upwards and outwards away from the geothermal reservoir, creating an aureole of enriched Hg in the soil above a geothermal reservoir. Such aureoles are typically much larger in area than a corresponding helium anomaly.

We collected 15 soil samples about 10 cm below the organic layer. The samples were air dried in the shade and sized to -80 mesh using a stainless steel sieve. The -80 portions were stored in airtight glass vials for analysis.

The Hg content of the sample was determined by use of a Jerome Instrument Corp., model 301 Gold Film Mercury detector with sensitivity of better than 0.1 ng of Hg. A standard volume of -80 mesh soil (0.25 cc) was placed in a quartz bulb and heated for one minute to volatize the Hg adsorbed on the mineral grains, which was collected on a gold foil. Heating of the gold foil in the analysis procedure releases the Hg for analyses as a gas in the standard manner. Calibration is accomplished by inserting a known concentration of Hg vapor with a hypodermic syringe.

The background concentration of Hg in soils varies widely from area to area, and must be determined from a large number of samples. It is generally on the order of 10 parts per billion. We calculated a mean value of 139 ppb for the 15 samples collected at Hot Springs Bay Valley and used that as an anomaly level.

Figure 18 shows a map with the mercury values plotted on our grid system. One of the largest values of 395 ppb is at 0 NW, 100 S several hundred meters away from the near surface temperature anomalies. As we did not sample the complete grid system, we cannot make a definitive statement regarding the mercury pattern. It does seem that mercury sampling might be useful for future surveys in this area because there is a wide range of Hg values probably related to the geothermal reservoir at depth.

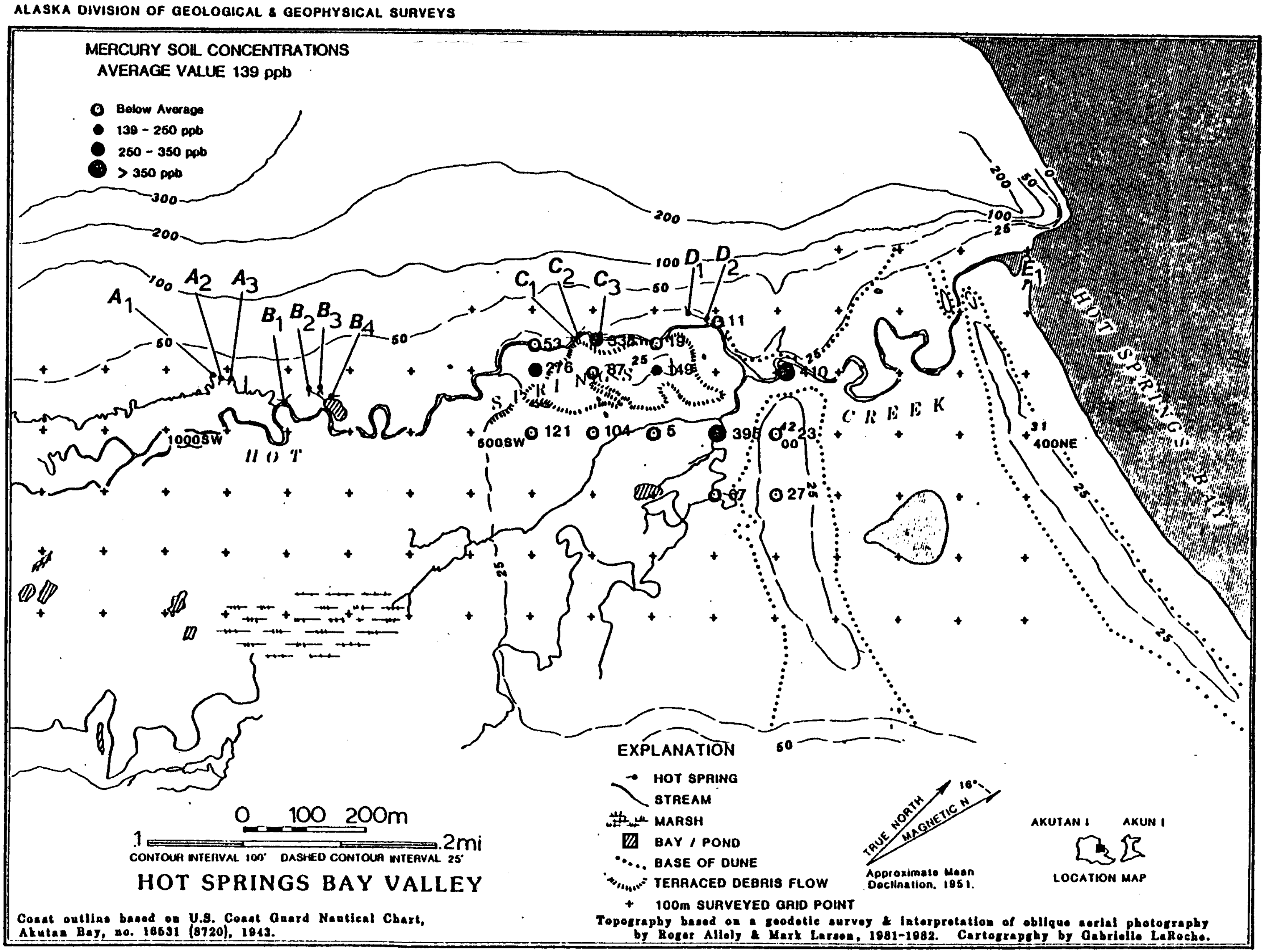

Figure 18. Mercury soil values at Hot Springs Bay Valley.

REFERENCES

Bergquist, L. E., 1980, Helium: An exploration tool for geothermal sites, Geothermal Resources Council Transactions, v. 3, 59-60.

Matlick, J. S., III, and P. R. Buseck, 1975, Exploration for geothermal areas using mercury: a new geochemical technique, In: Proceedings Second United Nations Symposium on the Development and Use of Geothermal Resources, v. 1, 785-792.

Mazor, E., 1972, Paleotemperatures and other hydrological parameters deduced from noble gases dissolved in groundwaters; Jordan Rift Valley, Israel, Geochimica et Cosmochimica Acta, v. 36, 1321-1326.

Wescott, E. M. and D. Turner, 1981a, A geological and geophysical study of the Chena Hot Springs geothermal area, Alaska, University of Alaska, Geophysical Institute Report UAG R-283.

White, D. E., 1967, Mercury and base-metal deposits with associated thermal and mineral waters, In: Barnes, H. L. Ed., Geochemistry of hydrothermal ore deposits, New York, Holt, Rinehart, and Winston, 575, 631.

Appendix A

Reports and Papers Prepared with Support of DE-FC07-79-ET-27034

East, J., Preliminary geothermal investigations at Manley Hot Springs, Alaska, Geophys. Inst. Univ. of Alaska Report UAG R-290, prepared for Div. of Geothermal Energy, U.S. Dept. of Energy. 76 pp, 1982.

Forbes, R. B., D. L. Turner, D. W. Naeser and D. B. Hawkins, Downhole fission track-$^{40}K/^{40}Ar$ age determinations and the measurement of perturbations in the geothermal gradient, Geophysical Institute progress report RDL-229-T11-1 to ERDA under contract No. #(45-1)-229, Task Agreement No. 11, 37 p., appendix, 1977.

Forbes, R. B., E. M. Wescott, T. E. Osterkamp, J. Kienle, D. L. Turner and J. Kline, The Pilgrim Springs hydrothermal system: theories and models (abs.) Proc. 30th Alaska Science Conf., A.A.A.S., p. 60-61, 1979.

Forbes, R. B., E. M. Wescott, D. L. Turner, J. Kienle, T. Osterkamp, D. B. Hawkins, J. T. Kline, S. Swanson, R. D. Reger and W. Harrison, A geological and geophysical assessment of the geothermal potential of Pilgrim Springs, Alaska, Univ. of Alaska, Geophysical Institute, Preliminary Report, 39 pp., 1 pl., 1979.

Hawkins, D. B. and W. Harrison, Measurement of flow rate of Pilgrim Hot Springs and estimation of ground water velocity in the upper 10 meters of unconsolidated sediments (abs.), Proc. 30th Alaska Science Conf., A.A.A.S., p. 57, 1979.

Kienle, J. and A. B. Lockhart, Seismic and gravity surveys of Pilgrim Springs Alaska (abs.), Proc. 30th Alaska Science Conf., A.A.A.S., p. 59, 1979.

Lockhart, A., and J. Kienle, Seismic refraction and gravity surveys of Pilgrim Springs K.G.R.A., Alaska, Geothermal Resources Council Trans., V. 4, p. 213-216, 1980.

Osterkamp, T. E., R. B. Forbes, R. G. Gaffi, J. T. Hanscom, M. Kane and C. Stephens, Shallow thermal, electrical conductivity and hydrologic measurements at Pilgrim Springs, Alaska (abs.), Proc. 30th Alaska Science Conf., A.A.A.S., p. 56, 1979.

Turner, D. L., S. Swanson, R. B. Forbes and D. Maynard, Geology and tectonic setting of Pilgrim Springs, Alaska (abs.), Proc. 30th Alaska Science Conf., A.A.A.S., p. 52-53, 1979.

Turner, D. L., R. B. Forbes, E. M. Wescott, J. Kienle, T. Osterkamp, S. Swanson, D. Hawkins, W. Harrison, J. Gosink, J. Kline, R. Motyka, R. Reger and M. Moorman, Summary of Results of Geological and Geophysical Investigation of of the Geothermal Energy Potential of the Pilgrim Springs, K.G.R.A., Alaska, Geotherm. Res. Council Trans., V. 4, p. 93-95, 1980.

Turner, D. L. and R. B. Forbes, Editors, A Geological and Geophysical Study of the Geothermal Energy Potential of Pilgrim Springs, Alaska, Rept. UAG-271, Geophys. Inst., University of Alaska, Prepared for Div. of Geothermal Energy, U. S. Dept. of Energy and State of Alaska, Div. of Energy and Power Development, 165 pp., 1 pl., 1980.

Turner, D. L., R. B. Forbes, M. Albanese, J. Macbeth, A. B. Lockhart and S. M. Seed, Geothermal Energy Resources of Alaska, Geo. Inst., University of Alaska Rept. UAG R-279, 19 pp., 2 pl., 1980.

Turner, D. L., S. Swanson and E. M. Wescott, Continental Rifting--A New Tectonic Model for Geothermal Exploration of the Central Seward Peninsula, Alaska, Trans. Geotherm. Res. Council, V. 5, p. 213-216, 1981.

Turner, D. L. and E. M. Wescott, A Preliminary Investigation of the Geothermal Energy Resources of the Lower Susitna Basin, Geophys. Inst. Univ. of Alaska Report UAG R-287, Prepared for Div. of Geothermal Energy, U.S. Dept of Energy, 50 pp., 3 pl., 1982.

Turner, D. L., E. M. Wescott, W. Witte and B. Petzinger, Preliminary Investigation of the Geothermal Energy Resources of the Lower Susitna Basin, Alaska, Geothermal Resources Council Trans., V. 6, 1982.

Wescott, E. M., R. Sydora, J. Peace and A. Lockhart, Electrical resistivity survey of the Pilgrim Springs geothermal area, Alaska, Geothermal Resources Council Trans., V. 4, p. 257-259, 1980.

Wescott, E. M., R. Sydora and J. Peace, Resistivity survey of Pilgrim Hot Springs (abs.), Proc. 30th Alaska Science Conf., A.A.A.S., p. 55, 1979.

Wescott, E. M. and D. L. Turner, Editors, A Geological and Geophysical Study of the Chena Hot Springs Geothermal Area, Alaska. Geophys. Inst., University of Alaska Report UAG R-283, prepared for Div. of Geothermal Energy, U.S. Dept. of Energy, 65 pp., 2 pl., 1981a.

Wescott, E. M. and D. L. Turner, Editors, Geothermal Reconnaissance Survey of the Central Seward Peninsula, Alaska, Geophys. Inst. Univ. of Alaska Report UAG R-284, prepared for Div. of Geothermal Energy, U.S. Dept. of Energy, 123 pp., 1981b.

Wescott, E. M., Helium and mercury in the central Seward Peninsula rift system, in Geothermal Direct Heat Program, Glenwood Springs Technical Conference Proceedings, V. 1, Earth Science Laboratory, University of Utah Research Institute, Salt Lake City, Utah, 1981.

Wescott, E. M., D. L. Turner, W. Witte, and B. Petzinger, A Geophysical Survey of Hot Springs Bay Valley, Akutan Island, Alaska, Geothermal Resources Council Trans., V. 6, 1982.

APPENDIX B

Recent Alaskan Geothermal Energy Publications

Biggar, N. E., A geological and geophysical study of Chena Hot Springs, Alaska, Geophysical Institute, Univ. of Alaska, Fairbanks, unpublished M.S. thesis, 72 pp., 2 pl., 1974.

Dean, K. G., R. B. Forbes, D. L. Turner and F. Eaton, Application of Radar and Infrared Airborne Remote Sensing to Geothermal Resource Assessment at Pilgrim Springs, Alaska, Final Report. NASA Grant NAG9-8, 21 pp., 1981.

Dean, K. G., R. B. Forbes, D. L. Turner and F. Eaton, Radar and Infrared Remote Sensing of Geothermal Features at Pilgrim Springs, Alaska, Remote Sensing of Environment (in press), 1982.

East, J., Preliminary Geothermal Investigations at Manley Hot Springs, Alaska, Geophys. Inst. Univer. of Alaska Report UAG R-290, prepared for Div. of Geothermal Energy, U.S. Dept. of Energy, 76 pages, 1982.

Economides, M. J., Reeder, J., and Markle, D., Unalaska geothermal development. In: Proceedings, Third Annual New Zealand Geothermal Workshop (Auckland, New Zealand: November 9-11, 1981), University of Auckland and the New Zealand Ministry of Works, pp. 7-12, 1981.

Forbes, R. B., The energy crunch...Alaska style, Proc. of the Public Meeting on a National Plan for Energy Research Development and Demonstration; Transcript of the Proc., U. S. Energy Research and Development Administration, Washington, D.C., December 1975.

Forbes, R. B., and N. Biggar, Alaska's geothermal resource potential, The Northern Engineer, Vol. 5, No. 1, p. 6-10, Geophysical Institute, University of Alaska, Spring 1973.

Forbes, R. B., L. Gedney, D. VanWormer and J. Hook. A geophysical reconnaissance of Pilgrim Springs, Alaska, Univ. of Alaska, Geophysical Institute Report UAG R-231, 26 pp., 1975.

Forbes, R. B., L. Leonard, and D. H. Dinkel, Total energy utilization potential of Alaskan thermal springs, Selected papers from the Proc. of the United Nations Geothermal Symposium, San Francisco, California, May 1975, pp. 2209-2215, 1975.

Forbes, R. B., L. Leonard and D. H. Dinkel, Utilization of geothermal energy resources in rural Alaska communities, Univ. of Alaska, Geophys. Inst. Rept. UAG R-232, 83 pp., 1975.

Forbes, R. B., D. L. Turner and C. W. Naeser, Downhole fission track-$^{40}K/^{40}Ar$ age determinations and the measurement of perturbations in the geothermal gradient (abs.), Int. Conf. on Geothermometry and Geobarometry, Penn. State Univ., Extended Abstracts Volume, 1975.

Forbes, R. B., D. L. Turner, D. W. Naeser and D. B. Hawkins, Downhole fission track-$^{40}K/^{40}Ar$ age determinations and the measurement of perturbations in the geothermal gradient, Geophysical Institute progress report RDL-229-T11-1 to ERDA under contract No. #(45-1)-229, Task Agreement No. 11, 37 p., appendix, 1977.

Forbes, R. B., E. M. Wescott, T. E. Osterkamp, J. Kienle, D. L. Turner and J. Kline, The Pilgrim Springs hydrothermal system: theories and models (abs.) Proc. 30th Alaska Science Conf., A.A.A.S., p. 60-61, 1979.

Forbes, R. B., E. M. Wescott, D. L. Turner, J. Kienle, T. Osterkamp, D. B. Hawkins, J. T. Kline, S. Swanson, R. D. Reger and W. Harrison, A geological and geophysical assessment of the geothermal potential of Pilgrim Springs, Alaska, Univ. of Alaska, Geophysical Institute, Preliminary Report, 39 pp., 1 pl., 1979.

Hawkins, D. B. and W. Harrison, Measurement of flow rate of Pilgrim Hot Springs and estimation of ground water velocity in the upper 10 meters of unconsolidated sediments (abs.), Proc. 30th Alaska Science Conf., A.A.A.S., p. 57, 1979.

Hickel, W. J., Geothermal energy - a national proposal for geothermal resources research, University of Alaska, 95 pp., 1972.

Kienle, J. and A. B. Lockhart, Seismic and gravity surveys of Pilgrim Springs Alaska (abs.), Proc. 30th Alaska Science Conf., A.A.A.S., p. 59, 1979.

Kline, J. T., Surficial geology of the lower Pilgrim valley and vicinity, western Seward Peninsula, Alaska, Alaska Division of Geological and Geophysical Survey Open File Map AOF-140.

Kline, J. T., Reger, R. D. and R. M. McFarlane, Surficial geology of the Pilgrim Springs vicinity, Alaska (abs.). Proc. 30th Alaska Science Conf., A.A.A.S., p. 54, 1979.

Leonard, L. E., What's old in geothermal energy?, The Northern Engineer, Vol. 6, No. 4, Geophysical Institute, Unversity of Alaska, Winter 1974-1975.

Lockhart, A., and J. Kienle, Seismic refraction and gravity surveys of Pilgrim Springs K.G.R.A., Alaska, Geothermal Resources Council Trans., V. 4, p. 213-216, 1980.

Markle, D., Geothermal energy in Alaska, site data base and development status, Report Contract DE-AC03-79SF1049, OIT Geo-Heat Utilization Center, Klamath Falls, OR, 572 p., 2 pl., 1979.

Markle, D., Prospects for geothermal energy development at Pilgrim Springs, Alaska (abs.), Proc. 30th Alaska Science Conf., A.A.A.S., p. 62, 1979.

Miller, T. P., Distribution and chemical analyses of thermal springs in Alaska, U.S. Geol. Survey Open File Map 570-G, 1973.

Miller, T. P., I. Barnes and W. W. Patton, Jr., Geologic setting and and chemical characteristics of hot springs in west-central Alaska, Jour. Res. U.S. Geol. Survey, V. 3, No. 2, 1975.

Motyka, R. J., Moorman, M. A., and Reeder, J. W., "Assessment of thermal spring sites in southern southeastern Alaska--Preliminary results and evaluation", Alaska Division of Geological and Geophysical Survey Open File Report AOF-127, 66 p., 1980.

Motyka, R. J., Moorman, M. A., and Liss, S. A., "Assessment of thermal spring sites, Aleutian Arc, Atka Island to Becherof Lake--Preliminary results and evaluation", Alaska Division of Geological and Geophysical Surveys, Open File Report AOF-144, 174 p., 1981.

Motyka, R. J., and Moorman, M. A., "Reconnaissance of thermal spring sites in the Aleutian Arc, Atka Island to Becherof Lake", In: Transactions, Geothermal Resource Council 1981 Annual Meeting (Houston, Texas, U.S.A.: Oct. 25-29, 1981), Davis, California, U.S.A., Geothermal Resource Council, v. 5, pp. 111-114, 1981.

Motyka, R. J., Forbes, R. B., and Moorman, M. A., Geochemistry of Pilgrim Springs thermal waters", In: "A geological and geophysical study of the geothermal energy potential of Pilgrim Springs, Alaska" (D. L. Turner and R. B. Forbes, Eds.), Geophysical Institute, Report UAG R-271 to: U.S. Department of Energy, 165 p., 1980.

Motyka, R. J., "High temperature hydrothermal resources in the Aleutian Arc", Abs. Alaska Geological Society 1982 Symposium on western Alaska geology and resource potential, February 1982.

Osterkamp, T. E., R. B. Forbes, R. G. Gaffi, J. T. Hanscom, M. Kane and C. Stephens, "Shallow thermal, electrical conductivity and hydrologic measurements at Pilgrim Springs, Alaska (abs.)", Proc. 30th Alaska Science Conf., A.A.A.S., p. 56, 1979.

Poreda, R., Craig, H., and Motyka, R. J., "Helium isotope variations along the Alaskan-Aleutian Arc", Abs. EOS, vol. 62, 45, p. 1082, 1981.

Reeder, J. W., Motyka, R. J. and Wiltse, M. A., "The State of Alaska geothermal program", In: Transactions, Geothermal Resource Council 1980 Annual meeting (Salt Lake City, Utah, U.S.A., Sept. 9-11, 1980), Davis, California, U.S.A., Geothermal Resource Council, v. 4, pp 823-826, 1980.

Reeder, J. W., "Initial assessment of the hydrothermal resources of the Summer Bay region on Unalaska Island, Alaska", In: Transactions, Geothermal Resource Council 1981 Annual Meeting (Houston, Texas, U.S.A., Oct. 25-29, 1981), Davis, California, U.S.A., Geothermal Resources Council, v. 5, pp. 1234-1236, 1981.

Reeder, J. W., "Vapor-dominated hydrothermal manifestations on Unalaska Island, and their geologic and tectonic setting", In: Abstracts, 1981 IAVCEI Symposium-Arc Volcanism (Tokyo and Hakone, Japan: Aug. 28-Sept. 9, 1981), The Volcanological Society of Japan and the International Association of Volcanology and Chemistry of the Earth's Interior, pp. 279-298, 1981.

Reeder, J. W., Economides, M. J., and Markle, D. R., "Geological and engineering studies for geothermal development on Unalaska Island", submitted, International Conference on Geothermal Energy, Florence, Italy, sponsored by BHRA, May, 1982.

Reeder, J. W., "Hydrothermal manifestations on Unalaska Island", Alaska Division of Geological and Geophysical Surveys, Open File Report, In press.

Turner, D. L. and R. B. Forbes, K-Ar studies in two deep basement drill holes: a new geologic estimate for argon blocking temperature for biotite (abs.) EOS, 57(4), 353, 1976.

Turner, D. L., S. Swanson, R. B. Forbes and D. Maynard, Geology and tectonic setting of Pilgrim Springs, Alaska (abs.), Proc. 30th Alaska Science Conf., A.A.A.S., p. 52-53, 1979.

Turner, D. L., R. B. Forbes, E. M. Wescott, J. Kienle, T. Osterkamp, S. Swanson, D. Hawkins, W. Harrison, J. Gosink, J. Kline, R. Motyka, R. Reger and M. Moorman, Summary of Results of Geological and Geophysical Investigation of of the Geothermal Energy Potential of the Pilgrim Springs, K.G.R.A., Alaska, Geotherm. Res. Council Trans., V. 4, p. 93-95, 1980.

Turner, D. L. and R. B. Forbes, Editors, A Geological and Geophysical Study of the Geothermal Energy Potential of Pilgrim Springs, Alaska, Rept. UAG R-271, Geophys. Inst., University of Alaska, Prepared for Div. of Geothermal Energy, U. S. Dept. of Energy and State of Alaska, Div. of Energy and Power Development, 165 pp., 1 pl., 1980.

Turner, D. L., R. B. Forbes, M. Albanese, J. Macbeth, A. B. Lockhart and S. M. Seed, Geothermal Energy Resources of Alaska, Geo. Inst., University of Alaska Rept. UAG R-279, 19 pp., 2 pl., 1980.

Turner, D. L., S. Swanson and E. M. Wescott, Continental Rifting--A New Tectonic Model for Geothermal Exploration of the Central Seward Peninsula, Alaska, Trans. Geotherm. Res. Council, V. 5, p. 213-216, 1981.

Turner, D. L. and E. M. Wescott, A Preliminary Investigation of the Geothermal Energy Resources of the Lower Susitna Basin, Geophys. Inst. Univ. of Alaska Report UAG R-287, Prepared for Div. of Geothermal Energy, U.S. Dept of Energy, 50 pp., 3 pl., 1982.

Turner, D. L., E. M. Wescott, W. Witte and B. Petzinger, Preliminary Investigation of the Geothermal Energy Resources of the Lower Susitna Basin, Alaska, Geothermal Resources Council Trans., V. 6, 1982.

Wescott, E. M., R. Sydora, J. Peace and A. Lockhart, Electrical resistivity survey of the Pilgrim Springs geothermal area, Alaska, Geothermal Resources Council Trans., V. 4, p. 257-259, 1980.

Wescott, E. M., Sydora R. and J. Peace, Resistivity survey of Pilgrim Hot Springs (abs.), Proc. 30th Alaska Science Conf., A.A.A.S., p. 55, 1979.

Wescott, E. M. and D. L. Turner, Editors, A Geological and Geophysical Study of the Chena Hot Springs Geothermal Area, Alaska. Geophys. Inst., University of Alaska Report UAG R-283, prepared for Div. of Geothermal Energy, U.S. Dept. of Energy, 65 pp., 2 pl., 1981a.

Wescott, E. M. and D. L. Turner, Editors, Geothermal Reconnaissance Survey of the Central Seward Peninsula, Alaska, Geophys. Inst. Univ. of Alaska Report UAG R-284, prepared for Div. of Geothermal Energy, U.S. Dept. of Energy, 123 pp., 1981b.

Wescott, E. M., Helium and mercury in the central Seward Peninsula rift system, in Geothermal Direct Heat Program, Glenwood Springs Technical Conference Proceedings, V. 1, Earth Science Laboratory, University of Utah Research Institute, Salt Lake City, Utah, 1981.

Wescott, E. M., D. L. Turner, W. Witte, and B. Petzinger, A Geophysical Survey of Hot Springs Bay Valley, Akutan Island, Alaska, Geothermal Resources Council Trans., V. 6, 1982.