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NANA Regional Corporation Geothermal Assessment Project

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Final Report

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Upper Division Hot Springs in summer (photo by US Fish and Wildlife Service)

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Project Summary

Since January 2008, NANA Regional Corporation (NRC) has been assessing geothermal energy potential in the NANA region for both heat and/or electricity production. The Geothermal Assessment Project (GAP) has been a systematic process that looked at community resources and the community's capacity and desire to develop these resources. In October 2007, the US Department of Energy's Tribal Energy Program awarded grant #DE-FG36-07GO17075 to NRC for the GAP studies.

Although several known hot springs exist in the NANA region, most of these geothermal resources are located too far from communities to be a practical source of electrical energy. The required length of electric transmission line was judged by the GAP research team to be far too expensive for the likely size of the electric load in all cases. Any "blind" geothermal resources that do not express at the surface as a hot spring would have to be reasonably close to a community (probably 10 miles or less) to be economically feasible. Consultation with experts at the University of Alaska Fairbanks has further ruled out a viable geothermal energy possibility for Kotzebue and its surroundings. Two moderately remote sites in the NANA region were judged to have the most potential for geothermal development (Figure 1): Granite Mountain, about 40 miles south of Buckland, and the Division Hot Springs area in the Purcell Mountains, about 40 miles south of Shungnak and Kobuk.

Data were collected on-site at Granite Mountain Hot Springs in September 2009, and at Division Hot Springs in April 2010. Although both target geothermal areas could be further investigated with a variety of exploration techniques such as a remote sensing study, a soil geochemical study, or ground-based geophysical surveys, it was recommended that on-site or direct heat use development options are more attractive at this time, rather than investigations aimed more at electric power generation.

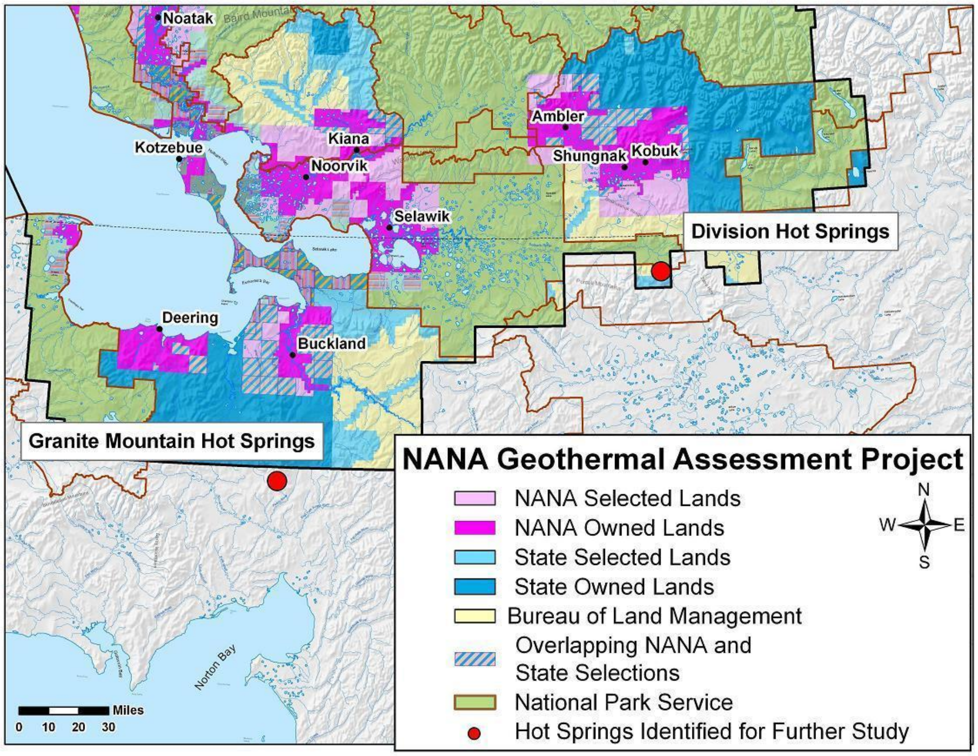

Figure 1: Map showing the locations of the Granite Mountain and Division hot springs sites (map by Paula Hansen)

Community Visits and Surveys:

Amanda Kolker, PhD, the GAP technical consultant, determined from a literature review, site visits, and local knowledge that only two areas within the NANA region appear promising for geothermal development. Dr. Kolker visited Kotzebue, Singaruk River, Deering and Buckland between February 27 and March 7, 2008. Public presentations were given in the three communities, outlining the NANA GAP study objectives, and information was collected from residents on possible hot spring sites in the area. The Singaruk River site, located 75 miles east of Kotzebue between Noorvik and Selawik, was described by locals as a location where water does not freeze. However, the springs were cold, showing no indication of geothermal activity.

In September 2009, ACEP researchers visited the Granite Mountain hot springs site to collect water samples, make temperature measurements, and assess the surface geology.

In April 2010, ACEP researchers and WHPacific staff visited Division hot springs to collect water samples, make temperature measurements, and assess the surface geology (Figure 2).

Figure 2: Lower Division Hot Springs in April 2010
(photo by Matt Bergan)

Technical and Socio-Economic Analysis of the Geothermal Resource

In January 2009, a report titled *NANA Geothermal Assessment Project (GAP) Results of Phase 1: Site Identification* was completed by Amanda Kolker with assistance from Brian Yanity (see Appendix A). This report briefly discussed seven hot springs in or near the NANA region: Serpentine, Lava Creek, Granite Mountain, Hawk, South, Division and Reed River hot springs. All seven of these hot springs are located more than 40 miles from the nearest community. A pre-feasibility reconnaissance screening during Phase 1 of the GAP concluded that geothermal energy potential should be further evaluated at only two of the seven sites: Granite Mountain and Division hot springs. These two sites were chosen as more attractive sites for additional geothermal exploration effort due to their relative proximity to communities as compared to the other hot springs.

At the time of this report, Kotzebue has been ruled out as a site for the use of geothermal energy. Gwen Holdmann and Kenji Yoshikawa of the Alaska Center for Energy and Power, University of Alaska Fairbanks, (see Appendix A) determined that it is almost impossible for a significant geothermal energy resource to exist beneath the city of Kotzebue. Holdmann and Yoshikawa reviewed the evidence for the claim that geothermal fluids, either in the form of hot water or steam, was encountered in Kotzebue at a depth of about 300 feet during the drilling of a well. WHPacific concurs with the findings of this paper, and recommends that no further resources be expended on geothermal energy exploration in the vicinity of Kotzebue. Investigation of a Kotzebue subsurface heat source would require a deep, and therefore expensive drilling effort that would have low potential for finding usable geothermal fluids or heat.

Natural gas exploration in the Kotzebue vicinity by NANA Regional Corporation will be able to provide data on subsurface temperatures and indicate whether a geothermal heat source may be present, if an effort is made to acquire temperature logs and water samples from the wells. Present exploration plans call for the nearest drilling to be approximately 15 miles southeast of Kotzebue on the Baldwin Peninsula. Natural gas exploration drilling is planned for the 2012 to 2015 timeframe.

The studies so far on geothermal resources in or near the NANA region concluded it would be un-economic to serve NANA region communities with geothermal electric power generation at either Granite Mountain or at Division hot springs. The only practical option for further development of these resources might be direct use on-site facilities. Enhancement of existing recreational use of the region's hot springs, including ecotourism, is also possible. Greenhouse agriculture, heated and powered by a combined geothermal heat-and-power system, is another possible on-site use for the hot springs. Such a project would have goal of growing fresh produce for communities in the region, and could employ several people on site.

Granite Mountain Hot Springs:

Granite Mountain hot springs, shown below in Figure 3, is located on Alaska Department of Natural Resources land about 40 miles south of Buckland (at coordinates 65°22'8.63"N, 161°15'25.56"W), within the region of the Bering Straits Native Corporation. In September 2009, a three-day Granite Mountain site visit was conducted by Dick Benoit and Peter Illig of the Alaska Center for Energy and Power (ACEP), based at the University of Alaska Fairbanks. Six water samples collected on site were analyzed by the Desert Research Institute in Nevada, and twenty two (22) shallow hole temperature measurements were made around the hot springs site, at depths ranging between 18 to 36 inches. The highest surface water temperature measured in the spring orifices was 48˚C (119˚F), with a spring outflow estimated at 190 liters per minute (50 gallons per minute). Surface geology of the metaphoric bedrock around the site was also assessed. The November 2009 reconnaissance study report by ACEP (attached in as Appendix B) concluded that it is unlikely to expect that the Granite Mountain geothermal system is capable of generating more than 1 MW of electricity. The thermal and chemical measurements made on site indicate that the subsurface temperatures of the geothermal system probably do not exceed 88˚C (190˚F). Due to the substantial cost of building a 40 mile-long power line to the nearest community (either Buckland or Koyuk), the only recommended development scenario would be an on-site direct-use heating, possibly in combination with low temperature geothermal power generation to power any on-site facilities.

Figure 3: Aerial view of Granite Mountain Hot Springs, manmade pool and buildings (photo by ACEP)

Purcell Mountains/Selawik River Area (aka Division Hot Springs):

The hot springs in the Purcell Mountains and Selawik River, shown on Google Earth in Figure 4, are located within the Selawik National Wildlife Refuge, as well as on land managed by the Bureau of Land Management. The US Fish and Wildlife Service (FWS) office in Kotzebue, which manages the Selawik refuge, has initiated hydrology and geology field studies in the Selawik River watershed.

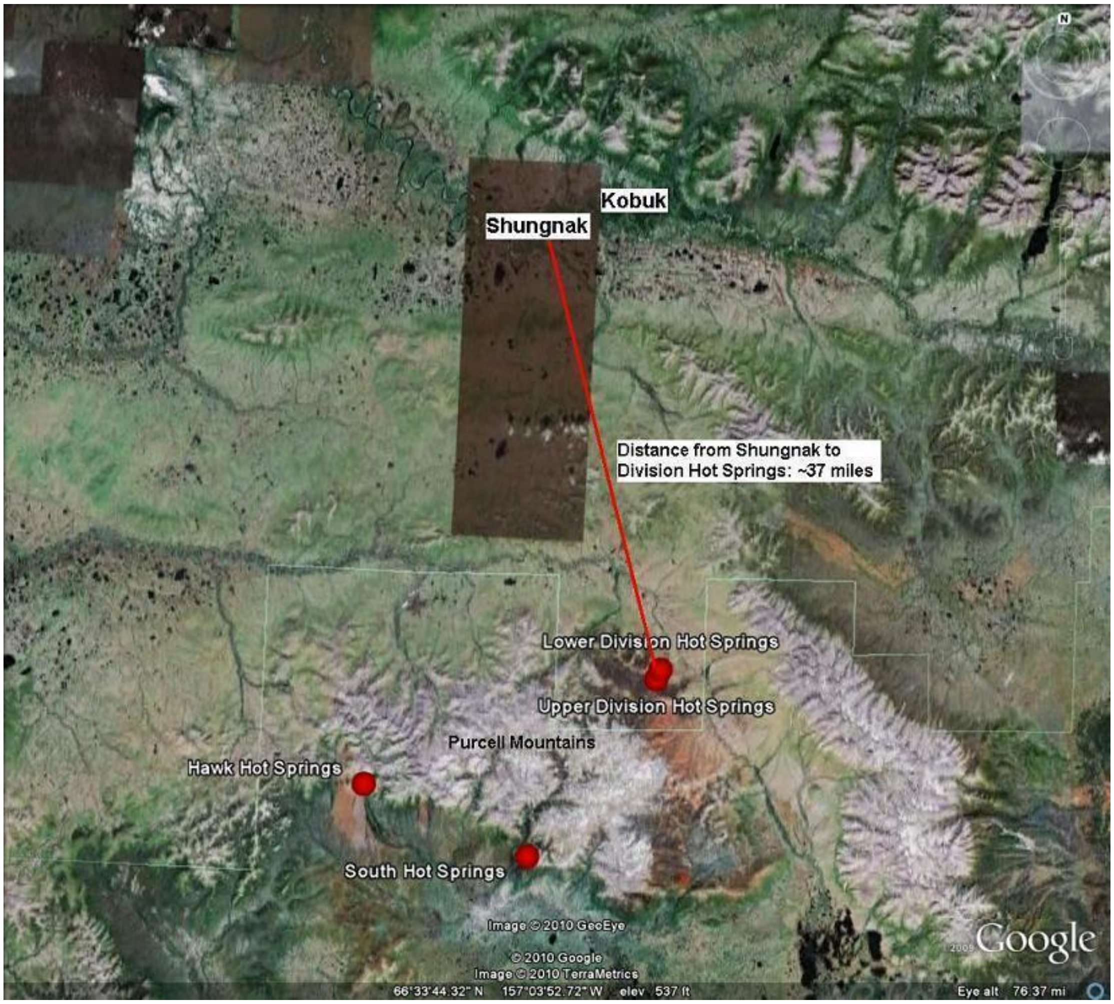

Figure 4: Google Earth map showing locations of known hot springs in the Purcell Mountains/Selawik River area (locations by Matt Bergan)

Division Hot Springs-

Division Hot Springs on the Selawik National Wildlife Refuge is also known as Selawik or Shungnak hot springs, and has both an “upper“ and “lower” thermal springs about 0.75 mile apart (Figures 5 and 6). Peter Illig of ACEP, with Steve Buckley and Matt Bergan of WHPacific, collected data at Division hot springs during a two-day site visit in April 2010. Work was performed at the Division site under a USFWS special use permit (#75625-1003). Students from the Shungnak School were also at the site, as part of an annual trip to Division hot springs organized by the Northwest Arctic Borough School District. The temperatures and flow rates given for each of the two adjacent sites below were recorded during the April 2010 site visit. The Division Hot Springs are approximately located at coordinates 66°22'40"N, 156°44'40"W.

Lower Division Hot Springs-
Water temperature: 57˚C (135˚F)
Estimated spring outflow: ~2 lpm (0.5 gpm)

Figure 5: Aerial view of Lower Division Hot Springs area and buildings during summer (photo by US FWS)

Upper Division Hot Springs -
Water temperature: 71˚C (160˚F)
Estimated spring outflow: ~20 lpm (5 gpm) or less

Figure 6: Upper Division Hot Springs in April 2010 (photo by Matt Bergan)

The May 2010 reconnaissance study report by ACEP (attached as Appendix C) predicted a subsurface temperature between 99˚C (210˚F) and 126˚C (259˚F). If the upper and lower Division springs are part of one contiguous geothermal system, it is possible that Division Hot Springs could produce hundreds of kW of geothermal electric power using a low-temperature system similar to that used at Chena Hot Springs. It would require deep drilling to confirm the amount of heat energy available in the reservoir and to assess the feasibility of geothermal power generation. The estimated cost of mobilizing a drill rig by helicopter, and drilling a 3000'-4000' deep core hole (not for production) would be between $1 million to $1.5 million. Because Division Hot Springs is located within the Selawik National Wildlife Refuge, obtaining permits for such a drilling operation could prove challenging. Due to the substantial cost of building a power line more than 40 miles long to the nearest community (either Shungnak, Kobuk or Huslia), and the high upfront exploration and development costs, the only recommended development scenario would be an on-site use combining low temperature geothermal power generation and direct-use heating, similar to uses proposed for Granite Mountain Hot Springs. At both Granite Mountain and Division Hot Springs, the cost of the 40 mile power line alone could be $20 million.

Two other hot springs in the Purcell Mountains, Hawk and South, were not visited by the GAP research team because they are further away from NANA communities. The South and Hawk sites are about 37 and 49 air miles northwest of the Doyon community of Huslia, respectively, and about 50 air miles south of the Shungnak-Kobuk area. However, they could also provide direct-use heat for applications similar to those proposed for Division and Granite Mountain. The numbers for each spring below are from a 1978 map and table by J.S. Gassaway and B.S. Abramson (USGS Open-File Report 77-168). To the knowledge of the GAP research team, no more recent measurements have been taken at these two sites. South Hot Springs looks more favorable for development compared to Hawk Hot Springs, as it is closer to Huslia, and has a higher reported temperature and flow rate. Higher surface flow rates are the best early stage exploration indication of how much fluid a geothermal system might produce as it is known that the geothermal system can sustain at least the visible flow. Higher flow rates can in most instances be pumped from geothermal systems but without drilling and testing there is no way to predict how much fluid might be sustainable produced.

Hawk Hot Springs-

Water temperature: 43˚C (109˚F)
Estimated spring outflow: 400 lpm (100 gpm)

South Hot Springs-

Water temperature: 67˚C (153˚F)
Estimated spring outflow: 1350 lpm (360 gpm)

End Uses for Geothermal Energy at Granite Mountain and Division Hot Springs

Both the Granite Mountain and Division geothermal sites have been used by the people of the region as a cultural and subsistence resource for centuries. The sites have more recently been utilized for recreational and other uses. Therefore, the cultural value of the hot springs to the people of the region should be a major consideration for further investigation and development. Any future geothermal development for these two sites needs to involve not only NANA region stakeholders but also people who live in communities to the south: Koyuk in the Bering Straits region and Huslia in the Doyon region. In particular, the Division hot springs are co-managed by the Huslia and Upper-Kobuk Elders Councils in cooperation with the USFWS. Further study of the Division hot springs will require the input of these three organizations.

Enhancement of Recreational Uses:

Recreation and subsistence are the main reasons that people visit Granite Mountain and Division geothermal areas, with most of the visitors traveling to the remote hot springs by snowmachine from communities in the region. At Granite Mountain Hot Springs and Lower Division Hot Springs, existing cabins provide shelter for visitors. These structures could be improved or expanded, if there was enough demand from recreational users, or new shelter buildings could be built. A small lodge, cabin or a simple covered shelter with hot tubs and geothermal hydronic space heating could be built at the remote hot springs sites, using the latest energy-efficient construction techniques. If a small amount of electricity is used by such a lodge or cabin, it may be possible that a low temperature geothermal power system could be developed on site, but micro-scale solar PV and wind options would likely be less expensive and simpler to install and operate for such a small-scale use. Such a development, 100% heated and powered by renewable energy, could fall under the loosely-defined term of “ecotourism.”

Greenhouses:

Greenhouse projects are being proposed across rural Alaska as a way of providing fresh, locally grown produce to isolated communities. Most fruit and vegetables consumed in rural Alaska are imported via barge or airplane, originating from farms thousands of miles away. These long supply chains translate to very high food costs, lower-quality produce, and unnecessary fuel consumption and pollution from transporting the food. The greenhouse agriculture projects could also provide economic development and job opportunities for local communities.

A properly designed and insulated greenhouse can utilize lower temperature fluid than an electric power generation plant. Therefore, greenhouses could be operated at far more hot spring sites than electric power generation schemes. Division Hot Springs in particular appears to have sufficient hot water to provide heating for a year-round greenhouse due to its higher temperature. Upper Division’s natural outflow of 19 liters per minute (5 gallons per minute) at 71°C (160°F) may be enough without any drilling to provide sufficient heating for such a project. However, direct-use heating for greenhouses could also be practical at Granite Mountain Hot Springs, with a 48˚C (119˚F) and a spring outflow estimated at 190 liters per minute (50 gallons per minute).

A feasibility study is needed to better quantify some the economic and technical challenges and opportunities of greenhouses at these remote hot spring sites, and to determine if the springs could support a commercial greenhouse operation. At Upper Division Hot Springs, and perhaps Granite Mountain as well, a small-scale greenhouse could be set up as a pilot project. Such a pilot project would consist of a greenhouse kit shipped to site and installed with re-circulating hot water pipes warmed by the spring, feeding radiators inside the greenhouse or hot water pipes in the floor. A 30' long 'hoop-style' greenhouse, similar to a Quonset hut, can be built with a PVC pipe frame and plastic sheeting, costing several hundred dollars or less in materials. Such a simple greenhouse may not be able to handle winter snows or high winds, but could be used to prove the geothermal heating concept between March and October. If there is little or no artificial lighting associated with the greenhouse pilot project, then a solar PV array or small wind turbine (site conditions permitting) would provide all the needed electricity to run the circulation pumps and other equipment during the growing season. The first pilot greenhouse at either site would likely not be operated during the November-February period. Agricultural development around geothermal resources is not new to Alaska, and in fact extensive beneficial use of resources throughout the state was made during the early and middle half of the last century, including Pilgrim Hot Springs (see below) and Manley Hot Springs. The only year-round agricultural operation in Alaska today is a small greenhouse operation located at Chena Hot Springs, where the geothermal resource is utilized both for heating and generating power.

One or more people would have to be hired as caretakers/greenhouse workers who would live out at the remote hot springs sites during the extended growing season. This would in effect create a continually-staffed agricultural camp from March to October. Food grown would be transported the 40 or more miles to local communities via snowmachine or aircraft, as ATVs are not feasible in this terrain.

If a small-scale greenhouse located at either hot spring site proves successful, more greenhouses could be developed. Depending on the amount of new development deemed environmentally and economically viable, a year-round small community could be established if enough jobs were created by the greenhouse operations and other activities related to the hot springs. As energy prices rise, the region's hot springs should be kept in mind as a future development scenario as people may want to move to a new community developed around a hot spring area. Three notable Alaska example projects similar to the proposed Division or Granite Mountain geothermal greenhouses are given below.

Pilgrim Hot Springs-

Pilgrim Hot Springs, located about 60 road miles north of Nome, has a recorded surface water temperature of about 60°C (140°F), cooler than Division but warmer than Granite Mountain.
Pilgrim Hot Springs was the site of a boarding school-orphanage operated by the Catholic Church between 1917 and 1941. During this period, agricultural crops and livestock were grown in the grounds surrounding the hot springs, taking advantage of the natural heat in the ground for permafrost-free growing. About 2 square miles of permanently-thawed ground exists around Pilgrim Hot Springs. According to church records, enough food was grown on site to make the boarding school-orphanage mission mostly self-supporting. Much later, during the period between 1975 and the late 1990s, a private leaseholder who operated the site cleared 10 acres to plant oats, barley, potatoes and other vegetables. Most of the crops were grown between 1975 and 1982, although gardening at the site continued until around the year 2000. Most recently, the site has changed ownership and has been acquired by a consortium of local tribal organizations operating under Unaatuq, LLC. ACEP has received a grant from the Department of Energy to test an innovative exploration technique at the site, which will result in a new drilling program and should determine whether the site could be developed to provide

electricity for Nome, as well as direct-use heat applications on site. Past exploration efforts dating to the late 1970s and early 1980s concluded the resource could be large enough, but the actual upflow zone of the geothermal fluid was never pinpointed and coupled with limitations in low temperature geothermal power generation equipment available during that era, further investigation of the resource stalled.

Chena Hot Springs-

The geothermal greenhouses at Chena Hot Springs Resort near Fairbanks utilize a geothermal heat source of up to 80°C (176°F), or about 9°C (16°F) warmer than the temperatures measured at Division Hot Springs, and 32°C (57°F) warmer than Granite Mountain Hot Springs. The two main Chena greenhouses have a combined floor area of 4320 ft^2, and are operated by the resort in collaboration with the UAF Agriculture and Forestry Experiment Station, as part of a controlled environment research project. Lettuce tomatoes, green beans, peppers, cucumbers, and numerous greens and herbs have been grown in these greenhouses. The lessons learned from this research at Chena will be valuable for new geothermal greenhouse projects in Alaska such as those possible at Division and Granite Mountain.

Galena recovered heat greenhouse project-

This Tanana Chiefs Conference, in partnership with ACEP, received Environmental Protection Agency (EPA) funding to construct and operate a 100’ x 30’ greenhouse using recovered heat from Galena’s diesel power plant. The goal is to extend the growing season by a few months in both the spring and the fall, growing fresh produce for the community and its schools, while employing several local high school students. The greenhouse project would be supervised by faculty from UAF’s Controlled Environment Agriculture Laboratory and the UAF School of Natural Resources and Agricultural Sciences. The City of Galena, and other local organizations are also participating in the project. In addition to the Galena greenhouse, this project will involve feasibility studies on six other rural Alaska communities in different regions of the state to evaluate their potential for similar greenhouse projects. The experience of diesel-engine heat recovery from these pilot greenhouse projects will prove valuable for diesel-dependent communities in the NANA region and elsewhere, but also for projects at remote hot springs sites.

Conclusions and Recommendations

NANA Regional Corporation should partner with other stakeholders in the region to apply for grants from the Alaska Renewable Energy Fund, USDA Rural Development and other funding sources for testing geothermal greenhouses and ecotourism at Division and Granite Mountain hot spring sites. The pilot geothermal greenhouse project(s) could be combined with continued geophysical/geological field study activities to further assess each resource for both on-site direct heat and power applications.

Even with small direct-heat applications such as ecotourism lodges or greenhouses, studies are needed on the potential environmental impacts of localized geothermal energy development at Granite Mountain and Division hot springs. Also important are studies of the cultural and archeological resources at or near each site that could be impacted by any future geothermal development.

NANA should consider and discuss co-development of geothermal resources with regional stakeholders such as communities, tribes, governments and Native corporations both inside and outside the NANA region.

For the most part, Granite Mountain Hot Springs is shared by users from Buckland to the north, and Koyuk to the south. Division Hot Springs is shared chiefly by residents of the Shungnak-Kobuk area with Huslia to the south. Thus, collaboration with these communities is essential for any successful geothermal energy development at these sites. NANA should also work with neighboring regional corporations of Bering Straits and Doyon on developing geothermal resources of the Granite Mountain and Division sites, respectively.

Appendices: Reports and Publications

Appendix A:

NANA Geothermal Assessment Project (GAP) Results in Phase 1: Site Identification: Amanda Kolker and Brian Yanity, NANA Pacific. January 2009. (within this report are an appendix for a preliminary financial analysis of Granite Mountain hot springs electric power, and the paper explaining the alleged geothermal fluids in reported in Kotzebue)

Appendix B:

Reconnaissance Study of the Granite Mountain Geothermal Area, prepared for NANA by Alaska Center for Energy and Power, University of Alaska Fairbanks: Dick Benoit, Peter Illig, and Gwen Holdmann, November 2009.

Appendix C:

Reconnaissance Study of the Division Hot Springs Geothermal Area, prepared for NANA by Alaska Center for Energy and Power, University of Alaska Fairbanks: Dick Benoit, Peter Illig, and Gwen Holdmann, with Steve Buckley of WHPacific, May 2010.

Appendix A:

NANA Geothermal Assessment Project (GAP) Results in Phase 1: Site Identification: Amanda Kolker and Brian Yanity, NANA Pacific. January 2009.

NANA Geothermal Assessment Project (GAP)
Results of Phase 1: Site Identification

Prepared by:
Amanda Kolker
January 19, 2009

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Identifying Unmapped Geothermal Prospects in NANA Region: Local Knowledge and Site Visits

Introduction: Geothermal Energy in Northwest Alaska

This preliminary report summarizes the geothermal energy potential of NANA lands based solely on available literature and data. It is intended to guide future geothermal studies of the region and should be considered preliminary in nature. The report was written by Amanda Kolker, with assistance from Brian Yanity of NANA Pacific.

Background: Low-Temperature Geothermal Energy Resources (<150 ºC)

Geothermal energy, which is earth-heat energy, exists in large amounts deep in earth's crust. It also exists at shallow levels in the crust at some locations: typically, though not always, in areas of active volcanism. Geothermal energy is used in many countries for power generation and/or non-electric applications such as heating. Geothermal heat is usually harnessed through hot water, or hydrothermal systems. In hydrothermal systems, deeply circulating groundwater brings heat to the surface or shallow subsurface. Hydrothermal systems are renewable because the two vital components (earth's heat + circulating groundwater) are constantly recharged. Theoretically, non-hydrothermal geothermal resources (such as geopressurized brine or hot dry rock) can also be exploited for energy, but in practice they are far less utilized than hydrothermal resources. Moreover, non-hydrothermal sources are non-renewable because recharge of heat and water do not occur at the same rate as production.

Low-temperature hydrothermal fluids (<150º C) must be run through a ***binary-cycle*** system to produce electrical power. In binary power systems, hydrothermal fluid and a secondary ("binary") fluid pass through a heat exchanger, vaporizing the binary fluid, which then drives a turbine. The temperature requirements for binary systems depend on site characteristics (available condensing temperature, volume of geothermal fluid, etc.). The binary system at Chena Hot Springs uses geothermal fluid at ~80° C.

Background: NANA Region Geothermal Resources

Hot springs in the NANA region are part of the Central Alaskan Hot Springs Belt (CAHSB). Chena Hot Springs is the only location in this belt of over 30 hot springs that has been exploited for power production. It is currently producing about 400 kW of power (www.yourownpower.com). The local geology of most CAHSB sites is poorly defined, and the heat source driving the geothermal activity has not been established. The geothermal potential of most of the CAHSB hot springs is unknown due to a lack of geologic information (Miller and others, 1975; Economides and others, 1982). Though the CAHSB spans numerous geologic provinces, the thermal springs in the CAHSB are remarkably similar. Nearly all of the hot springs occur in or near igneous intrusive rocks (also called "plutons" or "granites") and issue from fractured zones near the pluton margins (Miller and others, 1973), or from the intersection between plutons and faults or fault zones (Sainsbury and others, 1980; Kolker and others, 2007). This suggests that the reservoirs for CAHSB geothermal systems are not large. All CAHSB hot springs are low-temperature (<150° C). Most of the hot springs are non-volcanic (Miller, 1973); however the central Seward Peninsula contains several young lava flows, and may be an active rift zone with abnormally high crustal heat flow and the possible presence of shallow magma

(Turner and Swanson, 1981). Further exploration work is necessary in order to assess the geothermal resource capacity of most of the CAHSB hot springs.

Pilgrim Hot Springs, about 65 miles north of Nome, is the only prospect in Northwest Alaska to have been the subject of detailed geothermal exploration. The state-funded project was carried out between 1979 and 1982. The project included drilling six shallow wells (up to 304 m) and extensive geological and geophysical investigations. Results indicated a perched hot water reservoir at a depth of 15-37 m, underlain by a cold water aquifer. The thermal fluids, thought to ascend to the surface along any one of a number of steep faults, were estimated at 150° C and at depths of approx. 1.5 km. (Economides, 1982).

Known Hot Springs in the NANA Region

The Geothermal Resources of Alaska map identifies 7 hot springs in the NANA region (Fig. 1). None of them have been explored for geothermal potential beyond basic temperature and chemistry surveys. Unfortunately, all of the mapped hot springs are 40 miles or more from NANA region communities. This could mean that exploitation of these hot springs is uneconomic at this time, due to the high costs of transmission (see Dilley, 2007). It is possible that other geothermal sites exist in the NANA region, such as concealed hot springs or hot springs that were otherwise overlooked by this map. Data in the following tables comes from this map and/or from the USGS. Distances are approximate and will be modified based on discussion with NANA region residents.

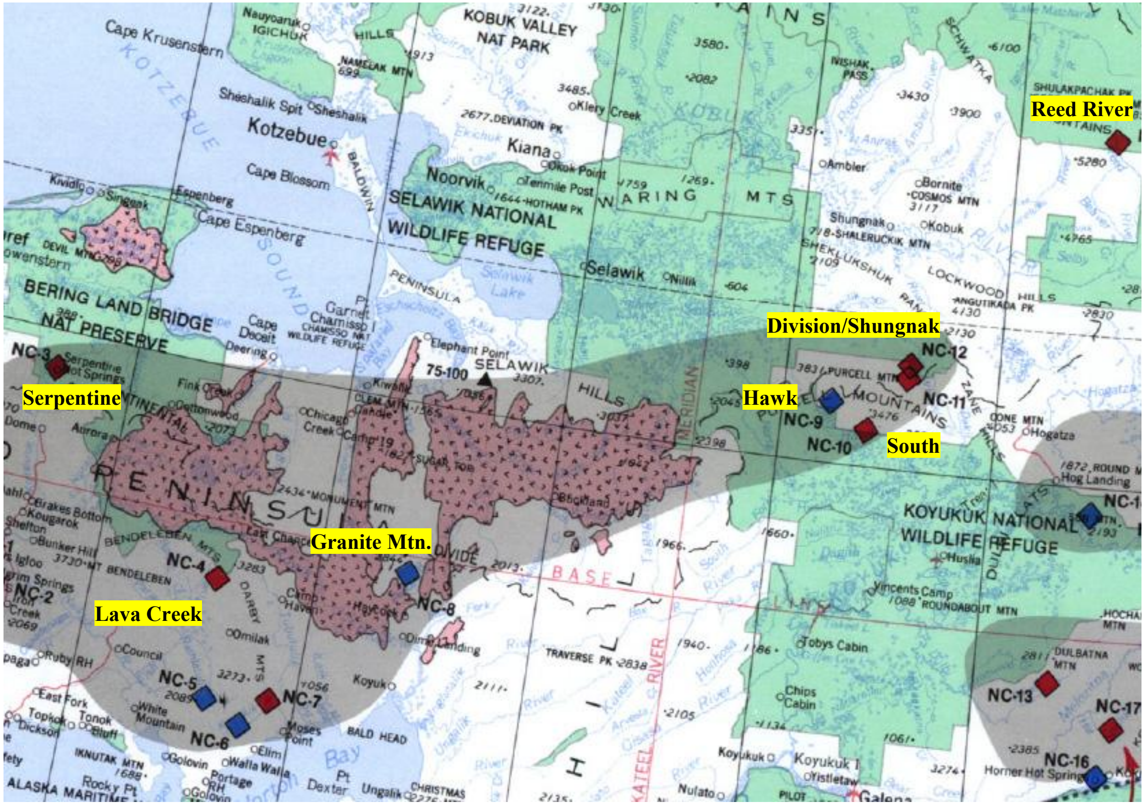

Figure 1. Hot springs in the NANA Region, as identified by the Geothermal Resources of Alaska Map (Motyka and others, 1983). Red diamonds = hot springs above 50°C; blue diamonds = hot springs below 50°C. Shaded areas indicate regions favorable for geothermal energy, but probably only small areas within the shaded region are viable for production.

Serpentine Hot Springs

Temp.	Flow (LPM)	TDS	SiO_2 geothermometer	Giggenbach geothermometer
75ºC / 167ºF	520	3290	137.10 ºC	119.0 ºC
60ºC / 140ºF	137 GPM	2472.7	130.8 ºC	111.4 ºC

Serpentine hot springs, located approximately 60 miles west of Deering in the Bering Land Bridge National Preserve, is the hottest of all the springs in the CAHSB. It is also anomalously saline relative to other CAHSB springs, containing elevated concentrations of total dissolved solids (TDS), mostly Cl, Na, Ca, K, Li , Br, and B (Miller, 1973). The hot springs issue out of the Serpentine Hot Springs granite, which is actually a composite body of several different granites emplaced at different times. The composite body is cut by several sets of steep faults. An intricate network of faults southeast of the granite is associated with major geochemical anomalies and mineralized areas lying along a NW-trending fault zone (Sainsbury and others, 1980). The Serpentine hot springs granite contains small amounts of radioactive material disseminated throughout; however not in large enough quantities to be commercially interesting (Moxham and West, 1953). Based on temperature data alone, these springs appear be suitable for Chena-type power generation, though the salinity of the fluids could be an issue in terms of scaling in wells and pipes.

Lava Creek Hot Springs

Temp.	Flow (LPM)	TDS	SiO_2 geothermometer	Giggenbach geothermometer
53ºC / 127ºF	360	330	118.2 ºC	96.6 ºC
50ºC / 122ºF	360	295.5	-	-

Lava Creek Hot Springs is located approximately 50 miles south of Deering and 70 miles southwest of Buckland. The hot springs are about 15 miles south of the Lost Jim lava flow and the Imuruk Lake volcanic field, some of the youngest lava flows in western Alaska. The Imuruk Lake volcanic field is a vast geologic feature consisting of flows and ~75 vents (cones) that covers nearly 2,300 km^2 of area. The largest and most recent cone is the Lost Jim vent, which erupted 1,655 years ago; but the bulk of the volcanic deposits are much older (5.7 to 2.2 million years old). This suggests that this part of the Seward Peninsula may still be a volcanically “active” region. The hot spring, however, issues from within granitic rocks of the Bendeleben Mountains, not the volcanic deposits. It is so named because the spring is located approximately 3 miles from the probable source area for the basalt that flowed down Lava Creek in the Bendeleben Mountains (Miller and others, 1973). The Imuruk Lake area lies in a poorly defined graben (Hopkins, 1959) with giant scarps as high as 30 m and as long as 5 km (Wood and Kienle, 1990). Several faults in the Bendeleben Mountains continue this trend, but it is not clear whether the Lava creek hot springs are situated on or near such faults. The hot springs are also about 10 miles northeast of the Death Valley / Boulder Creek uranium deposit, which follows a northwest-trending linear strike. If the geothermometer predictions are correct and hotter fluid exists at depth, then depending on the depth of the reservoir these springs could be suitable for Chena-type power generation. One concern is that the flow rate is somewhat low so substantial pumping may be required.

Granite Mountain Hot Springs

Temp.	Flow (LPM)	TDS	SiO_2 geothermometer	Giggenbach geothermometer
49ºC / 120ºF	1630	260	121.7 ºC	100.7 ºC
			117.5 ºC	95.7 ºC

Granite Mountain hot springs is located approximately 40 miles south of Buckland and 60 miles southeast of Deering. The springs issue from the contact between the anomalously radioactive Granite Mountain pluton and the Cretaceous age volcanic rocks. The Granite Mountain pluton is uranium-enriched, however not enough to be commercial (Gault and others, 1951). The springs are located on Spring Creek, a tributary of Sweepstakes Creek. The temperature of these hot springs is significantly below the temperature of the fluids utilized for power generation at Chena Hot Springs (~80º C) However, if the geothermometer predictions are correct and there is hotter fluid at depth, these springs could be suitable for development. The flow rate is fairly high relative to other CAHSB hot springs, meaning that less pumping may be required for production.

Hawk Hot Springs

Temp.	Flow (LPM)	TDS	SiO_2 geothermometer	Giggenbach geothermometer
43ºC / 109ºF	400	-	-	-

Hawk hot springs is located approximately 50 miles south of the Kobuk-Shungnak area, 60 miles south of Ambler, and 80 miles east of Buckland in the Purcell Mountains. The springs are located on the Hawk River, near the faulted contact of a Cretaceous pluton and older volcanic rocks (Gassaway and Abramson, 1978). The pluton, called the "Wheeler creek pluton" contains anomalous uranium concentrations (Miller and Johnson, 1978) and is highly fractured and faulted. The temperature of these hot springs is significantly below the temperature of the fluids utilized for power generation at Chena Hot Springs (~80º C), and there are no geothermometer predictions of hotter fluid at depth. Moreover, the flow rate is fairly low relative to other CAHSB hot springs, meaning that significant pumping may be required for production. Hence, based on resource factors alone, these springs should not be top priority for development.

South Hot Springs

Temp.	Flow (LPM)	TDS	SiO_2 geothermometer	Giggenbach geothermometer
67ºC / 153ºF	1350		114.5	92.2

South hot springs is located approximately 50 miles south of the Kobuk-Shungnak area. Like Hawk and Division hot springs, the South hot springs issue from the Wheeler Creek pluton (see description of Wheeler Creek pluton above). They are located very near to the contact between the pluton and older volcanic rocks. No fault has been identified in the area, but the springs are situated on a prominent lineament in the landscape (Gassaway and Abramson, 1978). The temperature of these hot springs is significantly below the temperature of the fluids utilized for power generation at Chena Hot Springs (~80º C). However, if the geothermometer predictions are correct and there is hotter fluid at depth, these springs would be suitable for development. The flow rate is fairly high relative to other CAHSB hot springs, meaning that less pumping may be required for production.

Division Hot Springs (also called Shungnak or Selawik HS)

Temp.	**Flow (LPM)**	**TDS**	**SiO_2 geothermometer**	**Giggenbach geothermometer**
68ºC / 154ºF	820	-	-	-
56ºC / 133ºF	2070	-	-	-

Several hot springs comprise the Division hot springs, which also have been referred to as the Shungnak hot springs and/or Selawik hot springs. They are approximately 40 miles from the Kobuk-Shungnak area and approximately 60 miles from Ambler. They are located on the north side of the Purcell Mountains, inside the Selawik National Wildlife Refuge. The lower springs are slightly cooler than the upper springs, so the thermal water upwelling location is probably topographically high. Like Hawk and South hot springs, the Division hot springs issue from within the Cretaceous-age, anomalously radioactive Wheeler Creek pluton (Miller and Johnson, 1978; see description of Wheeler Creek pluton above). Division hot springs are some of the hottest springs in the NANA region, but they are still significantly below the necessary temperature of ~80º C for Chena-type power generation. At this time, there are no geothermometer predictions of hotter fluid at depth – but this is due to a lack of data. The flow rate of the upper spring is extremely high relative to other CAHSB hot springs, which would reduce the amount of pumping required for production. Hence, based on resource factors alone, these springs should be prospective for development; however their location inside of a National Wildlife Refuge could complicate development plans.

Reed River Hot Springs

Temp.	**Flow (LPM)**	**TDS**	**SiO_2 geothermometer**	**Giggenbach geothermometer**
57ºC / 137ºF	160	-	-	-

The Reed River hot springs are located in the rugged terrain of the Brooks Range, approximately 50 miles from Kobuk/Shungnak and 70 miles from Ambler, on the east bank of the Reed River. The surrounding bedrock is granite of the Igikpak pluton, but the spring is just a few miles from the contact between the pluton and the country rock (Pessel, 1975). The hot springs are located in the Gates of the Arctic National Park, and are therefore off-limits for exploration and development for the foreseeable future. Resource-wise, they are some of the coolest hot springs in the NANA region and have the lowest flow rate all of the springs. Hence, these springs should be low priority for development.

Identifying Unmapped Geothermal Prospects in NANA Region: Geologic Setting

It is not unreasonable to think there are concealed hydrothermal resources in the NANA region due to recent volcanics, tectonic setting, and the presence of permafrost which would both serve as a sustained, abundant water source but would also potentially mask geothermal resources at the surface. The southernmost half of the NANA region is more prospective than the northern half for geothermal resources. This is because the southern half is closer to known hot springs, and also because it is geologically more favorable for the development of hydrothermal systems. Most of this region is covered by geologic maps at relatively coarse scales (1:250,000 or greater), so detailed information is limited with the exception of a few areas of geologic significance. The southern NANA region encompasses three distinct geological provinces: the Seward Peninsula, the Yukon-Koyukuk uplands, and the Selawik & Kotzebue Basins (Fig. 2). Identifying geologic provinces is crucial because heat flow trends tend to be constant over geologic provinces (Blackwell, 1971).

Figure 2. Rough outline of geologic provinces in southern NANA lands. Map from NANA website (http://www.nana.com/the%20land/regional_map.htm)

Since almost all of the hot springs in the NANA region occur in or near plutonic rocks, it appears that the intersection of granitic plutons and faults is an environment conducive to the formation of hydrothermal systems. Many of the hot springs occur on or near mapped faults (Fig. 3), at pluton margins; or if it is a composite pluton, at the contact between different plutonic phases (see Sainsbury and others, 1980; and Kolker and others, 2007). Moreover, many of these plutons contain anomalous concentrations of the radioactive elements uranium and thorium, which is also true for other CAHSB-related plutons. A large part of western Alaska has been is considered a uranium-thorium metallogenic province chiefly because of the occurrence of uraniferous plutonic rocks with local concentrations of uranium minerals (Miller, 1976). It should be noted that granite bodies without well-developed fractures (such as the Selawik Hills pluton) do not appear to host hot springs, probably due to a low fracture permeability (Miller, 1973). Hence, it appears that the host granite must be well-fractured – that is, have sufficient permeability – to allow deep circulation of meteoric water (local snowmelt and rainwater).

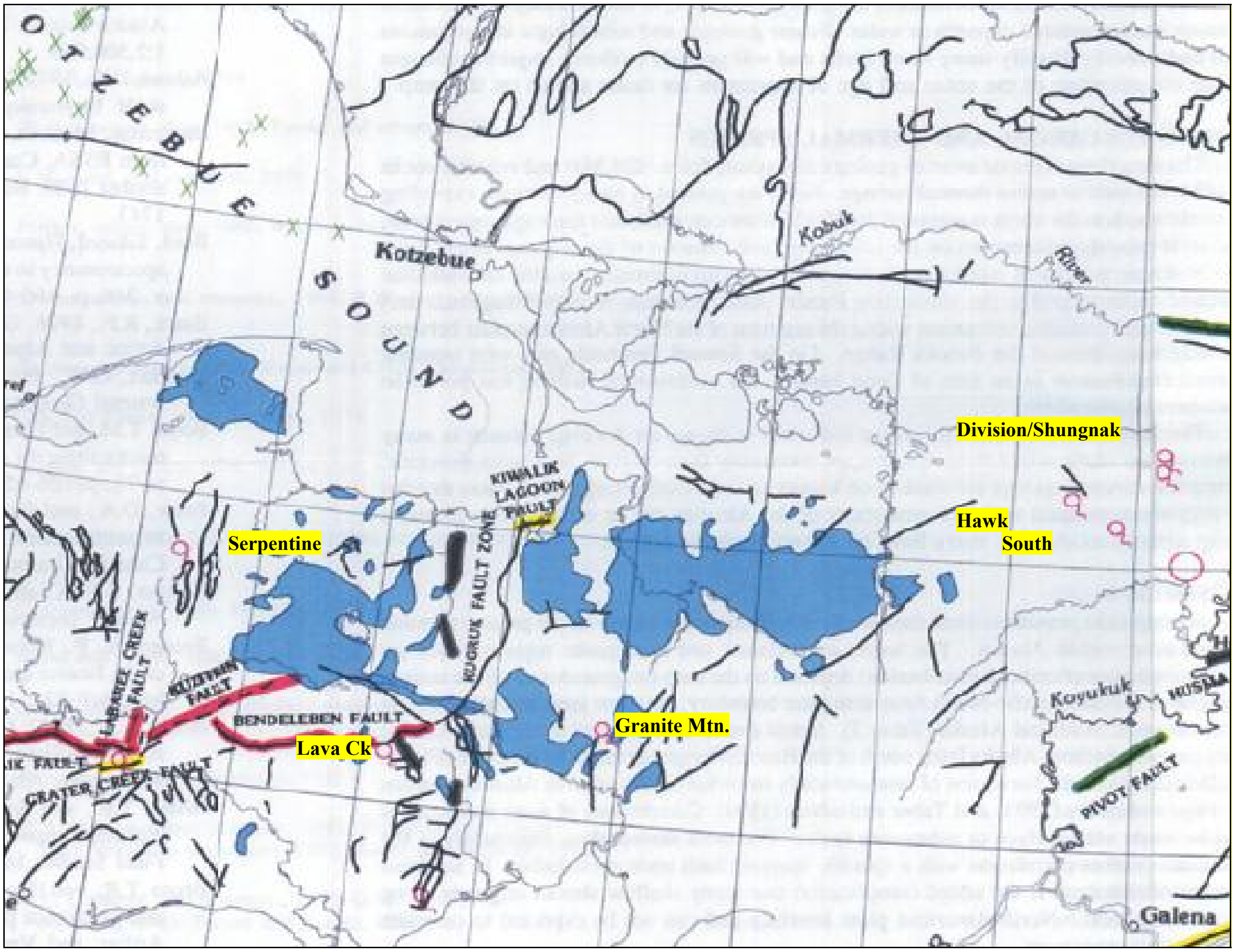

Figure 3. Neotectonic map of the NANA region, showing active faults and geologic structures. Taken from the Neotectonic map of Alaska by Plafker and others, 1994. Dark blue = basaltic rocks. Black lines = faults or lineaments; red lines = faults active in Holocene times; yellow lines = faults active in Pleistocene times, green lines = faults active in undifferentiated Quaternary times. Large red circles = earthquake epicenter; small red circles with tails = hot springs.

Surface heat flow tends to be constant over large regions, which are classified as heat flow provinces, though there can be local variations caused by radioactive heat sources in upper crust from uranium, thorium, and potassium in rocks (Blackwell, 1971). Regional trends in crustal heat flow are usually calculated from well data that is supplemented by geologic information. Well data includes geothermal gradient measurements from deep (>1000 feet) wells, such as dry oil & gas exploration wells.

A heat flow map was produced for Alaska in 2004 based on mantle heat flow estimates (see http://www.smu.edu/geothermal/heatflow/Alaska_hf.gif), but the map is too coarse in scale to be useful for this study. Heat flow data is presently being compiled by the Alaska Division of Geologic and Geophysical Surveys for a large number of wells across the North Slope. This data is sparse for the NANA region, as there are only two deep wells with available data. Both of these wells were drilled in the Kotzebue Basin and were evaluated in the 1981 study of the Kotzebue district heating system (ESI, 1981). These are: 1) The 8,373-foot deep Cape Espenberg well; and 2) The 6,311-foot deep

Nimiuk Point well. The geothermal gradient calculated for the Cape Espenburg well was more or less normal (approximately 30°C / 100 m), but the gradient calculated for the Nimiuk Point well was slightly above average (40-45°C / 100 m). Unfortunately, two data points are not sufficient to define any sort of regional trends. One of the aims of the site visits was to obtain logs for any additional wells in the NANA region, but none were obtained. Several other shallow wells on the Seward Peninsula, drilled at the turn of the century were identified by the Alaska Oil and Gas Conservation Commission; unfortunately there are no logs associated with those wells. These wells are called the Hastings Creek wells, drilled in 1906 by "Caen, S." and 1918 by an "unknown operator."

Deering-Buckland Region

Deering and Buckland are located on the northern part of the Seward Peninsula. The Seward Peninsula geologic province is characterized predominantly by metamorphic rocks of Paleozoic age that are locally intruded by several plutons of Cretaceous and Tertiary age. Quaternary volcanic rocks (basalt) cover large parts of the north-central part of the Peninsula, such as the Imuruk Lake volcanic field (Fig. 4). Parts of the Peninsula may be undergoing incipient crustal rifting (Turner and Swanson, 1981), which suggests that magma could be present at relatively shallow depths beneath the Peninsula. Such an explanation could account for the hot springs on the Seward Peninsula; however all the springs are clustered around granitic intrusions, not volcanic rocks. Hence, like the rest of the CAHSB hot springs, the heat source remains ambiguous. This geologic province could very likely be a high heat flow province, but there is insufficient data at this time to know for certain. Hot springs in this province include Lava Creek, Serpentine, Granite Mountain and several others outside of the NANA region.

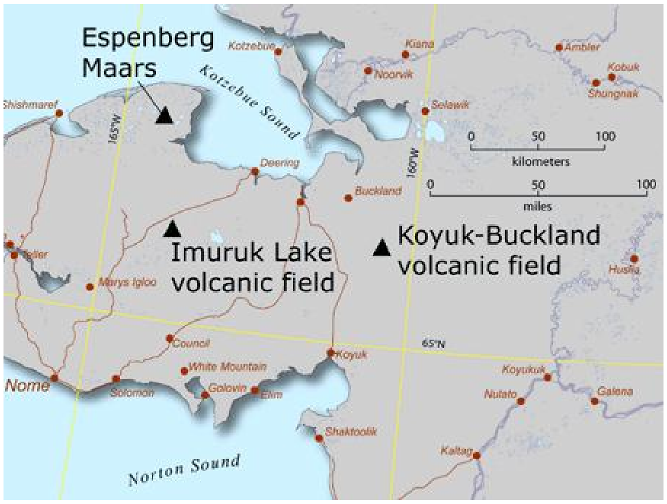

Figure 4. Volcanic fields in NW Alaska. Source: Alaska Volcano Observatory

Ambler-Shungnak-Kobuk Region

The Yukon-Koyukuk province is a large tract of volcanic and volcanic-sedimentary rocks intruded by an east-west belt of Tertiary and Cretaceous granitic rocks. All of the hot springs are associated with the granitic intrusions. Quaternary basalt covers several hundred square miles in the western part of the province, also called the Koyuk-

Buckland volcanic field (Fig. 4). The volcanic field contains large maars and 5 small shield-shaped volcanoes. The age of the basalts is unknown, but they are thought to be correlative with the Imuruk basalt field 100 km to the west (Wood and Kienle, 1990). The western part of the Yukon-Koyukuk province could be a high heat flow province, but more information is necessary to know for certain. Hot Springs in this province include Division/Shugnak, Hawk, South, and several other hot springs outside of the NANA region.

Kotzebue-Selawik Region

The Selawik and Kotzebue Basins are geologically distinct from the Seward Peninsula and the Yukon-Koyukuk provinces. Because it is a sedimentary and tectonic basin, this geologic province is probably a low or moderate heat flow province. Again, more information is necessary to know this for certain. There are no hot springs associated with this geologic province. Like the Hope basin to the west, these basins are large downdropped sections of the crust that have filled in with thousands of feet of sediments. The Selawik Basin should be considered the onshore extension of the Hope and Kotzebue Basins. The two deep wells that have been drilled into this province (at Cape Espenburg and at Nimiuk Point, 17 miles south of Kotzebue) confirm the sedimentary basin nature of this province: the wells encountered 4700 and 5000 feet of sedimentary rock, respectively. Most geothermal areas in the CAHSB occur in settings with relatively shallow bedrock; the deepest known basin is at Pilgrim hot springs, where the depth to bedrock (determined by seismic reflection) is approximately 400 ft (Wescott and Turner, 1981). The bedrock at ~5000 feet is small beds of volcanic rocks, probably contiguous with the volcanic rocks that outcrop on the Seward Peninsula.

There are several maars on the northwest Seward Peninsula. The Espenburg Maars is one of the larges maars on earth. They were formed by a series of Pleistocene basaltic eruptions through thick permafrost (Hopkins and others, 1996). Though these maars are located on the Seward Peninsula, geologically they appear to be part of the Selawik-Kotzebue Basin province. Hence, the Selawik-Kotzebue Basin province may be volcanically active as well.

A geothermal district heating system in Kotzebue was studied in the 1980s. That study explained that the proposed geothermal project "does not involve geothermal systems and geothermal wells as they are normally considered in geothermal exploration. That is… fault and fracture systems, influx of meteoric waters into the system, and resultant hot waters … are not involved. Rather, this geothermal system must rely on large volumes of warm water that can be produced from a sedimentary basin where the original formation waters are trapped" (ESI, 1981b).

Identifying Unmapped Geothermal Prospects in NANA Region: Local Knowledge and Site Visits

During the period February 27 – March 7 2008, visits were made by Amanda Kolker to the communities of Kotzebue, Deering and Buckland. The purpose of these visits was threefold: 1) To educate residents and stakeholders about the NANAGAP and to share preliminary results from the literature search; 2) to obtain local knowledge about geothermal activity in prospect regions; 3) to potentially visit previously unmapped geothermal sites, should any be identified.

At each of the three communities, public presentations were given describing the NANAGAP project to outline the project objectives and clarifying what sort of information is needed from the community. As part of the community meetings, residents were be queried as to their feelings about geothermal development at hot springs sites (Fig. 5). All those questioned were supportive of the NANAGAP project, many noted that they were interested in wind and/or hydroelectric power as well.

Figure 5. A. Kolker presents NANAGAP to Buckland residents at Buckland City Offices.

In addition to the presentations, interviews were conducted with as many area residents as possible to collect information relevant to geothermal investigations. Questions included, but were not limited to, the following:

1. **Please describe any hot springs or warm ground sites close to your community. Please include the name of the site (if any), distance from town, and any other relevant information. What are the hot springs used for, and what sort of facilities are out there?**

2. **Has any geothermal, geological, geochemical, or other exploration occurred in or near your community in recent years? If so, what was done, and by which organizations?**

3. **Are there any water wells in your community? If so, please describe the well(s) and provide contact information for the owners if possible.**

Kotzebue

There is an oral tradition that claims that hot fluid was once encountered at approximately 300 ft. depth beneath the city of Kotzebue. One single resident, Frank Stien, KEA board member, remembers the well and provided much of the following information. The water was reportedly found during foundation work for a hospital being built in the 1950s. This hospital is not the one used by the community at present. It was the second hospital in Kotzebue's history, and was located by the present-day Ferguson building. The well was drilled sometime between 1954 and 1958 by the Alaska Native Service (within the Department of Agriculture – now Public Health Service). The water was very brackish. The hole was sealed. Gerald Huttrer of the Geothermal Management company investigated this well in 2002 as part of a regional assessment, but no well logs or data were ever discovered to verify these claims (Huttrer, 2002).

In 2008, Gwen Holdmann and Kenji Yoshikawa of the UAF-based Alaska Center for Energy and Power reviewed the evidence for the claim that a geothermal energy resource, in the form of hot water or steam, was encountered beneath the city of Kotzebue during the exploration drilling for a water source. Attached in Appendix C is a brief paper by Ms. Holdmann and Dr. Yoshikawa that provides an alternative explanation, concluding that geothermal fluids were not observed. However, the unlikelihood that geothermal fluids exist at shallow depths (300 ft., as the rumor claims) directly below Kotzebue does not necessarily rule out the possibility of geothermal resources at other locations near Kotzebue, or much deeper underground.

Residents were also interviewed regarding potential geothermal areas not identified on the 1983 map. However, residents confirmed that the only known hot springs are the ones on the map: Serpentine, Division/Shungnak, and Granite Mountain. However, several other warm and/or cold springs that do not freeze in winter were identified:

1. ***Fish hatchery site*** (on Noatak River). Springs issue from north side of Igichuk Hills; probably groundwater upflow/overflow site. The distance from Noatak is about 30 miles; the distance from Kotzebue is about 30 miles (across bay).
2. ***Squirrel River site(s)***. Several warm springs or "seeps" coming from mountains. May or may not be associated with a U anomaly. The distance from Kotzebue is about 40 to 50 miles (across bay); distance from Noatak and Kiana: at least 40 miles each. Sites are:
   i. Junction between North Fork of the Squirrel River and Nookati Creek
   ii. North and south of Kiana hills
   iii. One creek over from Shiliak Creek
3. ***Selawik Lake site***. A linear zone on the lake that doesn't freeze is reported, possibly associated with natural gas.
4. ***Singaruk River site***. Cold springs that never freeze exist on the trail between Noorvik and Selawik. The distance from Kotzebue is about 75 miles (across sound), while the distances from Noorvik, Selawik and Kiana are about 15 miles each. Probably groundwater upflow/overflow site.

Site #4, the Singaruk river site, was visited by the author on February 29, 2008 by snow machine. The spring was cold (32 °F) but there were several open spots, one of which did not appear to have rapid flow. Water samples were collected from that location and sent to the Desert Research Institute laboratory in Reno, Nevada for chemical analyses. The other sites were not visited either because they are too far from population centers or because they were judged to be groundwater upflow features unrelated to geothermal activity.

Additionally, interviews were conducted in Kotzebue to obtain logs and/or data for any private water wells in the area. Several wells were identified but unfortunately no logs are available for those wells. Appendix A lists all wells identified. Almost all reported wells contained briney or brackish water. This should not be surprising considering that Kotzezbue is only several feet above sea level. One well, owned by Ms. Ada Ward, reportedly has constant fresh water that is pumped continuously into a sewer line in the backyard.

Deering

Several interviews with Deering residents confirmed that the closest hot springs to town are Serpentine and Granite Mountain. Before visiting Deering, this author had heard mention of an area called Inmachuk hot springs. However, Deering residents confirmed that the springs at the headwaters of the Imnachuk River are cold springs. They occasionally do not freeze during warm winters, presumably because they are related to pressurized groundwater upflow. The headwaters are ~30 miles from Deering. People usually go in fall or summer, as it is a good hunting spot.

Buckland

Several interviews with Buckland residents confirmed that the closest hot springs to town are Granite Mountain. However, several other warm and/or cold springs that do not freeze in winter were identified:

1. ***Creek site*** about 15 miles east of town. Springs do not freeze and a number of groundwater upflow features are present such as pingos.
2. Water coming out of hole at a ***gravel pit***, near river, 3 miles from town.
3. Cold spring at ***Bear Creek***, on the way to Granite Mountain hot springs

On March 6, 2008, an excursion was made to site #1, unfortunately due to several factors (guide unable to come at last minute; massive snowdrifts; limited timeframe) we were not able to find reported site. Bottles for sample collecting were given to Tim Gavin, a Buckland resident, who has agreed to collect water from the site in early summer in exchange for fuel compensation.

Prioritizing Geothermal Prospects in the NANA region

Through local knowledge, site visits, and consideration of broad-scale geological parameters, we had hoped to identify new and/or concealed ("unmapped") geothermal prospects closer to population centers in the NANA region. However, local knowledge and site visits did not reveal any such prospects. Geological considerations narrowed down the favorable areas the Seward Peninsula, the Yukon-Koyukuk uplands, while concluding that the Selawik & Kotzebue Basins and all areas in the northern part of the NANA region were not prospective. Hence, future geothermal work should focus on the known geothermal resources (hot springs) in the NANA region.

Granite Mountain appears to be one of the best candidates for geothermal exploration, based on a combination of resource and demographic factors. Like other Interior and Western Alaska hot springs, thermal fluids at Granite Mountain probably mix substantially with cold fluids upon ascent, making them relatively cold in the near-surface. The hot springs issue from the south side of the mountain, on its flank, high above the water table. It is possible that geothermal fluids exist not just to the south of the mountain but in fractured granitic rocks in the subsurface beneath the entire mountain and/or to the north/northeast within rocks of adjoining granitic plutons (in red, Fig. 6).

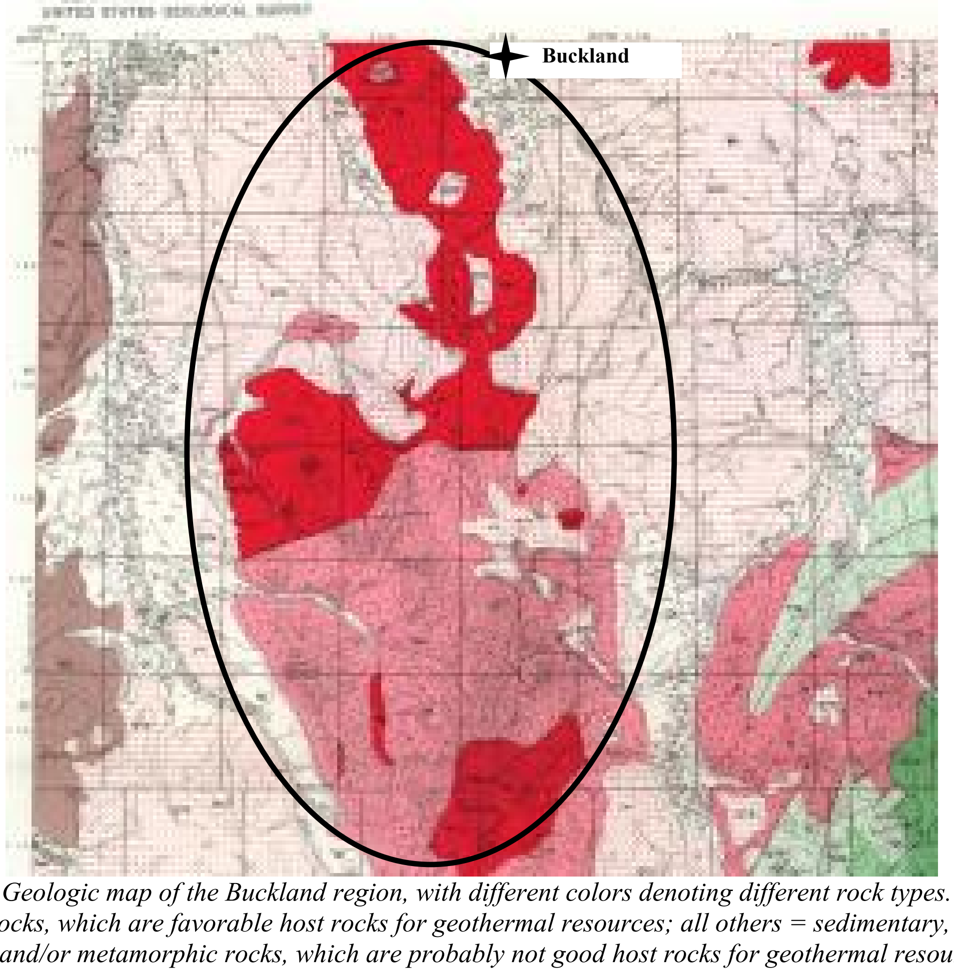

Figure 6. Geologic map of the Buckland region, with different colors denoting different rock types. Red = granitic rocks, which are favorable host rocks for geothermal resources; all others = sedimentary, volcanic, and/or metamorphic rocks, which are probably not good host rocks for geothermal resources. Since granitic rocks extend northwards toward the village of Buckland, there is a strong possibility that geothermal resources could extend northward as well. Geothermal exploration should focus on the circled area.

Should thermal fluids be accessible by drilling in the granitic rocks to the north of Granite Mountain, this could bring the exploitable geothermal resource significantly closer to the village of Buckland. A preliminary economic analysis for a geothermal power plant serving Buckland concluded that the resource must be less than 10 miles from the village to be economic (see Appendix A). Finally, the flow rate of the Granite Mountain hot springs is relatively high, which implies that less pumping would be required for production.

Several demographic considerations also make Granite Mountain an attractive prospect. First, the site is accessed by a well-used trail from Buckland. Second, its proximity to other villages such as Koyuk open up the possibility of a shared project. The combined energy needs of both Buckland and Koyuk would require a plant with approximately 620 kW of capacity– this could more than likely be met with the existing resource.

Division hot springs are another good candidate for development based on resource and demographic factors. The site is comprised of several springs, which are some of the hottest springs in the NANA region. They also flow at an extremely high rate relative to other springs in the region. The springs are located approximately 40 miles from Shungnak, which is connected to the village of Kobuk by an already existing intertie. The combined energy needs of both Shungnak and Kobuk require a plant with approximately 485 kW of capacity – this could more than likely be met with the existing resource. Moreover, proposed mining operations to the north of Shungnak and Kobuk could greatly increase electric power demand in the area. However, the 40-mile length of transmission line between Division hot springs and the Shungnak-Kobuk area could likely make geothermal power uneconomic for the two communities. Unlike Granite Mountain hot springs near Buckland, the geological evidence does not suggest a possible subsurface geothermal resource closer to the nearest village.

Given the uncertainty of a geothermal resource existing in the Kotzebue area, it is recommended that further geothermal exploration efforts for Kotzebue be coordinated with oil and gas exploration activities being conducted in that area. Exploration projects for natural gas in the Chukchi Sea and other parts of the NANA region have recently been proposed, and some geophysical data collected for this purpose could also be used to assess geothermal resource potential. The high costs of exploration drilling would make it difficult for Kotzebue stakeholders to raise enough funds to hire a drilling rig dedicated to geothermal exploration, but co-mobilization with a hydrocarbon exploration program could make it more feasible. Should drilling occur in the Kotzebue area, boreholes should take pains to avoid permafrost areas and/or be deep enough to get past permafrost. They should probably penetrate 2000 ft. or deeper and should follow guidelines outlined in a consultant's report (Huttrer, 2002). Prior to drilling, available data for the region should be evaluated to determine the best locations for boreholes. For example, marine seismic profiles obtained by WesternGeo for the Kotzebue area may be helpful in locating the depth to basement rock beneath the sedimentary basin, subsurface faults, and other features (data: http://walrus.wr.usgs.gov/NAMSS/bering_sea.html).

Even if a geothermal resource is discovered under Kotzebue, it will be necessary to determine whether the fluids are hydrothermal or geopressurized. Utilization of geopressurized fluids, whether for heat or power, is likely to be highly problematic, for the following reasons: 1) Either those fluids would have to be piped from a distant deep well, causing transmission issues *or* they would have to be pumped from beneath the city of Kotzebue, solving transmission problems but creating subsidence and/or contamination hazards for city residents; 2) Because geopressurized fluids are "formation" or "connate" waters, they are not renewable resources in the sense that hydrothermal fluids are renewable. Because these fluids are a finite resource, the lifetime of the extractability would be relatively limited; 3) Thermal exchange between a hot well and thick permafrost layers could also result in ground instability. An engineering/technical study would help elucidate these issues.

Conclusions and Future Work Priorities

Theoretically, most of the known hot springs in the NANA region could be used for heat and/or power using a plant similar to the one at Chena Hot Springs (see www.yourownpower.com). It is important to note that almost no data has been generated since the 1980s for these or any other hot springs. However, all of the hot springs discussed in this report are significantly far from population centers (40 miles or further), making electric transmission costs the main barrier to geothermal development at this time. Even if geothermal energy, either in the form of electricity or heat, could not be economically moved from remote hot spring sites to communities, other development opportunities exist. One geothermal development scenario that has been suggested for NANA region hot springs is the construction of on-site greenhouses directly using the heat of the hot springs.

In light of what is known at the present time, it is the recommendation of the authors that NANA focus on two hot springs sites for future geothermal work: ***Granite Mountain*** and ***Division***. This is because both Division and Granite Mountain hot springs are the only two known hot springs in the NANA region located within 45 miles of a community, and because the possibility that the hydrothermal fluids at Granite Mountain hot springs could extend in the subsurface northeast towards the village of Buckland.

Future work should include: 1) further exploration at each site, outlined below; 2) economic and/or technical feasibility studies of geothermal development at each site. It is recommended that field expeditions to both Granite Mountain and Division hot spring sites be undertaken during 2009. Recommendations for further geothermal exploration in the NANA region are listed in "phase 2" and "phase 3" below. Phase 1 consists of this report, based on review of literature and other data available to date. It is assumed that the more advanced, and costlier, recommendations of phase 3 would proceed only if the data collected during phase 2 exploration activities looks promising.

Phase 2. Exploration Recommendations:

1. ***Remote sensing study of Granite Mountain and Division hot springs regions.***
   Purpose: identify thermally anomalous areas.

Information from satellite imagery, such as the thermal images obtained from the Landsat 7 satellite and/or airborne instruments, could be a useful prospecting tool for NANAGAP. The images, or "scenes," should be processed for maximum thermal resolution and evaluated to determine fracture density north of Granite Mountain and possibly to determine the subsurface lateral extent of Granite Mountain geothermal area. One potential problem with a remote sensing study is that many hot spring areas in the

CAHSB have a small surface "footprint," and thus may not be visible on such images. Hence, it could be necessary to acquire other datasets to refine interpretations (see exploration option #3, below)

2. ***Soil geochemical surveys for Granite Mountain and Division hot springs regions.***

   Purpose: locate geothermal anomalies using geochemical "tracers" in soils such as helium, mercury, carbon dioxide, and arsenic.

   In the absence of surface geothermal expressions (e.g., hot springs), soil sampling for geothermal "tracers" or indicator elements is a useful and low-cost exploration tool. In the Seward Peninsula area and other places in Alaska, helium (He) studies have been especially useful in geothermal studies (Wescott and Turner, 1981). These should be conducted in the granitic rocks north of Granite Mountain and at the contacts between granitic and volcanic rocks.

3. ***Ground-based geophysical surveys (magneto-tellurics, SP, etc.) for Granite Mountain and Division hot springs regions.***

   Purpose: constrain subsurface structure (identify likely upwelling areas) and/or "see" geothermal reservoir fluids.

   All of the known hot springs described in this report issue from fractures within granitic intrusive rocks. It appears that the host granite must be well-fractured so that they have sufficient permeability to promote deep circulation of meteoric water (local snowmelt and rainwater). A variety of geophysical methods can target subsurface permeability by targeting identify zones of near-surface conductivity. Electromagnetic (EM), self-potential (SP), and audio magneto-telluric surveys are all examples of such methods. In addition to fluids, EM and AMT can also reveal concealed faults and other subsurface geologic structures. The results of these studies would have to be interpreted in the context of other data that exists for the region.

Phase 3. Advanced Exploration Recommendations:

1. ***Thermal gradient / exploratory drilling (shallow holes) in Granite Mountain/Buckland and Division hot springs areas.***

   Purpose: constrain thermal regime, confirm resource.

   Boreholes should avoid permafrost areas and/or be deep enough to get past permafrost. They should probably penetrate 2000 ft. or deeper and should follow guidelines outlined in a consultant's report (Huttrer, 2002). Prior to drilling, available data for the region should be evaluated to determine the best locations for boreholes.

2. ***Detailed technical and economic feasibility studies of proposed projects.***

   Purpose: determine feasbility of proposed project.

   Detailed economic analyses should follow exploration work to determine the feasibility of geothermal development at those sites. Unfortunately the economic analyses cannot be performed before this detailed work because the resource parameters are still unknown (distance from resource to load, production fluid temperature, etc.).

Glossary of Terms

Adapted from http://www.geotech.org/survey/geotech/dictiona.html *&* http://jersey.uoregon.edu/~mstrick/geology/geo_glossary_page.html

Basalt: A fine-grained, dark, volcanic rock (or lava) containing large amounts of iron.
Basin: A circular depression in the crust where sediments tend to accumulate.
Crater: A steep-sided, usually circular volcanic depression formed by either explosion or collapse at a volcanic vent.
Cretaceous: The geologic time period that spans from 144 million years ago (ma) through 65 ma, between the Tertiary (65-1.8 ma) and the Jurassic period (206 to 144 ma).
Fault: A crack or fracture in the earth's surface in which there has been movement of one or both sides relative to the other. Movement along the fault can cause earthquakes.
Geothermometry: A method of estimating geothermal reservoir temperatures from surface water chemistry based on temperature-dependent chemical reactions.
Granite: A coarse-grained, intrusive igneous rock composed of quartz, feldspar, micas, and other minerals.
Graben: A downthrown crustal block between two normal (extensional) faults.
Holocene: The present-day geologic time period, beginning 10,000 years ago.
Hydrothermal reservoir: A subsurface system of convecting hot H_20 (liquid or vapor phase) derived from meteoric water percolating into the subsurface.
Igneous rock: A rock formed by crystallization from a molten state. If crystallization occurs at the earth's surface (rapidly), it is ***volcanic***; if crystallization occurs in the subsurface (slowly), it is ***intrusive***.
Intrusive: see Igneous rock.
Lava: Magma that has reached the surface through a volcanic eruption -OR- rock created by cooled and solidified lava.
Maars: Explosion craters formed by hydro-magmatic eruptions (magma encountering large amounts of subsurface groundwater, ice, or permafrost).
Magma: Molten rock beneath the surface of the earth.
Metamorphic Rock: A rock that has experienced changes of mineralogy and texture due to pressure and temperature at depth.
Meteoric water: Rainwater, snow, hail, and sleet.
Paleozoic: The geologic period spanning 490 million years ago 295 to Ma.
Pleistocene: The geologic period spanning 1.8 million years ago to 10,000 years ago.
Pluton: A large igneous intrusion formed from the crystallization of one or more magma bodies at some depth in the crust (see Igneous Rock).
Rift: A tectonic spreading zone where two plates are separating and a new crust is being created. Usually associated with high crustal heat flow and shallow magma.
Sedimentary rock: A rock formed by cementation/solidification of sediment of smaller particles produced by mechanical or chemical weathering processes.
Tectonics: Large-scale structural setting of a geologic province.
Tertiary: The geologic epoch that spans from 65 to 1.8 million years ago (ma), between the Quaternary (1.8 ma – present) and the Cretaceous period (144 to 65 Ma).
Vent: The opening through which volcanic material is emitted
Volcanic Rock: See Igneous Rock.
Quaternary: The geologic epoch that spans from 1.8 million years ago through present times. Includes the Holocene, Pleistocene, and other subdivisions.

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Appendix A: Geothermal Electricity Financial Analysis for Granite Mountain Hot Springs and Buckland

Prepared by Brian Yanity, NANA Pacific

Based the assumptions listed below, a pre-feasibility financial analysis of a 400-kW geothermal power plant at Granite Mountain Hot Springs, and points closer to Buckland, was conducted using the software program RETScreen. The economic model is based on the 400-kW Chena Hot Springs geothermal power plant near Fairbanks, which at the end of 2006 had a total installation cost of about $2,000,000. This figure included the cost of the geothermal power generation equipment, as well as the feasibility study, development and engineering costs.

Assuming three-fold increase in cost of developing an unknown resource in a remote area as compared to Chena Hot Springs, the total installation cost of a 400-kW geothermal power plant at Granite Mountain Hot Springs is estimated to be $6,000,000. This figure includes the cost of the power plant as well as feasibility, development and engineering costs, but does not include the cost of a transmission line to Buckland, or a substation connecting to the City of Buckland's electrical distribution system.

According to the FY2006 PCE report, City of Buckland's 650-kW capacity diesel power plant generates about 1500 MWh annually. Assuming this level of power demand does not increase, a 400-kW geothermal power plant with an annual electricity production of 1507 MWh of electricity would serve Buckland's needs at an annual capacity factor of 43%.

With a benefit-cost (B-C) ratio of only 0.46, as calculated by the RETScreen software, a geothermal power plant located at Granite Mountain Hot Springs appears to be an un-economic source of electricity for Buckland. The majority of the project's cost is the 40-mile long a transmission line needed to connect the site at Granite Mountain Hot Springs to the community of Buckland. The length of the transmission line is chief reason why the project would not be economical, although the project's economic feasibility could be improved somewhat if Buckland's annual electricity demand increased significantly compared to 1500 MWh (the 2006 level). According to the RETScreen financial analysis, if the Granite Mountain Hot Springs geothermal power plant produced 3189 MWh of electricity annually (increasing the plant's capacity factor to 91%), the B-C ratio would increase to 1.00. The economics of a geothermal project at Granite Mountain Hot Springs may also improve if communities in addition to Buckland connected to the system, but due to the great distances of electric transmission lines needed this is not likely.

However, if a previously unknown sub-surface geothermal energy resource is discovered a much closer distance to Buckland, the economics improve significantly (all other costs remaining the same), as can be seen below in Table 1. At a distance of 9 miles, RETScreen calculates a B/C ratio of 1.00.

Table 1: B/C ratio of 400-kW Chena-type geothermal power plant for Buckland.

Transmission Line Length:	Transmission Line Cost:	Total Installation Cost:	B/C Ratio:
40 miles	$14,000,000	$22,937,585	0.46
30	10,500,000	18,972,085	0.56
20	7,000,000	15,006,585	0.71
15	5,250,000	13,023,835	0.82
10	3,500,000	11.041,085	0.96
5	1,750,000	9,058,335	1.18

List of Assumptions:

Granite Mountain Hot Springs/Buckland geothermal plant characteristics:

- 400-kW power generation plant (Chena-type)
- Annual electricity generated: 1507 MWh (43% capacity factor)

Installation cost assumptions (based on Chena Hot Springs geothermal plant):

- Feasibility, development and engineering costs- $ 2,000,000
- Geothermal power plant (400 kW) 4,000,000
- Transmission line (per mile)- 350,000
- Substation- 200,000
- Contingencies- 10% of installation cost
- Interest during construction- 6% over 12 months
- Spare parts- 15,000
- Transportation- 240,000

Financial assumptions:

- Electricity avoided cost (compared to diesel)- $0.20/kWh
- Annual electricity cost escalation rate- 10%
- Inflation rate- 2.5%
- Discount rate- 7%
- Project life- 25 years
- Annual operations and maintenance (O&M) costs: $110,000

Appendix B: Local knowledge (notes)

Sites identified by local knowledge

Kotzebue area

- Closest hot springs: Serpentine, Shungnak, and Granite Mountain.
- Fish hatchery site (on Noatak river). Springs issue from north side of Igichuk Hills. Distance from Kotz ~30 miles (across bay). Probably groundwater upflow/overflow site.
- Squirrel river site(s) – warm springs coming from mtns; associated with a U anomaly. Distance from Kotz ~45 miles (across bay), distance from Noatak and Kiana: ~45 miles each
- Warm "seeps" coming out of hills N. and E. of Kotzebue:
  - a) Junction between North fork of Squirrel river and Nookati Ck
  - b) North and south of Kiana hills
  - c) 1 creek over from Shiliak ck
- Selawik lake – linear place on lake that doesn't freeze, associated with natural gas?

Noorvik area

- Singaruk river site. Cold springs that never freeze on trail between Noorvik and Selawik. Distance from Kotz ~75 miles (across sound), distance from Noorvik, Selawik and Kiana ~15 miles each. Probably groundwater upflow/overflow site.

Deering area

- Closest hot springs: Serpentine and Granite Mtn.
- Imnachuk river site(s) – cold springs at head of river that sometimes do not freeze. Distance from Deering ~30 miles. Overflow right now, bad trail conditions. Springs coming out of mountains, fast flowing, more and more every year, probably because of melting permafrost. People usually go in fall or summer, good hunting spot. Probably groundwater upflow/overflow site.

Buckland area

- Closest hot springs: Granite Mtn.
- Creek site about 15 miles east of town, springs "do not freeze" and a number of groundwater upflow features are present such as pingos. Unfortunately due to several factors (guide unable to come at last minute; massive snowdrifts; limited timeframe) we were not able to find reported site.
- Water coming out of hole at gravel pit, near river, 3 miles from town.
- Another cold springs at Bear Creek, on the way to Granite Mtn. hot springs

Sources: Kotzebue

Ernie Norton (KIC)

- 1950's hot water well was near KIC garage (next to the Ferguson building).
- Discussed fish hatchery site (on Noatak river), its history and location and possible geothermal resource potential. About 40 miles from Noatak?
- Discussed Trio's interpretations of seismic results (from prior studies). Trio thinks that a "rise" feature in the seismic is geothermal. I indicated that seismic cannot "see" geothermal. Note: I did not see the data, just heard interpretations. I suspect Trio is hoping that someone, in drilling for "geothermal," will accidentally encounter gas.
- Discussed geologic structures in the sound and Hotham Bay. There is a trench east of Pipe Spit that runs the length of the spit. Ernie reports that the trench is related to a "fissure." Note: could be the margins of the basin, or an intra-basin fracture.
- Other private wells in area – none with hot water, no records:
    - FAA, near NANA
    - Dean's grandmother
    - Church of God

Henry Booth (KIC)

- Discussed location of shallow gas boreholes drilled by WesternGeo
- Q: Were all of the boreholes in permafrost? A: not all; one was warm, the other possibly warm, neither had fluid…?

Bob Schaeffer (NWAB), Charlie Greg (NWAB) and Herbert Walker

- Discussed warm "seeps" coming out of hills N. of Kotzebue:
    - d) Junction between North fork of Squirrel river and Nookati Ck
    - e) North and south of Kiana hills
    - f) 1 creek over from shellac ck.
- Discussed fish hatchery site at length – occurs at junction of Noatak river with small warm creek; down slope (1/.4 mi) from a lake with sulfur smell and gas bubbles! Juniper grows there… thawed ground.
- Omar river and Jack ck??
- Discussed Nimiuk Pt. well, very saline, very deep
- No other hot springs besides Shungnak and Granite Mtn.

Tom Bolen and Mark Caruthers (from public meeting at NWAB Chambers)

- Identified three sites:
    - N. Fork Squirrel River
    - Singaruk River between Noorvik, Kiana and Selawik
    - Selawik lake

Charlie Callahan (Red Dog mine)

- Water well: Ada Ward's well in house
    - Constant water, so much that they have a pump and a 7-foot pipe to sewer line.
    - Well feeds sewer line 24hrs/day.
    - Depth, salinity unknown.

Frank Stien (KEA Board of Directors) ***Recording of conversation available*

- Well drilled in 1950's:
    - Drilled between 1954-1958
    - Looking for potable water for hospital - this was Kotz's 2nd hospital – was by Ferguson Building
    - Drilled by AK Native Service (Dept. of Agriculture – now Public Health Service)
    - Water very brackish, well sealed

<u>Kotz Elders to talk to:</u>

Art Fields – Kotzebue
James McClellan (442-3250) Kotzebue
Herbert Foster (3712) – *no memory of well* Kotzebue
Bob and Carrie Uhl – senior citizen's home Iglu apt (3044) Kotzebue

Sources: Noorvik

Franklin ____

- Squirrel river site confirmed
- No other hot springs besides Shungnak and Granite Mtn.

Sources: Deering

Brian Weinard 363-2320 (Deering resident)

- Discussed Serpentine hot springs – confirmed 60 miles distance; said there is a road in summertime
- Discussed Imnachuk springs
    - ~25 mi from town
    - Not hot; possibly warm, nobody soaks in it
    - Head of Imnachuk river. River has overflow downstream for miles in winter.
    - People go in summer, there is a road part of the way, and more or less a trail from the road. In winter, dangerous, river has overflow and thin ice patches, also break trail on last bit, snow has crust you would break through, be prepared to dig out snowmachine and be prepared to camp! Should take longer route over 14 mile hill.
    - In summer, it's very hairy getting down into river valley, Brian turned around before getting to springs

    - Maybe crystalline rock, not lava rock

Gib and Jim Moto 363-2000 (Deering residents)

- Discussed Imnachuk springs
    - Overflow right now, bad trail conditions
    - Springs coming out of mountains
    - Never been in wintertime – usually go in fall or summer
    - Springs are cold – not freezing
    - Nobody soaks
    - Lots of overflow
    - 30 miles out or so
- Asked if other hot springs? No, just Serp and Granite Mtn (by Buckland)

Roy ___ (Deering resident)

- Discussed Imnachuk "springs"
    - Head of river
    - Maybe not open this winter because so cold and lots of snow – many winters it freezes
    - Not warm enough to get in
    - Doesn't steam
    - Nobody swims; maybe there were some people who used to soak? Dunno.
- Asked if other hot springs? Not that he knows

Taylor Moto Jr. 363-2127 (Deering resident)

- Discussed Imnachuk "springs"
    - Went in April once – distance depends on trail conditions – this year, expect 3 or more hours?
    - Followed old trail, went up with elders because one had camp
    - Used to soak.
    - Not really warm…? 50 F? rocks are warm though
    - Q: bubbles? A: Y…?

Bruce Moto 363-2235 (Deering resident)

- Discussed Imnachuk "springs"
    - Go in summer
    - Spring comes out of side of hill
    - Cold, doesn't freeze; it's an open spot
    - No gas bubbles but algae
    - 8 miles above last camp which is at 24 mi
    - just 2 miles or so before park lands

More Deering Elders to talk to:

Isaac Thomas – Kotz -442-2488
Laban Iyatunguk – Nome – 443-2812
Daniel Karmun – Nome – 443-2883
Wilbur Karmun – Anch – staying with Martin Karmun

Harry, Winona, and Alfred Karmun – Wasilla

Notes

- Of people who've been to Imnachuk, 5 say it's cold and 2 say it's warm
- Nobody knows of wells or other thermal areas
- Everyone says "talk to elders" but "most are gone"

Sources: Buckland

Tim Gavin and Amil Carter (Buckland residents)

- Pointed out several places where creeks don't freeze – see map
- Discussed local geology and mining potential

Percy Ballot and Darlene Hadley (Vice Mayor and City Manager)

- Closest hot springs = Granite Mtn. springs
- Discussed springs that don't freeze by gravel pit
- Lots of open parts along river, (fast current)
- Q: Wells in town or around? A: No, but dug pretty deep at gravel pit – bedrock is 40 ft. below town and gets deeper as you go south
- Lots of potholes in town
- Discussed change in river from clear to brown, probably due to illegal activity at Bear Ck. Mine – gold mine up by granite mtn. – ask Kim Franklin at NWAB
- River water analyzed periodically by Analytica in Fairbanks – high TMMS lately
- Red Dog Mine has apparently been telling people that they will get power from the mine via an underground cable…

Ernie Barger (Buckland IRA and other associations)

- Springs that don't freeze by gravel pit, 3 miles from town, gravel used for airport runway and other projects – sounds like granite
- Q: Any other hot springs around Buckland? A: No
- Q: Wells in town or around? A: No, been in town since 1969 and no wells but should ask elders
- Q: Some shallow drilling for school, roads, water & sewer? A: Ask John Minnow or Steve Merkel (city water and sewer) and Corps of Engineers
- Permafrost 3 or 4 feet down except by river
- Cold spring at fork b/w Buckland river and another one (see vellum sheets)
- Cold springs ~30 miles up Bear Ck. – ask Amal Carter

Jimmy Geary (Buckland elder)

- Q: Any other hot springs around Buckland? A: No
- Discussed springs that don't freeze – lots of open places on creeks and on river
- Q: Wells in town or around, or other drilling around town? A: No, not below gravel and ice anyway

Appendix C: Explanation for ‘Geothermal Fluids’ Reported in Kotzebue

Possible Explanation for ‘Geothermal Fluids’ Beneath Kotzebue

Gwen Holdmann and Kenji Yoshikawa, Alaska Center for Energy and Power, University of Alaska

This paper addresses the long-standing oral tradition in Kotzebue which alleges that geothermal fluid was once encountered at approximately 300 feet depth beneath the city of Kotzebue. The fluid was reportedly encountered during drilling for potable water for a hospital which was built between 1954 and 1958. The water was apparently very brackish, and the hole was sealed shortly after being drilled. Since that time, this story of a geothermal resource which was supposedly located beneath the town has been revisited on numerous occasions, and regional geothermal resource evaluations have attempted to verify or refute the existence of this resource. None of these reports were able to access any tangible evidence such as well logs or other data relating to the hospital project, so no definitive conclusions were ever reached.

We have obtained data from a report (Ground Water in the Permafrost Regions of Alaska, John R. Williams, 1970) which sites a number of wells drilled on the spit where Kotzebue is located between 1952 and 1961. These holes were reportedly drilled for the purpose of locating a potable waters supply within the community, and ranged in depths from 19 to 325 feet. Examples include a well drilled at the FAA station (southern end of the peninsula) to a total depth of 95 feet which hit unfrozen sand and silt at a depth of 67 to 85 feet, and gravel containing brine from 83 to 85 feet. Two other shallow test holes were drilled beneath shallow lakes on the spit by the U.S. Public Health Service. The wells drilled by the U.S. Public Health Service are of interest because this is the agency which has been attributed to drilling the ‘geothermal’ well in town. However these are the only two holes in the immediate vicinity of Kotzebue drilled by the Health Service which were cited in the report.

The well of most significant interest is the deepest one, drilled to a total depth of 325 feet. It is not clear whether this well corresponds to the one drilled at the hospital, but it was located in the main town location, in close proximity to several additional shallower holes. The 325 foot well was drilled as a USGS test well, and the diagrammatic cross section is included on the attached page. We have attempted to locate the well on an aerial image of Kotzebue taken in 1989 that includes the old hospital building, which has since been demolished. It was not possible to exactly pinpoint the well on this more modern aerial, but any error is likely to be no more than a couple hundred feet. While the 325 ft well does not exactly overlap with the location of the old hospital (see Figure 1), it is in extremely close proximity which makes it a valuable data point which should provide some indication of an elevated thermal gradient if a geothermal resource was encountered at a distance of less than a city block. Even a very isolated, moderate temperature resource would reach equilibrium with the surrounding ground and its signature should be visible in nearby well logs.

The cross section of the USGS well is interesting for several reasons. The base of permafrost was reached at 238 feet. However, a section of unfrozen brackish waters was accessed at a depth of 79-86 feet, isolated above and below by frozen blue silty clay.

This brine was probably below 0°C according to the report. Additionally, below the permafrost base, brackish water which increased in salinity with depth was also encountered, also in silt and clay. Bedrock was not reached, and in fact bedrock is expected to be quite a bit deeper in this region (up to several thousand feet).

Because these intra-permafrost aquifers which contained brackish waters are constrained by a relatively non-porous layer above and below (silt and/or clays) as well as ice bonded permafrost, if the aquifer is closed (i.e. is isolated) with enough porosity to moving water, it would likely pressurize by the aggradating freezing process resulting in the well exhibiting artesian flow characteristics. If one of these layers was encountered during cold conditions which can be expected at any time of year in Kotzebue, the possibly artesian flow could have been interpreted as steaming depending on temperature difference between air temperature and the intra-permatfrost aquifer temperature (around -3.5°F). Bigger temperature differences would generate more (steaming) artesian water. We postulate that this observed 'steaming' fluid was misidentified as being hot by witnesses.

In any case, there is verifiable evidence of a well drilled in the center of town in Kotzebue (exact coordinates are unknown), which did not encounter geothermal fluids and in fact encountered permafrost to a depth of at least 238 feet. This would make it almost impossible for a significant geothermal resource to exist under the community, as permafrost and near-surface geothermal fluids are generally thought to be mutually exclusive conditions.

Figure 1. Approximate site of USGS Well and old hospital building

Appendix B:

Reconnaissance Study of the Granite Mountain Geothermal Area, prepared for NANA by Alaska Center for Energy and Power, University of Alaska Fairbanks: Dick Benoit, Peter Illig, and Gwen Holdmann, November 2009.

Reconnaissance Study of the Granite Mountain Geothermal Area

Prepared for NANA Development Corporation by:

Alaska Center for Energy and Power, University of Alaska
Dick Benoit, Peter Illig, and Gwen Holdmann

November, 2009

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1.0 Background

In 2008 NANA Pacific embarked on a study of potential renewable resources in the NANA region surrounding the town of Kotzebue, Alaska. As part of this effort, a report titled '*NANA Geothermal Assessment Project (GAP) Results of Phase 1: Site Identification*' was completed by Amanda Kolker with assistance from Brian Yanity, and presented to the NANA Geothermal Working Group in January, 2009.

The GAP report identified and briefly described and discussed geothermal systems and 7 thermal springs within the NANA region; Serpentine, Lava Creek, Granite Mountain, Hawk, South, Division, and Reed River Hot Springs. The relatively well known Pilgrim Hot Springs are located west of the NANA region and were not considered in the GAP Report. Reported surface temperatures of these thermal springs ranged from 109 ^{o}F at Hawk to 167 ^{o}F at Serpentine. Reported flow rates ranged from 40 gpm at Reed River Hot Springs to about 500 gpm at Division Hot Springs. None of these thermal springs are closely associated with active volcanoes so it was recognized that all of these geothermal resources have subsurface temperatures less than 300 ^{o}F and are not large in terms of volume or potential megawatt capacity. All of the seven known thermal springs within the NANA region are more than 40 miles from NANA region communities.

Although it is possible that most or all of the known thermal springs in the NANA region might be theoretically capable of supporting direct use or small scale power generation projects like the one installed at Chena Hot Springs in 2006, the Granite Mountain Hot Spring, along with Division Hot Springs were identified in the GAP Report as being the two most attractive hot spring sites for additional geothermal exploration effort.

2.0 Proposed Work Plan

Building off the GAP report, a '*Proposal to Conduct Additional Reconnaissance Study of the Granite Mountain Geothermal Area'* was submitted to the NANA Development Corporation by the Alaska Center for Energy & Power (ACEP) at the University of Alaska Fairbanks in July 2009, and was ultimately approved for funding in the amount of $60,000.

The GAP Report recommended performing a remote sensing study of Granite Mountain and Division Hot Springs, performing a soil geochemistry survey, and running ground-based geophysical surveys as Phase 2 activities. A future Phase 3 was intended to utilize deep temperature-gradient holes and perform a detailed technical and economic feasibility study.

The ACEP proposal to conduct additional reconnaissance was different from the Phase 2 exploration recommendations in the GAP Report due to the limited budget and time frame allowed for completing the work during the 2009 season. To meet the time and budget constraints, the ACEP proposal involved chemically sampling the local hot and cold waters at Granite Mountain to determine the likely resource temperature with more precision than the GAP Report and to assess the heat flow from the Granite Mountain geothermal system. These values are critical to determining the maximum developable capacity of the resource.

3.0 Field Work

ACEP conducted the field work component of this project between Sept. 18 and 21, 2009 with the goal of sampling the hot and cold waters in the Granite Mountain area and assessing the heat flow from the resource. Dick Benoit and Peter Illig (student) flew by helicopter from Nome to the site on Sept 18, staying through the morning of Sept. 21. Weather during this time was dry and pleasant with light winds, temperatures above freezing, and no rain except during the last night spent at the site. Seven water samples were collected and six were ultimately analyzed by the Desert Research Institute Laboratory in Reno, Nevada. Twenty two (22) shallow holes were hand drilled to measure temperatures at depths, and ranged from a depth of 18 to 36 inches. The geology of the local area was also assessed during this time and the results of each of these activities are detailed below.

3.1 Geologic Assessment

3.1.1 Location

Granite Mountain Hot Springs are located on the southern flank of Granite Mountain, a large rounded hill at the far eastern edge of the Seward Peninsula. The center of the hot pool at Granite Mountain is N 65^o 22' 08.63" and W 161^o 15' 25.56". The area immediately around the thermal springs for hundreds of feet is largely covered by thick willows, which in turn are surrounded by tundra. The thermal spring can be accessed by snowmobile or ATV. There is an airstrip located about 2.2 miles NNE of the hot springs. There are 2 adjoining cabins located a few yards from the large thermal pool. The pool is obviously manmade and dug for bathing purposes. The area is heavily impacted by refuse. An additional area discharging warm water was discovered during this work about 1000 ft NE of the hot pool.

Figure 1. Aerial view of manmade pool and adjacent buildings.

3.1.2 Topographic Setting

The main Granite Mountain hot spring discharge area is on a gentle southeasterly sloping hillside. The main thermal springs and pool are located at the lower edge of the hillside about

50 vertical feet above a creek. The lower edge of this quite planar hillside is locally defined by a much steeper escarpment which drops down to a cold stream. During the September fieldwork, this creek could only crossed with dry feet in a few locations. The escarpment is an obvious linear feature that was easily recognized during the helicopter flight into the hot springs (Figures 2). The relief on the escarpment rapidly diminishes downstream (SW) of the thermal springs and gradually diminishes upstream (NE) over a distance of ½ mile. The total length of this escarpment is about 0.6 miles and for reasons to be discussed later it appears to be the most important geologic feature controlling the location of the geothermal system. Most likely this escarpment represents vertical displacement along a recently active fault, although no evidence was obtained to prove this hypothesis. In several nonvolcanic areas in the world such as the Basin and Range province in Nevada and Utah as well as in Turkey, there is a close association between many geothermal systems and recently active faults or fault zones.

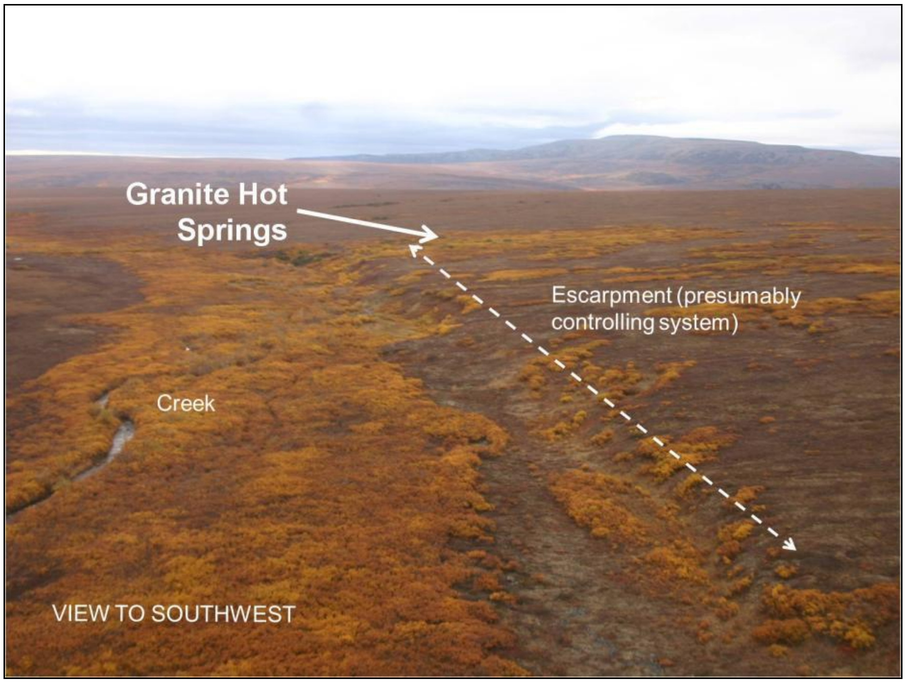

Figure 2. View of escarpment looking to the southwest.

3.1.3 Bedrock Geology

All of the area is covered by tundra and willows. Hand drilling showed impenetrable rock to be present everywhere at depths of 1 to 3 feet below the ground surface. The only actual outcroppings of bedrock are two small areas located about 350 ft east of the hot pool at the base of the escarpment on the north side of the cold stream (Figure 3). These are overlain by tens of feet of alluvium exposed on the face of the escarpment. No attempt was made to try to map or define units within this complex as bedrock outcrops occur in less than 1% of the area. A small percentage of the area consists of flat outcroppings of frost shattered rock generally broken into blocks less than a foot in diameter. In places there is also pattern ground (polygonal shaped), presumably due to annual freeze-thaw cycles and production of ice wedges. The bedrock in the vicinity of the thermal springs consist of either high grade metamorphic rocks intruded by abundant granitic material or are migmatites, mixed rock consisting of high temperature metamorphic rocks which have partially melted (Figure 4). In either case the overall chemical composition of these crystalline rocks is similar to granitic rocks.

Figure 3. River below escarpment with warm seeps within river bed.

Figure 4. Example of crystalline bedrock underlying Granite Mountain. This site is part of the Interior Alaskan Hot Springs Belt, which are all located within or along the margins of grantic plutons. Heat source is partially driven through radioactive decay of U and Th in the rocks, and partially through deep circulation.

3.1.4 Thermal Features

As a whole, the Granite Mountain Hot Springs appear rather unremarkable. The main thermal area near the cabin(s) has been heavily modified by man with a pool about 75 ft x 60 ft being excavated with a low dam on its lower side (Figure 1). The pool has a maximum depth of about 4 ft with a soft bottom, generally covered by algae. There are 4 orifices tens of feet uphill from the pool that produce water with a maximum temperature of 119 ^oF. These orifices are heavily coated with algae. In only one spot is a small area of cemented gravel visible. These springs do not precipitate any significant or noteworthy amount of travertine or sinter. The pool has 3 areas near its upper edge where bubbles signify additional inflow of thermal fluid. There is plenty of noncondensible gas available for sampling but no noticeable smell of hydrogen sulphide. No gas samples were collected. The total outflow of the pool is about 50 gpm with a temperature of 102 ^oF and a pH of 7.9. From the pool the thermal water cascades down the escarpment to flow into the cold creek. Just above this confluence the hot stream has a temperature of 89 ^oF. About 60 feet south of the pool there is another cluster of 3 or 4 orifices that produce a couple of gpm. These orifices have temperatures from 85 to 113 ^oF.

A third area of warm water was discovered about 350 feet east of the hot pool at the base of the escarpment near where the creek is actively eroding the escarpment. There are at least two seeps here with surface temperatures as high as 52 and 69.5 ^oF. The total surface flow rate from this area is less than 1 gpm. The warm water is found both immediately upstream and downstream of the steep hillside formed where the cold creek meanders against the escarpment shown on Figure 3. In fact, this is the only location where the cold creek actually is currently eroding the escarpment. A traverse along the entire length of the escarpment failed to detect any deposition of travertine or sinter which might indicate the presence of past thermal fluid flow. Nothing resembling hydrothermal alteration was noticed throughout the entire area surveyed.

4.0 Chemistry

4.1 Sample Descriptions and Basic Chemistry

Granite Mountain Hot Springs are one of 7 thermal springs known on the Seward Peninsula (Miller, 1973). There is another cluster of 4 thermal springs on NANA lands a little further east including Hawk, South and Division Hot Springs. The chemistry and temperatures of these springs varies quite widely and somewhat surprisingly, not all of these thermal springs have published water analyses. Serpentine and Pilgrim Hot Springs produce classical sodium chloride geothermal water while Granite Mountain and Hawk Hot Springs both flow a sulfate/bicarbonate water with very little chloride (Table 1). Reported temperatures of these hot springs range from 17 to 77 ^oC, with Serpentine Hot Spring being the hottest. The quality of the water analyses in Table 1 varies widely. By example the complete DRI analyses all have charge balances better than 5 % while the less complete analyses presented in Miller (1973) have only one analysis with an acceptable charge balance.

There are three chemical analyses of the Granite Mountain hot spring thermal water (Table 1). The oldest analysis (Miller, 1973) is the most saline of the three samples. The two samples of the hottest available water collected at Granite Mountain Hot Springs in September, 2009 and analyzed by the Desert Research Institute are virtually identical in chemical composition. Samples from the nearby cold stream both upstream and downstream of the thermal springs were analyzed for Na, Cl, SO4, and F. Two warm seeps located 120 to 140 yards due east of the Granite Mountain Hot Springs were discovered during this study and were also sampled and analyzed. The measured temperatures of these seeps (< 1 gpm flow) with minimum temperatures of 10.9 and 19.4 ºC should be viewed as minimum values.

Sample Location	Lab or Source	Temperature (ºC)	pH (field)	pH (lab)
1 Granite Mtn HS	Desert Research Inst.	48.2	7.9	7.9
2 Granite Mtn HS	Desert Research Inst.	44.7		7.9
3 Granite Mtn Warm Seep	Desert Research Inst.	19.4		8.67
4 Granite Mtn Warm Seep	Desert Research Inst.	10.9		7.48
5 Granite Mtn Cold Creek	Desert Research Inst.	4.2		
6 Granite Mtn. Creek below HS	Desert Research Inst.	6.6	5.0	
7 Granite Mtn HS	Miller, 1973	49		10.14
8 Lava Creek HS	Miller, 1973			9.1
9 Mt Kachaulk HS	Miller, 1973	17		8.97
10 Kwinuik River HS	Miller, 1973			7.3
11 Clear Creek HS	Miller, 1973	67		9.43
12 Serpentine HS	Miller, 1973	55		6.75
13 Pilgrim HS	Miller, 1973	60		7.91
14 South HS75	Miller, 1973	67		

Sample	Na	K	Ca	Mg	Li	B	SiO2	HCO3	CO3	SO4	Cl	F	Sum Cation	Sum Anion	Balance
1	64.9	1.19	1.09	0.05	.03	.21	68.2	16.4	37.6	48.6	5.6	7.85	2.92	3.10	.04
2	65.7	1.07	.96	0	.03	.22	67.4	13.8	38.2	49.8	5.7	8.1	2.94	3.12	.04
3	53.5	1.29	1.71	.42	.03	.16	58.8	73.5		39.5	5	6.45	2.48	2.51	.01
4	21.2	.61	9.7	1.54	0	.05	31.9	73.1		10.7	2.3	2.27	1.55	1.60	.02
5	2.21									0.8	0.9	0.05			
6	3.89									2	1.1	.28			
7	51	1.3	2	.04	.04	.13	75	45.7		62	9.3	8.2	2.36	2.73	.09
8	75	1.4	2	0		.8	70	100			8.0	9	3.40	2.34	.26
9	111	1.1	14	0.2		.6		40		16	122		5.57	4.43	.16
10	500	9	130	0.1		1	45	10.2			912	5.8	28.47	26.20	.06
11	54	1.4	5.6	0.06		.2		34		25	4.9		2.67	1.22	.57
12	1450	61	530	1.4	4	2.4	100	30.1		24	3346	4.7	91.77	95.62	.02
13	730	40	47	0.48	4.7	3.4	100	64.5		29	1480	6.7	35.84	43.76	.13
14	83	2.1	5.9	0.01			65			122	6				

Table 1. Water chemistry of hot springs on Seward Peninsula in the NANA Region

The six DRI analyses (Figures 5 and 6) define a classical mixing trend with the hottest springs and the cold stream being end members. Other combinations of chemical species show the same mixing trend but are not presented as figures. The 1973 Miller analysis of Granite Mountain Hot Springs does not fall on this trend, most like due to analytical differences between the laboratories. The two seep samples collected close to the cold stream fall on the straight mixing trend line between the two end members. One seep sample contains mostly thermal water while the other contains mostly creek water.

The dilute nature of the Granite Mountain Hot Springs thermal water indicates that the water has probably not reached very high subsurface temperatures. The small chloride content and the fact that the fluoride content is greater than the chloride content indicates that this water has equilibrated in contact with crystalline rocks with a granitic composition. This could be either granitic rocks or high grade metamorphic rocks with a granitic composition or some combination of both rock types.

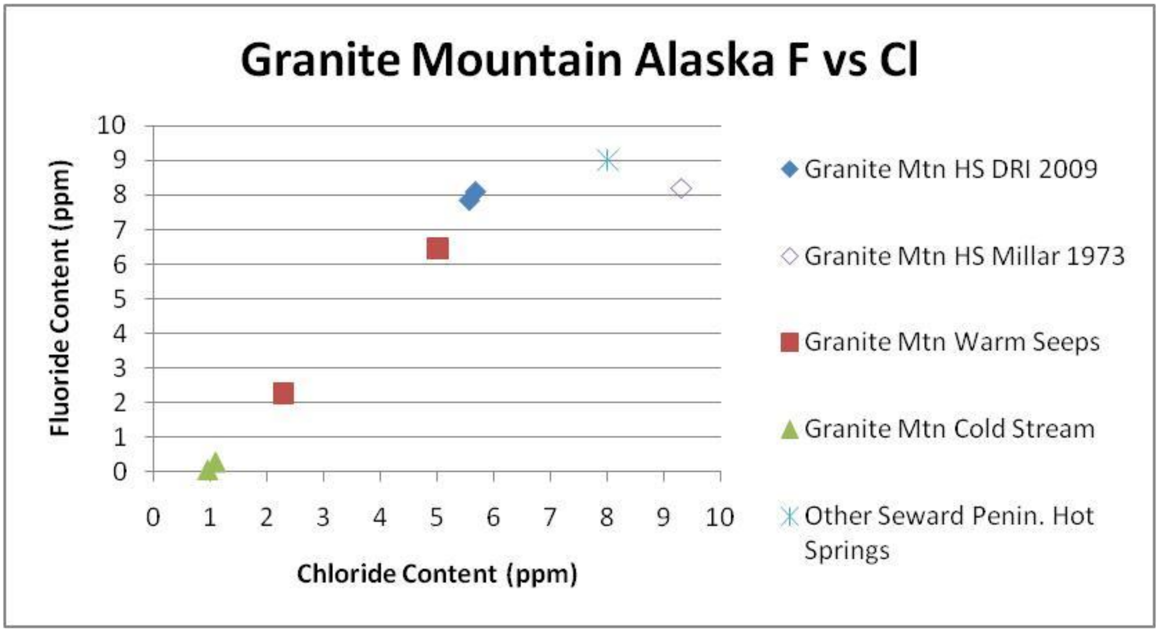

Figure 5. Mixing trend for DRI analysis of thermal and surface waters (F vs Cl).

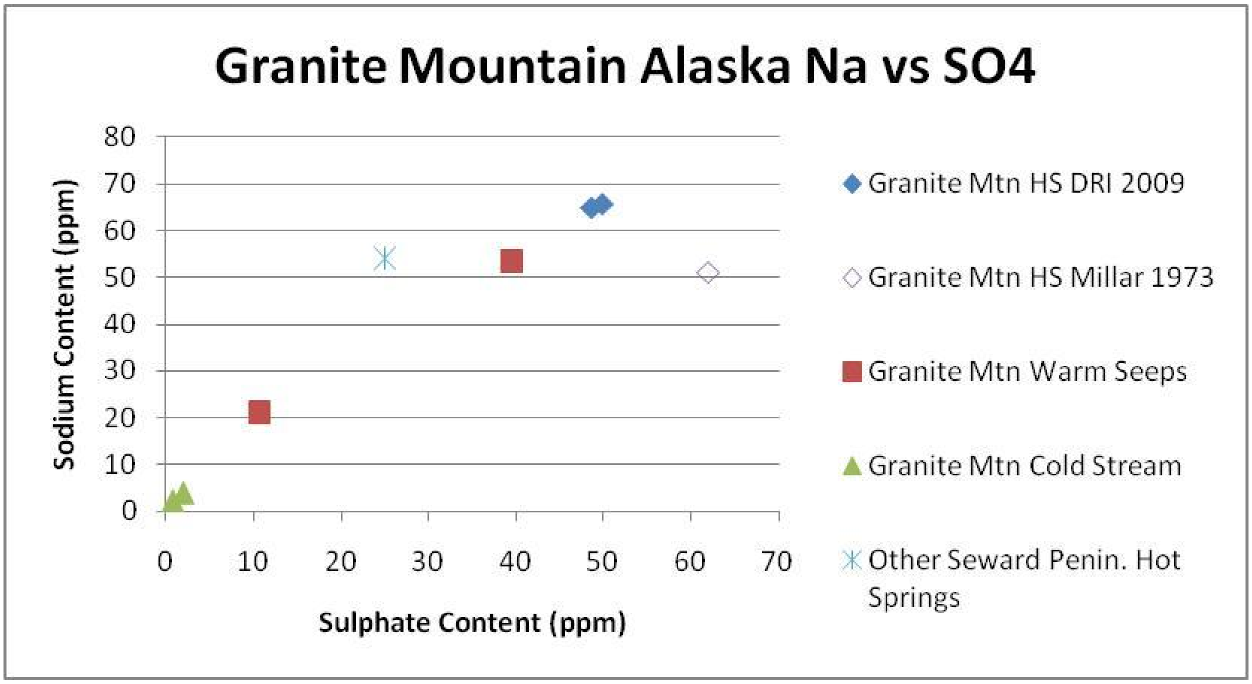

Figure 6. Mixing trend for DRI analysis of thermal and surface waters (Na vs SO4).

4.2 Geothermometry

There are several chemical geothermometers that have been developed over the past 40 years to estimate the subsurface temperatures of geothermal resources. Chemical geothermometers were originally developed with a focus on estimating higher temperatures (> 200 °C), and have not historically been accurate for moderate and low-temperature geothermal systems. However, in the past several years there has been an increased focus on more accurately estimating the subsurface temperatures of cooler resources.

The silica (SiO_2) content of the thermal water samples provides a very good geothermometer for estimating the subsurface temperature of the thermal water, provided it is properly applied. Geothermometers have been developed for 3 polymorphs of silica commonly found in rocks – quartz, chalcedony, and opal. It is necessary to apply the proper silica geothermometer, such as quartz or chalcedony, to the geothermal system in question. The opal geothermometer can very seldom be applied and is not further discussed. Between about 100 and 120 °C is where the transition from utilization of the lower temperature chalcedony geothermometer to the quartz geothermometer occurs making it unclear as to which is the appropriate one to use for any given geothermal system in this temperature range. Compounding this problem is the relatively high pH of the thermal waters shown on Table 1. A thermal water with a pH much above 8.0 requires a correction for the dissociated silicic acid in the waters. This is a recently developed correction factor.

A variety of silica predicted temperatures are shown on Table 2 giving the entire range of possible subsurface temperatures. The near neutral pH of the Granite Mtn hot springs makes any pH correction very small. Unfortunately, the chalcedony geothermometer of 88 °C is the silica geothermometer most likely to be correct as the temperature is less than 120 °C. This is 40 °C greater than the maximum surface temperature that was measured in September, 2009.

Sample	Surface Temp (C)	Quartz (C)	Calcedony (C)	Quartz (C) (pH corr)	Chaldedony (C) (pH corr)	Na-K-(1/3)Ca (C)	Na-K-(4/3)Ca (C)
1 Granite Mtn HS	48.2	117	88	116	87	110	88
2 Granite Mtn HS	44.7	116	88	115	86	107	87
3 Granite Mtn Warm Seep	19.4	110	80	107	77	116	78
4 Granite Mtn Warm Seep	10.9	82	51	82	51	99	19
5 Granite Mtn Cold Creek	4.2						
6 Granite Mtn. Creek below HS	6.6						
7 Granite Mtn HS	49	122	93	51	19	116	75
8 Lava Creek HS		118	90	115	86	109	81
9 Mt Kachaulk HS	17					80	40
10 Kwinuik River HS		97	67	97	67	105	72
11 Clear Creek HS	67					111	57
12 Serpentine HS	55	137	110	137	110	146	120
13 Pilgrim HS	60	137	110	135	109	167	163
14 South HS75	67	114	86			115	72

Table 2. Common geothermometers applied the Granite Mountain Hot Springs thermal waters

The other geothermometer commonly utilized by the geothermal industry is the Na-K-Ca geothermometer which again has two variants depending upon the temperature of the water. If the water is above 120 °C then the Na-K-(1/3)Ca version is utilized, while if the water is below about 100 °C the Na-K-(4/3)Ca variant is utilized. If there is appreciable magnesium (>0.5 or 1 ppm), then a magnesium correction should be added to this geothermometer. At Granite Mountain no magnesium correction is warranted and so it is not shown on Table 2.

The Na-K-(4/3)Ca geothermometer predicts a subsurface temperature of 87 to 88 ºC, which happens to be identical the chalcedony geothermometer. The silica and cation geothermometers agree so closely there is little or no reason to expect that subsurface temperatures above boiling can be found in the Granite Mountain geothermal system.

The geothermometers for the two warm seep samples collected at Granite Mtn (samples 3 and 4 on Tables 1 and 2) have appropriately reduced values as would be expected for a fluid containing a mixture of hot and cold end members.

No stable isotopic analyses were performed on any of the collected samples and no noncondensible gas samples were obtained.

5.0 Heat Flow Assessment

Once the escarpment (probable fault) was recognized at Granite Mountain, the heat flow assessment was focused along this feature. Due to weight limitations, only very light hand drills and wooden augurs were flown in to Granite Mtn. A total of 22 holes were drilled over about a half square mile area strung out along the escarpment to determine if the ground was anomalously warm or not. The hand drills could not penetrate bedrock or rocky ground but holes were consistently drilled from 18 to 36 inches below the surface of the tundra. Half inch diameter PVC pipes with caps on the bottom were installed in the holes and then partially filled with water. Temperatures at the bottom of the PVC pipes were measured after the holes had sat for a few hours or overnight. These holes showed that there are anomalous temperatures along most or all of the length of the escarpment. No significant heat was found away from the escarpment. The regional background temperature at depths of 18 to 36 inches was found to be about 33 or 34 ºF. Temperatures in the holes along the escarpment ranged from about 40 ºF to as high as 55 ºF.

The temperature data gathered at Granite Mountain are not suitable for determining a temperature gradient which is needed to calculate the actual conductive heat loss of the geothermal system.

The size or potential megawatt output of a geothermal resource can be estimated by three different methods with relatively little data available. A theoretical maximum potential output can be determined by the volumetric method developed by the U. S. Geological Survey decades ago. In this method, the amount of heat in a block of earth is largely assumed with commonly used factors. This is a highly unconstrained method and commonly results in a large overestimate of the amount of heat the can actually be recovered. It can be applied before a single hole is drilled.

A second method of estimating the possible megawatt output is to drill enough holes to outline the thermal anomaly resulting from the geothermal system and calculate the amount of heat being lost to the surface from the convective and conductive movement of heat. This requires a number of shallow holes in which temperature gradients can be determined. It is empirically known that geothermal resources can be produced at up to about 10 times the amount of the natural heat loss. Therefore this method gives bounds as it is fairly certain that a geothermal resource can be produced at its natural state heat loss.

The third, and unpublished empirical method, notes that in the Basin and Range province for geothermal systems located along faults (Dixie Valley, Desert Peak, Roosevelt, Beowawe, Bradys), it has been possible to inject somewhere between 2000 and 4000 gpm of cooled geothermal water per mile back into the fault zone for periods exceeding 20 years with acceptable amount of resource cooling. Therefore, if we assume that the fault at Granite Mountain Hot Springs is ½ mile long, it may be possible to produce and inject up to 2000 gpm without having rapid cooling of the fault. At Chena it takes about 500 gpm to make 250 kW of net electricity, so this means that Granite Mtn may be capable of producing and injecting up to about 1 MW worth of thermal fluid. Of course, this needs to be treated as a very preliminary and highly uncertain number subject to a number of unproven assumptions.

6.0 Discussion and Conclusions

The Granite Mountain geothermal system is probably fairly typical of geothermal systems in the interior of Alaska. It is located along, and probably controlled by, a fault which has created some permeability for hot water from depth to rise up to the surface. The thermally active portion of this fault, based on very shallow holes, is about 0.5 miles. The dilute chemistry of the water and relatively high fluoride content indicate that the geothermal system is hosted by rocks with a granitic composition. The silica and Na-K-Ca chemical geothermometers strongly indicate that the subsurface temperatures of the geothermal system do not exceed 88 ºC. This combination of factors indicates that there is no reason to expect this geothermal system to be capable of generating more than about 1 MW of electricity. If the Granite Mountain geothermal system were located next to a population center with reasonable road access it might be possible to develop it in a manner similar to Chena with a combination of direct use and low temperature electrical power generation. For comparison purposes, the maximum temperature measured in the Chena geothermal system to date is 80 ºC.

If additional exploration at Granite Mountain were to occur, there are a number of different possible techniques or strategies that could be employed but sooner or later drilling must occur. It is possible to helicopter in core rigs to drill small diameter exploration holes but it is expensive, costing perhaps $1 to $1.5 million to drill a 3000 to 4000 ft deep hole which would not be usable for production or injection purposes. It is hard to see how this could be justified for a resource that is unlikely to exceed 1 MW in electrical output. Drilling a production sized well with 9 - 5/8 inch or 13 - 3/8 inch casing will require a road (not a primitive track) to bring in the rig. It is not within the scope of this project to provide or estimate road costs, but constructing over 40 miles of road with bridges is likely to be a multimillion dollar exercise. In this case the road will cost more than the well(s), something which has not happened elsewhere in the United States.

In summary, any plant construction costs at Granite Mountain would be abnormally high due to the remote location and short construction season, and there would be a substantial cost for installing a transmission line to the nearest village (Buckland). In comparison, most alternative to geothermal should have a very large cost advantage, including convention diesel fuel.

Based on the results of this preliminary survey of the site, it is recommended that NANA focus on other alternative and renewable energy resources within their region. Even if some of the other identified geothermal sites would have greater developable potential than Granite Mountain, the remoteness of these sites coupled with the expense of roads and transmission lines will almost certainly make them uneconomical to develop.

GRANITE MOUNTAIN SITE VISIT REPORT SEPTEMBER 19-21, 2009

By
Dick Benoit & Gwen Holdmann
October 19th, 2009

LOCATION

Granite Mountain Hot Springs are located on the southern flank of Granite Mountain, a large rounded hill at the far eastern edge of the Seward Peninsula in Western Alaska. The center of the hot pool at Granite Mountain is at N 65^{o} 22' 08.63" and W 161^{o} 15' 25.56". The area immediately around the thermal springs for hundreds of feet is largely covered by willows, which in turn are surrounded by tundra. The thermal spring can be accessed by snowmobile or ATV. There is an airstrip located about 2.2 miles NNE of the hot springs. There are 2 adjoining cabins located a few yards from the large thermal pool which was obviously dug by man for bathing purposes. The area is heavily impacted by refuse. An additional area discharging warm water was discovered during this work about 1000' NE of the hot pool.

BEDROCK GEOLOGY

The rocks in the vicinity of the thermal springs consist of either high grade metamorphic rocks intruded by abundant granitic material or are migmatites. No attempt was made to try to map or define units within this complex as bedrock outcrops in less than 1% of the area.

TOPOGRAPHIC SETTING

The main hot spring area is on a gently planar slope dipping to the southeast. The main thermal springs are located at the lower edge of the planar slope about 40 to 50 vertical feet above the creek. A modest sized creek, which can locally be crossed on foot, drains off of Granite Mountain and flows toward the SW and SSW below the hot springs. This creek has a sharp change in direction from NE-SW to NNE-SSW adjacent to the thermal spring. Between the thermal springs and the creek there is a much steeper escarpment which can be as high as 30 to 40 feet. This escarpment rapidly diminished downstream of the thermal springs and gradually diminishes upstream over a distance of ½ mile. The total length of this escarpment is about 0.6 miles and it appears to be perhaps the most important geologic feature controlling the location of the geothermal system.

Over 95% of the area is covered by tundra and willows. The only actual outcroppings of bedrock are two small areas located about 350' east of the hot pool at the base of the escarpment on the north side of the cold stream. These are overlain by alluvium exposed on the face of the escarpment. A small percentage of the area consists of flat outcroppings of frost shattered rock generally broken into blocks less than a foot in diameter. In places these appear to be pattern ground (polygonal shapped).

THERMAL FEATURES DESCRIPTION

The Granite Mountain Hot Springs rather unremarkable. The main thermal area near the cabin(s) has been heavily modified by man with a pool about 75' x 60' being excavated with a dam on its lower side. The pool has a maximum depth of about 4' with a soft bottom, generally covered by algae. There are 4 orifices tens of feet above the pool that produce water with a maximum temperature of 119 ^{o}F. These orifices are heavily coated with algae. In only one spot is a small area of cemented gravel visible. These springs do not precipitate any significant or noteworthy amount of travertine or sinter. The pool has 3 areas near its upper edge where bubbles signify additional inflow of thermal fluid. There is plenty of noncondensible gas available for sampling but there is no noticeable smell of hydrogen sulphide. No gas samples were collected. The total outflow of the pool is about 50 gpm with a temperature of 102 °F and a pH of 7.9. From the pool the thermal water cascades down the escarpment to flow into the cold creek. Just above this confluence the hot stream has a temperature of 89 °F.

About 60 feet south of the pool there is another cluster of 3 or 4 orifices that produce a couple of gpm. These orifices have temperatures from 85 to 113 °F.

A third area of warm water was discovered about 350 feet east of the hot pool at the base of the escarpment. There are at least two seeps here with surface temperatures as high as 67 °F. The total flow rate from this area is less than 1 gpm. The warm water is found both immediately upstream and downstream of a steep hillside formed where the cold creek meanders against the escarpment. In fact, this is the only location where the cold creek actually is currently eroding the escarpment. A traverse along the entire length of the escarpment failed to detect any deposition of travertine or sinter which might indicate the presence of past thermal fluid flow. Nothing resembling hydrothermal alteration was noticed in the overall area.

TEMPERATURE MEASUREMENTS

Twenty two holes were drilled with a hand drill and a 1 1/8” diameter bit to depths of 15” to 38”. The great majority of these holes were terminated by drilling into either bedrock or boulders. Capped ½” PVC pipes were inserted into the holes and then partially filled with water. A thermocouple wire was later used to measure the temperatures at the bottom of the PVC pipes. The measured temperatures ranged from 34 to 67 °F. Holes furthest from the thermal springs consistently showed temperatures close to 34 °F so this is taken as the background temperature at depths of 15 to 38” in the area.

THE ESCARPMENT

The obvious modest escarpment located between the creek and the thermal pool is the primary feature of interest for two reasons. First, the thermal waters found to date are all located either just above or at the base of this escarpment. This makes it tempting to further describe the escarpment as a young fault scarp which is controlling the upflow of thermal water. Second the anomalous shallow temperatures strongly appear to be aligned with this escarpment. The main spring discharge is located above the location where the escarpment has its maximum topographic expression of about 50 feet. At only one place does a meander of the cold stream flow along the base of this escarpment.

Figure 1. View of Hot Springs looking toward Granite Mountain

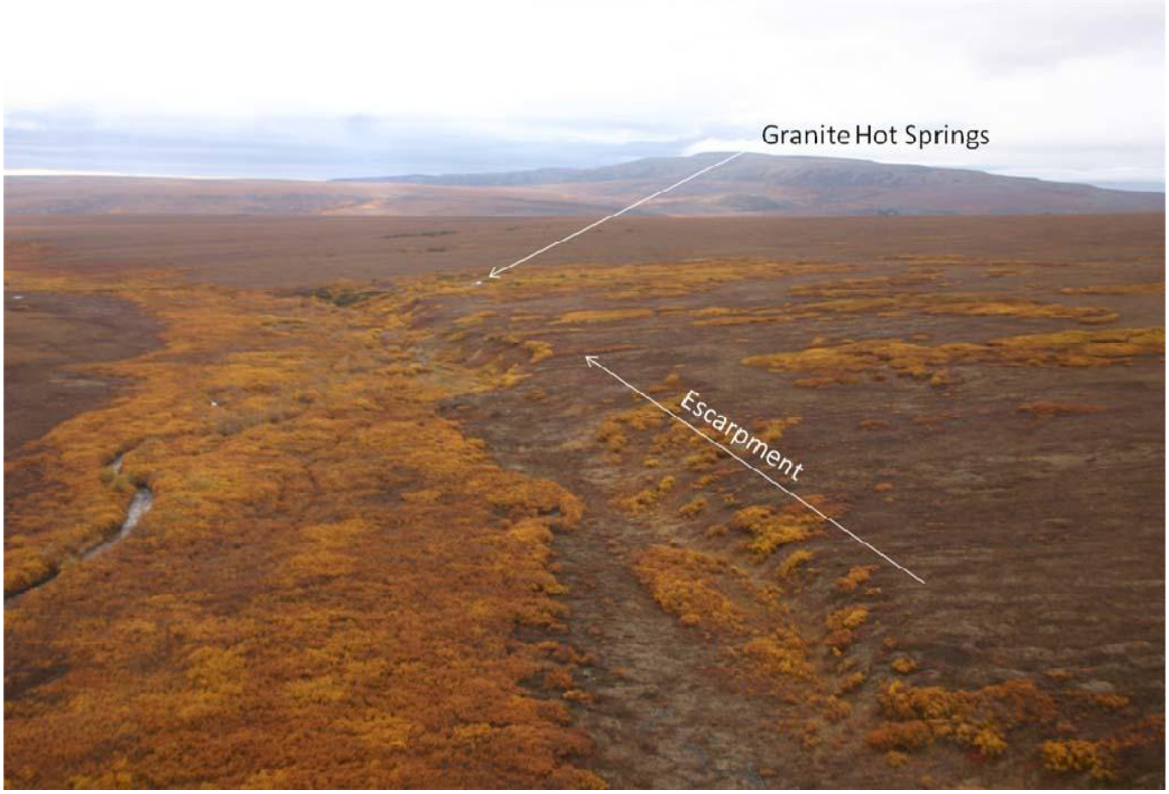

Figure 2. Oblique airphoto looking downstream along escarpment to Hot Springs at metal building

Figure 3. Student researcher Peter Illig drilling below the escarpment

Figure 4. Granite Mountain escarpment below hot springs

Appendix C:

***Reconnaissance Study of the Division Hot Springs Geothermal Area*, prepared for NANA by Alaska Center for Energy and Power, University of Alaska Fairbanks: Dick Benoit, Peter Illig, and Gwen Holdmann, with Steve Buckley of WHPacific, May 2010.**

Reconnaissance Study of the Division Hot Springs Geothermal Area

Prepared for NANA Regional Corporation by:

Alaska Center for Energy and Power, University of Alaska
Peter Illig, Dick Benoit and Gwen Holdmann

WHPacific
Steve Buckley, Geologist

May, 2010

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1.0 Background

‘In 2008 NANA Pacific embarked on a study of potential renewable resources in the NANA region surrounding the town of Kotzebue, Alaska. As part of this effort, a report titled ‘*NANA Geothermal Assessment Project (GAP) Results of Phase 1: Site Identification*’ was completed by Amanda Kolker with assistance from Brian Yanity, and presented to the NANA Geothermal Working Group in January, 2009.

The GAP report identified and briefly described and discussed geothermal systems and 7 thermal springs within the NANA region; Serpentine, Lava Creek, Granite Mountain, Hawk, South, Division, and Reed River Hot Springs. The relatively well known Pilgrim Hot Springs are located west of the NANA region and were not considered in the GAP Report. Reported surface temperatures of these thermal springs ranged from 109 °F at Hawk to 167 °F at Serpentine. Reported flow rates ranged from 40 gallons per minute (gpm) at Reed River Hot Springs to about 500 gpm at Division Hot Springs. None of these thermal springs are closely associated with active volcanoes so it is recognized that all of these geothermal resources most likely have subsurface temperatures less than 300 °F and therefore are not large in terms of potential megawatt capacity. All of the seven known thermal springs within the NANA region are more than 40 miles from NANA region communities.

Although it is possible that most or all of the known thermal springs in the NANA region might be theoretically capable of supporting direct use or small scale power generation projects like the one installed at Chena Hot Springs in 2006, the Granite Mountain Hot Spring, along with Division Hot Springs were identified in the GAP Report as being the two most attractive hot spring sites for additional geothermal exploration effort.’[1]

The Alaska Center for Energy and Power conducted a reconnaissance study of Granite Mountain hot springs in the fall of 2009 as part of NANA’s GAP project. The possible electrical production capacity of the springs was determined to be less than adequate to provide power to any nearby village or town at a reasonable price.

In the spring of 2010, WHPacific geologist Steve Buckley, ACEP/UAF geology student Peter Illig and WH Pacific Engineer Matt Bergan conducted a similar study of Division hot springs south of the villages of Shungnak and Kobuk and located within the Selawik National Wildlife Refuge. The goal was to gather baseline physical data on the Division hot springs and determine the potential for geothermal power production that could aid the rising energy costs of the surrounding communities.

2.0 Proposed Work Plan

As a continuation of the GAP study, ACEP proposed performing geochemistry, temperature measurements and basic geologic mapping of the Division hot springs area. In addition, shallow temperature probes would be drilled to establish an area affected by the thermal anomaly. With the hot springs located within the Division Wildlife Refuge, a special use permit was obtained from the Refuge administration in Kotzebue, which included approval of the logistical plan and site work plan.

3.0 Field Work

Field work was completed by Peter Illig (ACEP), Steve Buckley (WHPacific) and Matt Bergan (WHPacific) from April 15th to the 17th. The group drove snowmachines from Kobuk to Division hot springs on the 15th and completed the mapping, temperature measurements and sample collection on the 16th. The 17th was spent traveling back to Kobuk and Kotzebue. Three water samples were collected with the sample from the hottest spring (160°F) being analyzed by the Desert Research Institute in Reno Nevada for silica and the basic anions and cations. The results of the field work are detailed below.

3.1.1 Location

Division Hot Springs is located northeast of the Seward Peninsula and north of the Yukon-Koyukuk basin at the headwaters of the Division Selawik (Figure 1). It can be reached by a snowmachine trail from Huslia, Shungnak or Kobuk. The hot springs are located in the center of the Shungnak quadrangle.

There are two main springs located at approximately 66° 22’ 40” N 156° 44’ 40” W. The springs lie in a valley that runs downhill to the NE. The surrounding vegetation is comprised of tundra and small spruce trees, while the spring area has little vegetation aside from moss and some smaller plants. The overburden of the vegetated areas is >1m in most areas while the area of the springs it is only a few centimeters thick. The stream running down the valley, cuts through the upper springs and flows around both sides of the lower springs.

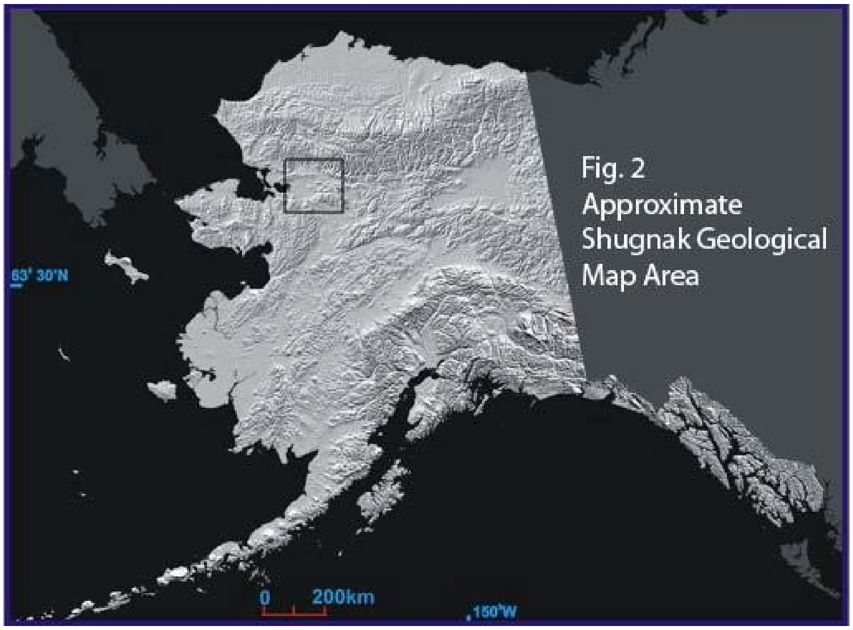


Figure 1 Digital Elevation Map of Alaska

3.1.2 Geologic Background

Division hot springs is surrounded by a suite of volcanic, intrusive and quarternary alluvium formations (Figure 2). The springs discharge directly from andesite and basalt flows (Kv) dated between 137-120 million years old (Ma). These volcanic deposits are a remnant of a Mesozoic volcanic arc. A large granodiorite body (Kgd) is located SW and up valley from the hot springs. The granodiorites range in age from 89-78 Ma in the Yukon-Koyukuk basin[2]. Seismic activity in the region is documented with the Kobuk fault to the north having a 4.6M earthquake in 1980[3]. No structural control of the hot springs had been mapped previous to this field exercise.

3.1.3 Hydrogeology

Thermal fluids of the Division Hot Springs are transported to the surface via a probable fault defining the edge of the valley bottom (Figure 3). The heat driving the geothermal system originates from a combination of decay of uranium in the ~75 Ma granodiorite which presumably underlies the volcanic formation at the surface and the background heat flux from deep within the earth. Cooling plutons lose most of their magmatic heat from formation within about 1 million years[4] which is why radioactive decay must be a primary heat source from a pluton of such an old age. There is a very small chance that younger intrusional activity not seen at the surface provides some percentage of the heat but obtaining evidence for such a heat source by stable isotopes or helium isotope studies is beyond the scope of this project.

3.1.4 Methods

Initially the project plan was to drill 1 meter holes with a portable auger with a 2 in. diameter around the springs to document the extent of high heat flow in the vicinity of the thermal springs. This would have been done by deploying PVC piping with a food grade water mixture to measure the temperature at depth after an equilibration period. The goal was to qualitatively compare the overall heat loss with other geothermal systems such as Granite Mountain and Chena Hot Springs. Temperature gradients would not be derived from these data as the holes would have been far too shallow. Installation of the temperature probes was precluded due to the concerns of local residents for the disruption to the ground at the site by the 2” auger holes.

Similar data was obtained by observing where the edge of the snow melt was which indicated where major heat loss was occurring. Both hot spring areas had snow melt patterns that were oval shaped. The lower spring was surrounded by the creek and had a melt area of 100m in length and 50m in width. The upper spring (upstream) was larger with a length of about 150m and a width of 75m. The next task was to determine the temperatures of all springs and seeps in the area, collect water samples for geothermometry analysis and get a general idea of the snow melt area .

Figure 3 Lower springs showing melt areas and cabins

3.1.5 Thermal Features

The lower spring is located in the northern section of the valley where the cabins are located. The highest temperature of the springs in this area was 135°F (57°C) with a flow of .5 gpm or less (could not measure accurately). Other than infrequent, small bubbles in the waters, there was no direct evidence of a fault at this location. Up stream of the lower hot springs there is no surface expression of heat loss before the upper spring location.

Between the two springs there is approximately .75 miles of swampy overburden that masks any surface expression of the thermal anomaly. The upper spring has a larger surface expression and lines up with the lower springs parallel to the valley floor (Figure 4). It is much more likely that the two thermal areas are part of the same geothermal system and are located along one fault or structure rather than being independent thermal anomalies. Additional evidence for this was the appearance of fault breccia (silicified, angular pieces of the surrounding volcanic rocks) at the upper spring. The fault breccia is representative of crushed rock from fault displacement that is cemented together with large amounts of silica deposited from hydrothermal waters. The lineation of the valley with the two springs, and the appearance of large cobble sized fault breccia oriented parallel to the valley at the upper springs identified the structural control of the thermal anomaly to be a fault running along the valley. The highest temperature reached at the upper springs were 160°F (71°C) with a flow rate ~5 gpm. Taking both springs into consideration, the discharge of the area came nowhere close to 500 gpm which is mentioned in 1.0 Background. The group was not able to identify any springs which produced more than ~5 gpm. Most all of the springs were seeps with little to no flow.

Figure 4 Upper Springs and Approximate Fault Location

3.1.6 Geochemistry

Water samples were taken from the upper and lower Division springs. Only the sample from the upper springs was analyzed due to the fact that it had the highest flow rate (~5 gpm) and the highest temperature (160°F or 71°C).

The upper Division Hot Springs flows a dilute sodium sulfate water. The fact that the fluoride content of the water is equal to the chloride content suggests that the thermal water chemically equilibrated within granitic rocks. The low magnesium content of 0.3 ppm indicates that there has been little or no subsurface mixing of the thermal water with cool groundwater prior to the sample being collected.

This analysis provides an insight into probable temperatures at depth determined by silica geothermometry. The tables below show field measurements, silica/ion concentrations and geothermometry data.

Sample Location	Lab or Source	Temperature (^oC)	pH (field)	pH (lab)
1 Division HS	Desert Research Inst.	71.1	6	8.46
2 Granite Mtn HS	Desert Research Inst.	48.2	7.9	7.9
3 Granite Mtn HS	Miller, 1973	49		10.14
4 Lava Creek HS	Miller, 1973			9.1
5 Mt Kachaulk HS	Miller, 1973	17		8.97
6 Kwinuik River HS	Miller, 1973			7.3
7 Clear Creek HS	Miller, 1973	67		9.43
8 Serpentine HS	Miller, 1973	55		6.75
9 Pilgrim HS	Miller, 1973	60		7.91
10 South HS75	Miller, 1973	67		

Table 1. Surface Temperatures and pH measurements

Sample	Na	K	Ca	Mg	Li	B	SiO2	HCO3	CO3	SO4	Cl	F	Sum Cation	Sum Anion	Balance
1	123	7.97	11.9	0.3	0.14	0.1	93.9	84.8	2.8	198	7.7	7.19	6.19	6.11	0.01
2	64.9	1.19	1.09	0.05	.03	.21	68.2	16.4	37.6	48.6	5.6	7.85	2.92	3.10	.04
3	51	1.3	2	.04	.04	.13	75	45.7		62	9.3	8.2	2.36	2.73	.09
4	75	1.4	2	0		.8	70	100			8.0	9	3.40	2.34	.26
5	111	1.1	14	0.2		.6		40		16	122		5.57	4.43	.16
6	500	9	130	0.1		1	45	10.2			912	5.8	28.47	26.20	.06
7	54	1.4	5.6	0.06		.2		34		25	4.9		2.67	1.22	.57
8	1450	61	530	1.4	4	2.4	100	30.1		24	3346	4.7	91.77	95.62	.02
9	730	40	47	0.48	4.7	3.4	100	64.5		29	1480	6.7	35.84	43.76	.13
10	83	2.1	5.9	0.01			65			122	6				

Table 2. Silica and Ion concentrations (mg/l)

Sample	Surface Temp (C)	Quartz (C)	Calcedony (C)	Quartz (C) (pH corr)	Chaldedony (C) (pH corr)	Na-K-(1/3)Ca (C)	Na-K-(4/3)Ca (C)
1 Division HS	71	134	107	126	99	168	117
2 Granite Mtn HS	48.2	117	88	116	87	110	88
3 Granite Mtn HS (1973)	49	122	93	51	19	116	75
4 Lava Creek HS		118	90	115	86	109	81
5 Mt Kachaulk HS	17					80	40
6 Kwinuik River HS		97	67	97	67	105	72
7 Clear Creek HS	67					111	57
8 Serpentine HS	55	137	110	137	110	146	120
9 Pilgrim HS	60	137	110	135	109	167	163
10 South HS75	67	114	86			115	72

Tabe 3. Geothermometry data

Low concentrations of sodium (Na) and chlorine (Cl) at Division Hot Springs are similar to the Granite Mountain thermal water (Table 2) but are much different than Pilgrim hot springs and Serpentine which have much higher Na and Cl concentrations. Presumably the higher dissolved solids concentrations at Pilgrim and Serpentine Hot Springs involve much higher subsurface temperatures and perhaps longer subsurface residence times.

The silica geothermometer suggests subsurface temperatures as high as 134 C using the solubility of quartz (Table 3). However, applying the pH correction to the silica geothermometer reduces this predicted temperature to 126°C and utilizing the pH corrected chalcedony geothermometer gives a predicted subsurface temperature of 99°C. Therefore, it is safe to say that the most likely predicted subsurface temperature based on silica is somewhere between 99°C and 126°C. The depth at which water of this temperature may be found is unknown given the absence of any nearby temperature gradient data.

The Na/K/4/3Ca geothermometer gives a predicted subsurface temperature of 107°C, which is in reasonable overall agreement with the silica geothermometers (Table 3).

4.0 Discussion

With the field work completed and analysis complete, the following topics will provide a discussion about comparisons between Interior Alaska hot springs, possible geothermal electricity production at Division hot springs, costs and alternative uses.

4.1.1 Comparison with Granite Mountain and Chena Hot Springs

Using temperature, flow and area data from this area we can make a qualitative comparison with other known geothermal sites such as Granite Mountain (GM) and Chena Hot Springs. The length of the thermally active sites or fault at Division is larger than that of GM by a factor of two, and the temperatures exceed GM's by ~40°F. This indicates that there are considerably larger resources in interior Alaska than GM. The Division Hot Springs area however, does not surpass Chena hot springs in overall length or in obvious surface discharge

If the area within the swampy ground between the two hot springs truly is part of the thermal anomaly, then this comparison changes and Division Hot Springs may very well be comparable to Chena Hot Springs. With 3/4 mile long structure producing surface temperatures from 140-160°F there is a possibility of producing geothermal power. This is however speculative without knowing the subsurface temperatures between the springs. *It should be noted that the drilling technique that would have been deployed at the springs would probably have not been sufficient to penetrate below the swampy area.*

4.1.2 Power Generation and Costs Associated

Assuming that the area between the two springs is part of one contiguous geothermal system, it is possible that the area could provide hundreds of kilowatts of geothermal power. Feasibility of power generation from this site would require deep drilling to confirm the amount of heat available in the reservoir. It would be possible to helicopter in a drill rig and spend $1-1.5 million to drill a small diameter 3000-4000 foot core hole for characterization purposes. This hole could not be used for production purposes but would be suitable for determining the resource temperature and chemistry.

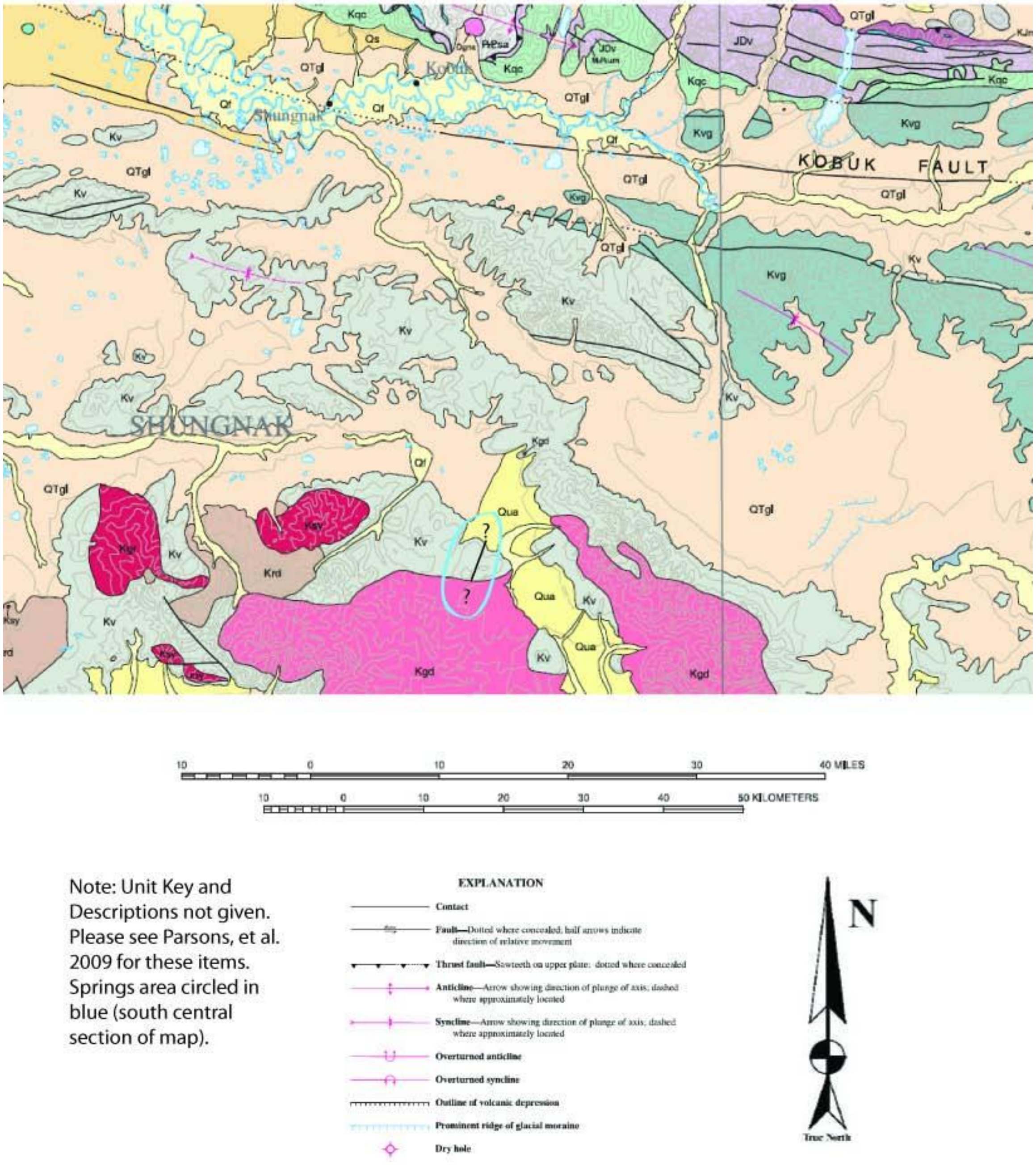
Due to the remoteness of the springs, drilling exploration, production, and injection wells and creating a geothermal power plant would cost upwards of tens of millions of dollars. In addition to these costs, power lines would have to be established from the hot springs to the customer. These power lines can easily cost $500,000 per mile. With approximately 50 miles between the hot springs and Shungnak, the cost could be about 25 million dollars for power lines alone. The third and final issue is that few small geothermal reservoirs of this nature have long operating histories. The feasibility of maintaining power for 20 years and upwards is uncertain. Similar to GM, it would be more feasible if a community were located adjacent to the springs to eliminate power line costs. Lastly, due to the Division hot spring’s location within a federal wildlife refuge, obtaining permits for further exploration would be a major undertaking.

4.1.3 Conclusion

Although Division hot springs would not be economical to develop to power Huslia, Shungnak, Kobuk or another town in the region, the study provided a deeper understanding of plutonic geothermal resources on NANA lands. Alternative uses for the hot springs should also be considered. Division hot springs has sufficient hot water to provide heating for a winter greenhouse. 5 gallons per minute at 160°F may be enough without any drilling to provide sufficient heating for such a project. Projects like these would have low impact environmentally and provide a greater use for the springs. Consideration of the cultural value of the springs to the people of Selawik, Shungnak, Ambler , Kobuk and Huslia should be a major consideration for further investigation and development. Division hot springs should be kept in mind as a future alternative energy resource as communities may move closer to the area or as energy prices rise. The costs currently are too high to provide cost effective power to the local populace, however that may change in the future.

Shungnak Geological Map

Edited by Steve Buckley and Peter Illig from Patton et al (2009)



Note: Unit Key and Descriptions not given. Please see Parsons, et al. 2009 for these items. Springs area circled in blue (south central section of map).

Figure 2 Shungnak Area Geological Map

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