Reconnaissance Study of the Granite Mountain Geothermal Area

Prepared for NANA Development Corporation by:

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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.

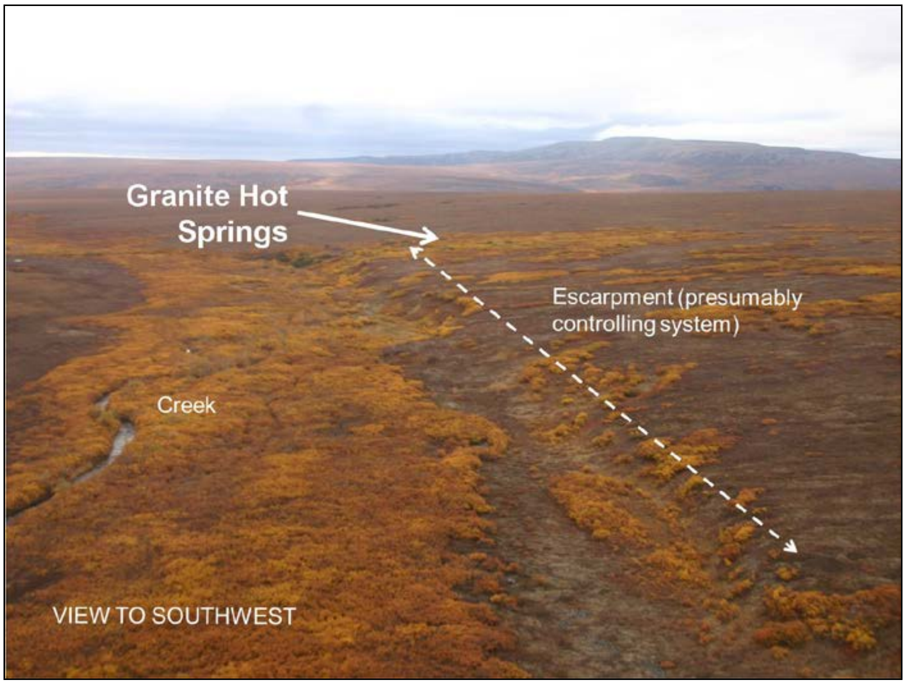

Figure 2. View of escarpment looking to the southwest.

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 ^{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 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 ^{o}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 ^{o}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 ^{o}F.

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 ^{o}F. 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 ^{o}C should be viewed as minimum values.

Sample Location	Lab or Source	Temperature (^{o}C)	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.

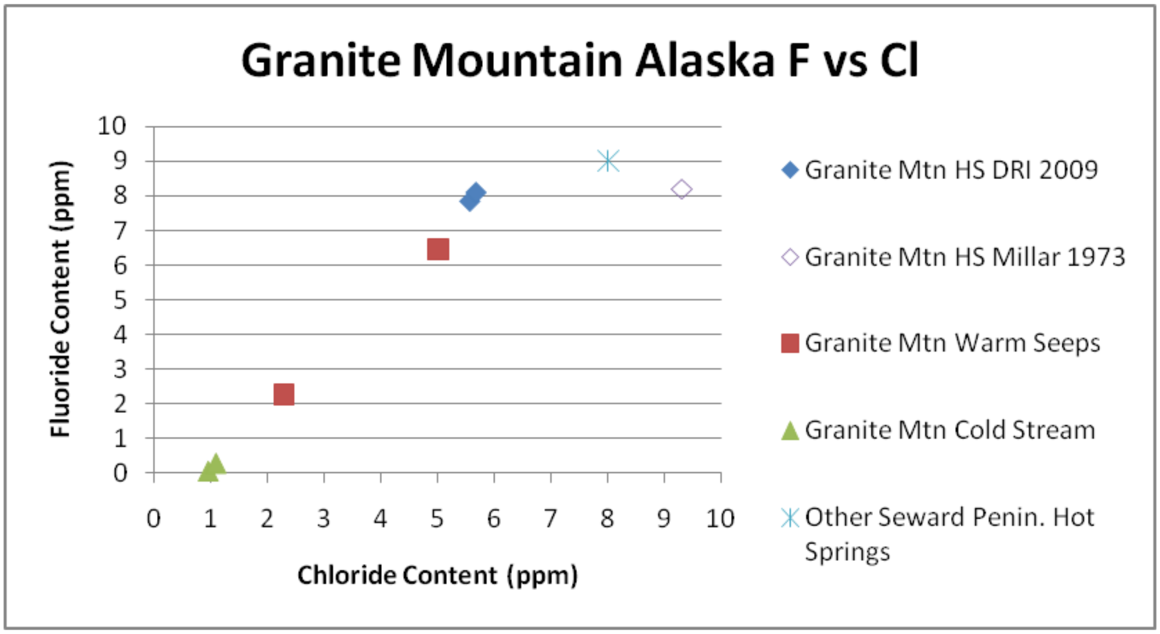

Figure 5. Mixing trend for DRI analysis of thermal and surface waters (F vs Cl).

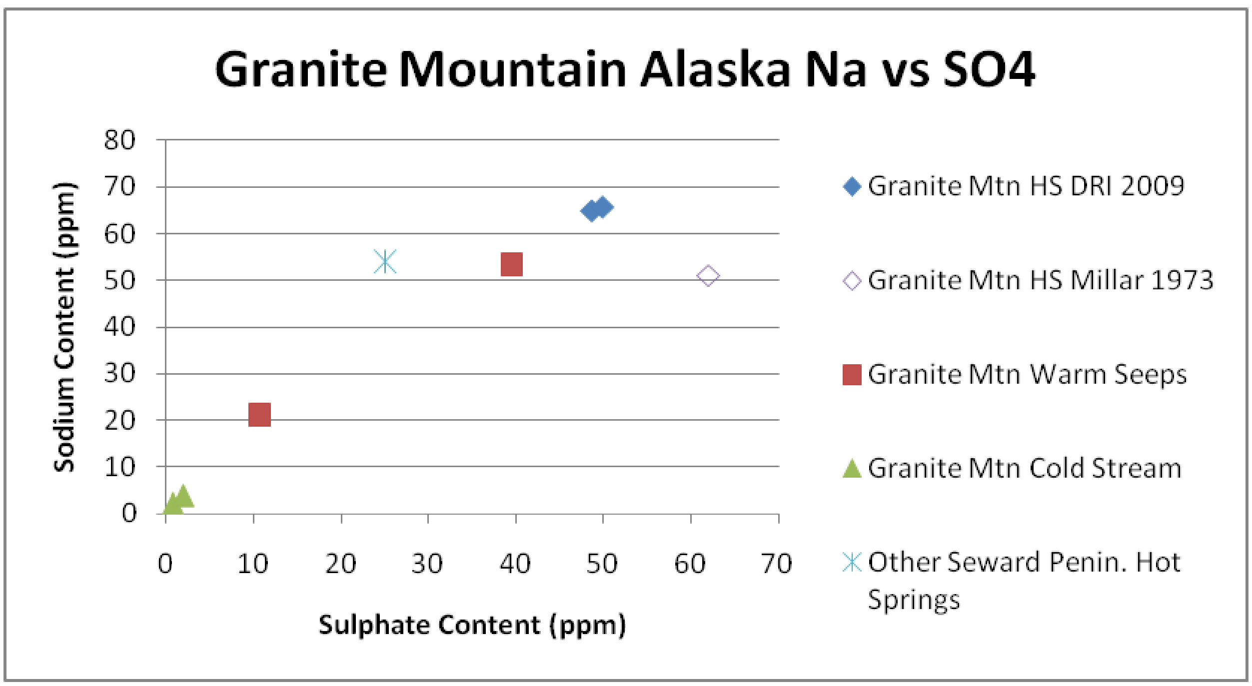

Figure 6. Mixing trend for DRI analysis of thermal and surface waters (Na vs SO4).

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 ^{o}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 ^oC 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 ^oC is the silica geothermometer most likely to be correct as the temperature is less than 120 ^oC. This is 40 ^oC 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 ^oC then the Na-K-(1/3)Ca version is utilized, while if the water is below about 100 ^oC 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 ^{o}C. 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 ^{o}C.

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.