Reconnaissance of a Low-Temperature Geothermal Resource, Tenakee Inlet, Alaska

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ABSTRACT

A reconnaissance study of the Tenakee Inlet geothermal resource was conducted in order to evaluate its nature and determine if there is potential for power generation. The resource is in a remote, rugged area of southeastern Alaska, accessible via helicopter. A prior hot spring temperature measurement was 176 °F. Tenakee Creek is located to the immediate northeast of the hot springs. The Queen Charlotte Fairweather fault system lies to the west of the resource and is part of a transform plate boundary with associated earthquakes and linements aligned north to south. Fieldwork consisted of a shallow soil temperature survey and collection of soil, water, and rock samples. The shallow soil temperature survey indicated a broader thermal area than just around the hot springs and includes portions across Tenakee Creek. Soil samples had chemical species that were anomalous near the hot springs as well as across the creek in the same areas as the higher temperature readings. Water samples from the hot springs indicated fluids low in chlorine and bicarbonate but high in sulfate. The hot springs waters are most likely associated with volcanic waters and perhaps heated by steam from a deeper reservoir. Surface temperatures of the hot springs ranged from 161 to 177°F over the course of the 15-day long field effort. Based on the chalcedony geothermometry the hot springs fluids may have been heated to 260°F. The surface and subsurface temperatures are in the range appropriate for a binary geothermal power plant.

Introduction

The purpose of the reconnaissance study was to evaluate the nature of the resource and determine if there was potential for power generation to serve the communities of Pelican and Hoonah. The resource is located near the head of Tenakee Inlet on northern Chichagof Island, in southeast Alaska. The Tenakee Inlet Geothermal Resource is located approximately 19 air miles southwest of Hoonah Alaska along an un-named river we have called Tenakee Creek. Figure 1 presents a location map for the hot springs. The area is characterized by rugged, steep terrain covered with thick vegetation typical of the southeastern Alaska rainforest. Topography limited the exploration area to the valley floors and to the first bench above the river valley.

The resource is characterized at the surface by at least four small hot springs that occur together on the southeast side of the Tenakee Creek located at approximately 57° 59' 24" N and 135° 56' 20" W. An aerial photograph of the vicinity of the hot springs is presented in Figure 2. The focus of the study was the immediate hot springs area and approximately ¼ to ½ square mile surrounding the hot springs. There are two streams that bound the study area on its southwestern and northeastern sides.

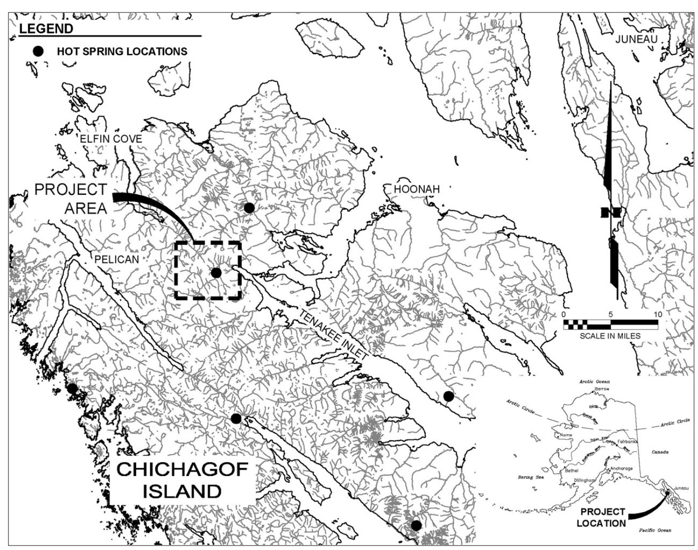

Figure 1. Location map for Tenakee Inlet hot springs. Hot springs located approximately 19 miles southwest of Hoonah Alaska in southeast Alaska. There is a number of hot springs on Chichagof Island as shown by black circles on the vicinity map.

The hot springs shown in Figure 1 have been documented and tested for minerals and temperature. The reported surface temperature of the Tenakee Inlet hot springs is 176°F with geochemistry of the waters indicating a maximum subsurface temperature of 243°F (Motyka et al, 1983). The other hot springs in the region have lower surface temperatures.

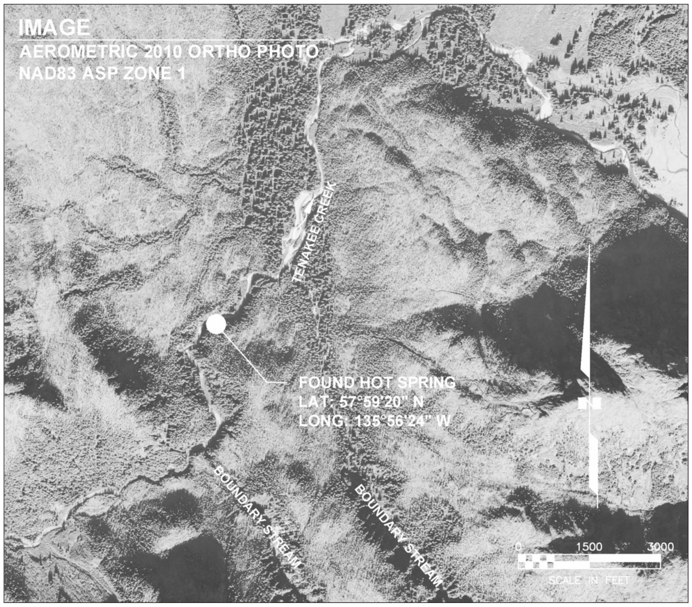

Figure 2. Aerial photograph of vicinity. Note location of the hot springs on the southeast side of Tenakee Creek. Flow as indicated by blue arrow is to the northeast and then near the top of the photograph, Tenakee Creek turns to the southeast and flows into Tenakee Inlet. Boundary streams occur to the northeast and southwest of the hot springs.

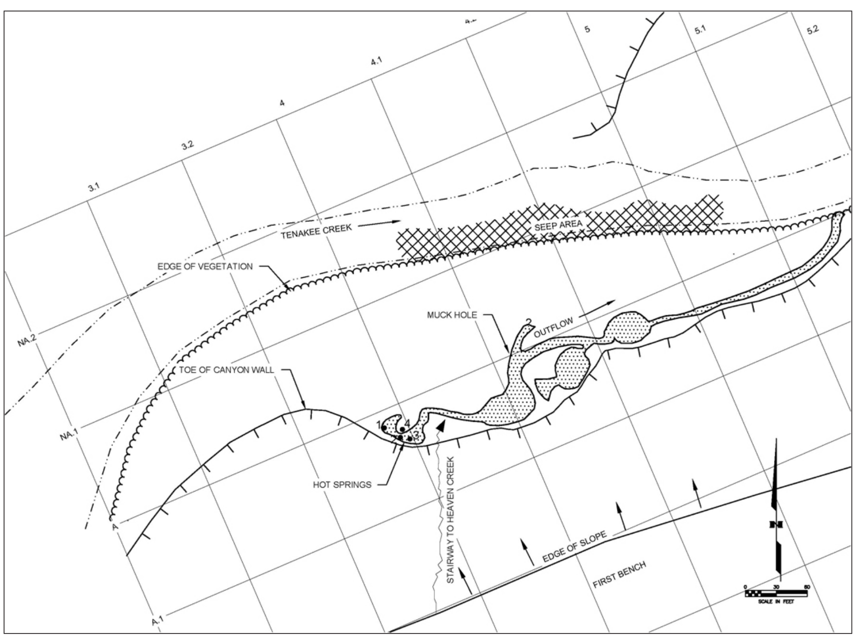

Figure 3. Site map of hot springs area. Note the location of the four hot springs, the seeps at the edge of Tenakee Creek and the outflow from the hot springs. The first bench located above the hot springs is approximately 40 to 50 feet higher than the base of the slope. The sampling grid is partially drawn for reference. The hot springs occur at grid point A4.

The Tenakee Inlet springs are comprised of four small springs that flow from the base of a rock cliff approximately 40 to 50 feet in height. The hot springs area is small about 50 feet long by 20 feet wide occurring on a gravel bar that is heavily vegetated with alders, willows, and spruce trees. The gravel bar is approximately 800 feet long and 100 feet wide. The hot spring site and the location of the four hot springs are shown in Figure 3. There is an outflow creek from the spring site that leads to Tenakee Creek. A stream named the Stairway to Heaven Creek cascades down the slope and mixes with the outflow near the spring sites. Seeps occur along the shore of the gravel bar and are periodically inundated by Tenakee Creek.

Fieldwork consisted of collecting shallow soil temperature data, as well as soil, water and rock samples from various locations surrounding the hot springs and the immediate vicinity. A grid was established to systematically collect temperature data and soil samples. Water and rock samples were more varied and were dependent upon their location with respect to the hot spring.

Regional Characteristics

General Geology

The Tenakee Inlet area is composed of Devonian argillite, graywackes and limestones that were subsequently intruded by a wide variety of igneous rocks (Loney, et al 1975). These rocks outcrop near the study area and north of it. The intrusives vary in age, but are primarily Cretaceous in the study area and are mainly diorite to granodiorite in nature. These rocks are widely distributed on Chichagof Island. To the south of the study area there is a large body of Tertiary intrusives consisting of hornblende leuoconorite and troctolite. The Devonian sedimentary rocks have undergone extensive regional and contact metamorphism. The intrusives have metamorphosed them into hornfels, and marbles. The rocks are intensely folded and faulted. The fold axes trend northwest.

Structural Geology

The geologic structure of the area is dominated by the Queen Charlotte-Fairweather (QCF) fault system and the Chatham Strait Fault. The QCF fault system lies to the immediate west of Chichagof Island and the Chatham Strait Fault defines the Chatham strait between Chichagof Island and Admiralty Island to the east. The faults of the QCF system are active right-lateral structures with large displacements. The Chatham Strait Fault offsets rocks as young as middle Tertiary and by as much as 90 miles. (Gehrels and Berg 1994).

The QCF fault system defines the boundary between the Pacific and North American plates. In the middle Mesozoic prior and/or concurrent with the intrusion of the igneous rocks in the study area, southeast Alaska was involved in the subduction of the Pacific Plate beneath the North American Plate, which over time evolved into the dominant transform plate boundary seen today. This tectonic activity has resulted in a complicated pattern of thrust, oblique slip, and strike-slip faults on Chichagof Island. The rocks in the study area are part of the Alexander Terrane, which is inferred to have continental origins (Karl, 1999). The rocks are interpreted to represent intermittent volcanic arc activity.

Modern earthquake activity occurs along the QCF fault system. The most recent large magnitude earthquakes in the area of the hot springs occurred in 1927 and 1939. The epicenter of the 1927 magnitude 7.1 event occurred at latitude 57.69 and longitude -136.07. The 1939 magnitude 6 event occurred at latitude 58.00 and longitude -136.0. The hot springs are located at latitude 57.99 and longitude -135.939.

Climate

Climate in the region is maritime characterized by cool summers and mild winters. Foggy periods typically occur in the spring and fall. Summer temperatures in Hoonah average from 52 to 63 °F, and winter temperatures from 26 to 39 °F. Precipitation in Hoonah averages 100 inches annually, with 71 inches of snowfall.

During our fieldwork we established a small weather station at the base camp near the hot springs. The temperatures in late September – early October ranged from 36 to 48 °F. Precipitation occurred on six of the 15 field days and ranged from 0.04 inches to 1.02 inches.

Methodology

Fieldwork began on September 21, 2011 and was completed on October 9, 2011. The Hattenburg Dilley & Linnell six-man field team was based out of Hoonah and supported with full-time helicopter transport provided by Coastal Helicopters. A grid was developed based on 300 feet by 300 feet squares prior to the fieldwork. This grid and the study area proposed were limited due to topography, vegetation, and subsurface temperature information. Three survey control points were established (two near the hot springs and one on the east side hill) in order to maintain accurate survey control for future fieldwork and development. A rectangular grid was then established from the base line onto the surrounding hot springs area. GPS coordinates were collected at grid points. These points were used as the locations to collect the soil samples and install shallow temperature probes. The field crew started from the hot spring location and worked outward in a spiraling pattern to gather the data, with tightly-defined 100 foot spacing nearest the hot spring, then expanding to 300 ft spacing. At the conclusion of the 15 day field work, the team had established over 120 grid points. Eighty-four temperature readings were obtained; and 37 water, 63 soil and 7 rock samples were collected. Rock outcrops were difficult to find, therefore only a few samples were collected for petrographic analysis.

Field Work

Shallow Soil Temperature Survey

The shallow soil temperature survey used steel pipes as probes inserted into the ground and a thermistor was installed. The equipment included 5-1/2 foot long sections of 3/4” steel pipe for probes, RTD (Resistance Temperature Detector) temperature measuring devices, demolition hammers for driving probes up to 5 feet into the ground, and data loggers/meters to record the temperature measured by the RTD. The steel pipe was fabricated into a probe by welding one end closed and hard facing it to allow it to penetrate hard ground. Forty probes were fabricated and reused during the study. The field work involved inserting the steel probes in the ground, waiting for thermal equilibration, installing thermistors, and measuring the temperature at the bottom of the probe, then moving the probes to a new location and repeating the operation. Readings that indicated higher temperatures were remeasured. It took approximately 1 to 2 hours for the thermistors and ground disturbance to equilibrate.

Selective Extraction Geochemical Analysis

We conducted a selective extraction geochemical study consisting of obtaining samples from the B soil horizon and conducting enzyme leach and terrasol selective digestion on the soil sample. The method relies on the fact that geothermal systems, like mineral deposits, have at the surface a number of chemical elements that get distributed around their margins. Trace elements can be trapped in amorphous oxide coatings on sand and silt grains in soil near the surface. Enzyme leach and Terrasol digest these coatings and releases the trapped trace elements. An analysis of the sample is conducted for up to 68 trace and major elements by ICP-Mass Spectrometry. The concentrations of these elements are mapped and distinct patterns indicate areas of interest. Sampling consisted of using a clean spoon to obtain soil from a hole excavated below the organic layers. Care was taken to maintain clean spoons and sampling equipment. An approximately 25 gram sample collected using a stainless steel table spoon was placed in a 50 ml plastic tube that was supplied by the laboratory. The samples were typically fine-grained. Care was taken to avoid and/or eliminate particles larger than about coarse sand.

Water Sampling

Water samples were collected for chemical analysis from the hot springs, and Tenakee Creek. Additional samples were taken upstream and downstream of the hot spring location and from the two boundary streams. Temperature, pH, and conductivity were collected on-site at each location. Sampling consisted of collecting approximately 800 ml of water in several bottles supplied by the laboratory. The bottles were washed using the fluid to be collected. The water was filtered if it appeared to be cloudy. The majority of the samples were not filtered due to the clear nature of the water. In addition to the water samples collected for chemical analysis, additional 25 ml samples were gathered at select locations for isotope analysis.

Laboratory Analysis

Skyline/Actlabs of Tucson Arizona analyzed the soil samples. The water samples were submitted to WetLab of Nevada for cations/anions analyses, and geothermometer components, and to Southern Methodist University in Texas for isotope analysis. A selective extraction process (enhanced enzyme leach) was used at Skyline Laboratories on the soil samples. The extraction process leaches amorphous MnO_2 and analyzes 68 trace and major elements by ICP-Mass Spectrometry. The detection limits are typically on ppb levels with a few elements at the ppm level.

Water samples were analyzed for silica, metals, and various anions and cations.

Data

Soil Temperature

The shallow soil temperature data obtained are presented in Figure 4. The hottest temperatures occurred near the hot springs and at the seeps found at the edge of Tenakee Creek. Temperatures near the hot spring range from 81.2 to 108.9 °F. The hot springs outflow had soil temperatures of between 58.3 and 86.1°F. Seeps were observed when the water level in Tenakee Creek was lowered during a few days of no rain. The one seep had a nearby soil temperature of 130.5 °F. Temperatures on the hillside above the spring ranged from 49.9 to 46.4 °F. A relatively cool temperature of 44.3 °F was measured upstream of the hot springs located near the edge of the gravel bar that hosts the hot springs. The temperature readings in the 40’s were considered background soil temperatures.

Additional temperatures above background were encountered at several spots across Tenakee Creek at the base of the slope. The hottest shallow soil temperatures across the creek from the hot springs were 88.8 °F and 59.5°F. There were several points across the creek above 50 °F with one (56.5 °F) occurring about 1,200 feet downstream of the hot springs. These temperatures do not appear to be the result of outflow from the hot springs. The temperature of the water in Tenakee Creek was approximately 40°F.

Water Data

The average chemical concentrations for the hot spring, seep, and surface water samples were calculated. A location map of these features is presented in Figure 3. The temperature of the hot spring waters averaged 170°F with Hot Spring #1 having the hottest temperature of 177 °F on two sampling events and Hot Spring #4 having the coldest at 161°F. The average water temperature for hot springs #1 through #3 was 172°F. The average surface water temperature was 40°F.

A spreadsheet developed by Powell and Cummings (2010) was used to evaluate the chemistry of the water samples. Laboratory data were entered into the spreadsheet and a series of standard geothermal plots were developed. Geothermometers were calculated and ternary plots were produced. The CL-F-B plot shown in Figure 4 indicates that the collected hot spring waters (HS) and the surface water (SW) samples are from different populations. This is important in that the two waters clearly represent separate types of fluids. The often used Cl-SO_4-HCO_3 ternary plot illustrates the amounts of major anions present in the geothermal waters (Figure 5). This plot indicates that the hot spring waters are low in chlorine (Cl) and bicarbonate (HCO_3) and high in sulfate (SO_4). It also indicates that the hot spring waters are associated with volcanic waters and perhaps heated by steam from a deeper reservoir. A high sulfate spring is typically associated with deeper boiling zones.

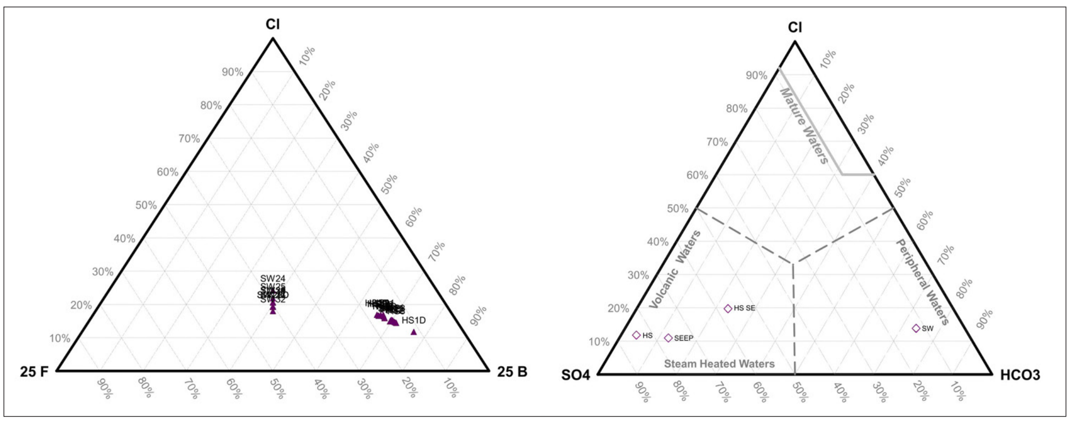

Figure 5. Plots of water chemistry data. The hot springs water (HS) is clearly different from the surface water (SW) samples collected. The hot springs waters are high in SO_4 and low in HCO_3 and Cl indicating possibly waters associated with volcanic waters.

The isotope plot (Figure 6) indicates that both the hot springs and surface waters are primarily meteoric and have not mixed with other fluids. The chalcedony geothermometer provides a more accurate temperature for the hot spring fluid at depth based on the concentrations of silica and potassium/magnesium (Figure 6); it shows that the hot spring fluids have been heated to 260°F.

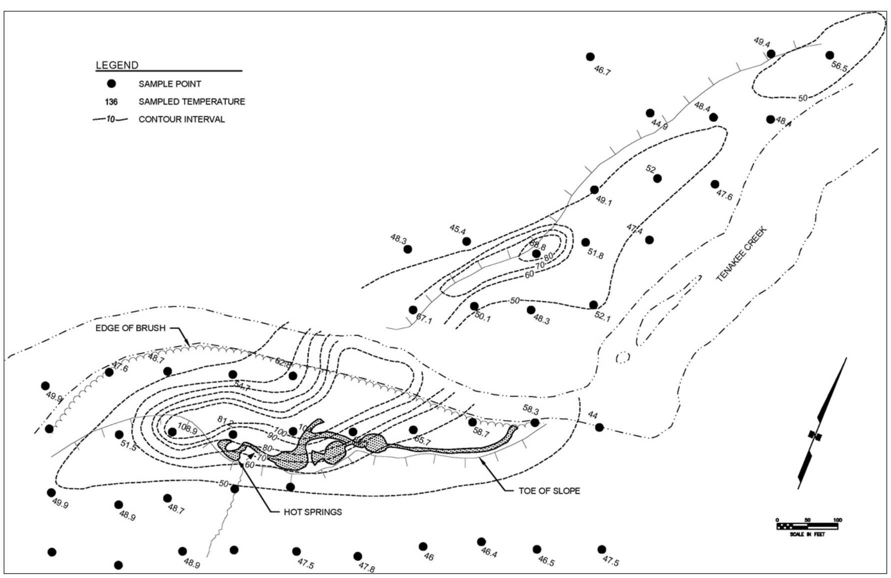

Figure 4. Shallow soil temperature survey results. Note the higher than background temperatures on the north side of Tenakee Creek.

Soil Data

The soil chemistry was plotted for six elements; i.e., Arsenic (As); Cobalt (Co); Gold (Au);

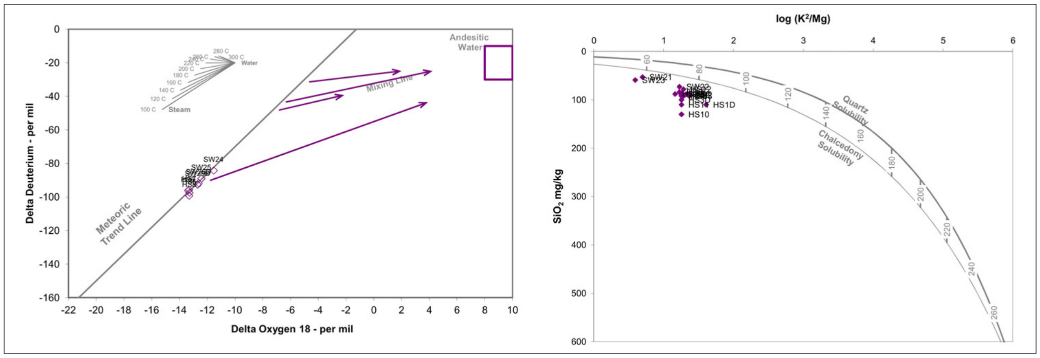

Figure 6. Isotope plot on the left indicates that the hot springs waters are primarily meteoric. The geothermetry was based on the chalcedony geothermetry due to the concentrations of silica and potassium/magnesium as shown in the plot on the right.

Manganese (Mn); Titanium (Ti); and Vanadium (V). These chemical species had orders of magnitude changes in concentrations across the sampling area. Data were contoured using roughly the standard deviation in a particular elements concentration. Mercury is usually used in geothermal exploration; however, the results did not indicate a large variation in mercury concentration.

The species plotted indicated anomalous concentrations generally near the hot springs and along the outflow but also across Tenakee Creek where the concentrations were higher in areas of elevated soil temperatures. The highest concentration of gold was near the confluence of the hot spring outflow and Tenakee Creek. The highest concentration for arsenic was across the river from the hot springs at the grid point that recorded the highest temperature on that side of the river. In addition, vanadium had higher concentrations along the ridge above the hot springs perhaps indicating a fracture or fault.

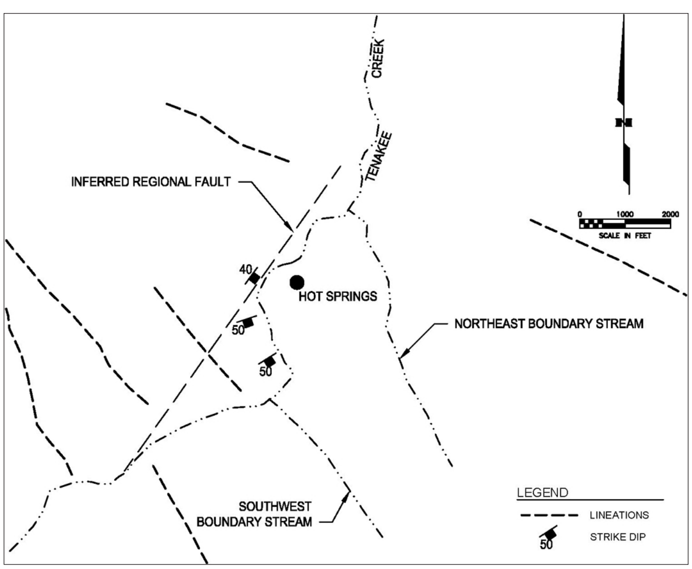

Figure 7. Major lineations in the study area. Note the offset of Tenakee Creek near the hot springs possibly indicating a wrenching effect creating permeability for the springs.

Lineations

Lineations were determined from stereographic aerial photographs and may represent faults or joints. The lineations were not observed on the ground due to the dense vegetation, however during the helicopter flights over the area, many of the lineations could be seen on a regional scale. Figure 7 presents the more notable lineations and the course of Tenakee Creek. The lineations are typically aligned northwesterly with some cross lineations. This alignment is typical over the entire southeast region and is due to the large QCF fault system and regional tectonics. Particularly interesting is the offset in Tenakee Creek near the hot springs. There is a set of lineations that occur northwest and the creek is offset on east-west lineations. The measurements obtained from geological maps indicated steeply dipping lineations.

Preliminary Interpretations

In the Tenakee Inlet Area, based on shallow temperature probe and soil analysis data there appears to be additional thermal areas across Tenakee Creek from the known four hot springs. These thermal areas would suggest that the geothermal source is larger than just the known four hot springs. The occurrence of chemical anomalies in the soil in the hotter areas across Tenakee Creek also suggests that the hot fluids are circulating near the surface indicating permeability.

The lineations and general tectonics of the region suggest that the hot springs were developed due to the wrenching of the cross cutting lineations near the hot springs which led to the fracturing of the rocks. Also given the high angle nature of many of the lineations, it is reasonable to assume that high angle faults bring the geothermal fluid to/near the surface. The earthquake data suggest that the study area is tectonically active and that the igneous intrusives are permeable.

Based on the water chemistry, the hot springs fluids are most likely associated with volcanic waters and perhaps heated by steam from a deeper reservoir. The chalcedony geothermometer indicates that the hot spring fluids have encountered temperatures on the order of 260°F. The average surface temperature of the hot spring waters is 170°F. These surface and subsurface temperatures are in the range that binary geothermal power plants operate. Much like Chena the site benefits from having cool waters at approximately 40°F as a sink.

Additional Work

A conceptual model of the area still needs to be developed. In addition, the hydrology of the study area should be evaluated. Geophysical studies such as self potential (SP) would assist in characterizing the area and provide additional subsurface information. We will be conducting additional fieldwork in the summer of 2012. The following presents some of the fieldwork that still needs to be done:

1. Fly overs with an infrared camera in the spring to evaluate potential other "hot" areas. During the summer of 2012 we will collect surface water temperatures and estimate the flow of Tenakee Creek (Does it freeze, does it still flow, partially frozen during the early spring?).
2. Conduct a SP geophysical survey in order to evaluate the hydrology of the area and provide additional subsurface information.
3. Conduct additional studies of the area across Tenakee Creek from the hot springs where we measured high temperatures and obtained anomalous soil data.
4. Investigate further the seeps near the edge of Tenakee Creek to determine if they are related to the known or other hot springs. Excavate holes along the gravel bar to collect groundwater samples and to evaluate possible flow from the hot springs to the seeps.
5. Collect flow data from the hot springs, creek, and outflow areas.

Acknowledgements

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