DATE: March 16, 2012

TO: Lee Robinson, Martin Booth

FROM: Rick Zehner

SUBJECT: Analysis of Top 5 Colorado Targets

This memo is meant to evaluate and rank the top 5 targets that were selected during Flint Geothermal LLC's ("Flint") 2011 field reconnaissance of western Colorado.

TARGET #1: Routt (aka Strawberry Park) Hot Springs, Routt County

Main Points:

1. The geology and consistent geothermometery suggests a ~150^{o}C reservoir.
2. Concise target area: the geothermal upwell zone seems to be constrained to a small (2-3 mi^2) area.
3. Approximately two miles to nearest 230kv transmission line.
4. Although the [seeming] best part of the target area is on private land and thus leasable, land owners and acquisition may be the biggest challenge. USFS land surrounds the private parcels.

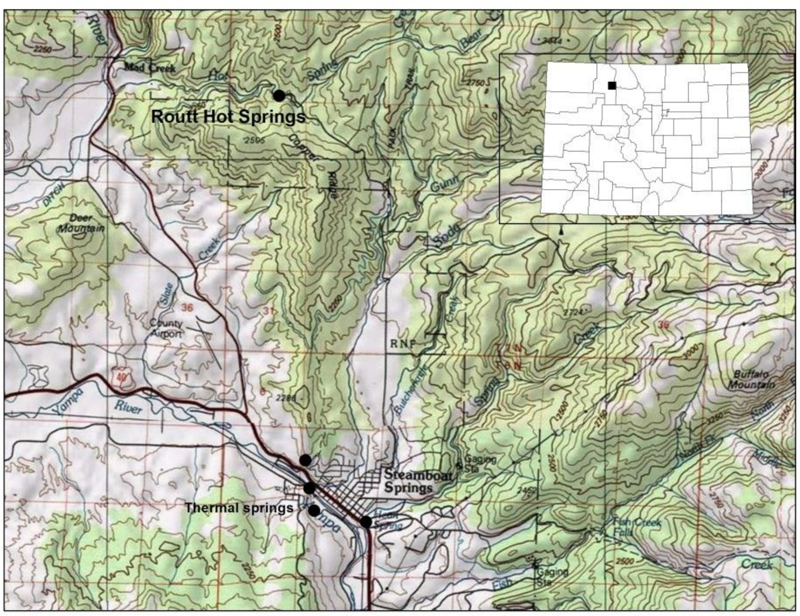


Figure 1. Location of Routt Hot Springs

Site Description

Routt, or Strawberry Park Hot Springs ("RHS"), is located in the Park Range approximately 5 miles north of Steamboat Springs in Routt County, Colorado (Figure 1). The springs occur along Hot Springs Creek at 7500' elevation in a rural part of Colorado that is a mix of private and National Forest Land. A 230kv transmission line passes within about 2 miles of the springs.

An estimated 250 g/min flow emerges from several springs in Precambrian granitic rocks; the maximum measured temperature is 63.1°C. The water is currently used for bathing at the Strawberry Hot Springs resort (http://www.strawberryhotsprings.com/2005/), which overlies the main springs.

RHS is one of two clusters of thermal springs in the area; the other consists of several warm and hot springs in and around the town of Steamboat Springs, south and downhill from RHS. The warmest of these, Sulphur Cave warm springs, vents 39°C water from a large travertine mound adjacent to the Yampa River. Other, cooler thermal springs occur nearby. Hot water was encountered at shallow depth during construction of the high school at Steamboat Springs north of and slightly closer to RHS. Pearl et al (1983) mentions that residents of Strawberry Park (just north of town) claim that snow doesn't last long in spots, suggesting areas of geothermally warmed ground there.

Land Status

The area around RHS consists of 3 owners: 1) Don Johnson, owner of the 40 acre parcel containing the Strawberry Park hot springs resort, and 2) James Mann, owner of 172.68 acres of land in 3 parcels south and uphill of the springs, and 3) Routt National Forest, owning most land surrounding these 4 parcels.

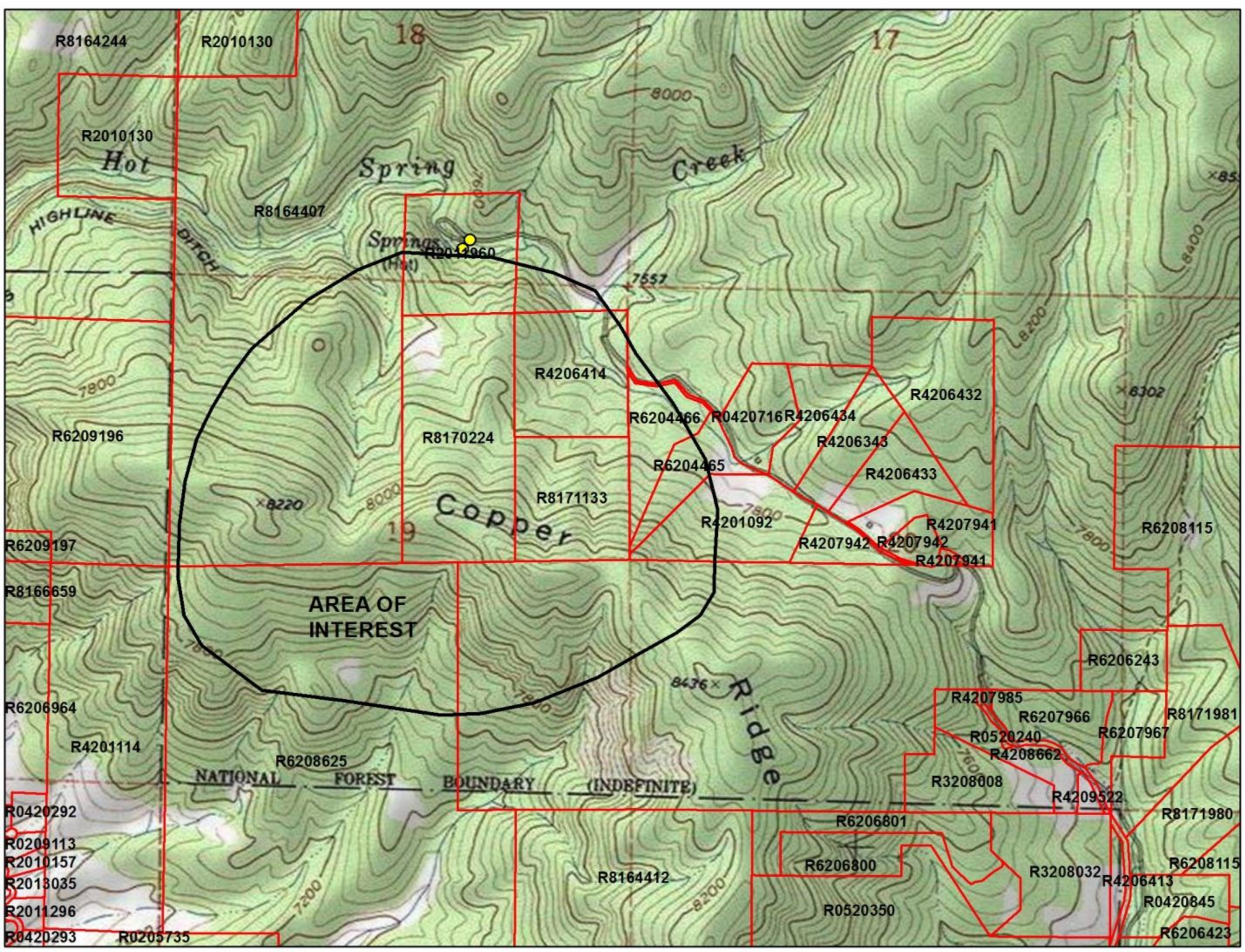


Figure 2. Land parcels in the Routt Hot Springs area along with a proposed "area of interest.

Previous Work

A number of published articles discuss the regional geology and the geothermal potential of Colorado, as well as the Steamboat Springs-Routt Hot Springs area. Christopherson (1979) completed geophysical surveys around the geothermal systems as part of his MS Thesis. Pearl et al (1983) made a geothermal resource assessment of these two areas, which included limited resistivity and mercury and helium soil surveys. The Colorado Geological Survey ("CGS") analyzed water samples for trace elements and isotopes.

Flint Geothermal LLC personnel visited the area in August of 2011, with a focus on Routt Hot Springs. Water samples were collected at the springs, along with rock structural data, and land owners Johnson and Mann were contacted. In addition, a 2m survey was conducted on the south side of Copper Ridge south, of the springs.

Geology

Regionally, the area lies on continental cratonal rocks at the eastern edge of a Paleozoic to Tertiary basin that accumulated thousands of feet of sediments over its long history. The Park Range to the east is an uplifted block of Precambrian rocks that forms this cratonal basement. RHS occurs just mile east of the basement margin in Precambrian coarse-grained orthoclase-biotite granite and gneiss that comprises part of the Precambrian package.

The northwest-striking contact between the basement and the sedimentary rocks occurs approximately 1.5 miles west of the springs and has been variously mapped as either a reverse or thrust fault. Numerous photo-lineaments in the area around RHS have this orientation. Northeast and north-south lineaments also occur in the area, and measured fracture orientations within the granite at and around RHS parallel these three orientations (Figure 3).

The main hot springs issue from the south side of Hot Springs Creek perhaps 40 feet vertically up the hill from closely-spaced fractures that locally resemble weak, narrow shear zones. These shears have a dominant N5^{o}W, 80^{o}NE orientation but N15^{o}E and N32^{o}W, and N40^{o}E and N73^{o}W conjugate shears are present. Warm water (~90^{o} F) was also encountered while drilling a water well last year north of Hot Springs Creek. The depth where warm water entered the hole was reportedly several hundred feet below creek level.

Hydrothermal alteration occurs immediately adjacent (<30 feet) to the spring vents. There, biotite has been completely destroyed, plagioclase is fresh or altering to clay, and opal is depositing within altered plagioclase molds and even on fresh twigs from forest litter. Larger areas of hydrothermal alteration were not observed, although a north trending zone of chlorite-epidote alteration was reported by Pearl et al (1983) approximately one half mile west (downstream) from the springs.

71^{o}C water, hotter than RHS, was encountered at ~80 foot-depth ¼ mile southeast of the springs several years ago during the drilling of water wells for Jim Mann's mansion (Figure 3). Apparently finding cold water for drinking in the vicinity of the mansion was a problem, for several wells were drilled, all of them thermal. Mann currently uses the hottest well to heat his house.

Mann's mansion (and the hot wells) are located approximately a quarter way up the north side of Copper Ridge, uphill from RHS (Figure 3). Interestingly, the flat area he chose to build corresponds to a saddle formed by a northwest-striking air photo lineament that is probably a fault. Other NS, NW, and NE lineaments occur in the area around Routt Springs and these hot wells, which correspond to fracture orientations mapped at the spring vents.

The thermal waters apparently do not make it over to the south side of Copper Ridge. Field work there in August 2011 found only cold wells and a lack of warm ground as measured by shallow (2m) survey rods. Therefore it appears that at least one fracture zone where geothermal fluids are rising (and thus a drill target) lies somewhere between the RHS (and Hot Springs Creek) and the top of Copper Ridge. Thermal waters could also be flowing down the hydrologic gradient from some upflow zone to the north, as evidenced by Johnson's warm water well. However, since the thermal well water was lower temperature and encountered below creek level, it is more likely that hot water mixed with colder creek waters in fractures before entering this well from the south.

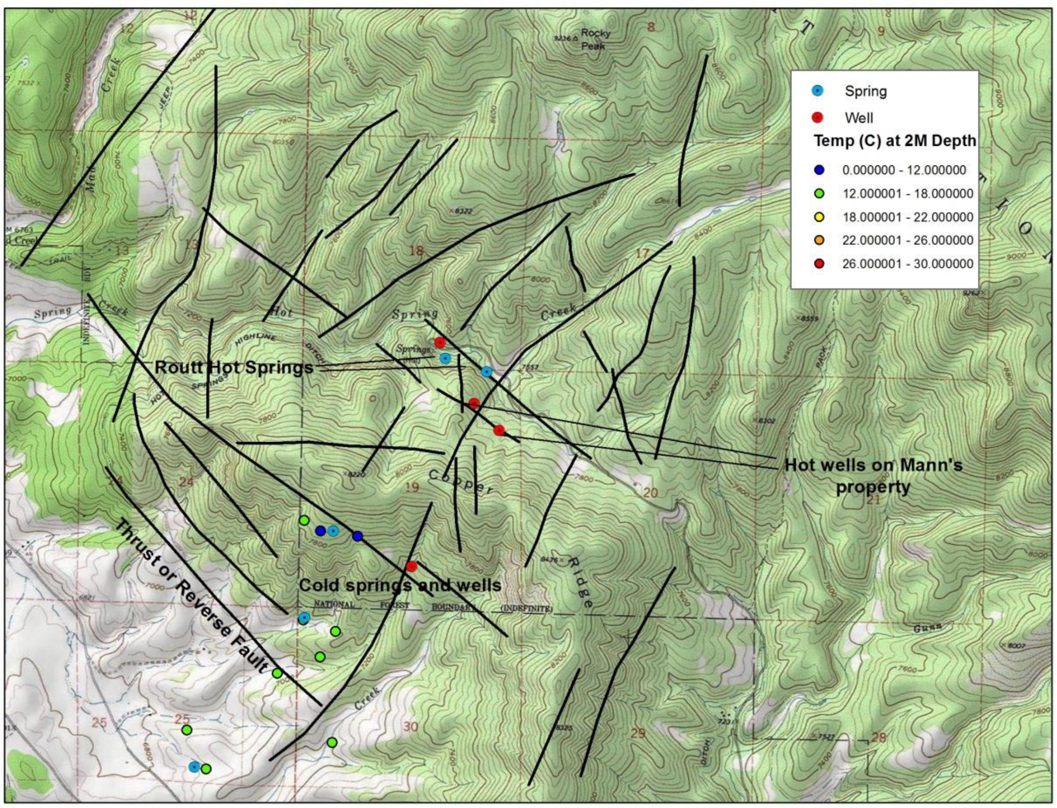


Figure 3. Location of air photo lineaments, springs and wells, and shallow (2m) sampling in the Routt Hot Spring area.

Geochemistry

Water samples from Routt Hot Springs show it to be a sodium dominated, chloride +/-bicarbonate system, with high silica and fluoride. The waters appear to be more or less in equilibrium with reservoir rocks, which suggest that the geothermometer values are trustworthy. Overall, these geothermometer estimates indicate a reservoir temperature in the 125°C-150°C range (Table 1). Note that the cation values of the sample we took ("Routt: Flint Sample") are similar to published values, but the silica geothermometer values we took are considerably higher, indicating possible equilibration within a +200°C reservoir. This could be due to our care in separating and diluting that portion of the sample designated for silica analysis, to prevent precipitation of silica in the bottle.

Sample Name	Amorphous Silica	Chalcedony cond	Quartz cond	Quartz adiabatic	Na-K-Ca	Na-K-Ca Mg corr	Na/K Fournier	Na/K Truesdell	Na/K (Giggenbach)	K/Mg (Giggenbach)
ROUTT HOT SPRING A	10	101	129	126	124	124	168	128	186	124
ROUTT HOT SPRING A	12	104	132	128	126	126	171	131	189	126
ROUTT HOT SPRING A	6	97	125	122	155	155	167	126	185	113
ROUTT HOT SPRING A	15	109	136	131	154	152	172	133	190	106
ROUTT HOT SPRING B	16	109	136	132	158	121	173	134	191	103
ROUTT: FLINT SAMPLE	122	238	250	221	153	153	165	124	183	264

Table 1: Cation and silica geothermometer estimates for Routt Hot Springs (in degrees Celsius).

Discussion

Routt Hot Springs has very good evidence suggesting that its reservoir meets binary power plant temperatures. Furthermore, the location of the upwelling fracture zone appears to be tightly constrained spatially. The two together make for an excellent exploration target.

1. Reservoir temperature: The presence of opal precipitating directly from the spring, together with the geothermometry data, suggests that waters from Routt Hot Spring came from a 125°C-150°C reservoir, hot enough to support a binary power plant.
2. Location of Upwell zone: The available geology seems to imply the upwelling zone occurs within a small target area, without much lateral outflow. Water hotter than RHS is found at the Mann mansion partly up Copper Ridge to the south of RHS. Fractures of several orientations and air photo lineaments cut through this area. Only cold springs are found on the south side of Copper Ridge. This suggests that at least one fracture zone with upwelling geothermal fluids lies between RHS and the top of Copper Ridge.
3. Reservoir, additional: The Precambrian granites and gneisses that comprise the bedrock in this area would maintain fractures under geothermal conditions, and serve as a good reservoir rock. However, if the fault to the west of RHS that separates the Precambrian rocks from the sedimentary basin package is in fact a thrust fault, it probably underlies RHS. If this is the case, geothermal fluids could be traveling laterally along the thrust fault or the Dakota Sandstone (just underneath the thrust fault), and the reservoir may not be directly underneath RHS. An MT survey could probably determine this.
4. Relationship of Routt Hot Springs to Steamboat Springs: Although the geochemistry of both sets of springs is similar, Steamboat Springs is uniformly cooler and has lower geothermometer values. It is also lower in elevation, and spots in Strawberry Park, intermediate between the two, has areas of hot ground and geothermal water at depth. The implication is that Steamboat Springs is the down-gradient outflow of the Routt Hot Springs system.

5. Land Ownership: The Johnson and Mann land parcels seem to overlie the apparent upwelling zone. Acquiring this land for geothermal development will probably be the toughest obstacle to first-year exploration. Care must be taken to find an acquisition scenario suitable to everyone. In addition, since most of the surrounding land is Federal National Forest land, further work might indicate that the Forest Service land has high(er) geothermal potential and should be acquired.

Suggested next steps:

1. Negotiate geothermal rights to parcels R2011960 (Johnson), and R8170224, R8171133, and R4206414 (Mann).
2. Consult with Colorado Geological Survey to acquire any data they have on the geothermal system.
3. Approach Routt County officials to obtain 'buy-in'.
4. Based on (1), submit permitting plans for drilling a large suite of temperature gradient holes throughout the project area, only a portion of which will be drilled.
5. Plan and implement a magnetotelluric survey within the area shown on Figure 4. This would be an excellent site for MT, as the granites and gneisses have very high resistivity, and clay alteration from a geothermal system would make a pronounced resistivity low.
6. Although our general exploration plans call for it, I would not recommend a gravity survey here, as we can expect no real density contrast between the underlying granites and gneisses.
7. After the snow melts, the area should be mapped in detail, primarily for structure.
8. After permitting is complete, implement a temperature gradient drilling program on those sites (permitted in #4 above) adjacent to areas targeted by #5 and #7.

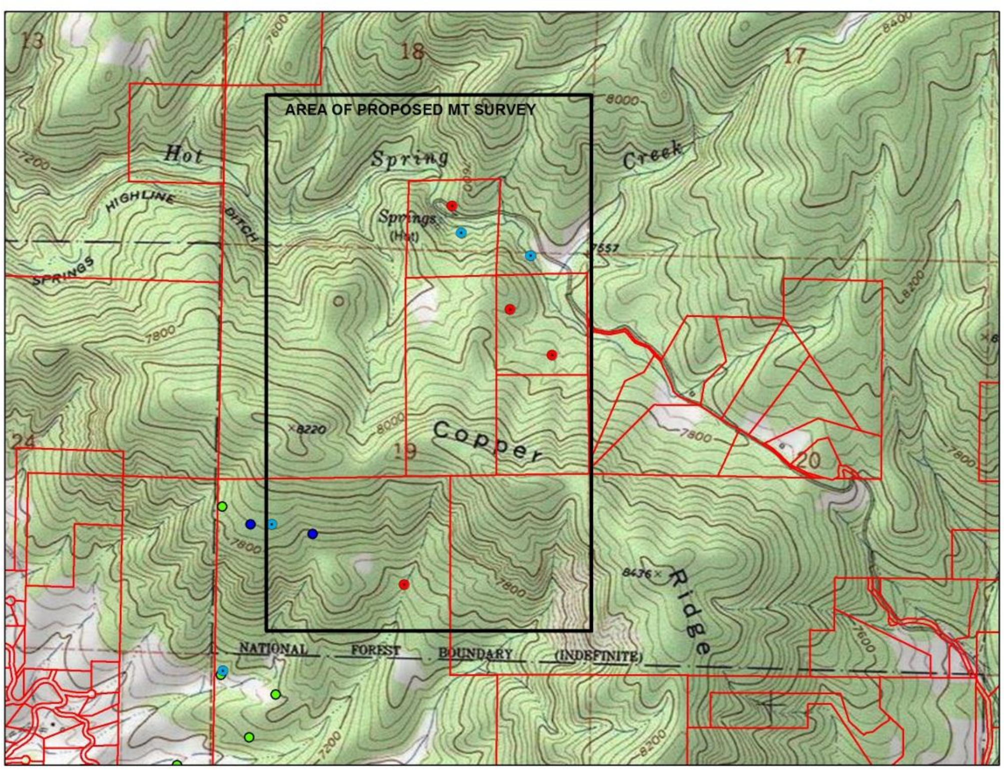


Figure 4. Area of proposed MT survey at Routt Hot Spring. Parcel outlines from Figure 2 and point data from Figure 3 are also shown.

<u>TARGET #2: Rico Area (including Paradise Hot Springs), Delores County</u>

Main Points:

1. Several interesting geothermal systems occur in this area with power plant potential.
2. A private land package has already been put together by willing developers in San Juan National Forest.
3. Low-hanging fruit: known geothermal resource that can provide direct use heating to existing Rico community, or (better yet) a ski resort and spa.
4. Mid-hanging fruit: silica geothermometer suggests geothermal reservoir temperatures in the binary plant range.
5. "Upper tree" fruit: possibility of high-temperature magma system(s) at depth.
6. Specific targets have not yet been identified in this large area having geothermal systems, hydrothermal alteration, and epithermal ore deposits.

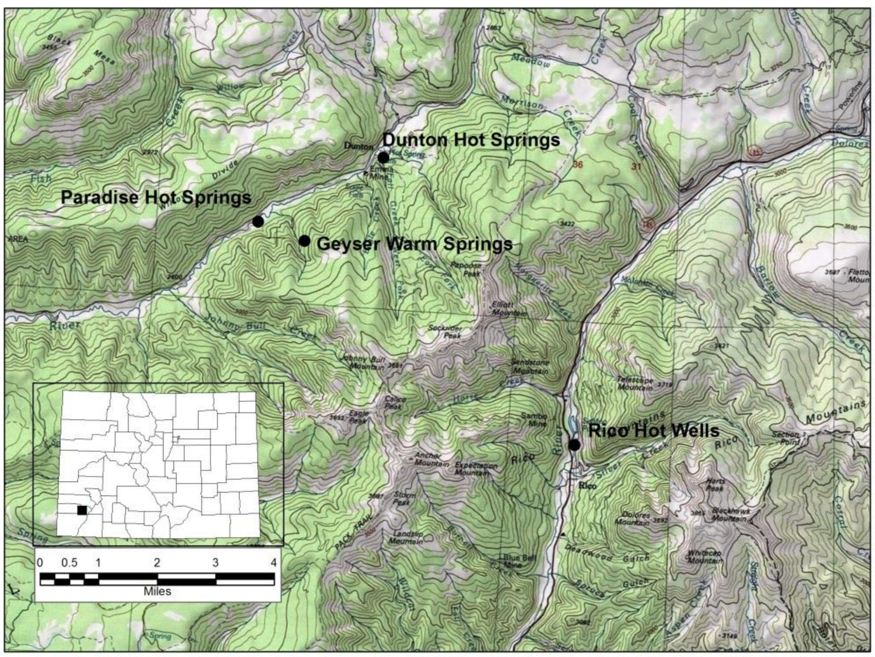


Figure 5. Location of the Rico geothermal area

Site Description

The Rico area comprises a 30-40 mi^2 area in southwestern Colorado with active geothermal features. This is an area of high elevation, ranging from 8,800' ASL at Rico, to over 12,000' ASL on the higher mountains. Land ownership consists of multiple patented mining claims surrounded by San Juan National Forest. Transmission lines are 20 miles away.

Rico with a population of about 200, is a lazy hamlet in a beautiful location. Incomes are low, and a lot of townspeople work in nearby Telluride. However, a group of businessmen are striving to put a ski resort at Rico, which would "put it on the map". If this happened, the known 43.8°C geothermal waters, which flow out of old drill holes 0.2 miles uphill from town, could provide direct use for both soaking and space heating in Rico. Cation geothermometry from the Rico wells are ambiguous (probably due to Pliocene hydrothermal alteration), but silica geothermometers suggest reservoir temperatures in the 116°C-142°C range. The presence of young silicic intrusions in the area may indicate that a cooling magma body may exist at depth.

Land Status

Land ownership in the Rico area consists almost exclusively of patented mining claims surrounding Federal (San Juan National Forest) lands (Figure 6). The group of ski resort developers controls Rico Properties and is looking into a land swap wherein all of Dolores Mountain is acquired in exchange for the patchwork of mining claims. They have expressed willingness to retain those areas Flint Geothermal LLC considers important for geothermal development.

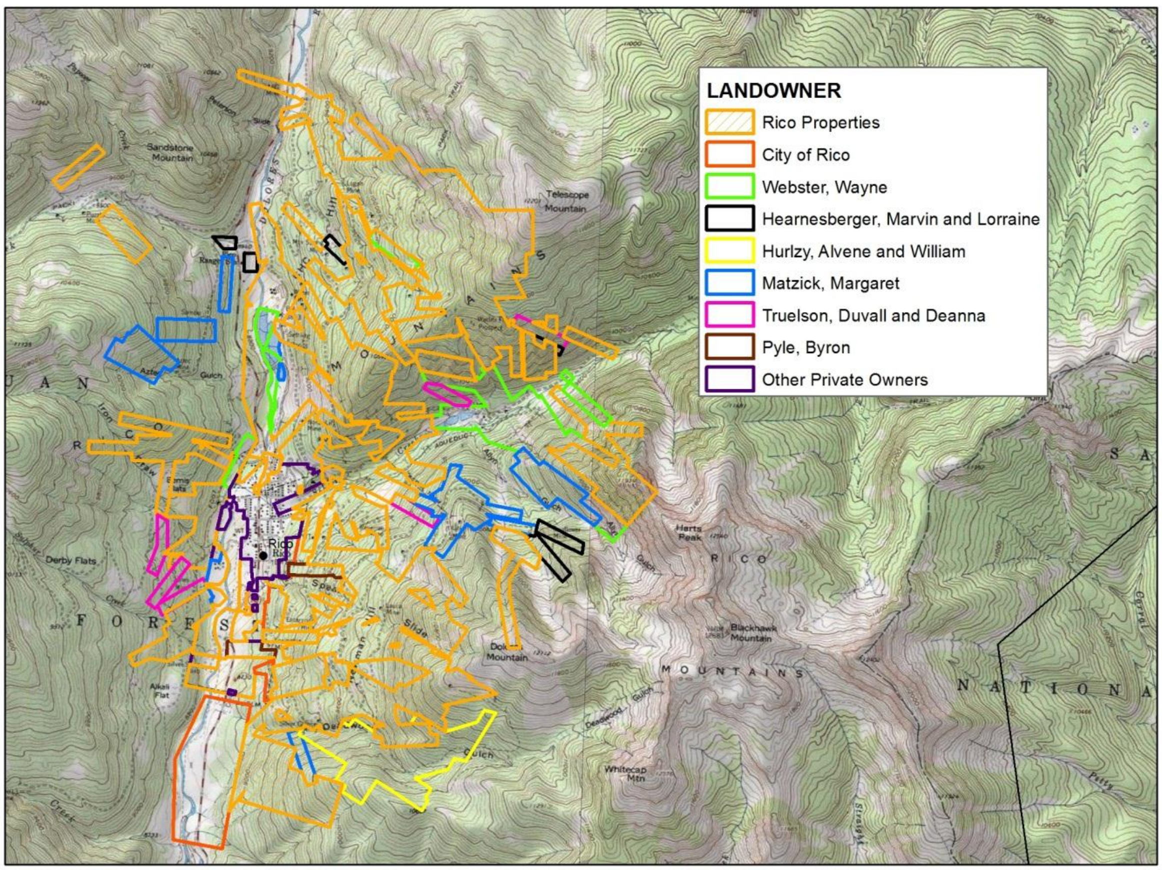


Figure 6. Land ownership in the vicinity of the town of Rico. Areas outside the patented claims belong to San Juan National Forest.

Land ownership outside of Rico contains only a scattering of private land within the National Forest. Some private land occurs in the valley of the West Fork Dolores River in the vicinity of Paradise and Denton Hot Springs.

Previous Work

Numerous published papers discuss the geology and epithermal ore deposits of the Rico area. Relatively recent mineral exploration drilling was responsible for discovering the geothermal system along the Delores River near Rico. IP/resistivity, VLF/EM, and magnetic geophysical surveys were carried out by mining companies, as well as copious drilling. Larson (1983) discusses the location and depth of a Pliocene molybdenum intrusion at Rico, and delineation drilling of this deposit encountered thermal waters. Ramon Escure (personal communication, 2011) mentioned he has hundreds of in-house mining company reports and maps on Rico in a storage area in Montrose which he would make available to Flint Geothermal LLC.

Several papers specifically discuss the geothermal potential of the Rico area, beginning with Medlin (1983), who examined heat flow from 4 Rico drill holes and compared it to gravity data. The CGS sampled geothermal waters, and described them in Oerter and Sares (2010), and Oerter (2011). In addition, Nakagawa of the Colorado School of Mines is currently conducting research at Rico as part of his geothermal geophysical program.

Flint Geothermal LLC visited the Rico area twice in 2011. Attempts were made to visit all the geothermal features shown on Figure 1. Water samples were taken at Geyser warm Springs and Rico. A shallow (2m) survey was conducted, and fracture orientations taken, at Rico.

Geology

The geology of the Rico area consist of thousands of feet of Paleozoic through Cretaceous aged sediments lying on top of Precambrian (Andean arc?) basement rocks. These rocks include permeable rocks such the Dakota Sandstone and Leadville Limestone. This package of rocks has been gently folded, and has been cut by north-south, east-west, and northeast striking faults. The Laramide folding event created a domelike, east-west striking structure (the “Rico Dome”) that apparently guided emplacement of a series of late Tertiary silicic intrusive rocks, including numerous stocks, dikes and sills. The fossil geothermal systems heated by these intrusives caused widespread hydrothermal alteration and mineralization.

Gold was discovered at Rico in 1866 that led to the later discovery of rich silver deposits in 1879. The Rico district produced in excess of 14,500,000 ounces of silver, 84,000 tons of lead, 83,000 ounces of gold, 83,000 tons of zinc, and 5,600 tons of copper. Based on known high-sulfidation epithermal alteration and mineral assemblages from this historic mining, the Anaconda Mining Company targeted the area for molybdenum exploration in the mid-1970’s, culminating in the discovery of the Silver Creek molybdenum stockwork deposit approximately 1.5 km northeast of Rico. The Pliocene intrusion responsible for this deposit has been dated at 3.9 m.y.b.p. Another, younger intrusion dated at 3.5 m.y.b.p. is located several miles west of Rico. These intrusions have long since cooled, and are not responsible for the current geothermal occurrences. However, since Climax-type stockwork Mo deposits consist of multiple episodic intrusive episodes over several millions of years, the possibility exists that a still younger, hot intrusive body is present at depth somewhere in the area, and has an associated high-temperature geothermal system.

The active geothermal systems in the Rico area can be seen as being centered on this area of young silicic intrusives, as shown in Figure 7. At Rico, the red stars show the reported location of exploration drill holes where hot water was encountered (depths and temperatures are currently unknown). Note the correlation between the location of the Silver Creek Porphyry, the hot drill holes (presumably used to delineate the Mo deposit), and shallow (2m) temperature anomalies. So one idea is that another, younger intrusion lurks somewhere around the Silver Peak porphyry, and hydrologic flow is occurring down Silver Creek to the southwest. However, the sedimentary rocks dip gently eastwards here, suggesting that deeper hydrologic flow might occur along permeable beds in the other direction.

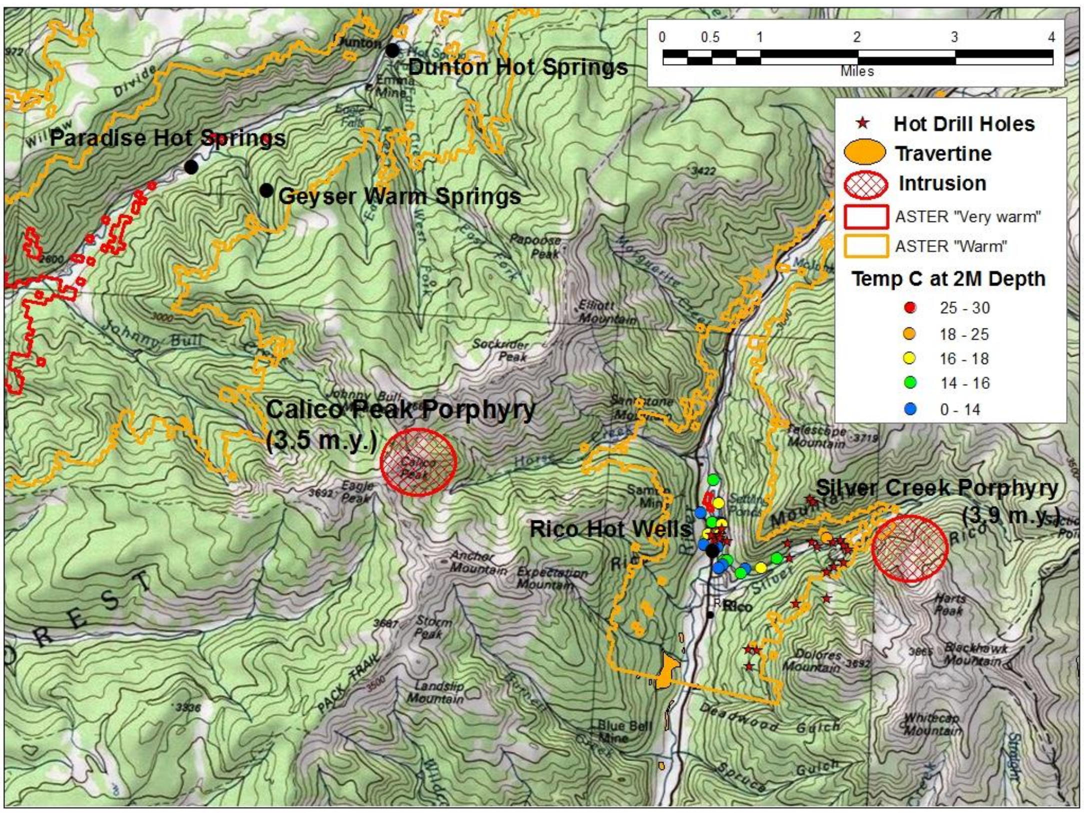


Figure 7. Geothermal indicators of the Rico area. Locations of the buried intrusions are approximate.

The existence of fossil travertine deposits southwest of Rico, on the hillside west of the Dolores River, (from Pratt et al, 1969), seems to indicate the possibility of another zone of upwelling. It is difficult to envision an upwelling zone at Silver Creek forming travertine several hundred feet up the other side of the river (Figure 7). The location of the travertine seems to indicate that geothermal fluid flow is coming from the west (uphill), from the Expectation Mountain area.

The recently modeled ASTER data seems to indicate areas of warm ground surrounding both of the known geothermal areas, including the known or suspected warm ground around Rico delineated by the 2m survey and Silver Creek drill holes. The area around and uphill of the travertine deposits southwest of Rico are also within this anomaly. The location of the ASTER anomalies within the deep San Miguel River basins is suspect, however. Even with the limited road access in this area, testing the ASTER anomalies with 2m surveys would be easy to accomplish, and if confirmed, this data may help delineate a future MT and/or drill program.

Thermal waters of the Paradise-Dunton hot springs area seem to have a source to the south, based on 1) the location of Geyser Warm Springs, 2) young intrusions with copious alteration, and 3) sedimentary rocks are dipping gently north or northwestwards. Geothermal exploration in this area would presumably have to await the nomination process and NEPA scoping requirements necessary for a Federal geothermal lease.

Hydrothermal alteration at Rico occurs adjacent to the Pliocene intrusive rocks, and also along faults and permeable sedimentary units where geothermal waters could flow. This "fossil alteration" will probably obscure efforts to trace the active geothermal system(s) using visible alteration or electrical resistivity (including MT) methods. It also seems to have affected the geochemistry of [current] groundwater, as fossil and active geothermal waters may have shared similar flow paths.

Geochemistry

The geothermal springs and wells of the area each have distinctive geochemistry.

Paradise Hot Springs issues at 46^{o}C out of alluvium along the banks of the West Fork Dolores River. The waters are of a sodium chloride composition, having the most evolved fluids of any thermal spring of the Rico area. They have highly elevated potassium, sodium, chloride, boron, fluoride, and lithium. Cation and silica geothermometer temperatures are pretty consistent at 135^{o}C-160^{o}C. As mentioned above, the geology suggests a source to the south.

Sample Name	Amorphous Silica	Chalcedony cond	Quartz cond	Quartz adiabatic	Na-K-Ca	Na-K-Ca Mg corr	Na/K Fournier	Na/K Truesdell	Na/K (Giggenbach)
RICO BIG GEYSER WARM	22	116	143	137	56	19	368	399	369
RICO BIG GEYSER WARM	22	116	143	137	56	26	396	445	394
RICO GEYSER WARM SP	22	116	143	137	59	17	374	408	374
DELORES RIVER	-82	-15	13	28					
RICO LITTLE SPRING	26	122	148	141	16	16	192	157	209
RICO LITTLE SPRING	26	122	148	141	58	27	380	418	379
RICO DIAMOND DRILL HOI	26	122	148	141	56	24	383	423	382
GEYSER WARM SPRING	-26	57	89	91	160	-54	191	155	208
NB04001106	-20	64	95	97	154	-284	187	151	204
PARADISE HOT SPRING	39	137	161	153	252	112	285	277	294
PARADISE HOT SPRING	50	151	173	162	250	112	282	273	292
PARADISE HOT SPRING	56	159	181	168	248	125	285	277	294
PARADISE HOT SPRING	50	151	173	162					
NB04101132D	-30	52	84	87	52	31	446	529	436
NB04101132D	-31	51	83	85	51	40	446	529	436
NB04101132D	-29	54	85	88	50	29	423	489	417
DUNTON CREEK	-81	-13	14	29					
Soda Spring Geyser	26	122	148	141	55	22	369	401	370
Warm Geyser, San Miguel	-23	61	92	94	158	-57	186	150	204
Dunton Hot Spring	-29	54	85	88	50	29	423	489	417
Dunton Hot Spring	-31	51	83	85	51	40	446	529	436
Dunton Hot Spring	-30	52	84	87	52	31	446	529	436
Dunton Hot Spring									
Paradise Hot Spring	39	137	161	153	250	112	282	273	292

Table 2: Cation and silica geothermometer estimates for the Rico area (in degrees Celsius).

Dunton Hot Spring (41.4°C) has a calcium sulfate-bicarbonate composition and Geyser Warm Spring (28.2°C) is sodium bicarbonate spring. The cation ratios indicate a lack of equilibrium. Neither have highly anomalous boron, fluoride, lithium, or silica. While Dunton Hot Springs emits small quantities of $C0_2$ gas, Geyser Warm Springs gets its name from copious CO_2, occurring in frequent bubbly eruptions. These springs, while indicating the presence of geothermal activity, do not have the geochemistry suggesting a nearby hot geothermal reservoir.

Samples from the Rico warm wells (maximum measured temperature 43.8°C) indicate a predominantly calcium sulfate geochemistry similar to Dunton Hot Springs, but with high silica. Like Geyser Warm Springs, they are high in K, Ca, Mg, and CO_2 and are actively depositing travertine at the wellheads. Silica geothermometer values range from 116°C to 148°C (chalcedony vs. quartz). The cation ratios can't be trusted, and are strongly influenced by the high Ca and Mg, which drop the cation geothermometer to below the measured outflow temperature. However, potassium to sodium ratios are high, probably indicative of a reservoir temperatures at least as high as the silica values indicate.

It is interesting to note that at both Dunton and Rico, these springs flow from rocks very close to major epithermal systems that deposited high sulfidation mineralization along permeable faults and sedimentary layers. It is likely that current thermal fluids flow along many of the same paths as the fossil geothermal systems that created the alteration. The high sulfate concentrations from waters at both these places could well have been picked up between the geothermal reservoir and the surface.

Discussion

Unlike Routt Hot Spring, which has a fairly tightly constrained target area and well-defined geothermometer temperatures, the Rico area has geothermal occurrences spread out over a wider area, much of which cannot be explored in 2012 due to Federal land ownership. Also unlike RHS, the town of Rico has willing land owners and a probability of success with direct use (the "low hanging fruit") if binary plant temperatures are not encountered. Further exploration here will involve different tactics that depend on the time frame that Flint Geothermal LLC is willing to put into the project.

1. Geothermal reservoir(s): The exact locations of upwelling fracture zones are unknown at this time. The possibility exists that multiple geothermal systems exist in the Rico area. The sodium chloride waters of Paradise Hot Springs do not seem tainted by too much dissolution or precipitation, suggesting proximity to a reservoir. The Rico hot wells are pretty distant from Paradise Hot Springs, and can be explained by westward flow downhill from a source somewhere up Silver Creek. The fossil travertine mapped by Pratt et al (1969) are not easily explained by upwelling near Silver Creek, and suggest a source coming from the west of Rico.
2. Reservoir temperatures: Geothermometry data suggests that reservoir temperatures from these (separate?) sources could be sufficient for binary power plants. The reservoir estimates are more straightforward at Paradise Hot Springs (a pretty consistent ~150°C), but the silica geothermometer from Rico waters makes a fairly convincing case for a +120°C reservoir feeding it. The presence of young, episodic silicic intrusions at Rico suggests the upside potential for a hot (>200°C) magmatic geothermal system.

3. Land Ownership: The land developers at Rico seem to be welcoming Flint Geothermal LLC with open arms. This not only eases concerns about establishing a land position, but their connections with county and state officials will probably save time and money during the permitting and approval process. Moreover, should their plans come to fruition, Flint would have a willing buyer of spent power plant brines or even simple off-take from exploration-turned –production wells.

Suggested next steps:

1. Decide on an exploration strategy for Rico that a) prioritizes power plant versus district heating goals, b) establishes project time frames for work during the short summer field season, c) determines whether USFS lands should be included for possible future exploration.
2. Test the recently derived ASTER data with a 2m survey to confirm a geothermal source to the anomalies.
3. Begin discussions with the Rico developers concerning an exploration agreement by which Flint Geothermal LLC could proceed with geothermal exploration on their land package.
4. Allocate time for a geothermal geologist to travel to Montrose to examine the geophysical programs, geologic mapping, and drill data from their extensive mining files.
5. Similarly, allocate time to meet with Professor Nakagawa at CSM to discuss their past work at Rico, and possible future collaboration.
6. Consult with a geophysicist as to whether and how a MT survey could be implemented in the hydrothermally altered areas around Rico. The pre-existing alteration will form resistivity lows that will probably not be associated with resistivity lows from the active geothermal system.
7. Based on 1-5 above, come out with a stepwise exploration plan for Rico.
8. Based on 1-5 above, submit permitting plans for drilling a large suite of temperature gradient holes on the private patented claims, remembering that only a few of which will be drilled.

Target 3: Edith (Pagosa Springs) – Archuleta Co.

Main Points

1. Enigmatic but potentially positive geochemistry and geothermometry
2. Target not defined: high lateral flow (either porosity or fracture controlled) of 55°C – 65°C water is occurring along permeable Dakota Sandstone. High-temp upwell zone feeding the lateral flow has not yet been located but could be miles up-gradient from town.
3. Existing high-end direct use will make for downstream resource competition and NIMBY problems.
4. Willing state, county, and DOE officials.

Site Description

The town of Pagosa Springs ("PS") consists of 2000 people at an elevation of 7,000' ASL in southern Colorado, an area of relatively high unemployment and low wages (Figure 8). The geothermal system at PS consists of numerous springs and wells located directly within the city limits. The springs ("Big Springs") come out of an impressive travertine terrace along the banks of the San Juan River. Most of the wells are north of the river, up the presumed hydrologic gradient. The surrounding area is privately owned for miles around, but is in turn surrounded by the San Juan National Forest. Three phase power lines run into the city, and a larger 115kv line comes to within 3 miles of the springs.

The 55°C – 65°C flow from the wells is measured in thousands of GPM and supports several high-end resorts as well as a district heating system. This not only indicates a robust geothermal system, but suggests future headaches convincing these downstream users that power plant development 'upstream' won't affect their resource.

These springs and wells seem to tap a laterally flowing aquifer (the Dakota Sandstone); drilled holes go isothermal in the rock formations beneath this unit. So although the site of the outflow zone is well known (no pun intended), the site up the target upflow zone is not.

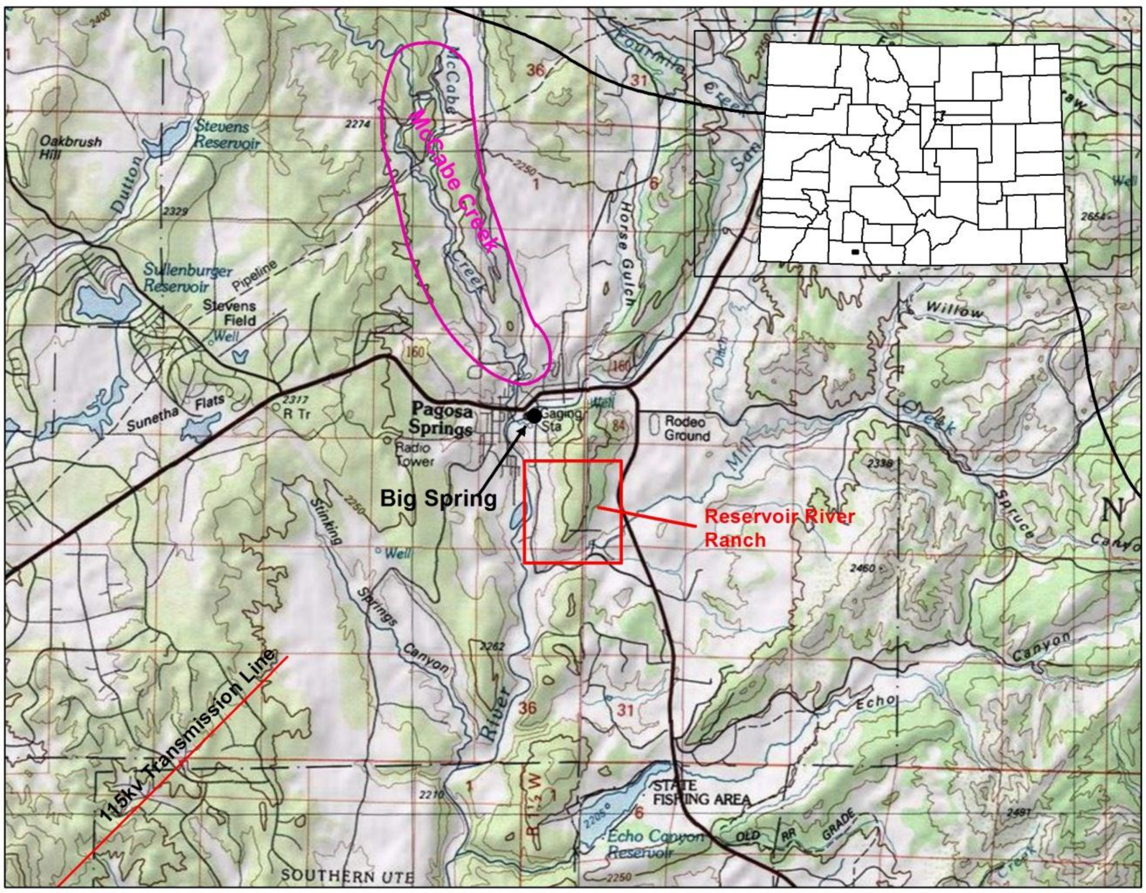


Figure 8. Location map of the Pagosa Springs area. Reservoir River Ranch and McCabe Creek areas will be discussed in text.

Land Status

Pagosa Springs consists of a hodge-podge of small parcels within the city limits, surrounded by larger ranches outside of town. National Forest land comes within 3 miles of the springs in an east-west direction, and perhaps 6-8 miles in a north-south direction. Since exploring for the upflow zone that feeds the springs will likely involve tracing the geothermal waters up-gradient, having a large private amount of private land around the springs is advantageous.

Previous Work and Political Landscape

Numerous papers and reports document the geology and geothermal occurrences at Pagosa Springs, including Galloway (1982) and Warren (1986). The hot water has been used for soaking and heating of individual building since before 1900. The DOE became involved in the 1970's with generous grants designed to explore and develop direct use geothermal at PS. DOE-sponsored work included seismic and resistivity geophysical surveys, soil mercury sampling, and drilling. Work was focused more on identifying where the water could come out as opposed to identifying its source. So far in my reading only Warren (1986) mentions the latter.

The first direct heating system at PS went on-line in December 1982. The system currently has 13 commercial and 2 residential customers, and an annual budget of $40,000. However, there are some problems. There is concern regarding the impact of established users on the aquifer, primarily the district heating system and the spas. Test wells that were originally to be drilled to determine the hydrogeological and geothermal characteristics of the aquifer were not completed due to numerous budget and drilling problems (Galloway, 1980). The town formed a Geothermal Advisory Committee to resolve issues among geothermal users. Numerous attempts have been made to resolve these issues (primarily from the resort users) without a court trial. Currently, the system is reaching its designed capacity, and new customers wish to join.

Michael Whiting, of the Archeleta County Board of Commissioners, is the outspoken proponent who intends to upgrade and expand the district heating system. In order to do this, the political resource issues first need to be resolved. To accomplish this, a field program to hydrologically test the production capacity of the geothermal resource has been approved, and funding has been allocated. The next step must involve agreement of the allocation of the resource by all stakeholders.

One barrier to entry for Flint Geothermal into this fray will be convincing those stakeholders that any exploration work to be performed will not diminish the quality or quantity of the geothermal resource. This may be difficult, as Flint would be attempting to find and utilize the source of their hot water.

Geology

Pagosa Springs sits on top of a thick sequence of Paleozoic to Tertiary sedimentary rocks that rest unconformably on top of Precambrian gneisses and schists. Laramide deformation and basement uplifts caused northeast and northwest block faulting, which led to open, drape-style folding of these sedimentary rocks. The dominant structural pattern consists of NE and NW faults of relatively low displacement (<100m), which act as the cores or hinges of the drape faults. Even with this faulting and folding, bedding is horizontal to gently dipping. Measured fracture orientations are parallel to this structural pattern (Figure 9). PS lies at the intersection of several of these fault/fold structures.

The subhorizontal bedding has created "layer cake stratigraphy" in the vicinity of PS. The Mancos Shale usually forms the surface unit around the town. The Mancos is a relatively non-permeable unit (containing some semi-confined aquifers), which sits directly on top of the Dakota Sandstone. The Dakota is a very permeable unit, known for its fine reservoir characteristics (both water and oil) throughout much of Colorado. Interestingly, Galloway (1980) seems to suggest that in Pagosa Springs, the Dakota Sandstone has more fracture permeability than sedimentary permeability. Directly below the Dakota Sandstone is another non-permeable unit, the Morrison Formation. Thus the permeable Dakota Sandstone is sandwiched between two impermeable units above and below it. Precambrian schists and gneisses occurring deeper in the section form the cratonal basement.

The San Juan River flows south through PS, following faults and fractures until it makes a sharp turn south near its junction with McCabe Creek. Hydrologic flow is also to the south (Warren, 1986).

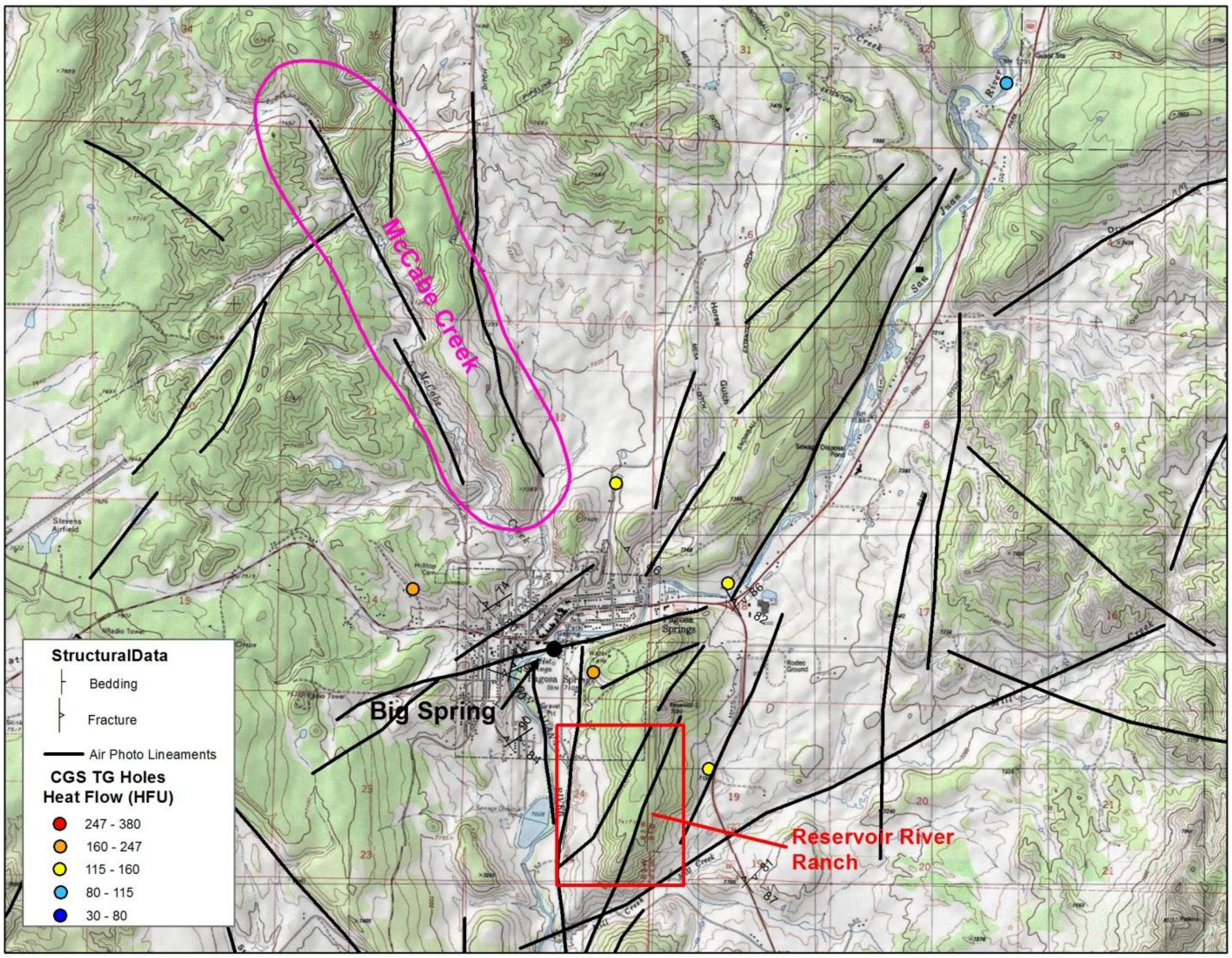


Figure 9. Structure and heat flow in the Pagosa Springs area. The two CGS holes mentioned in the text were drilled within 100m west of the main travertine terrace ("Big Springs").

The terrain-corrected recent ASTER imagery of PS shows a few interesting features (Figure 10). One thermal anomaly occurs along a NE-striking structure that, allowing for slight georeferencing problems, could be seen as "nailing" the hot spring and travertine area. Another ASTER anomaly occurs just south of the Reservoir River Ranch, seemingly at the junction of two air photo lineaments. Several other smaller anomalies occur several miles southeast of PS, along other lineaments. There is no anomaly to the northwest of PS along McCabe Creek (see below).

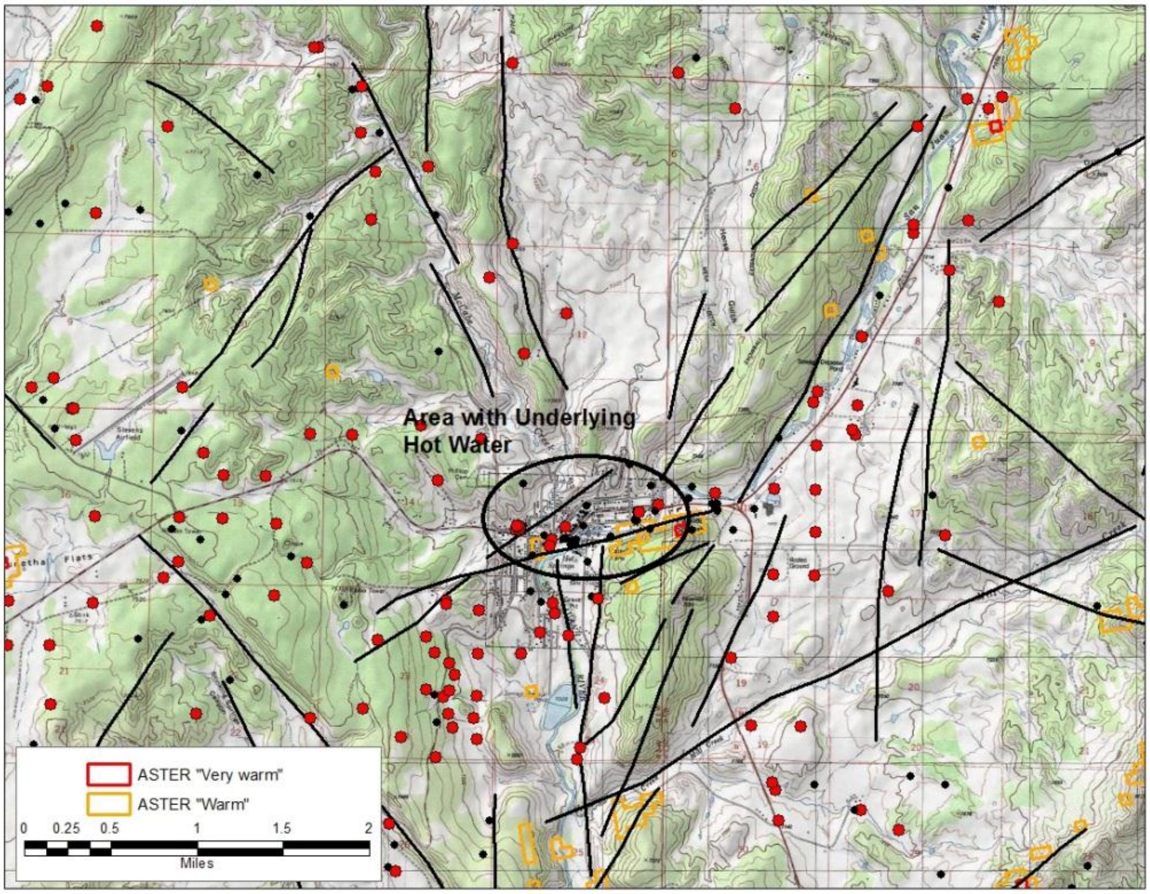


Figure 10. Locations of water wells around Pagosa Springs. Wells greater than 250 foot depth are shown as red dots, that presumably intersected the Dakota Sandstone; shallower wells are small black dots. Corrected ASTER imagery is also shown.

Hydrology

Many shallow wells and one deeper hole have been drilled in and around town, giving some indication of the subsurface hydrology of the geothermal system. The Dakota Sandstone, the primary aquifer of the region, is commonly found at depths around 240-280 feet.

Warren (1986) explains in detail the drilling of the deeper P-1 hole, which reached a total depth of approximately 450m. The hole was located approximately 600 northwest of the main springs. The target of this hole was the intersection of NE and NW structures which presumably formed the conduit for the springs.

P-1 was collared in the lower Mancos Shale and encountered one permeable horizon in the Mancos that yielded up to 500 gpm at 56°C (Figure 11). Penetration of this horizon caused a rapid drop in pressure in several wells in town, but did not affect the Big Springs. Further drilling intersected the Dakota Sandstone at 69m (240 ft) depth, and hit a fault (lost circulation zone?) at 77m (252 ft) that flowed around 2000 gpm at 61.5°C. This caused wells up to 300m away to fail and a substantial drop in the levels of the Big Spring. Cuttings from this portion of the Dakota Sandstone were silicified and pyritized. Casing and cementing these zones caused pressures to rise back to their previous levels. The temperature in this zone was the highest encountered in the hole; temperatures dropped steadily to 45°C at 243m (800 ft), after which the hole went isothermal. Weathered (but not altered) Precambrian basement was intersected at 418m (1371 ft): there high flows (1400 gpm) were encountered, but at temperatures of only 45°C. Drilling into these high flows did not affect any of the geothermal features at Pagosa Springs.

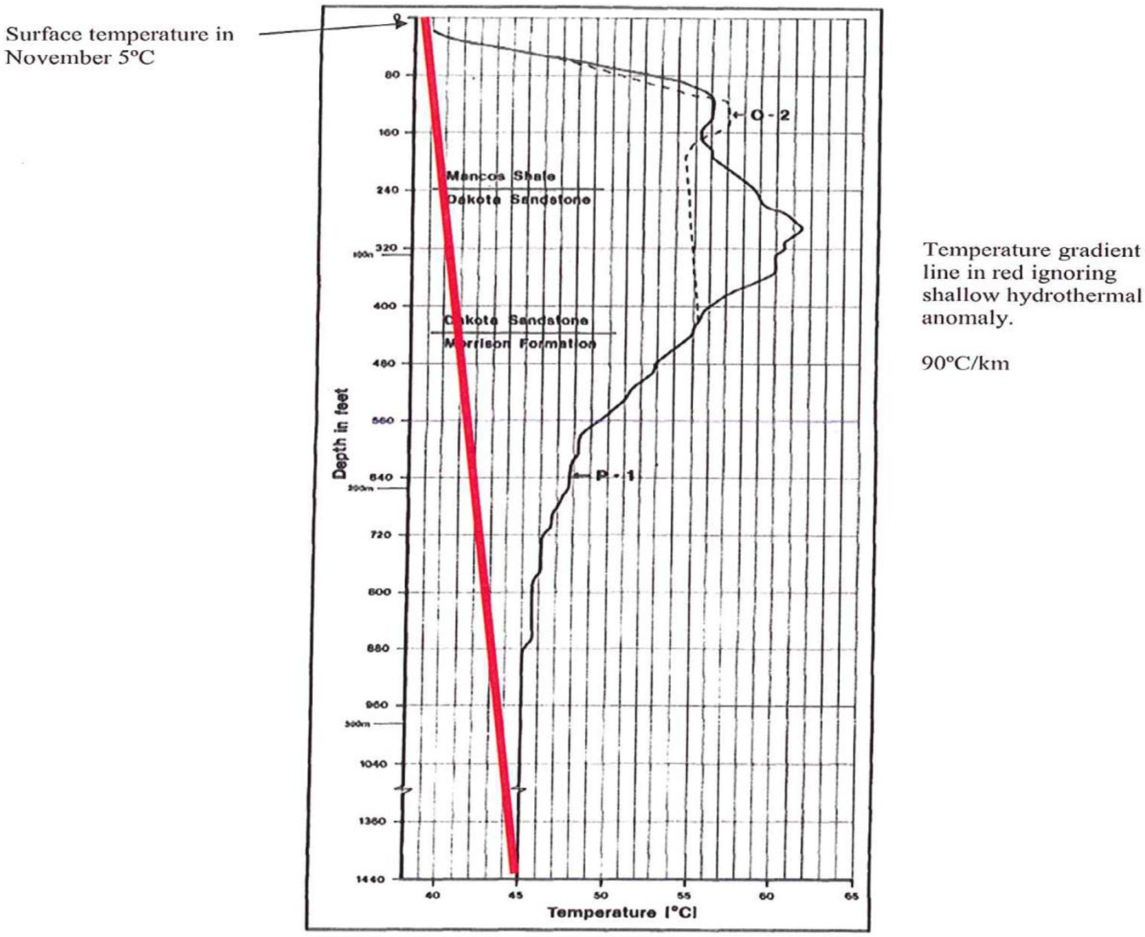


Figure 9. Geothermal Gradient of P-1and O-2 Geothermal Exploration Well
(Adapted from Galloway, 1980)

Figure 11 (from Figure 9 of 1/11/2012 Just Hot confidential report). Temperature log of Hole P-1. The highest temperature zone ("shallow hydrothermal anomaly") likely represents lateral flow of geothermal waters along the permeable Dakota Sandstone.

The drilling of Hole P-1 pointed out several important factors relating to the plumbing of the Pagosa geothermal system:

1. The primary geothermal aquifer is in the Dakota Sandstone.
2. Strong evidence for lateral flow in the Dakota aquifer comes from the fact that temperature and flow rate decrease in units below the Dakota Sandstone.
3. Galloway (1980) seems convinced that most of the permeability in the Dakota is fracture (e.g. fault) permeability. Warren (1986), following Galloway (1980), believes that geothermal source

exploration should be conducted around known structures, particularly a possible fault up McCabe Creek.

4. A second, cooler aquifer exists in the Precambrian basement rocks that is hydrologically distinct (and unconnected) with the primary aquifer in the Dakota.

Existing water well data might be useful in identifying the up-gradient source of the geothermal fluids at Pagosa. Figure 10 shows the location of existing water wells greater than 250 foot depth, likely intersecting the Dakota Sandstone. It also shows the restricted area in which thermal waters have been encountered. Assuming that encountering warm or hot water in local wells would likely be public knowledge, the wells that intersect the Dakota probably indicate places where hot water doesn't exist in that aquifer.

Temperature Gradient Drilling and Geophysics

Six short (~100m) temperature gradient holes were drilled in the Pagosa Springs area to try and identify additional thermal anomalies and/or the flow path of the geothermal waters (Figure 9). Moderate to high heat flow was encountered in all five holes, and contouring by Warren (1986) indicated to him that higher heat flow values paralleled a NNW-striking fault that underlies McCabe Creek.

Two DC resistivity surveys were conducted in the PS area: a reconnaissance bipole-dipole survey over a 400km^2 area, and a detailed dipole-dipole survey over the Big Springs. The bipole-dipole survey showed that the Mancos Shale and Dakota Sandstone have background resistivities on the order of 200-400 ohm-meters. Superimposed on this background were several resistivity lows. The first and largest low corresponded with the Big Springs. A second, larger, elongate low follows McCabe Creek to the NNW for several miles. A third, broader low occurred to the northeast of town, along the trace of the San Juan River. The dipole-dipole survey essentially confirmed the first two anomalies in greater detail.

The high heat flow contours correspond spatially with the elongate resistivity low and the mapped structure up McCabe Creek. This led Warren (1986) to conclude that this structure (herein called the McCabe Creek Fault) was the source of the PS geothermal system.

A seismic survey was conducted in the PS area in July 1977, which consisted of one 5-mile long north-south line centered on the town of Pagosa Springs, and two short east-west lines to provide 3-D control and to examine the Big Springs area. Problems occurred with data acquisition of the east-west lines. However, the study confirmed the block fault/sedimentary drape model as well as the depth(s) to basement and the location of several mapped faults.

Geochemistry

Pagosa Springs geothermal waters are somewhat enigmatic. Their composition shows a lack of equilibration using a Na-K-Mg plot (Figure 12) and this in turn suggests that geothermometer temperatures should be taken cautiously. PS waters are sodium sulfate dominated waters with high potassium, sulfate, magnesium, and relatively high boron, fluoride, and lithium. Silica values are in the 50-70 ppm range.

Samples of cold groundwater from the PS area have extremely variable geochemistry, based primarily on the formation that is the source of the water. Well water from siltstones in the area commonly violates drinking water standards due to high sulfate, magnesium, and other dissolved constituents (the shallow Mancos shale is known for its lousy water). Most of the cold groundwater samples in our database from the area have magnesium concentrations equal to or higher than those from the springs.

As would be expected in unequilibrated waters, cation (e.g. magnesium-corrected) geothermometer values range from about the measured spring temperature (46^{o}C) up to 230^{o}C. Without the Mg correction, the Na-K-Ca geothermometer values form a pretty tight cluster around 150^{o}C – 195^{o}C.

Silica geothermometers range from 73^{o}C – 99^{o}C (chalcedony) to 103^{o}C – 127^{o}C (quartz). Silica versus log(K^2/Mg) plots suggest that the quartz geothermometer is more applicable (Powell and Cummings, 2010). Silica geothermometers are sensitive to precipitation and dilution, and both may be occurring.

Since high magnesium is commonly found in the local groundwater, the high and variable magnesium in the PS geothermal waters could have been introduced during lateral flow through the Dakota Sandstone or other units. Similarly, the slightly low quartz geothermometer can be explained by dilution with groundwater. One simple explanation to the lack of equilibrium in the geothermal samples is that the thermal waters are mixing with cold groundwater rich in Mg, SO_4, and other constituents. Although we should not entirely trust the geothermometry, they are still suggestive of a geothermal system hot enough to support a binary power plant.

It should be noted that Galloway (1980) observed quartz deposition in P-1 drill cuttings that had fluid inclusions indicating ~232^{o}C equilibration temperatures. This quartz almost certainly represents deposition from a time, possibly back in the Cretaceous, when the rocks were older and much hotter. It may have nothing to do with the currently active geothermal system.

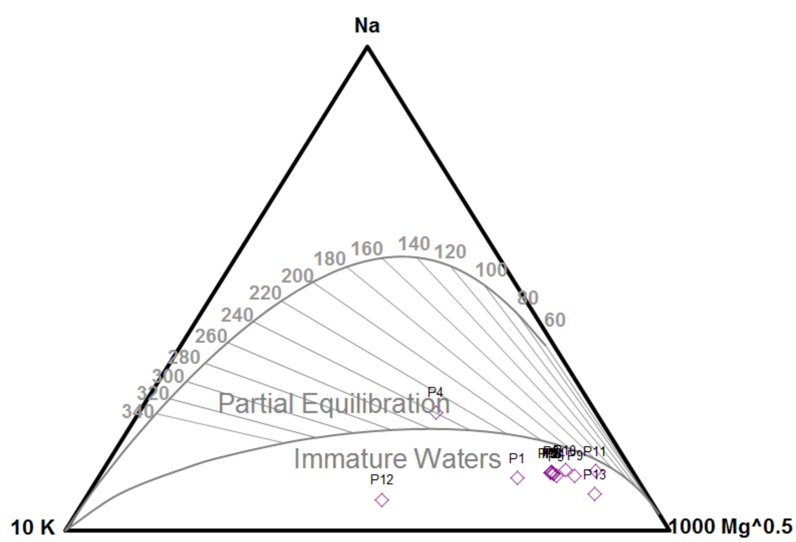


Figure 12. Trilinear plot of Na-K-Mg from Pagosa Springs thermal waters (diamond shaped sample values with ‘P’). The high magnesium suggests a lack of equilibration.

<u>Reservoir River Ranch</u>

The Reservoir River Ranch consists of approximately 500 acres located immediately 0.5 miles south of Pagosa Springs (Figure 8). Just Hot Resources (“Just Hot”) is currently exploring the ranch for its geothermal potential. Flint has signed a Confidentiality Agreement with Just Hot covering the Ranch. Two reports sent to Flint from Just Hot form the basis of the data for this section. These reports encapsulate earlier reports on the geology and hydrology of the PS geothermal system, and discuss work carrier out on the Ranch to date.

Work by Just Hot seems to have consisted of 1) field and aerial photo examination for structures, and 2) soil gas surveys. Just Hot identified two potential faults on the property, one NE striking structure following Mill Creek, and another NNE structure paralleling County Road 119. The Mill Creek structure follows an air photo lineament identified in 2011 by Flint and tagged as a potential target for exploration. The CR 119 structure is close to (if not identical with) another air lineament identified by Flint at the same time. Both these structures have a good possibility of being actual faults with high permeability and measureable displacements. Gas sampling has been used in the geothermal industry for decades, and Just Hot's sampling procedure is (I believe) similar to standard practices. Just Hot analyzed for most of the gases the geothermal industry uses.

The line of evidence Just Hot uses to argue that a geothermal resource lies under the River Ranch property includes:

1. The Ranch is close to Pagosa Springs, and is part of the geothermal system.
2. There are probably two faults that represent conduits on the property.
3. There is a cold sulfur spring on the property that is related to the geothermal system.
4. The temperature gradient on the property is 90°C/km (from nearby Hole P-1).
5. The gas geothermometers estimate a 73°C – 105°C geothermal-derived resource.
6. Combining the temperature gradient with the geothermometer data, a resource of 73°C – 105°C lies at 3000' to 6000' depth beneath the property.

I will discuss these points more or less in order. 1) First, it is true that the Reservoir River Ranch is close to Pagosa Springs, and that its geothermal potential is probably higher than the regional average. 2) I agree that the two lineaments identified by both Flint and Just Hot probably represent faults; however there is no evidence presented that they are conduits for geothermal fluids (no alteration, etc.). 3) The cold sulfur spring may or may not be affiliated with a geothermal system. The spring issues from Mancos Formation shales, which are known for their perched aquifers containing high sulfate, magnesium, etc. This spring could simply be tapping the perched aquifer, and low flow rates would tend to concentrate these constituents by evaporation.

In answer to '4' above, t may be true that the geothermal gradient of the area is 90°C/km. If so, this is the gradient related to the cool, 45°C Precambrian aquifer, and not the hot 'target' aquifer that feeds Pagosa Springs. The "shallow thermal anomaly" that Just Hot ignored was the target aquifer, which may or may not be flowing along the Dakota Sandstone which is underneath the Reservoir River Ranch. If it does, then the 73°C – 105°C gas geothermometer values are probably derived from the Pagosa Springs aquifer, and associated with a distal source. Finally, even if the temperature gradient and geothermometer data are right that a 73°C – 105°C resource underlies the Ranch, these temperatures are insufficient to drive a binary power plant, except at very high flow rates. For all intents and purposes, those temperatures do not constitute a target.

In summary, the available evidence Just Hot provides does not support any higher geothermal potential on the Reservoir River Ranch than any other spot in the neighborhood of Pagosa Springs.

Discussion

Geothermal exploration in this area will require tracing the geothermal flow from its outflow at the Big Springs in PS up the hydrologic gradient to its fracture-controlled source. All though it seems evident that these fluids are flowing laterally along the Dakota Sandstone, it is by no means clear the direction they are flowing. Galloway (1980) and Warren (1986) present evidence that flow is from the north, from the vicinity of McCabe Creek. Although a structure seems to follow the creek, and a structure was presumably encountered in Hole P-1 in the Dakota Sandstone, the relationship between lateral flow and vertical flow is unknown.

There does not seem to be any convincing evidence that the Reservoir River Ranch stands out in terms of geothermal potential.

The principle issues concerning geothermal exploration and development at Pagosa Springs will likely include the following, in rough descending order of importance:

1. The politics of developing a geothermal resource up the hydrologic gradient from pre-existing users
    a. Public relations efforts to get stake holder buy-in
    b. Interfacing with local officials to identify the “politically correct” path forward
    c. Liability mitigation
2. Reconnaissance exploration to identify the target upwelling zone amidst a patchwork of private (and possibly USFS) landowners
    a. Obtaining landholder permission to gain access to land in a timely basis
    b. Permit and configure a MT survey on this patchwork of permissible ground, and adjacent to electrical sources of noise
    c. Quickly signing up targeted land and instigating permitting for temperature gradient drilling.

Suggested Next Steps

1. Re-establish connections with Pagosa Springs commissioners and influential businessmen.
2. Have conversations with Huttrer, Lund, and other DOE personnel regarding regarding the status of work on the new direct use heating system.
3. Have conversations with locals to identify any/all geothermal indicators in the area.
4. Review geologic literature to determine depth to the Dakota Sandstone around Pagosa Springs, and determine if any area water wells have intercepted it.
5. Obtain all existing geophysical data and give it to a geophysicist for re-interpretation.
6. Determine if reconnaissance MT could be done to follow the Pagosa thermal anomaly up gradient, and if so, costs, the suggested minimum station spacing, etc.
7. Wells > 227m deep in vicinity of PS (hit Dakota)
8. Acquire seismic lines from the CSM.

9. Acquire resistivity data from the CSM(?)
10. Test the ASTER thermal anomaly south of the Reservoir River Ranch.

Target 4: Alamosa (Alamosa and Conejos Counties

Main Points:

1. Geochemical and geothermal targets exist in the San Luis Valley, which is an extensional basin somewhat similar to the Basin and Range of Nevada.
2. Measured temperatures of up to 128°C occur in oil wells, but at depths too great for economic commercial development.
3. Gravity, magnetics, and seismic surveys indicate a complex basement structure, with high-magnitude normal faults forming buried horsts and grabens underneath the targets.
4. The trick here will be to inexpensively test for a geothermal resource at depths consistent with economic binary plant development.

Site Description

The north trending San Luis Valley occurs along the Rio Grande Rift in south central Colorado. Elevations range from ~7500' ASL in the valley to over 12,000 feet in the Sangre de Christo range to the east. The valley is agriculture and tourist oriented; income is lower than the Colorado average.

Water is a big concern in the area. The San Luis Valley is a true desert, receiving less than 8 inches of rain a year. The northern part of the valley is a closed depression with no surface outlet. The Rio Grande River flows down the southern part of the valley. In the valley are two primary aquifers: a shallow unconfined surface aquifer up to 200 feet deep, and a deeper confined aquifer characterized by flowing wells, some of them thermal. The water table is commonly less than 12 below ground level. Excessive irrigation has led to water-sogging and salty, alkaline soils.

Sites along the central and eastern side of the valley have encouraging temperatures and geochemistry (Figure 13). The 9,400' Mapco deep well on the east side of the valley had a bottom hole temperature of 128°C. Other, shallower thermal wells in the vicinity have geothermometer temperatures between 150°C and 210°C. South of Alamosa are several shallow warm wells with similar geothermometry. Throughout the valley, wells intersecting the deeper aquifer have high concentrations of 'indicator minerals' such as boron, fluoride, and lithium.

Land Status

Most of the land on the flat San Luis Valley bottom is private land, but some BLM land occurs in the low hills in the south and west. The Great Sand Dunes National Park lies in the northeast part of the valley, along the range front.

Previous Work

Previous work in the area includes the standard geologic mapping, plus evaluations by various groups for water quality, oil and gas exploration, and some work on geothermal. Figure 1 shows the results of water sampling and geochemical analysis, primarily by the USGS. The area was examined extensively by oil companies in the 1970's and 1980's (e.g. Brister and Gries (1994), but the only public seismic data are several seismic cross sections published by Kluth and Schaftenaar (1994). There is extensive public gravity and magnetics data that we obtained, converted into grids, and contoured, in order to get an idea of basin geometry. There is a lot of spatial data available on the National Park website for the area of Great Sand Dunes national park. Geothermal papers of the area include Ganser et. al (2011) and Morgan (2010).

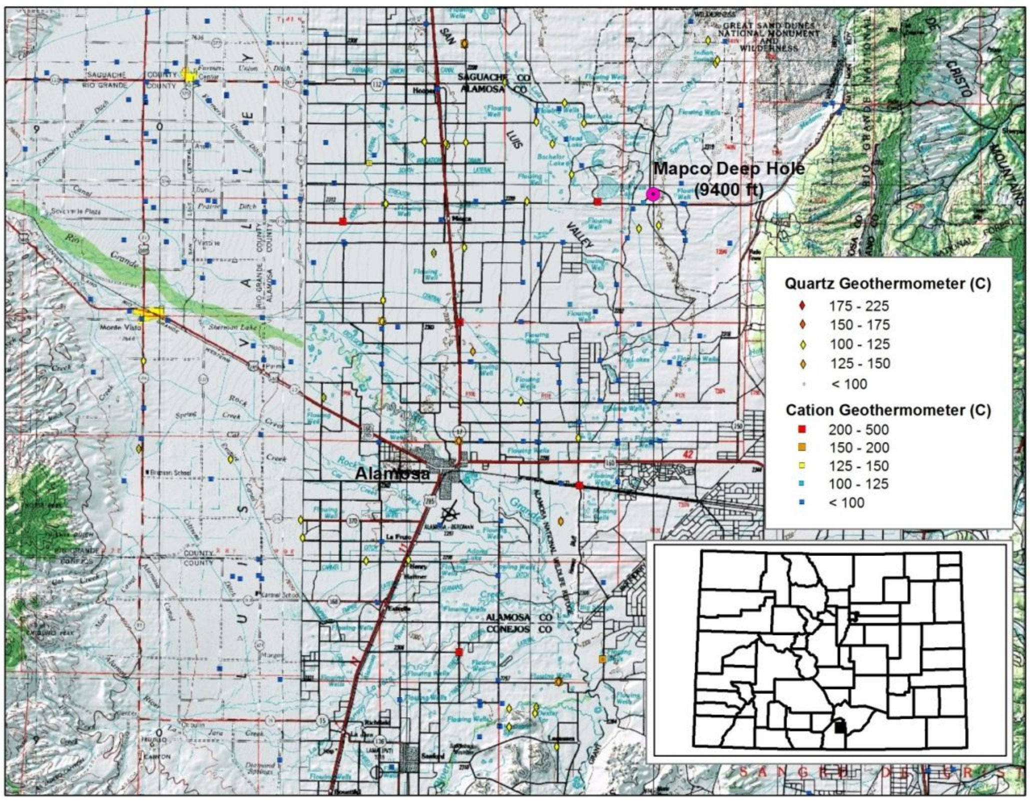


Figure 13. Location map showing a portion of the San Luis Valley around Alamosa. Quartz and cation geothermometry, mostly from wells, are shown as colored squares and diamonds. The bottom hole depth of the Mapco Deep Hole reached 128°C.

Geology

The San Luis Valley is one of several north-south trending extensional basins that are part of the Rio Grande Rift system. Asymmetrical faulting along the east side of the valley may have total displacement of 9km (29,500 feet) along steep faults forming the boundary with the Sangre de Christo Mountains (Kluth and Schaftenaar, 1994). Deposition of sediments began in late Oligocene time, and continues to the present day. This sedimentary package, collectively called the Santa Fe formation, consist of alluvial fan deposits at the valley edges that grade laterally into finer sediments derived from pre-Cenozoic basement rocks, as well as volcaniclastic rocks from the San Juan volcanic field to the west. The thickness of these sediments range up to 3.1km (over 10,000 feet).

A buried horst block lies underneath the center part of the San Luis Valley near Alamosa, splitting the valley into two separate basins: the Monte Vista graben on the west, and the deeper Baca graben to the east. Precambrian basement rises to within ~4,500 foot depth at the top of the Alamosa horst.

Geothermal activity occurs throughout the valley in the form of thermal springs and wells, some with encouraging geothermometer temperatures (Figure 13). In the eastern and deepest part of the valley, deep wells tap hot water with both cation and silica geothermometer temperatures suggesting a ~150°C resource. For example, the 4,480 foot deep well serving the San Dunes Swimming Pool emits 800 gpm of 43.4°C water with 150°C quartz and cation values. However, this is not a great temperature gradient, and results from this well and the MAPCO well suggest that depths of greater than 2km are necessary to reach hot enough temperatures in this portion of the basin. This would probably not be economic.

Oil and gas wells from the valley show a higher than normal geothermal gradient (Figure 14). Assuming these holes are random samples of bottom hole temperatures, binary power plant temperatures could generally be reached at around 10,000 – 12,000 foot depths. Morgan (2010) points out that stratigraphic columns suggest that highly permeable units exist only in the upper portions of the sedimentary pile, so intergranular permeability could become a problem at depth. The question becomes, is there anywhere in the valley one could drill and reach these temperatures at a shallow depth?

Geochemistry

As mentioned above, numerous wells in the San Luis Bain have one or more of the following encouraging geochemistry: high silica and associated high silica geothermometer values, high cation geothermometer values, and/or high boron, fluoride, and lithium. Many of these constituents occur in thermally heated water.

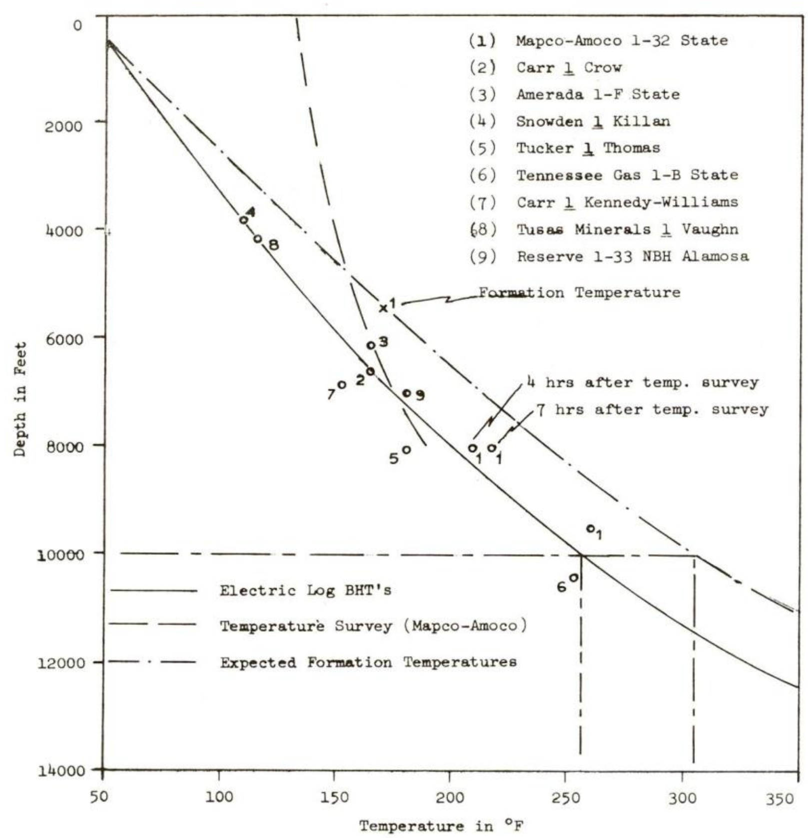


Figure 14: Temperature-depth plot showing bottom hole temperatures from oil and gas wells drilled in the San Luis Valley. From Morgan (2010).

ASTER Imagery

Recent terrain-corrected ASTER imagery indicates that thermal anomalies may exist along the west flank of the Sangre de Christo Mountains in the Twin Peaks area (Figure 15). This target is mostly on National Forest land in terrain too steep to develop. Alternatively, if georeferencing is poor (i.e. displaced to the east by 2-3 km), this could represent a range front thermal anomaly associated with the steep range front fault that bounds the east side of the basin. If this is the case, then the ASTER data may have identified the geothermal system responsible for the deep hot wells down-gradient in the valley, which is accessible at a shallower depth than generally supposed. If true, this would be a good target to explore.

Discussion

I will propose that geothermal targets might exist in the center of the San Luis Valley, along range front fault structures of the Alamosa Horst (Figure 15). Shallow wells in this area (~350 foot depth) occasionally yield warm water and/or encouraging geochemistry, in the form of high geothermometer values or trace elements. Contoured gravity data, in this area shows areas of high horizontal gravity gradients, which correspond to buried normal faults. Some of these are likely conduits to geothermal fluids, and the depths to them (and basement rocks) are considerable more shallow than the deep well targets in the northeast part of the valley.

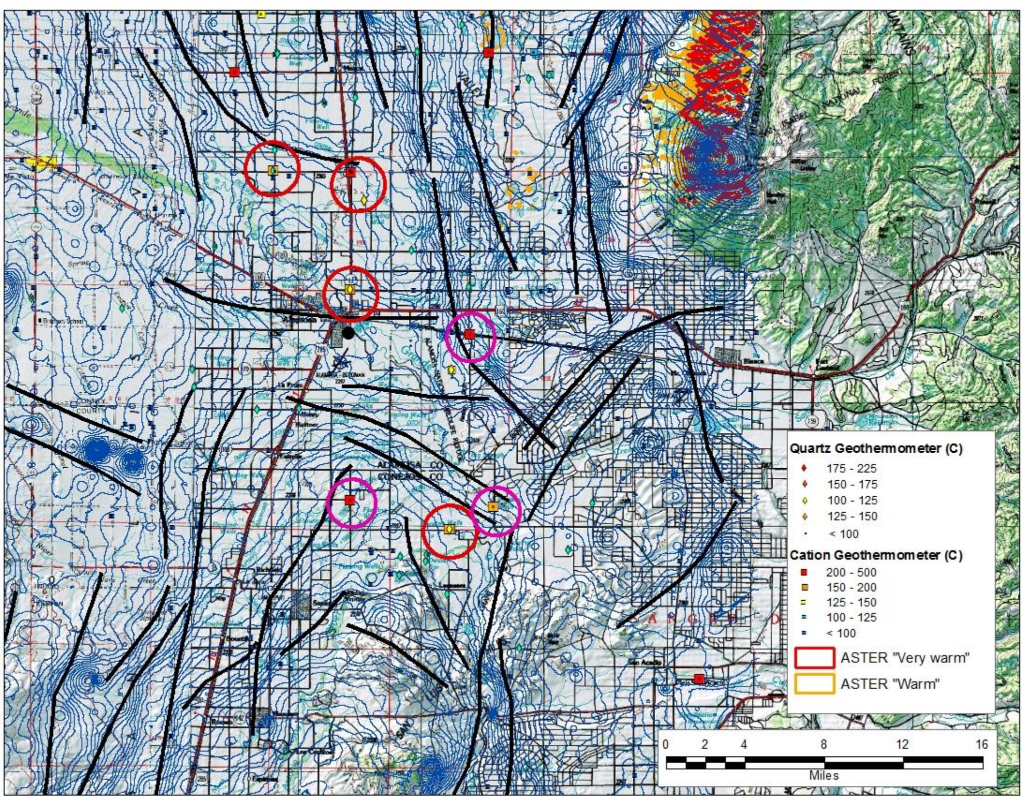


Figure 15: Potential geothermal targets in the southern San Luis basin. Gravity contours are in blue; possible buried normal faults derived from the gravity data are solid black. Possible targets are circled: thermal wells are in red, non-thermal wells

are magenta. Alamosa is adjacent to the northernmost (red) circle. An ASTER anomaly occurs along the east flank of the Sangre de Christo Mountains ENE of Alamosa. Note other geochemical targets are in the neighborhood.

Several factors would have to be considered in exploring these targets. First, surface data is limited. Direct structural mapping is impossible, and the location of geochemical anomalies (springs and wells) will have been offset some unknown amount by groundwater flowing down the hydrologic gradient. Second, while the gravity data can indicate the general location of subsurface structures, it can give only a general area (within, say ½ to 1 mile). Third, MT data would be necessary to identify zones of low resistivity (i.e. hydrothermal alteration). To perform an MT survey in a large, unconstrained area such as this, a coarse grid will have to be laid out, with anomalies identified to be fleshed out later in detail. This would require a more costly approach of asking landowners for permission to place MT probes on the ground, probably prior to negotiating an agreement.

Regarding the ASTER anomaly on the east flank of the Sangre de Christo Range, this might be an excellent target to pursue if found to be along the range front, and verified by shallow 2m surveys. The Great Sand Dunes National Park is in this area, and possible environmental concerns need to be considered.

Suggested next steps

1. Discuss reconnaissance magnetotelluric survey with geophysical companies to ascertain sample spacing, site requirements, and budget with respect to the known targets.
2. Obtain hydrologic information regarding hydrologic flow direction, and other subsurface factors.
3. Employ a geophysicist to perform gravity modeling of the target area to site faults better.
4. Talk with local authorities to ascertain whether MT stations can be sited on county road easements, etc.
5. Determine the level of local interest or resistance to geothermal exploration in the area.
6. Attempt to determine if the location of the ASTER anomaly is georeferenced too far to the east; if so, plan a shallow temperature survey at judicious points along the range front.

Target 5: Redvale (Lemon Hot Springs) - San Miguel Co.

Main Points

1. Warm spring with interesting geochemistry issues from a travertine mound on the banks of the San Miguel River
2. The spring occurs on private land surrounded by steep (undevelopable) BLM land, which in turn is surrounded by flat tabletop lands that are privately owned.
3. Little structural or alteration data to suggest up-gradient direction to source.

Site Description

Lemon Hot Springs (33^{o}C) comes out of the Permian Cutler Formation from an adit at river level in the hamlet of Placerville, Colorado (Figure 16). The adit was dug underneath a travertine terrace that underlies older river alluvium of the San Miguel River. The river has cut through perhaps a thousand feet of mixed Cretaceous and Tertiary rocks, forming steep hillsides (owned by BLM) that climb up to flat table lands (private land). The property that the springs are on is part of a subdivided patented mining claim that has several other owners. Several other patented claims comprise the private land that Placerville is situated on.

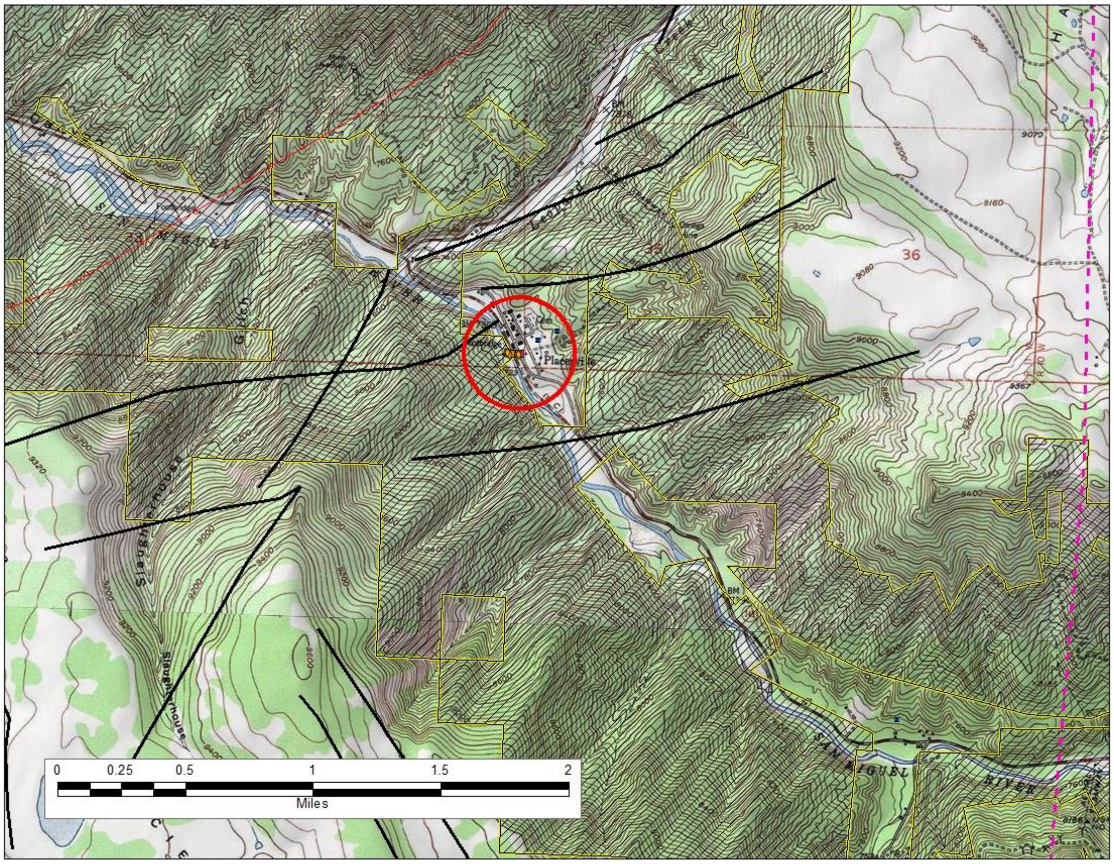


Figure 16. Location map showing Lemon Hot Springs area (red circle). BLM land is cross-hatched. Solid black lines show air photo lineaments. A transmission line (red) lies within about a mile of the project area.

The springs were identified during the geochemical assessment of Colorado, near but not part of the Redvale ASTER thermal anomaly (Polygon 23). This anomaly was tested approximately 18 miles from the springs and was interpreted to be the result of solar heating of the Dakota Sandstone.

Land Status and Ownership

The land around Lemon Hot Springs encompassing the town of Placerville consists of subdivided patented mining claims. Surrounding this is a mixture of private and BLM lands (Figure 16).

An ACEC (Area of Critical Environmental Concern) occupies the San Miguel River gorge and a narrow track along Beaver Creek. The San Miguel River portion of the ACEC comes upstream to within perhaps a kilometer of Lemon Hot Springs. This may affect exploration operations upstream in the vicinity of Lemon Hot Springs.

Previous Work

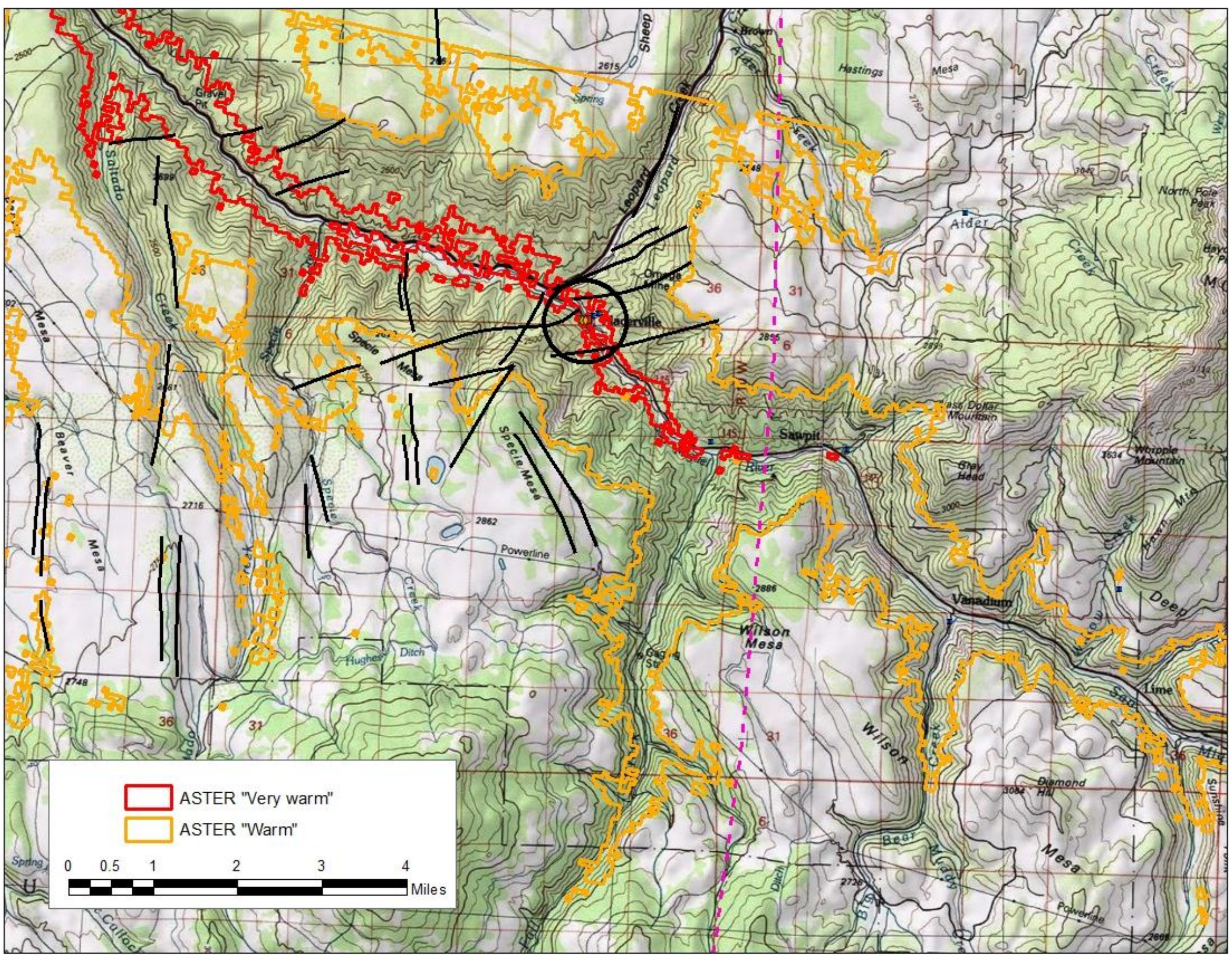
Aside from the usual regional geologic mapping, little is known about Lemon Hot Springs.

Geology

Rocks in the target are composed Permian through Cretaceous sedimentary rocks that have been intruded by early to mid-Tertiary volcanic rocks. The Permian Cutler Formation (sandstone) forms the bottom of the San Miguel River Gorge, while the Dakota Sandstone forms the topmost “table land” unit.

Surface structural measurements and air photo lineament analysis suggest that these sedimentary rocks are cut by weak NE- and NW-striking fracture sets along which some faulting has occurred. Rocks adjacent to the warm springs show ENE-striking fractures that could represent a structure along which geothermal fluids are flowing.

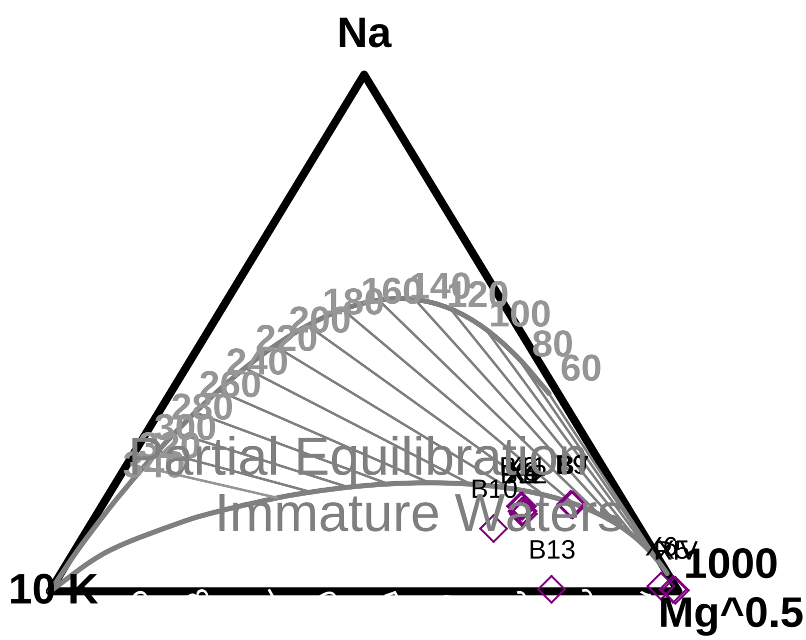
Recent terrain-corrected ASTER imagery shows large areas around Placerville to be thermally anomalous. The anomalous areas correspond extremely well with the San Miguel River Valley, leading me to conclude that they are river or topography related.



Geothermometry

Lemon "Hot" Springs (actually an adit with warm water coming out at 33^{o}C) is one of the few geothermal springs or wells in Colorado that has both a high cation (152^{o}C) and silica (various estimates between 106^{o}C and 130^{o}C) along with high boron and fluoride. The adit is located at river level.

The waters of Lemon Hot Springs show a sodium bicarbonate chemistry with high sulfate values. Like Pagosa Springs, the waters fall in the 'immature' or 'partially equilibrated' fields of a Na-K-Mg ternary plot (Figure 17; compare with Figure 12). Also like Pagosa Springs, this could be due to picking up Mg and other constituents during lateral flow through sedimentary rocks.



Silica geothermometers show a remarkably consistent 135^{o}C quartz and 110^{o}c chalcedony temperatures. The Na-K-Ca geothermometer is more variable, with most samples in the 155^{o}C-162^{o}C range. The relatively high magnesium values drive the cation (Na-K-Ca-Mg) geothermometer values to the 100^{o}C-112^{o}C range. While we shouldn't trust the exact values of the geothermometer temperatures (particularly the cation values), the geology and geochemistry are consistent with a "high-temperature" geothermal system that has travelled laterally through rock units and picked up magnesium and sulfate.

Discussion

As with the Pagosa Springs geothermal system, a big question is: where is the upwelling fracture zone, and how would we find it? Consider:

- There is no hydrothermal alteration in the sedimentary rocks associated with the warm springs that could help point out the direction of fluid flow.
- The area is surrounded by very steep, government owned ground that would probably preclude a MT survey.
- The springs may have come out of the sedimentary rocks well upstream, and traveled downstream underneath the alluvium.,

- On the positive side, unlike Pagosa, there are very few people living in these parts, and only one user of the springs.

References

Brister, B.S., and Gries, R.R., 1994, Tertiary stratigraphy and tectonic development of the Alamosa basin (northern San Luis Basin), Rio Grande rift, south-central Colorado in Keller, G.R., and Cather, S.M., Basins of the Rio Grande Rift: structure, stratigraphy, and tectonic setting: Geological Society of America Special Paper 291, p. 39-58.

Chapin, C.E., and Cather, S.M., 1994, Tectonic setting of the axial basins of the northern and central Rio Grande Rift, in Keller, G.R., and Cather, S.M., Basins of the Rio Grande Rift: structure, stratigraphy, and tectonic setting: Geological Society of America Special Paper 291, p. 5-25.

Christopherson, K.R., 1979, A geophysical study of the Steamboat Springs, Colorado geothermal systems: MS Thesis, University of Colorado, 107 p.

Galloway, Michael J., 1980. "Hydrogeologic and Geothermal Investigation of Pagosa Springs, Colorado." Colorado Geological Survey, Department of Natural Resources.

Ganser, M., Del Real, P.G., Murphy, M., Perkins, L., and Pistone, S., 2011, A report submitted to the National Renewable Energy Laboratory: NREL Report RXH-0-40456.

Kluth, C.F., and Schaftenaar, C.H., 1994, Depth and geometry of the northern Rio Grande rift in the San Luis Basin, south-central Colorado in Keller, G.R., and Cather, S.M., Basins of the Rio Grande Rift: structure, stratigraphy, and tectonic setting: Geological Society of America Special Paper 291, p. 27-37.

Larson, P.B., 1983, Stable isotope and fluid inclusion investigations of epithermal vein and porphyry molybdenum mineralization in the Rico mining district, Colorado: Economic Geology, v. 82, pp. 2141-2157.

Medlin, Eric, 1983, Modeling Local Thermal Anomalies: Constraints from Conductivity, Gravity, and Heat Flow. MS Thesis, University of Wyoming.

Morgan, Paul, 2010, Geology and geothermal energy potential of the San Luis Valley: Workshop for geothermal uses in the San Luis Valley, Adams State Community College, Feb. 27, 2010 (PowerPoint presentation).

Morgan, P., Barkmann, P., Kluth, C., and Sares, M., 2010, Prospects for electrical generation in the San Luis Basin, Colorado, USA: Geothermal Resources Council Transactions, v. 34, p. 615-625.

Oerter, E.J., 2011, Geothermometry of Thermal Springs in the Rico, Dunton, and West Fork Dolores River Areas, Dolores County, Colorado: Colorado Geological Survey, 95 p.

Oerter, E.J., and Sares, M.A., 2010, Geothermometry of warm springs in the Rico area, Colorado: Geothermal Resources Council Transactions, v. 34, pp. 703-707.

Pearl, R.H., Zacharakis, T.G., and Ringrose, C.D., 1983, Geothermal Resource Assessment of the Steamboat-Routt Hot Springs area, Colorado: Colorado Geological Survey Resource Series #22, 86 p.

Powell, T., and Cummings, W., 2010: Spreadsheets for geothermal water and gas geochemistry: Proceedings, Thirty-Fifth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 1-3, 2010, SGP-TR-188

Pratt, W.P., McKnight, E.T., and DeHon, R.A., 1969, Geologic Map of the Rico Quadrangle, Dolores and Montezuma Counties, Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-797.

Warren, W.J., 1986, A geothermal exploration project in Pagosa Springs, Colorado: Unpublished M.S. Thesis T3211, Colorado School of Mines.