

## GEOTHERMAL EXPLORATION AT FORT BIDWELL, CALIFORNIA

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### **ABSTRACT**

Preliminary geochemical and geophysical exploration has begun at the Fort Bidwell Indian Reservation (FBIR) which will lead to siting a 1500 m slim exploration well in the summer of 2005. Unusually enriched helium isotope values, geothermometry in nearby gradient wells and encouraging results from time-delay SP surveys are favorable indicators in the work to date.

### **BACKGROUND**

The Gidutikad Band of the Northern Paiute, known as the Fort Bidwell Indian Community (FBIC), resides in the extreme northeast corner of California. This area, now known as the Fort Bidwell Indian Reservation, was established in 1866 as a military outpost to subdue the Paiute people. The Reservation is situated within the Tribe's aboriginal territory in Modoc County, 12 miles south and east of the Oregon and Nevada borders.

The FBIR lies on the high-desert, eastern slopes of the 10,000 ft Warner Mountain Range. It is bordered by the Modoc National Forest to the west, private ranch land to the north and south and the town of Fort Bidwell to the east. FBIR land totals 3,543 acres, about 2,600 of which are forested with stands of fir, pine and cedar at elevations ranging from 5,000 to 8,000 ft.

Like many rural communities, the FBIR suffers from a lack of local job opportunities, a lack of basic facilities (e.g., grocery and gasoline) and a declining population. The FBIC's unemployment and poverty rates are estimated by Federal agencies to be more than three times the national average for Indian Reservations. The tribal leadership has identified sustainable development of FBIR's natural resources as its preferred path of economic development, with

geothermal resources having a high priority. In June, 2004 the Tribal Council approved an application to the DOE's GRED III program for the project that is the subject of this report.

### **PRIOR EXPLORATION**

Fort Bidwell is at the north end of Surprise Valley and has very little surface expression of the geothermal system beneath. A single natural hot spring is on a ranch north of the reservation. Shortly after the fort was established a hot water well was drilled to supply the soldiers' domestic needs. The rusted end of the well casing is still exposed and flow from it supplies a small bathing pool known as the reservation hot spring.

Geothermal direct use and small hydroelectric generation projects on the reservation were supported in the early 1980's by the California Energy Commission (CEC) with some success. Three wells were drilled and tested with modern equipment and the data from them tells a lot about the shallow aquifers. The wells were also planned to provide deeper temperature gradient information, and the third well, FB-3, provides very useful indications of deeper conditions.

The flow rates and geochemistry found in the wells drilled with CEC support are listed in Table 1. Well FB-1 is located near the reservation hot spring and produces substantially the same fluid as that issuing from the remains of the soldiers' well. The composition of the FB-2 fluid was reportedly more similar to that of the natural hot spring north of the reservation (Juncal, 1984). These results are consistent with a model of near-surface mixing of fresh water from precipitation in the Warner Range to the west and upwelling geothermal waters from a deep fault zone.

**Table 1: Properties of 1981-1985 Wells**

Well		FB-1	FB-2	FB-3
Completion data				
(m)	depth	155	396	890
(l/s)	flow rate	28	50	25
(C)	flow temp.	46.7	35.6	92.2
Water analysis				
(mg/l)	sodium	108	66	326
	potassium	9	6	8.55
	calcium	21	7	14
	magnesium	0.6	<0.49	0.05
	silica	91	76	138
	bicarbonate	68	133	184
	sulfate	84	35	370
	chloride	36	17	203
	TDS	348	250	1075
Geothermometry				
(C)	Na-K-Ca	n/a	n/a	143
(C)	chalcedony	105	94	132

Well FB-3 was fortuitously drilled deep enough to confirm the existence of a subhorizontal outflow from a significantly hotter source. FB-3 encountered an artesian flow of approximately 25 l/s (400 gpm) with a flowing temperature of 92 C (198°F). The inflow zone extends from 654 to 732 m depth, emitting from a layer of volcanic cinders. The maximum temperature was measured at 710 m and this was followed by a temperature reversal of 10 C in the next 100 m. The geothermometry indicates a temperature of at least 92 C, sufficient to consider binary electric generation technology.

**CURRENT PROJECT PLANS**

The project objectives as approved by the DOE under GRED III are divided into three phases.

- Phase I: Conduct geothermal exploration and evaluate the preliminary geologic model to assess the validity of the targeted drillsite on the FBIR and select an optimum drilling location. Conduct environmental field surveys, and agency consultations. Conduct environmental review and obtain permits for the well scheduled to be drilled in Phase II and tested in Phase III.
- Phase II: Drill a slim-hole geothermal well and perform preliminary testing.
- Phase III: Conduct testing to demonstrate commercial potential of the resource.

The contract between DOE and FBIC was signed at the end of September 2004. This allowed time for some preliminary work on Phase 1 before snow halted operations. The major geophysical work,

including a CSAMT survey, will be done when the ground clears in 2005.

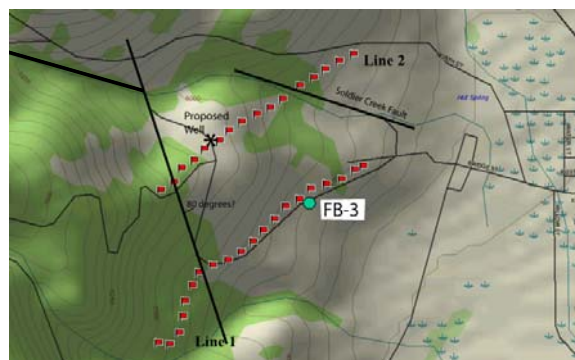
Initial wellhead inspections of FB-1, -2 and -3 were conducted in early October 2004. Wellhead vandalism had been reported at FB-3 and the condition of all three wells' valves was unknown, so equipment was not mobilized for any extended flow. The wellhead valves were serviced as necessary for fluid sampling. In early November each well was produced long enough to obtain samples of formation fluids and record stable temperatures.

All three wells showed flow rates and temperatures near those reported in the 1980's. A modest amount of plumbing would be required for extended production, as in a time-delay SP survey or tracer test, but no major obstacles were found.

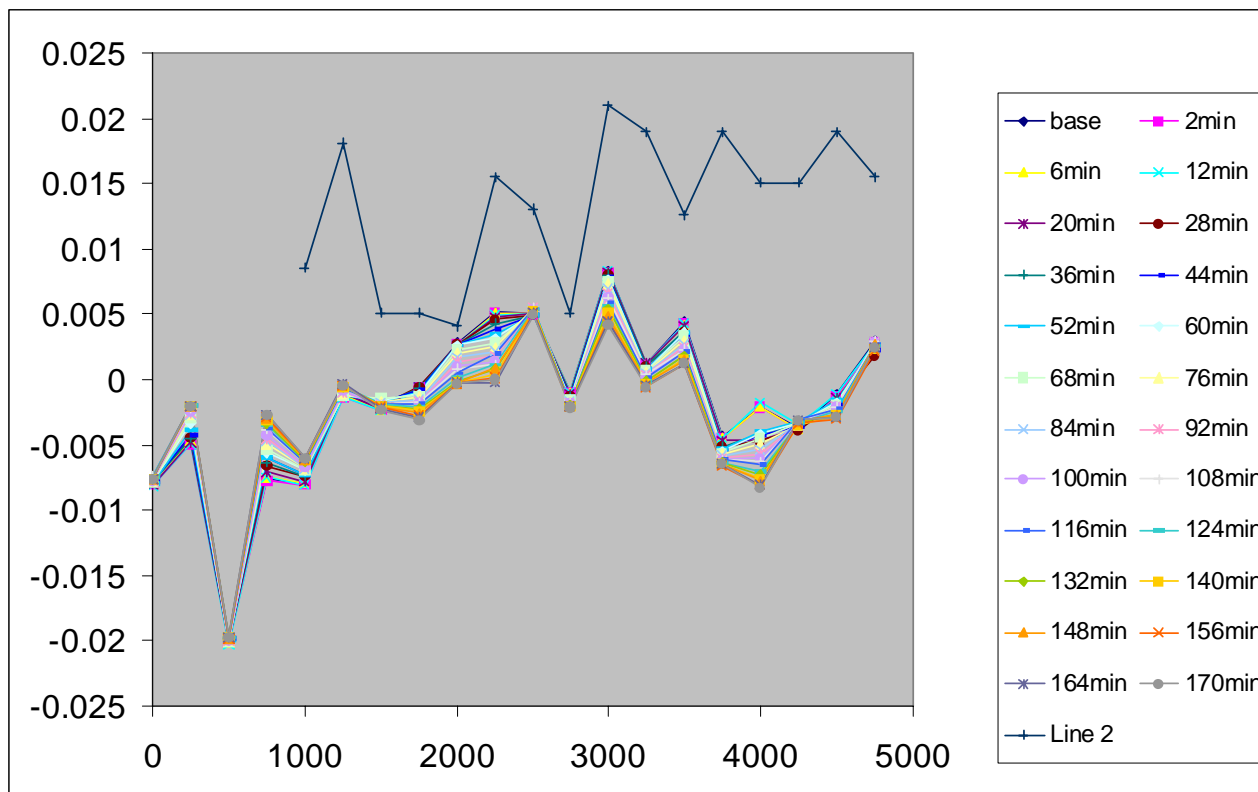
During the October inspection a self-potential (SP) survey that yielded interesting results was run in the vicinity of FB-3. Helium isotope analysis of the fluid samples also produced unusual results. The progress of field work and the survey results are very encouraging and will be discussed in turn.

**SP Surveys**

SP survey lines were run by LBL geophysicists on the same day as the FB-3 inspection in hopes the well could be produced, as it was. The locations of the survey lines are indicated by the lines of flags on Figure 1. Lines 1 and 2 were run from South-west to North-east with station 0 being the first station. Well FB-3 was opened approximately 12 minutes after SP measurements began. The well flowed continuously for the first 19 minutes and for several intervals thereafter. Over a total period of two hours and 38 minutes the well produced at full capacity for 57 minutes and at about one-third capacity for 15 minutes.



**Figure 1: Site map for SP flow test.**



**Figure 2: SP signal measured on Line 1 at time intervals shown in legend. FB-3 began flowing at 12 minutes into the SP measurements.**

Figure 2 shows the voltage measured on SP line # 1. There are two areas of large deviation as a function of time. The first occurs between sites 7 and 11 and the second between sites 16 and 18. A major north-west to south-east fault is mapped between sites 7 and 8 and the well location is between sites 15 and 16. This preliminary data indicates that time-lapse SP measurements have the potential to map the spatial location of subsurface pathways that act as fluid conduits.

The plan for future work is to lay out a surface array of SP lines that covers the prospective area. With this array in place, measurements will be made for a week or so prior to any well flowing to establish a baseline for the time-varying SP signals. In addition, a monitoring magnetotelluric station will be set up to at some distance from the site to measure the electric fields induced by the MT signal.

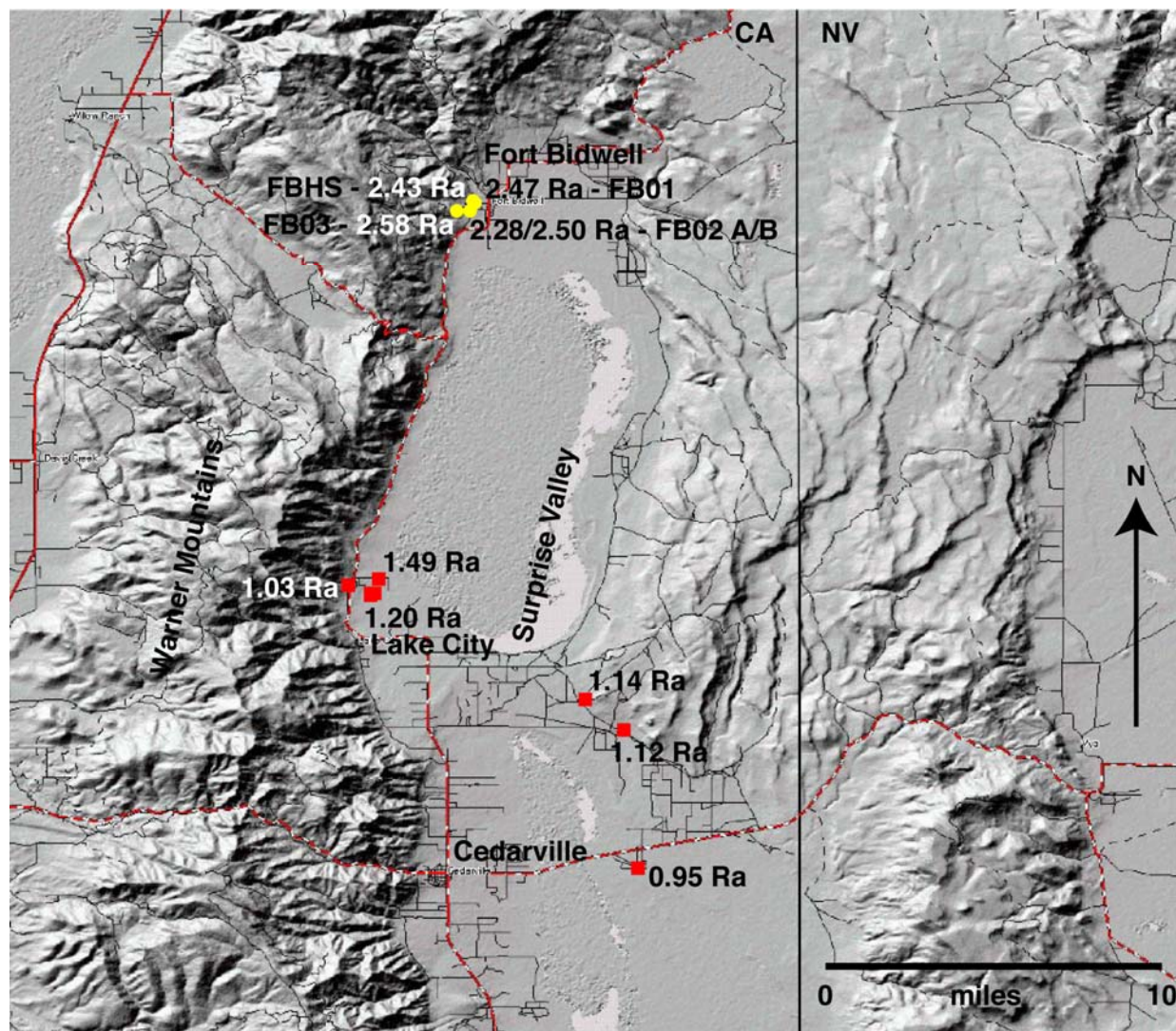
Once the base line data is acquired the array will be monitored during a controlled set of well production periods. The test periods will be structured so that FB-3 creates a pre-defined flow signal. This signal will consist of a series of on-off flow periods with variable duration of the on and off intervals. This will allow time-series analysis of the SP data to extract signals in the SP data that correlate with the flow pattern and help to reduce the SP signal that is

not related to flow. The processed SP data will be used to interpret the flow pathways in the geothermal system at depth.

### **Helium Isotopes at Fort Bidwell**

Water and gas samples were collected from FB-1, -2 and -3 and from the reservation hot spring during the October and November 2004 flow periods. They were analyzed for helium isotopes at the Center for Isotope Geochemistry, Lawrence Berkeley National Laboratory.

The Fort Bidwell geothermal resource appears to be a typical Basin and Range (B&R) style occurrence where deep circulation of fluids along a range front fault with large offset provides a conduit for the delivery of heat- and mantle-derived volatiles to the surface. Figure 3 shows the topography of the Fort Bidwell – Cedarville area with sampling points indicated. The presence of geothermal fluids at the surface in the Lake City area south of Fort Bidwell confirms that the range front fault along the east edge of the Warner Mountains acts as a permeable pathway for such fluids. More hot springs occur along this fault further to the south of Cedarville, while several can also be found along the east side of the Surprise Valley as indicated by the red dots on Figure 3.



**Figure 3: Relief map of Fort Bidwell and surrounding areas. Dots represent wells and springs sampled in this project; numbers are measured helium isotopic ratios (normalized to air, Ra).**

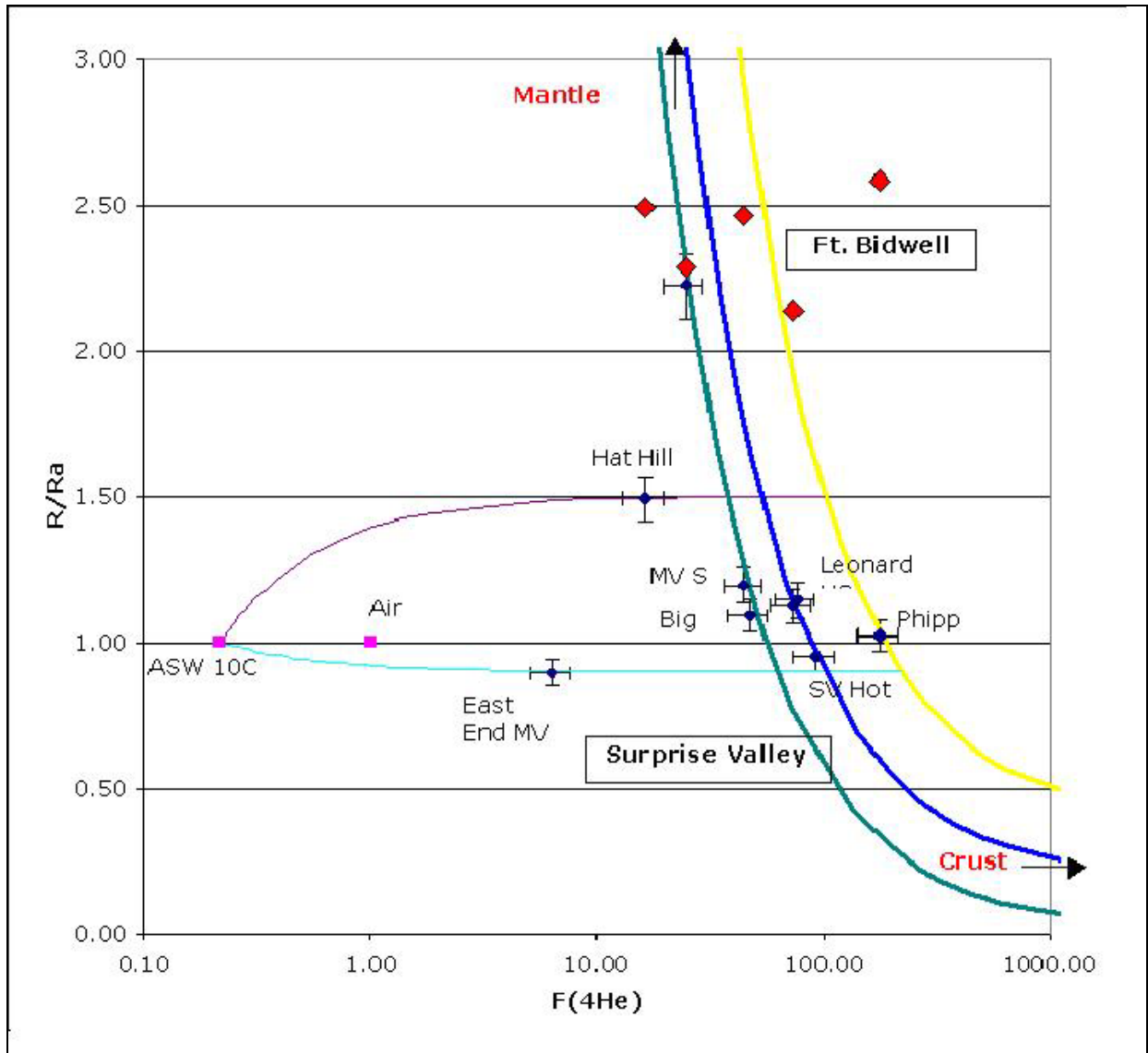
Helium isotope results for the Fort Bidwell geothermal resource range from 2.28 Ra to 2.58 Ra (where Ra is the  $^3\text{He}/^4\text{He}$  ratio in the atmosphere). These are the highest ratios observed to date in the B&R for what is believed to be a non-magma hosted geothermal resource. The Fort Bidwell area really stands out in comparison to the Lake City/ Surprise Valley area and to Dixie Valley. Lake City is about 22 km directly south of Ft. Bidwell and is characterized by R values of 0.95 to 1.49 Ra. The Dixie Valley system is 300 km southeast of Fort Bidwell and shows maximum ratios of 0.86 Ra (Kennedy and Van Soest, 2005).

There is also a trend of increasing mantle influence from south (Surprise Valley) to north (Ft. Bidwell), as shown by Figure 4 on the following page. It is

evident that all of the sampled geothermal features conform to the mantle-crust mixing model, except for a few which appear to be strongly influenced either by air contamination or air saturated water (ASW).

We do not have sufficient information to assess whether the higher helium isotope ratios at Ft. Bidwell reflect recent volcanism and, perhaps, the presence of a small shallow magma chamber or, more likely, the range front fault serves as a highly permeable fast path for the transport of heat and mantle volatiles from deep crust and/or mantle to the near surface (e.g., Kennedy and van Soest, 2005).

Either possibility bodes well for success of the planned well FB-4 if the upflow zone can be identified.



**Figure 4:** Helium isotopic compositions ( $R/Ra$ ) plotted as a function of  $^4He$  enrichment factors [ $F(^4He)$  refers to the  $^4He/^{36}Ar$  ratio normalized to the ratio in air]. The Ft. Bidwell data are shown as red diamonds; the other data points are features to the south of the Ft. Bidwell area and predominately are from Surprise Valley. The Green, Blue, and Yellow lines are mixing lines between mantle and crustal end-member compositions.

#### **ACKNOWLEDGEMENTS**

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