

To: Todd Jaffe, Davenport Newberry Holdings
Al Waibel, Columbia Geoscience
From: Jill Robinson Haizlip, Geologica
Date: 4 February 2010

Re: Gas Analysis of Newberry wells

Analyses of gasses produced from high temperature geothermal systems have been used to understand the relationship between gas phases, liquid phases and solid (mineral) phases. This has led to the formulation of chemical geothermometers based on gas populations.

Chemical geothermometers are based on the understanding of temperature-dependent chemical reactions and chemical equilibria between gas, liquid and/or solid phases. Gas geothermometry techniques are applicable under three primary types of conditions. The first considers only gas-gas equilibrium. The second considers gas-mineral equilibrium using H_2S , CH_4 and H_2 . The third includes gas/water reactions and uses gas analysis from well production fluid which includes measurement of a gas-water ratio. The most comprehensive and useful gas geothermometers are based on substantive gas-water well test samples where partial pressures of gasses and gas-water ratios can be reliably estimated. These geothermometers work well for samples collected at hot springs, boiling springs, and flowing geothermal wells. The sampling conditions and springs and wells provide constraints on temperature, pressure, and relationships between steam and non-condensable gasses.

The well status and sampling conditions at well 46-16 present some significant limitations with regard to gas geothermometry interpretations. In October 2008, the well reached TD, and was cooled by circulation of water and remnant drilling fluid, in preparation to running a suite of geophysical logs. A process was then initiated to unload the hole, to test production potential from promising zones within the well bore. As the fluid pressure within the well bore was decreased, a section of tuff just below the casing shoe bridged the hole. Multiple attempts to clear the bridge were unsuccessful, and flow test efforts were suspended. No fluid samples from a flowing well were possible. Currently the hole remains bridged at and below the casing shoe. The water left in the well bore was a combination of fresh water from a shallow coldwater well and remnant drilling fluid. When the well was shut in for the season the water level was at the well head.

A visit to the 46-16 well site noted gas under pressure venting from the well head. The well head pressure gage registered 600 psi. The pressure was bleed off and the leak was repaired. The well head pressure built back up to 600 psi within a matter of hours. In October of 2009, samples of the gas were collected and a TP log was run. The static water level was observed to be at 2070 ft. The well was bridged at 5000 ft., about 200 ft. below the casing shoe. A maximum temperature was recorded at the bridge of 304°F, though the water was observed to be slowly circulating within the well bore.

The depth(s) of gas entries and corresponding formation temperature(s) for well 46-16 are unable to be measured at this time. Geothermal gas is entering the well bore at some depth below the bridge. The gas is percolating upward thru the well bore water, possibly chemically shifting with reactions with the well bore water, and accumulating in the well head. The source depth of the gas entry is unknown, though one notable possibility is around 9,000-10,000 foot depth, particularly between 9100 and 9400 ft. This zone produced marked gas entries during drilling, with CO₂ values exceeding 15,000 ppm. Temperature data for the well below the bridge are minimum temperatures in that the temperature survey was run with other geophysical logs after the hole had been intentionally cooled to protect the instrumentation.

Geophysical logs show a temperature of about 410°F at 9000 ft. on run 1, and about 450°F on run 2. These temperatures are similar to that observed in well 55-29 taken under comparable conditions and timing. Due to bridging, no thermal equilibrated temperatures are available for well 46-16. With well 55-29 the final equilibrated temperature at that point was about 590°F at 9,000 ft. and above 600°F at 10,000 ft. Therefore all that can be said for well 46-16 is that the minimum formation temperature at 9,000 ft. is 450°F, with a likelihood of the actual formation temperature being 100°F higher than the measured temperature.

This all results in the limited application of gas geothermometry on samples collected in October of 2009. There are, however, some qualifying conclusions that can be made.

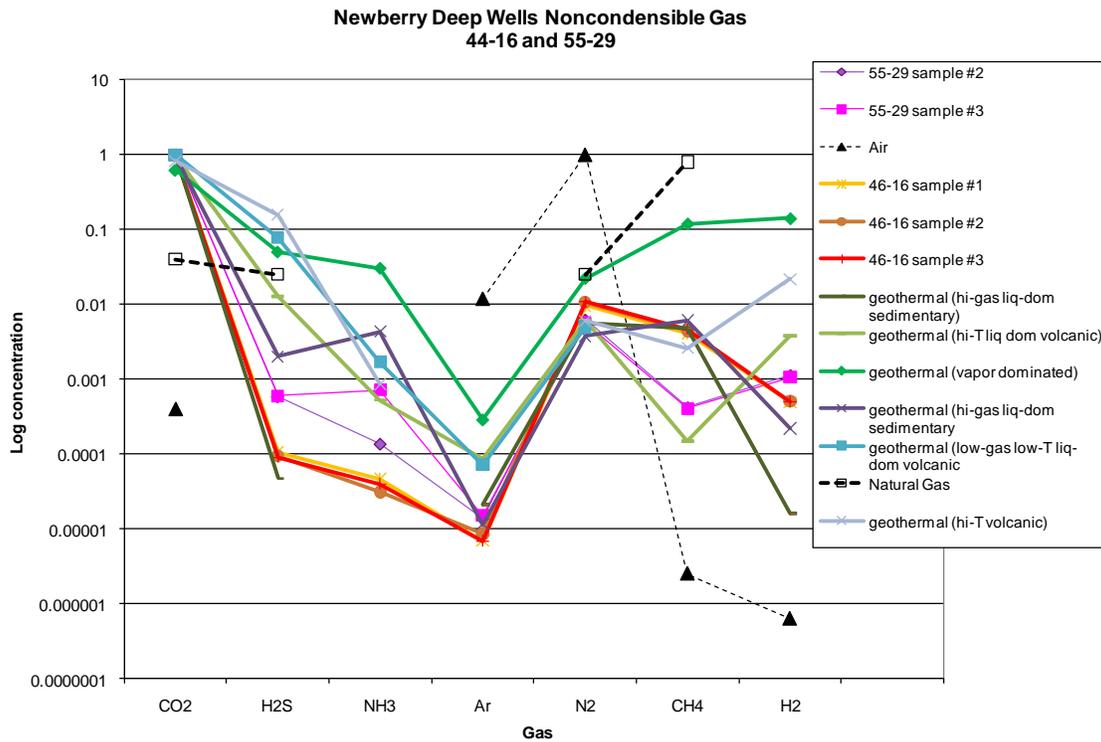
Geologica has reviewed results from recent gas sampling (by Geologica) and analysis of gas (by Thermochem) accumulated in well Newberry Geothermal Well #46-16. The gas sampling was performed in October 2009 during the venting of gas built up at the wellhead. During sampling, the gas did not include significant amounts of water and therefore no gas/water ratios were available. The analytical results presented below are compared with those collected during the flow test of 55-29 and evaluated for temperature indications based on gas composition.

Noncondensable Gas Analysis

Well-Sample	Date-Time	carbon dioxide, CO2 % by volume	hydrogen sulfide, H2S % by volume	ammonia, NH3 % by volume	argon, Ar % by volume	oxygen, O2 % by volume	nitrogen, N2 % by volume	methane, CH4 % by volume	hydrogen, H2 % by volume
NWG-46-16	10/25/2009 13:10	98.6	0.0107	0.004715	0.000695	0.00791	0.961	0.412	0.0491
NWG-46-16	10/25/2009 13:50	98.4	0.00952	0.00314	0.000867	0.0109	1.06	0.442	0.0509
NWG-46-16	10/25/2009 14:05	98.4	0.00913	0.004	0.000689	0.00459	1.08	0.47	0.0508
NWG-55-29 FT	7/19/2008 0:00	99.2	0.0589	0.0137	0.00138	0.0234	0.622	0.042	0.113
NWG-55-29 FT	7/19/2008 0:36	99.2	0.0601	0.072	0.00151	0.0028	0.562	0.0408	0.106

A comparison of gas analyses indicates that the gas collected at the end of the attempted flowing of well 55-29 and the gas collected recently from 46-16 were similar but not identical in composition. As shown in the Schoeller diagram below, relative concentration patterns of major noncondensable gas samples from the Newberry wells (carbon dioxide (CO₂), hydrogen sulfide (H₂S), ammonia (NH₃), argon (Ar), nitrogen (N₂), methane (CH₄) and hydrogen (H₂) are within the range of geothermal gases from other geothermal systems. The composition of geothermal gas is distinct from air, which has negligible hydrogen sulfide and ammonia and from natural gas which is almost all carbon dioxide and has negligible amounts of ammonia, argon and hydrogen

The composition of gas samples from both wells appear to be hydrothermal (geothermal) gas similar to that from known liquid-dominated geothermal systems hosted in volcanic rocks. In addition to the proportions of major noncondensable gas, the hydrothermal character of these gases is indicated by the ratio of nitrogen and argon (N₂/Ar) which averages almost 1400 in 46-16 and over 400 in 55-29 (although in 55-29 it may have probably been lowered by air contamination). The average N₂/Ar in air saturated meteoric water is 38. The average N₂/Ar ratio in magmatic "andesitic" gas typical of gas discharges from geothermal and volcanic centers is between 800 and 2000.



The hydrothermal nature of the gases indicates that they have interacted with water at high temperatures. The composition of the gases is consistent with a magmatic gas which subsequently interacted with water. This may allow the application of gas geothermometers: temperatures estimated from temperature-dependent gas reactions. Because no water was produced with the gas, the gas/water ratio is unknown, preventing the application of geothermal industry standard gas geothermometers. When applying the gas geothermometers which are independent of water, results indicate that these gases may originate at a range of from 458°F up to 617°F (well 44-16) and 535 to 590°F (well 55-29). Assuming these gases have equilibrated in the presence of water as would be expected in a hydrothermal system, and some assumptions are made regarding the water pressure it appears that the temperature of this system averages around 470°F (ranging between 420-492 in 46-16 (dry gas sample from wellhead) and 458-529F in 55-29 (dry gas sample during flow test)). This range of temperatures may reflect differences in equilibrium of various gas reactions or they represent a mixture of gases from different zones which vary in liquid water saturation and temperature.

In summary, based on the analysis of gas sampled from 46-16 and 55-29, it appears there is evidence that geothermal fluid exists in the vicinity of the wellbores. The temperature of these fluids is in the range of the measured temperatures.

In order to improve confidence of, and possibly expand on these tentative conclusions the following tests should be conducted:

1. Helium and helium isotope measurements to assess the magmatic contribution to these gases;
2. Comparison of gas results to alteration mineralogy in order to select optimum geothermometers;
3. Additional analyses to speciate sulfur and sulfur isotopes; and
4. Comparison with gas analysis of fumaroles within the caldera.

Attachments: Calculated Gas Geothermometer Results for 44-16 and 55-29

46-16 Gas Temperature Estimated from Gas Geothermometers											
Estimated Total Pressure	Ptot=PCO2 by D/Am-P=10 bar		PCO2= Ptot-by mineral equilibria		Max WHP=600 psig=42 bar		sat water@550F=72 bar		=BHP-hydrostatic@550F=139bar		
	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	
Estimated Temperature											
Empirical (D'Amore & Panichi 1980)	169	335	171	341	200	392	213	416	241	467	
Pyrite-Magnetite (Giggenbach 1980)	179	354	181	358	205	402	216	421	230	446	
Pyrite-Pyrrhotite (Giggenbach 1980)*	236	456	236	456	236	456	236	456	236	456	
H2S (Giggenbach 1997)	167	333	170	338	200	392	213	416	231	448	
Ammonia Breakdown (Giggenbach 1980)	147	296	151	303	192	377	211	413	238	460	
H2/Ar (Giggenbach 1991)*	288	550	288	550	288	550	288	550	288	550	
H2/Ar-CO2/Ar grid (Powell 2000)*	325	617	325	617	325	617	325	617	325	617	
Average of Select Geothermometers (*independent of gas/water)	283	541									
Average of All Geothermometers	227	440									

55-29 Flow Test Subsurface Temperature Estimated from Gas Geothermometers											
Estimated Total Pressure	P _{tot} =PCO ₂ by D/Am-P=10 bar		PCO ₂ = P _{tot} =by mineral equilibria		=Max WHP=600 psi.g=42 bar		sat water@550F=72 bar		=BHP-hydrosstatic@550F=139bar		
	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	
Estimated Temperature											
Empirical (D'Amore & Panichi 1980)	225	438	229	445	248	479	265	509	321	609	
Pyrite-Magnetite (Giggenbach 1980)	223	434	226	439	256	492	269	516	286	547	
Pyrite-Pyrrhotite (Giggenbach 1980)*	279	535	279	535	279	535	279	535	279	535	
H ₂ S (Giggenbach 1997)	209	408	213	415	248	479	265	509	286	548	
Ammonia Breakdown (Giggenbach 1980)	117	242	120	248	155	311	172	341	194	381	
H ₂ /Ar (Giggenbach 1991)*	291	556	291	556	291	556	291	556	291	556	
H ₂ /Ar-CO ₂ /Ar grid (Powell 2000)*	310	590	310	590	310	590	310	590	310	590	
Average of Select Geothermometers (*independent of gas/water)	293	560									
Average of All Geothermometers	258	496									

