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Gold, Silver and Other Metals in Scale— Puna Geothermal Venture, Hawaii

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ABSTRACT

Recent analyses of scale collected from the surface equipment at PGV yielded highly anomalous values of gold, silver, copper, zinc, lead and multi-elements. The results from 12 separate sample locations of scale analyzed high-grade gold, ranging up to 17.2 troy ounces per ton (opt), and high-grade silver ranging up to 400 opt. Copper ranged up to 5.19 percent, zinc to 24.0 percent, and lead ranged to 4.44 percent. Other metals were also anomalous, with arsenic to 6,960 parts per million (ppm), selenium to 7,700 ppm, cadmium to 2,029 ppm, molybdenum to 2,060 ppm, antimony to 1,510 ppm, tellurium to 284 ppm, and thallium to 115 ppm.

Introduction

Puna Geothermal Venture (PGV) produces electricity from a geothermal field located on the island of Hawaii approximately 21 miles south of Hilo.

PGV currently has five active production wells. All of the production wells have ground elevations of +620 ft. These wells that range from 4427 to 6532 ft. in true vertical depth have encountered a 640°F liquid-dominated geothermal reservoir. These production wells yield a mixture of steam and brine at the surface with nominal total mass flow from the five wells being approximately 1,800,000 pounds per hour containing about 600,000 pounds per hour of steam and 1,200,000 pound per hour of brine.

Geology

The PGV project is located on the Lower East Rift Zone of Kilauea Volcano (LERZ). Kilauea is the youngest of five active basalt shield volcanoes that form the Island of Hawaii. It is estimated that eruptions began on the seafloor from the Kilauea vent between 300,000 to 600,000 years ago. Eruptions from Kilauea have continued continuously since this time. Approximately

50,000 years ago, Kilauea began surface venting and formed an island. A molten magma chamber exists beneath Kilauea. This magma feeds molten lava to the summit caldera and to satellite cones along the rift zones through lava tubes.

The LERZ was the site of several eruptions from 1955 to 1960. During this time, basalt lava flowed to the surface from at least two vents located on the PGV lease. In addition, young basalt dikes have been intersected in the PGV wells. This clearly shows that magma or recently solidified magma is the heat source at Puna.

The LERZ is a large-scale fault that is down-dropping or allowing the southern flank of Kilauea to slide into the ocean. This constant movement is believed to continuously generate new fractures and reopen existing fractures. In addition, the LERZ is offset northward by a transform fault system at Puna. This transformed movement appears to have created a pull-apart feature which generated additional fractures. Faulting associated with this tectonically active LERZ has resulted in fracture permeability that supports the PGV geothermal reservoir.

PGV Geology

The only lithology at Puna is basalt. Below a depth of approximately 1000 ft, these basalts were formed in a subaqueous environment. Geologists working at Puna have divided the basalt stratigraphy into the following divisions: Cinders, lavas, hyaloclastite, pillow basalt and basalt dikes. The basalt dikes are encountered in the deeper drilling.

Geological Structure

Well drilling and testing results have shown that the production reservoir permeability is controlled by geological structure (faults/fractures). The wells have encountered two major fracture systems at Puna. The first known fracture is informally named the KS-8 Fracture. A second fracture zone is encountered in Wells KS-5ST and KS-11 and is informally named the KS-5 Fracture. Both of these fractures have large openings with drill characteristics of total void with 8 ½ -in. drill bits falling for a distance ranging to 30 feet.

Chemistry

The PGV production wells boil in the wellbore and yield two-phase fluids at the surface. Attempts have been made to obtain samples of unboiled fluids without success. Therefore, only samples of the fluids at the surface have been analyzed. This fluid typically contains 19,100 mg/kg of TDS with sodium as the primary cation at a concentration of 5890 mg/kg and chloride as the primary anion at a concentration of 10,800 mg/kg.

Analyses and Geochemistry

Recently, a total of 12 samples of geothermal pipe scale were collected from surface equipment located between the wellheads and the geothermal plant. The first two samples labeled KS-5 and KS-10 in Table 1 were collected in June 2005 from a cleanout of two years operation for those pipes that resulted in approximately 24,000 pounds of scale. The samples were selected from a part of that cleanout and do not represent an average for the total amount of material. The next 10 samples in Table 1 were collected in October 2005 and referenced to the specific location of each sample such as the separator, specific pipe, valve or other piece of equipment. This set represents scale accumulated over a one-year period of operation. In all of the sampling, the samples were collected and labeled in the field by the plant staff as the material was placed in barrels for subsequent disposal as a normal activity during the cleanout. Subsequently, D. Fitch made sub samples of these for submitting for assay. All twelve of the samples were analyzed by American Assay Laboratories, Inc., Sparks, Nevada. The commercial multi-element package was run for 69 elements by aqua regia digest and inductively-coupled plasma (ICP), with a separate fire-assay (FA) with gravimetric finish on 30 gram pulps for the gold and silver. Additionally, in cases that copper, lead, and zinc values were greater than the ICP upper limits they were then analyzed by ore-grade assay methods using aqua regia digestion and AA analysis. For the first set of two samples, duplicate pulps were sent to ALS Chemex for assay checks. The gold values checked within 1 to 3%. For the next set of 10 samples, American Assay ran ICP multi-element and triplicate fire-assays of gold and silver to provide an internal check. Copper, lead, and zinc were run by the four-acid digestion, ore grade method (Table 1).

Gold ranged up to 17.2 troy ounces per ton (opt), equivalent to 590 parts per million (ppm) and high-grade silver ranging up

to 400 opt, equivalent to 13,700 ppm. Copper ranges up to 5.19 percent, zinc to 24.0 percent, and lead to 4.44 percent. Other metals were also highly anomalous, with arsenic to 6,960 parts per million (ppm), selenium to 7,700 ppm, cadmium to 2,029 ppm, molybdenum to 2,060 ppm, antimony to 1,510 ppm, tellurium to 284 ppm, and thallium to 115 ppm. The analyses also contain high or anomalous values of Al, Ca, Cr, Fe, K, Mg, Mn, Na, Ni, and S. Notably Pt and Pd are quite low and are below the 0.25 ppm limit of detection for the ICP method of analysis used.

SEM-EDS Analyses

A polished section of KS-5 was prepared and examined under the optical microscope to search for visible gold particles and to examine mineralization textures. Textures are typical of hydrothermal veining, albeit on a miniature scale. The microveins exhibit colloform banding with evident growth formation from the pipe wall outwards toward the pipe center. Gold particles were not observed and it was concluded that the gold occurs as sub-microscopic size particles. The polished section was then examined under the scanning electron microscope-energy dispersive X-ray spectrometer (SEM-EDS) at the Electron Microbeam Laboratory, Mackay School of Earth Sciences and Engineering, University of Nevada for the purpose of identifying the mineral form and character of the gold, silver, lead, zinc, and copper. Mineralization in the sample occurs in a microveinlet, approximately 3mm thick comprised of at least eight separate colloform bands. The individual bands alternate between 50-micron bands of mostly silica and 200-micron bands of dendritic lead sulfides (with silver, zinc, copper and iron) in a matrix of mostly siliceous material (Figure 1).

Common lead sulfides were detected, as well as relatively common zinc sulfides, and rare copper sulfides. One grain of copper sulfide, approximately 5 microns in size was detected. A number of the scans returned silver, zinc, copper, sulfur and silica. All of the mineralized material is extremely fine-grained, perhaps in the sub-micron size, suggesting colloidal deposition.

Several discrete particles of silver-selenium bearing minerals, each less than one micron in diameter were identified and photographed by backscatter (Figure 2). This is probably the silver selenide mineral naumannite. No gold particles were found, and it is concluded that the gold determined by assay is very fine-grained. Additionally, gold may be masked by the abundant lead in the sample. Lead produces the same energy reflection as gold.

Table 1. Analytical results of selected metals from Puna Geothermal Venture, Hawaii. Analyses by American Assay Laboratories, Sparks, NV

Samples	Location	Au (opt)	Ag (opt)	Cu (%)	Pb (%)	Zn (%)	As (ppm)	Cd (ppm)	Hg (ppm)	Mo (ppm)	Sb (ppm)	Se (ppm)	Te (ppm)	Tl (ppm)
KS- 5	16" Iso valve at 24" hdr.	17.209	399.6	1.84	4.44	6.67	102	59.29	-0.5	2.01	162	7770.0	284.9	-3
KS- 10	Side 18" geohdr ISO	0.735	30.1	2.09	1.31	13.28	95	2029.43	-0.5	120.00	92	1930.0	5.7	-3
KS5-02	KS-5, East rockcatcher	0.700	8.5	5.19	2.23	24.00	25.1	1128.51	-0.02	2.24	5.53	1510.0	68.3	-0.09
Sep-1	Separator (Man Hole)	2.979	51.4	1.37	NA	4.22	136.0	590.67	0.10	81.30	54.80	1330.0	20.1	-0.09
Sep-2	KS-11 Separator	2.547	81.0	3.12	3.15	8.08	437.0	1566.42	0.20	363.00	175.00	2400.0	18.6	12.50
Sep-3	KS-11 Separator	3.516	87.4	2.49	2.22	6.62	267.0	1111.57	0.18	218.00	148.00	2200.0	24.3	7.31
Sep-4	KS-11 Separator discharge	1.400	8.2	NA	NA	NA	47.0	67.95	0.09	21.30	10.20	199.0	2.2	-0.09
BR-1	Brine pump, 16" valve	0.474	16.0	NA	NA	NA	2540.0	88.59	1.92	682.00	412.00	3030.0	6.1	61.90
BR-2	Brine pump, suction 16"													
	Mix Inl Area	0.245	9.8	NA	NA	NA	1990.0	53.07	1.06	653.00	288.00	2120.0	7.0	38.70
TR-21	Steam trap #21	-0.003	-0.2	NA	NA	NA	1900.0	-0.03	0.02	20.20	22.00	2400.0	14.3	-0.09
TR-25	Steam trap #25	-0.003	-0.2	NA	NA	NA	36.2	-0.03	0.13	54.20	25.30	732.0	6.6	-0.09
TIE-1	Tie in area, downstream	0.284	10.4	NA	NA	2.13	6960.0	-0.03	2.87	2060.00	1510.00	3280.0	7.2	115.00

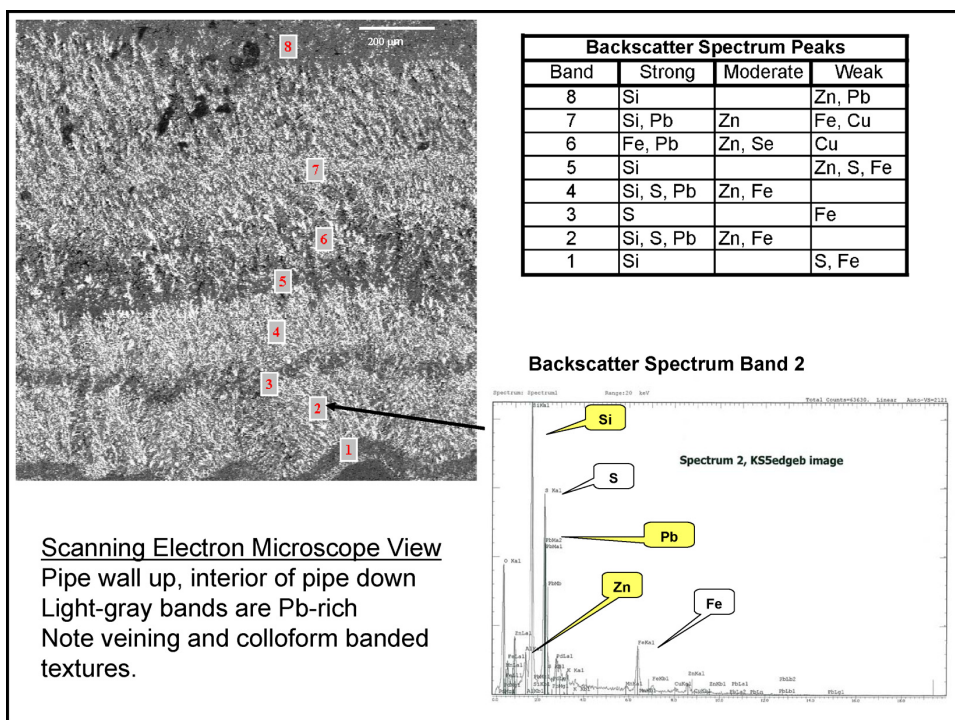


Figure 1. Metal Distribution in Banded Microveinlet, KS-5.

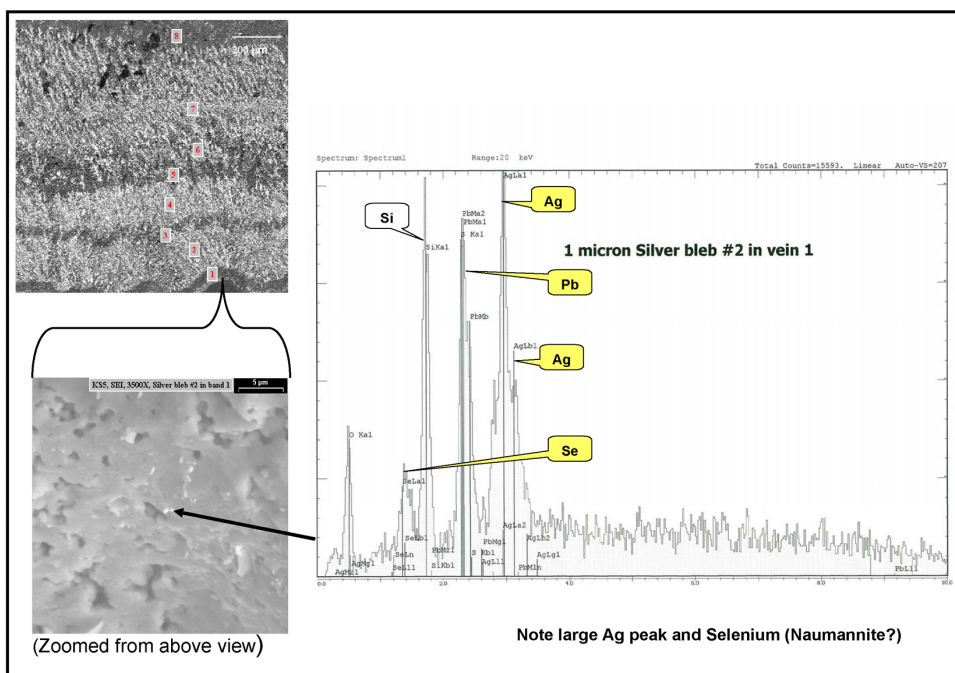


Figure 2. Silver-selenium Mineral Blebs. Scan is of thin light-gray band below Band 1.

Discussion of Results

To the authors' knowledge, this is the first report of high-grade gold and metals from the island of Hawaii. Previous workers have reported trace amounts of gold including a 0.75 micron gold particle from a petrologic study (Sisson, 2003) and analyses with gold ranging from 0.95 to 2.58 parts per billion (ppb) in Kilauea volcanics (Tatsumi and others 1999).

This occurrence of such high-grade gold and other metals at PGV is curious geologically. The source of the metals is a puzzle, and the processes of deposition are not fully understood. The deposits formed in a geological instant.

After scale is removed from pipes, it accumulates again by fluid flow. Therefore metal-rich scale must be directly formed by precipitation from the geothermal fluids. The enrichment mechanism is most likely a very efficient precipitating environment created by the design of the plant equipment, especially the separator. By design, the separator induces a significant drop in the pressure and a change in pH of geothermal fluids. A rough order-of-magnitude estimate of the gold delivered to the separator can be made with the following assumptions: Geothermal fluid flow at a nominal 1,000,000 lb per hour containing 70% brine over a two-year period flows a total of about 6,132,000 tons of brine. During this two-year period these fluids produce about 12.5 tons of scale averaging roughly 3.0 opt Au or a total of about 38 ounces Au. Assuming 100% extraction of the Au, the original Au concentration of the brine could be as low as 0.19 ppb Au to generate the 38 oz gold.

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References

Hirtz, Paul, 2006, Report of analysis for KS-5 brine and steam. Email from Paul Hirtz, Thermochem dated February 22, 2006.

Sisson, T.W., 2003, Native gold in Hawaiian alkalic magma, *Economic Geology*, v. 98, p. 643-648.

Tatsumi, Y, Kiwamu, O., and Shioda, G., 1999, The behavior of platinum-group elements during magmatic differentiation in Hawaiian tholeiites, *Geochemical Journal*, v. 33, p. 237-247.

