

Gaseous Emissions from Steamboat Springs, Brady's Hot Springs, and Desert Peak Geothermal Systems, Nevada

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ABSTRACT

Gaseous emissions from the landscape can be used to explore for geothermal systems, characterize their lateral extent, or map the trends of concealed geologic structures that may provide important reservoir permeability at depth. Gaseous geochemical signatures vary from system to system and utilization of a multi-gas analytical approach to exploration or characterization should enhance the survey's clarity. This paper describes differences in the gaseous geochemical signatures between the Steamboat Springs and Brady's Hot Springs geothermal systems and illustrates the usefulness of Hg vapor in soils at Desert Peak for mapping the trends of concealed geologic structures. Ion chromatography, gas chromatography, atomic absorption spectrometry, and inductively coupled plasma-mass spectrometry have been used to characterize the gas geochemistry of these systems.

Introduction

The use of soil gas surveys to infer the nature of subsurface geology and geochemistry has been applied to several domains, including exploration for concealed ore deposits, hydrocarbon deposits, and geothermal fields (Kesler, 1990 and Klusman, 1993). The concept that gases being released from buried metallic mineralization, hydrocarbon concentrations, or active geothermal systems, can freely rise through overlying cover to be detected in the near-surface environment is fundamentally sound and has been demonstrated in many case studies (e.g. Murray, 1997, Klusman et al., 2000, Lewicki and Oldenburg, 2005). The high mobility of gases makes them potentially the best pathfinders for concealed natural resources, including geothermal systems. Commonly, gas is sampled from the interstices of soil at a depth of up

to one meter, or a chamber or other collector is placed over the soil surface to trap emanating gases for later analysis. Many gases have been detected by these methods, including: Hg, O₂, CO₂, CO, COS, CH₄ (and other hydrocarbon gases), Rn, Ar, He, H₂S, SO₂, and H₂ (Rose et al., 1979; Kromer et al., 1981; Hale, 1992; Klusman, 1993). Other, less common, more exotic gases that might occur would include: AsH₃, AsCH₃H₂, As(CH₃)₂H, As(CH₃)₃, (CH₃)₂S, (CH₃)₂S₂, CH₃SH, CS₂, SbH₃, SeH₃, TeH₃, HF, NH₃. The specific suite of gases detectable at a given site likely will depend on the nature of the heat source, the country rocks hosting the geothermal system, the temperature, degree of oxidation, etc. Moreover, the suite may evolve with time and/or vary with location over a geothermal system, as fluids cool and oxidize as they move from upflow zones to discharge zones, for example with the oxidation of H₂S to SO₂ and SO₃. This can be very helpful in developing a deeper understanding of the geometry and dynamics of a system.

Analytical Approach

Gases are collected from soil probes at a depth of nominally 1 m or from fumaroles either by pumping through a scrubbing solution or into a glass collection bottle, or simply by filling gas-tight syringes. When collecting gas samples from fumaroles or steaming ground, both a gas phase and a condensed phase were collected. The gas phase was analyzed by gas chromatography (GC) or by direct injection into a Micromass inductively coupled plasma-mass spectrometer (ICP-MS). The condensed phase was analyzed by ICP-MS and ion chromatography (IC). Gases were collected by pumping through a scrubbing solution, either an alkaline solution (sodium carbonate-bicarbonate buffer solution) or an acidic solution (2% nitric acid). Acidic gases were collected in the alkaline solution (e.g. the gases HF, HCl, HNO₃, H₂S, H₂SO₃, H₂SO₄) and were quantified by IC (as F⁻, Cl⁻, NO₃⁻, SO₃⁻², and SO₄⁻²). Other gases and metals (e.g. Hg) were collected by the acidic solution and were determined by ICP-MS. Gases collected into bottles and gas-tight syringes can also be analyzed for radon by injection into Lucas cells

and quantification with a Pylon radon detector. Mercury (Hg) vapor soil gas is collected by amalgamation onto gold wires, with subsequent quantification by desorption into the light path of an atomic absorption spectrometer upon heating to 720°C in a heated graphite atomizer, according to the method of Lechler (1993).

Study Areas

Three geothermal systems have been studied to varying degrees in west-central Nevada, at Steamboat Springs, Bradys Hot Springs, and Desert Peak. Steamboat Springs and associated geothermal power plants are located just south of Reno, Nevada along the eastern front of the Sierra Nevada mountains, where near-surface lithologies consist of Mesozoic granodiorite, Tertiary volcanic rocks, and Quaternary gravels and sinter. Bradys Hot Springs are located approximately 16 km NE of Fernley, Nevada on the northwest side of the Hot Springs Mountains, and the Desert Peak geothermal field is a separate system on the east side of Desert Peak proper, about 6 km east of Bradys Hot Springs. The Bradys and Desert Peak geothermal systems are hosted by Mesozoic plutonic and metamorphic rocks, with Tertiary volcanic rocks present in the shallower subsurface above the reservoirs.

Work Completed

Because of the proximity of Steamboat Springs to the laboratories at Nevada Bureau of Mines and Geology, most of the gas sampling in support of method development was done here. Direct access to geothermal steam is available at an abandoned, leaking geothermal well, and other sampling has been guided by heated ground and steaming ground. Direct gas and condensate collection, as well as gas collection with alkaline and acidic scrubbers, has been conducted at Steamboat. Gases have been analyzed by ICP-MS, IC, GC, and Pylon.

At Brady's Hot Springs, sampling of fumaroles through direct gas collection and via alkaline and acidic scrubbers has been accomplished. These samples were analyzed by ICP-MS, IC, GC, and Pylon.

At Desert Peak, only Hg vapor was measured, using gold wires at the surface and a sample integration period of 7 days, in a large soil gas survey of 1100 samples. Because of leakage of Hg vapor along geologic structures, this survey successfully delineated extensions of

mapped faults where they trended beneath aeolian sand cover. These structures are believed to be important hosts of geothermal fluids in the Desert Peak geothermal reservoir.

Results

The characterization of gas species at Steamboat Springs and Bradys Hot Springs is more complete than at Desert Peak, although the number of Hg vapor samples and the amount of landscape that was sampled at Desert Peak is more extensive. The results reported here are from limited geographic areas at each of the sampled areas. These are the first steps in larger, more extensive surveys planned to compare fumaroles, steaming ground, hot ground, and background areas in these and other geothermal areas.

Steamboat Springs

Sampling at Steamboat Springs shows the presence of the following gases, probably as the noted compounds: CO₂, (N₂), (O₂), H₂O, HCl, H₂S, SO₂, SO₃, B, Mo, W, Rn, SbH₃, and Hg, as well as two unidentified ion chromatography peaks, one of which is probably acetate. Nitrogen and oxygen are probably mainly due to entrainment of atmosphere during sampling. The presence of Mo and W in geothermal steam condensate is unusual but can be explained by the presence of bedrock Mo mineralization present in the subsurface as reported by Johnson and Hulen (2006), and the common association of Mo and W. In reduced environments Mo and W can form carbonyls in the gas phase as reported by Feldmann and Cullen (1997) for lower temperature environments. This preliminary sampling was

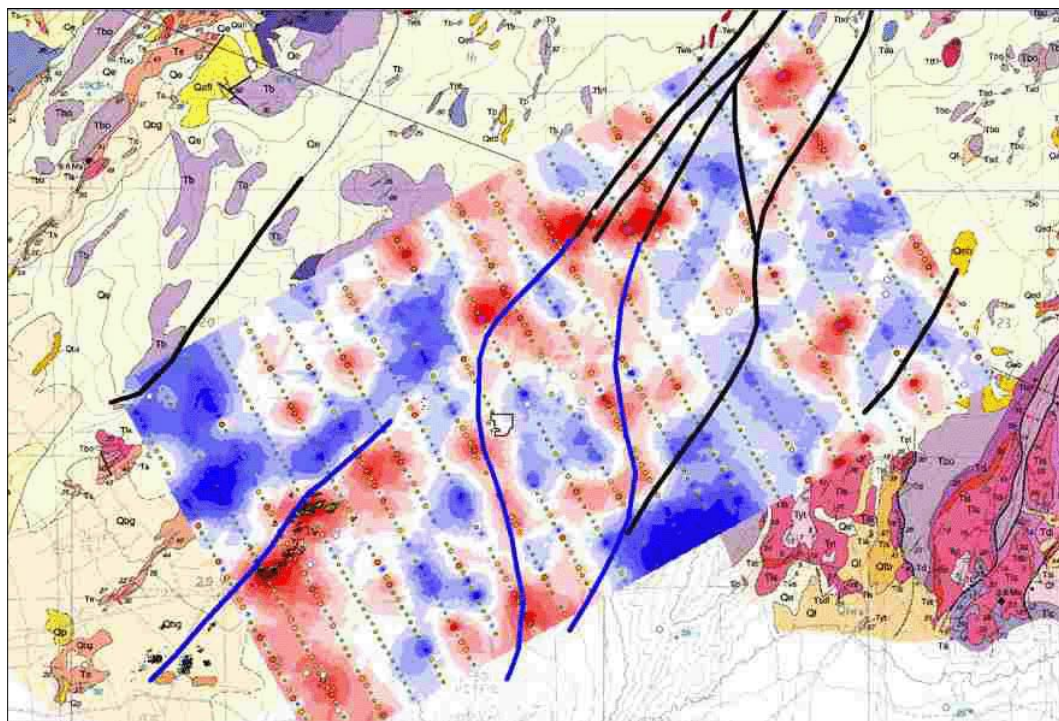


Figure 1. Desert Peak Hg soil gas survey results overlain on geology. Faults mapped geologically are in black and geochemically-mapped extensions are in blue. Warm colors indicate higher Hg soil gas concentrations. Polygon in center of the survey area is Desert Peak geothermal plant. Survey area is 2.4 by 4.4 km; true north is up.

conducted mainly at an abandoned, leaking geothermal well and steaming ground just south of the University of Nevada Redfield Campus south property boundary.

Bradys Hot Springs

Fumarole gases at Bradys hot springs contain the following compounds, probably as the reported compounds: CO₂, (N₂), (O₂), H₂O, HCl, SO₂, SO₃, Xe, B, Rn, and two unidentified peaks, one of which is probably acetate. The ICP-MS identified the presence of excess xenon (Xe) at Brady's Hot Springs and also indicated the shift of ^{129/132}Xe from atmospheric ratio to one reflecting excess ¹³²Xe. The anomalous xenon detection here may indicate a deep crustal source for this noble gas and perhaps some of the other gases as well. The shift in observed ^{129/132}Xe from atmospheric ratio to one reflecting excess ¹³²Xe, along with the greater Xe abundance, implies a significant input of Xe from a deep fissiogenic source of either ²³⁸U or primordial ²⁴⁴Pu (Kaneoka, 1998). Distinguishing between the two sources is difficult and not possible from the data collected in this study. To our knowledge, anomalous Xe has not been reported from Bradys Hot Springs before.

Desert Peak

The Desert Peak Hg soil gas survey showed clearly that leakage of gases along permeable geologic structures into overlying soil can be detected with surficial sampling. Mercury vapor concentrations for approximately 1100 soil gas samples covering an area of 2.4 by 4.4 km ranged from 0 to 155.6 ug Hg/m²/day, with a mean of 13.36 and a standard deviation of 22.32. Results of this survey are shown in Figure 1.

The strongest Hg anomaly found at Desert Peak corresponds to an area of opalized Quaternary sands which overlie the southwestern outflow aquifer (Figure 1). Although hot springs are no longer present here, the presence of opalized sands suggests that hot springs were formerly present, perhaps during the time of Lake Lahontan (~ 5-10Ka) when water tables were much shallower. The trend of Hg anomalies in this area clearly points to a structural control to outflow within this southwestern aquifer, a fact not previously recognized.

Discussion and Conclusions

Although the use of a single gas (Hg) at Desert Peak has been shown to effectively delineate and map blind geologic structures, the use of multiple gases may enhance the reliability and signal-to-noise of such surveys and also augment the understanding of a subsurface geothermal system. Similarities in the gas signatures between Steamboat Springs and Bradys Hot Springs (CO₂, H₂O, HCl, SO₂, SO₃, B, and Rn) indicate that their use in soil gas surveys may be broadly applicable. The identification of sulfur gases of varying valence states (i.e. H₂S, SO₂ and SO₃) suggests the possibility of mapping upflow

versus outflow areas within a given system. The presence of very unusual gases such as the probable carbonyls of Mo and W at Steamboat, and the anomalous Xe of non-atmospheric isotopic makeup, indicate that gas geochemistry will be very useful for developing a deeper understanding of the nature and dynamics of a geothermal system at an early exploration stage.

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