GEOTHERMAL APPLICATIONS OF MULTI-GAS GEOCHEMISTRY

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Proposal submitted in response to a REQUEST FOR PROPOSALS from the
Great Basin Center for Geothermal Energy
Proposal Deadline: Feb. 18, 2005

ABSTRACT

This project is intended to expand on the success of using a mercury soil gas survey to identify concealed geologic structures at Desert Peak, Nevada in 2003-4. It is proposed that a suite of additional gases be used to characterize and fingerprint magmatic and amagmatic geothermal systems, map geologic structures conducting geothermal fluids, and define resource boundaries. Use of existing instrumentation at UNR, including Pylon radon-measuring instruments and a gas chromatograph-mass spectrometer, will allow quantification of hydrocarbon gases, sulfur gases, and radon emanating through soils from subsurface geothermal reservoirs. The use of methane, ethane, hydrogen sulfide, sulfur dioxide, sulfur trioxide, carbonyl sulfide, carbon disulfide, radon, and other gases will enable geochemical characterization of geothermal systems of possible magmatic and amagmatic types. Once systems are characterized and methods refined, multi-gas surveys can be used to map important geologic structures and define lateral boundaries of these systems.

Radon will be determined in near-real-time in the field while other gases will be collected at field sites and transported to UNR in Teflon gas collection bags for characterization and quantification by GC-MS. Several field sites have been chosen to optimize characterization of the gas geochemistry signature of magmatic versus amagmatic geothermal systems, and to demonstrate the usefulness of multiple gases to delineate concealed geologic structures and reservoir boundaries. Field sites at Steamboat Hot Springs (possible magmatically-heated system), Buffalo Valley, Salt Wells, New York Canyon, Tipton Ranch, and/or the southern portion of the Brady's geothermal system will be characterized.

Requested Federal Funds:	
Year 1:	$45,108
Year 2:	$47,118
2-Year Total:	$92,226

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[1] Nevada Bureau of Mines and Geology; [2]Great Basin Center for Geothermal Energy.
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Introduction

The analysis of soil gas to infer the nature of subsurface geology/geochemistry has been applied to several geologic domains, including exploration for concealed ore deposits, hydrocarbon deposits, and geothermal fields (see, for example, compilations by: Kesler, 1990; Klusman, 1993; Nicholson, 1993). The concept that gases which are released from buried metallic mineralized zones, hydrocarbon concentrations, or active geothermal systems, can freely rise through overlying cover to be detected in the near-surface is fundamentally sound and has been demonstrated in many case studies. Recent results by Lechler et al. (2004) demonstrated the usefulness of a mercury soil gas survey in defining the locations of concealed geologic structures important to the geothermal reservoir at Desert Peak, Nevada.

The high mobility of gases makes them potentially the best pathfinders for concealed natural resources, including geothermal fields. 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, O_2, CO_2, CO, COS, CH_4 (and other hydrocarbon gases), Rn, Ar, He, H_2S, SO_2, and H_2 (Rose et al., 1979; Kromer et al., 1981; Hale, 1992). Other, less common, more exotic gases include: AsH_3, $AsCH_3H_2$, $As(CH_3)_2H$, $As(CH_3)_3$, $(CH_3)_2S$, $(CH_3)_2S_2$, CH_3SH, CS_2, C_2H_6, C_3H_8, C_4H_{10}, C_5H_{12}, SbH_3, SeH_3, TeH_3, HF, and NH_3, etc. Many of these less-common gases may not be detected in the present study, depending on the nature and chemistry of the geothermal system and the concentrations at which discrete gases are present. Clearly, a sophisticated analytical instrument and careful methodology are required to identify and quantify these gaseous analytes. State-of-the-science gas chromatography-mass spectrometry (GC-MS) is the instrument of choice for this analytical application. GC-MS is sensitive, providing suitably-low detection limits, and the combination of gas chromatography with mass spectrometry ensures the high specificity required to reliably identify individual gases within the complex gas mixtures characteristic of the soil gas environment. A careful characterization of the gaseous geochemical fingerprint of the spectrum of geothermal systems, and a characterization of the 2D spatial zonation of gaseous species, has not been documented. This type of analysis will provide a clear picture of the gaseous plumes emanating from geothermal systems, useful for target identification and drill hole vectoring.

A number of field sites in Nevada have been evaluated for suitability in demonstrating (1) similarities and differences in the multi-gas geochemical fingerprint of magmatic versus amagmatic systems, (2) the ability of the method to define and trace concealed bedrock geologic structures that are often important features conducting fluids in geothermal reservoirs, and (3) ability of the technique to define lateral limits of geothermal reservoirs.

Approach

Soil gas samples will be collected by driving a sampling probe into the ground, nominally to 1 m depth. The headspace gas of the probe will be removed with a hand vacuum pump, and analytical gas samples of 10 to 100 ml size will be withdrawn with gas-tight syringes. One gas sample will be transferred to a Lucas cell for subsequent measurement of radon gas concentration, and a second sample will be transferred to a Teflon gas collection bag for transport to UNR for subsequent multi-gas analysis by GC-MS.

During each day’s sampling campaign, a base station will be established at which periodic gas samples will be re-collected to monitor effects of changes in atmospheric temperature and pressure which are well known to otherwise bias gas concentration measurements. Atmospheric temperature and pressure will also be frequently monitored to allow modeling of these effects, which can then be used to correct the survey data. Application of these operational precautions along with geostatistical data processing are expected to adequately correct for extraneous analytical artifacts. All field samples will be located by GPS.

As field operational details dictate, radon measurements will be made either in-situ while powering the Pylon monitor by 12 volt battery, or the gas samples will be returned to a local motel or

UNR for immediate measurement. Additional, multi-gas analyses will be performed by GC-MS in Dr. Glenn Miller's laboratory at UNR. Teflon gas-collection bags will be sampled through their Teflon septa with a gas-tight syringe. The large sample collection volumes will enable replicate analyses, if necessary, and separate analyses following instrument re-configuration, if necessary and useful.

All data will be transferred to an Excel spreadsheet for processing, and presentation of project results will be in a GIS format.

Results

The GC-MS analytical method is a multi-gas technique. Along with the radon data, the quantification of a suite of gases produces a tremendous amount of valuable geochemical information. These multi-parameter data must be interpreted in terms of the subsurface sources and processes responsible for the observed gas patterns, both spatially and in a multi-gas context. Multivariate statistical procedures like principal components analysis or factor analysis can extract important geochemical fingerprints of these various sources and processes using all measured parameters simultaneously. This approach minimizes the ambiguities of gas anomaly sources, adding a high degree of reliability to the surveys. Geostatistical Z-score analysis may or may not be applied to the data, as required, as was done for the mercury soil gas data sets at Desert Peak (Lechler, et al., 2004).

Case studies of soil gas signatures over known geothermal fields have demonstrated the efficacy of the method even when using only one gas. For example, mercury vapor in soil gas has been shown to delineate the hottest part of the geothermal field at Dixie Valley, Nevada (Klusman, 1993), and a recent survey at Desert Peak, Nevada successfully delineated geologic structures beneath young cover(Figure 1).

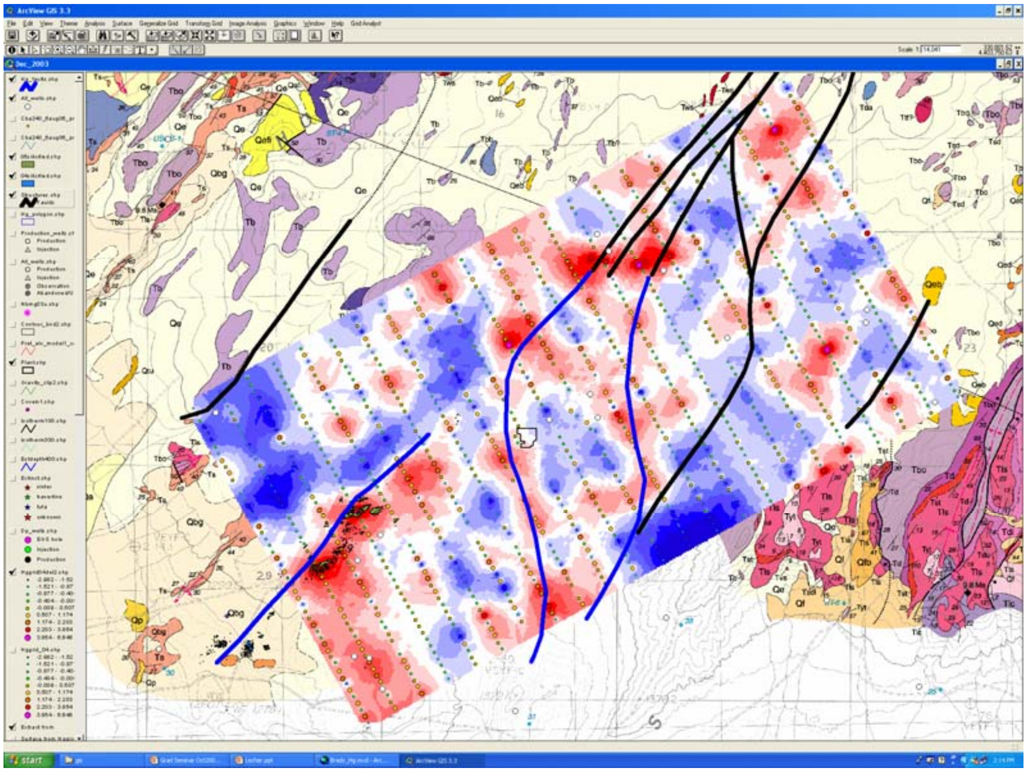

Figure 1. Mercury vapor in soil gas confirms location of hypothesized extensions (blue) of mapped faults (black) at Desert Peak (from Lechler et al., 2004).

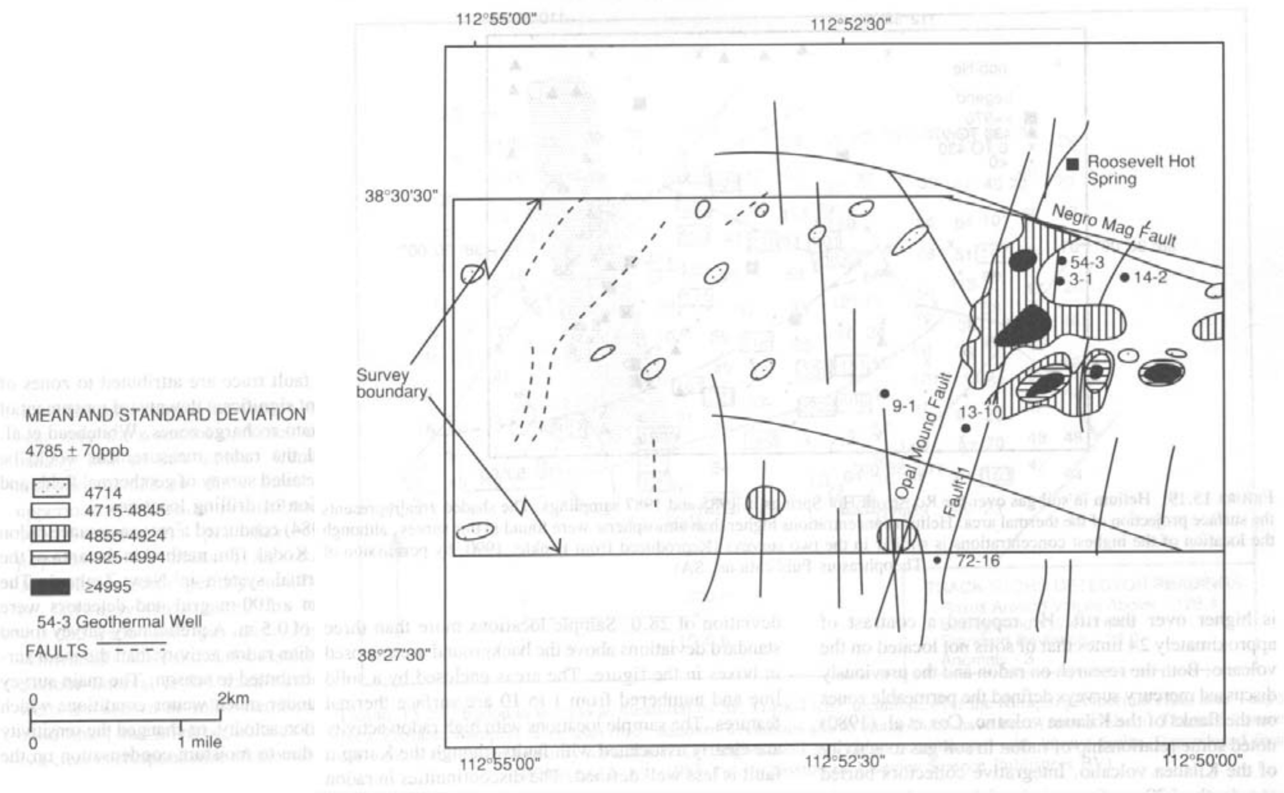

Figure 2. Helium concentrations in soil gas above the Roosevelt Hot Springs, Utah (from Klusman, 1993).

At Roosevelt Hot Springs, Utah, helium in soil gas provided accurate targeting for geothermal wells (Figure 2). These case studies and others show clearly that even soil gas surveys relying on simple analytical approaches using only one analyte can vector exploration into successful drill targets in some settings. However, there are several geologic environments that can release mercury vapor or helium, for instance, to the overlying soil gas environment. Thus, mercury vapor anomalies can be pathfinders for concealed mineral deposits formed millions of years ago as well as for active geothermal fields. Moreover, helium anomalies might represent leakage of helium along deep seated faults whether or not thermal anomalies are also associated. For these and other reasons, multiple-gas analytical capability will be more successful in characterizing the soil gas signature for geothermal resources and removing the source ambiguities that might otherwise attend soil gas anomalies.

Several Nevada locations have unique settings and features that will provide natural field laboratories for testing the concepts and analytical approaches described above, and these will be the focus of this project.

<u>Salt Wells:</u> The Salt Wells geothermal system southeast of Fallon exhibits a very large heat flux anomaly (Edmiston and Benoit, 1984). Surface geothermal features are subtle but extensive; they extend over a distance of more than 8 km (Coolbaugh et al., 2004) and include silicified Quaternary sediments, multiple hot springs and seeps with current temperatures up to 81°C, and a number of linear zones of warm ground (steam-heated) with near surface (< 30 cm) temperatures of up to 50°C that correspond to the surface traces of active faults (Coolbaugh, personal communication, 2005). Because of the widespread but subtle nature of these surface geothermal anomalies, Salt Wells would be an ideal area to test the efficiency of a variety of surface gas sampling techniques to help identify which features may currently be active.

South Brady's Hot Springs: Surface geothermal features along the active Brady's fault northeast of Fernley, which include steam vents, warm ground, and silicified sands and gravels, extend over a strike length of 4 km. Preliminary mercury surveys in 2003 using gold wires identified strong Hg anomalies along faults near the south end of this trend. Recent analysis of InSAR remote sensing radar images, however, clearly indicate that the fluid-conductive portion of the Bradys fault extends an additional 4 km southward, beyond the zone of observable surface features, suggesting a potential for future expansion of the producing zone of the Bradys system southward. This would be an ideal place to test the ability of surface gas analyses to detect a subsurface conductive fault zone that is not otherwise observable at the surface. An initial characterization of the multi-gas fingerprint of this system to the north, would enhance the reliability of survey results from the southern frontier area.

Buffalo Valley: Buffalo Valley southwest of Battle Mountain, and north of the area of observable hot spring discharge, has been identified as a regionally favorable location for high-temperature geothermal resources because of the presence a regional crustal strain-rate anomaly defined from GPS stations, the presence of Quaternary cinder cones, an anomalously thin crust, and numerous northeast-trending Quaternary fault scarps. In particular, a swarm of at least a dozen Quaternary fault scarps define a northeast-trending zone of tectonic activity on the opposite side of a horst block from which Nevada's largest historic earthquake occurred: the 1915 Pleasant Valley earthquake with a magnitude of 7.8. Temperature gradient wells are notably lacking in an area where several warm springs occur on the northwest side of the valley, where most fault scarps occur at elevations well above the regional water table. A reconnaissance multi-gas sampling survey could be used to search for evidence of steam-heated ground above the water table along the trace of the active faults in this area and identify conductive faults located north of the hot spring area.

New York Canyon: This concealed, fault-controlled geothermal system is located in Buena Vista Valley east of Lovelock. The associated surficial clay alteration is probably the result of solfataric action, which is either active or was so in the recent past. The vapor emitted by the hot (boiling?) subsurface water probably includes hydrogen sulfide, which would oxidize and combine with condensed water vapor to form low pH fluids capable of leaching rock near the surface. The limits of the geothermal system at New York Canyon are poorly known, but the system has been estimated to have the potential to produce 26 Mw of electrical power (GeothermEx, 2004). Several geothermal leases are in place or pending in the area. Because of its concealed nature, relatively expensive drilling has been used to attempt to outline the limits of the reservoir, and the application of soil multi-gas sensing has the potential of providing important new data to constrain this young, fault-controlled system.

Tipton Ranch in Pumpernickel Valley: There are numerous springs and seeps (up to 87°C), some discharging gas, along a N20°E fault that forms the boundary of the Sonoma Range in the area near the hot springs at Tipton Ranch in Pumpernickel Valley. The spring deposits are predominantly travertine with a trace of siliceous sinter. In 1974 Magma Power Co. drilled a geothermal well at Tipton Ranch to a total depth of 919.6 m (3,071 feet). Bottom-hole temperature was logged at 135°C after 10 hours of circulation. In 2004, Noramex Corp. began to re-evaulate the area for its geothermal potential for electrical power generation. Conducting gas studies at this site might assist in identifying conductive fractures and faults in the area and help bring this system on-line more rapidly.

Deliverables

Individual multi-gas surveys will be documented in a GIS format and made available to interested parties. Principal investigators will present results at professional conferences, including the Geothermal Resources Council annual meeting where continuing results of the research will be presented.

1. Present update and summary at annual Geothermal Resources Council meeting: Sept 2005

2. Present update and summary at annual Geothermal Resources Council meeting: Sept 2006

3. Complete final report: Sept 2006

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Budget

See attached Excel file (Multi-gas proposal budget.xls)

Dr. Paul J. Lechler

EDUCATION

Ph.D. Geology/Geochemistry, University of Nevada, Reno, NV, 1995
M.Sc. Geochemistry, Rutgers University, NJ, 1978
B.A. Geology, Montclair State College, NJ, 1974

AREAS OF EXPERTISE

Analytical geochemistry, environmental geochemistry, exploration geochemistry

PROFESSIONAL WORK EXPERIENCE

Chief Geochemist, Nevada Bureau of Mines and Geology, Reno, Nevada (1983-present)
Company Geologist, Reed Rock Bit Company, Houston, Texas (1981-1983)
Research Geochemist, Bendix Field Engineering, Grand Junction, Colorado (1980-1981)
Geochemist, Indiana Geological Survey, Bloomington, Indiana (1977-1980)

SELECTED PUBLICATIONS

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Larry J. Garside

EDUCATION

B.S. Geology, Iowa State University, 1965
M.S. Geology, University of Nevada, Reno, 1968

AREAS OF EXPERTISE

Geologic mapping, volcanic geology, energy resources geology, hydrothermal mineral deposits, isotopic dating of igneous rocks and mineralization.

RESEARCH GRANTS

Twenty-seven funded research projects, as principal and co-principal investigator, for a total of approximately $2,800,000.

PROFESSIONAL WORK EXPERIENCE

A. Research Geologist (Rank I - IV), Nevada Bureau of Mines and Geology,
University of Nevada, Reno (1968-present).

B. Research Assistant, Nevada Bureau of mines and Geology,
University of Nevada, Reno, Mackay School of Mines
(1965-1968)

SELECTED PUBLICATIONS (of more than 120 citations on Nevada geology)

<u>Related Publications (Geothermal)</u>

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CURRENT SUPPORT

Great Basin Center for Geothermal Energy (($95,811) Structural and Geophysical Analysis of the Desert Peak-Bradys Geothermal Area, Nevada (Faulds, Garside) 3/30/02-9/30/03.

Fallon Indian Reservation ($39,686) First-Stage Data Collection for Geothermal Assessment of Fallon Paiute Shoshone Indian Reservation Lands (Shevenell, Garside) 8/10/02-10/9/03.

Great Basin Center for Geothermal Energy (U.S. Department of Energy pass-through) ($117,359) Geochemical Sampling of Thermal and Non-thermal Waters in Nevada. 3/20/02-9/30/03.

Nevada State Energy Office (DOE, Geothermal Division pass-through) ($74,728) Nevada Geothermal Resources Database and Web Site (Shevenell, Garside) 9/1/01-8/31/03.

U.S. Geological Survey (STATEMAP) ($20,008 plus $29,264 cost share) Geologic map of the north half of the Virginia City Quadrangle, Nevada (Garside, Castor) 5/1/01-4/30/02.

U.S. Geological Survey (STATEMAP) ($14,000 cost share only) Geologic map of the Minden Quadrangle, Nevada (Ramelli, dePolo) 5/1/01-4/30/02.

U.S. Geological Survey (STATEMAP) ($7,440 cost share only) Geologic map of the Sutcliff Quadrangle, Nevada (Faulds, dePolo, Henry) 5/1/01-4/30/02.

Dr. Mark F. Coolbaugh

Professional Preparation

Ph. D., Geology, 2003
University of Nevada, Reno, Mackay School of Mines, Reno, Nevada
M. S., Geological Engineering, 1985
University of Arizona, College of Mines, Tucson, Arizona
B. S., Geological Engineering, 1978
Colorado School of Mines, Golden, Colorado

Professional Assignments

Research Assistant Professor, March 2002 to Present

Great Basin Center for Geothermal Energy, University of Nevada, Reno. Research on modern geothermal systems using a GIS, spatial statistics, remote sensing, aqueous and gas geochemistry, and GPS-based crustal strain measurements. (For more detail, see research projects listed below.)

Research Assistant and Teaching Assistant, August 1998 – March 2002

Arthur Brant Laboratory for Exploration Geophysics, Dept. of Geological Sciences, UNR. Dissertation research develops geothermal and mineral exploration models using a GIS, spatial statistics (weights-of-evidence and logistic regression), and remote sensing imagery (including ASTER, TIMS, and AVIRIS). Additional research included the use of a GIS to assess natural sources of mercury to the atmosphere.

Exploration Manager – Mongolia, September 1996 - February 1998

Cascadia Chemicals & Minerals Corp., Ulaanbaatar, Mongolia
Developed and managed all corporate exploration programs for copper and gold.

Research Assistant and Teaching Assistant, **July 1995 - August 1996**

University of British Columbia, Vancouver, B.C., Canada
Development of new lithogeochemical exploration tools in the search for mineral deposits, particularly Carlin-type, sediment-hosted gold deposits.

Chief Geologist, April 1994 - June 1995

Carson Gold Corp., Vancouver, B. C., Canada
Designed and managed all corporate overseas exploration programs, with projects in South and Central America, the Philippines, and Mongolia.

Senior Exploration Geologist/Geological Engineer, November 1991 - January 1994

Coeur Rochester, Inc., Lovelock, Nevada, USA
Development of district-wide gold exploration program. Assistance with open-pit mine geology, ore control, and engineering.

Consultant, February 1991 - October 1991

Mine and Exploration Services, Monte Vista, Colorado, USA
Mine permitting and compliance issues, exploration programs, production geology, and ore reserve development.

Chief Geologist/Manager/Senior Geologist, June 1984 - January 1991

Summitville Consolidated Mining Co., Inc., Del Norte, Colorado, USA
Supervision of mine geology and exploration departments responsible for development of ore reserves, open-pit ore control, regional exploration, and land acquisition.

Geologist, **June 1983 - June 1984**

Pegasus Gold Corporation, Reno, Nevada, USA
Management of district exploration program.

Associate Geologist, **June 1980 - Dec. 1982, summers of 1977 - 1979**

Climax Molybdenum Co., div. of AMAX, Golden, Colorado, USA
Geologic mapping and field work for molybdenum exploration and mining.

Underground Motorman’s Assistant, **June 1976 - September 1976**

ASARCO, Inc., Leadville, Colorado, USA
Track haulage of ore, equipment, and supplies in an underground lead-zinc-silver mine.

Selected Publications and Presentations

Coolbaugh, M.F. and Bedell, R., 2005, A Simplification of weights of evidence using a density function and fuzzy distributions: a comparison of probability modeling techniques in the designation of geothermal systems in Nevada; Geol. Assoc. Canada Special Paper “GIS applications in the Earth Sciences”, *in press*.

Coolbaugh, M.F., Arehart, G.B., Faulds, J.E., and Garside, L.J., 2005, Geothermal systems in the Great Basin: modern analogues to the roles of magmatism, structure, and regional tectonics in the formation of mineral deposits; *in* Geological Society of Nevada Symposium Proceedings, May 11-21, 2005, *under review*.

Coolbaugh, M. F., Gustin, M. S., and Rytuba, J. J., 2002, Annual emissions of mercury to the atmosphere from natural sources in Nevada and California: Environmental Geology, v. 42, n. 4., p. 338-349.

Coolbaugh, M.F. and Shevenell, L.A., 2004, A method for estimating undiscovered geothermal resources in Nevada and the Great Basin: Proceedings, Annual Meeting, Palm Springs, CA, Aug. 29-Sep. 1, 2004, Geothermal Resources Council Transactions, v. 28, p. 13-18.

Coolbaugh, M. F., Taranik, J. V., and Kruse, F. A., 2000, Mapping of surface geothermal anomalies at Steamboat Springs, NV. using NASA Thermal Infrared Multispectral Scanner (TIMS) and Advanced Visible and Infrared Imaging Spectrometer (AVIRIS) data; *In:* Proceedings, 14th Thematic Conference, Applied Geologic Remote Sensing, Environmental Research Institute of Michigan (ERIM), Ann Arbor, MI., p. 623-630.

Coolbaugh, M. F. and Stanley, C. R., 1996, A lithogeochemical evaluation of feldspar hydrolysis, decarbonatization and jasperoid alteration from the Jerritt Canyon district, Nevada, using Pearce element ratio analysis; Technical Document #11, MDRU Lithogeochemical Exploration Research Project, Annual Technical Report, year 1, Dept. of Geol. Sciences, University of British Columbia.

Gray, J. E., and **Coolbaugh, M. F.**, 1994, Geology and geochemistry of Summitville, Colorado: An epithermal acid sulfate deposit in a volcanic dome: Economic Geology, Special Issue on Volcanic Centers as Targets for Mineral Exploration, v. 89, no. 8, p. 1906-1923.

Gray, J. E., **Coolbaugh, M.F.**, Plumlee, G. S., and Atkinson, W. W., 1994, Environmental geology of the Summitville Mine, Colorado: Economic Geology, Special Issue on Volcanic Centers as Targets for Mineral Exploration, v. 89, no. 8, p. 2006-2014.

Current and Past Geothermal Research

1) Regional Assessment of Exploration Potential for Geothermal Systems in the Great Basin using a Geographic Information System (GIS): Collaborators: Mark F. Coolbaugh, Gary L. Raines, Lisa A. Shevenell, Tim B. Minor, Don L. Sawatzky, and Gary Oppliger: funded by DOE.
2) Remote Sensing for Exploration and Mapping of Geothermal Resources: Collaborators: Wendy Calvin and Mark F. Coolbaugh: funded by DOE.
3) Geochemical Characterization of Magmatic-related vs. Extension-related Geothermal Systems in the Great Basin: Implications for Exploration, Exploitation, and Environmental Issues: Collaborators: Greg B. Arehart, Mark F. Coolbaugh, and Simon R. Poulson: funded by DOE.
4) Targeting of potential geothermal resources in the Great Basin from regional relationships between geodetic strain and geological structures: Collaborators: Geoff Blewitt and Mark F. Coolbaugh: funded by DOE.

Dr. Lisa Shevenell

Education

New Mexico Institute of Mining and Technology	Geology	B.S.	1984
University of Nevada, Reno	Hydrogeology	Ph.D.	1990

Areas of Expertise

Groundwater hydrology, geothermal systems, isotope hydrology, aqueous geochemistry

Research Grants

Thirty (12 geothermal) funded research projects for a total of $5.5 million

Positions

Director, Great Basin Center for Geothermal Energy, UNR, 2004 – present
Associate Director, Great Basin Center for Geothermal Energy, UNR, 2001 – 2004
Research Professor, Nevada Bureau of Mines and Geology, 1993 –present
Research Associate, Oak Ridge National Laboratory, 1990-1993.
Research Assistant, Desert Research Institute, Reno, Nevada 1987-1990.
Research Assistant, Los Alamos National Laboratory, 1984-1987.

Selected Publications (of 27 refereed journal articles, 22 peer reviewed publications, 20 symposium papers, 13 other articles, 75 abstracts, and 78 contract reports)

Coolbaugh, M., and **Shevenell,** L., 2004. A method for estimating undiscovered geothermal resources in Nevada and the Great Basin. Geothermal Resources Council *Transactions*, v. 28 (Best Paper Award)

Shevenell, L., and Garside, L., 2003, Nevada Geothermal Resources. Nevada Bureau of Mines and Geology Map 141.

Skalbeck, J.D., **Shevenell**, L., and Widmer, M., 2002, Mixing of thermal and non-thermal waters in the Steamboat Hills area, Nevada: Geothermics, v. 31, no. 1, p. 69–90.

Garside, L., **Shevenell**, L., Snow, J., and Hess, R., 2002. Status of Nevada geothermal resource development - Spring 2002. Transactions Geothermal Resources Council 26: 527-532.

Shevenell, L., and J.V. Taranik, 2002. Summary of Activities of the Great Basin Center for Geothermal Energy - *Bulletin Geothermal Resources Council* 31(5): 179-182.

Shevenell, L., P. Kasameyer, C. Bruton, J.L. Renner, and B.M. Kennedy, 2002. Executive Summary of the Workshop on DOE Sponsored Research at Dixie Valley, Nevada (June 12-14, 2002). http://www.unr.edu/geothermal/meetingsandpresentations/intro_summarydv.pdf

Coolbaugh, M., Taranik, J., Raines, G., **Shevenell**, L., Sawatzky, D., Bedell, R., Minor, T., 2002. A geothermal GIS for Nevada: Defining regional controls and favorable exploration terrain for extensional geothermal systems. *Trans. GRC* 485-490.

Garside, L., **Shevenell**, L., Snow, J., and Hess, R., 2002. Status of Nevada geothermal resource development - Spring 2002. *Trans. GRC* 26: 527-532.

Shevenell, L., and Taranik, J.V., 2002. Overview of Activities of the Great Basin Center for Geothermal Energy. *Trans. GRC* 26: 507-510.

Skalbeck, J.D., Karlin, R., **Shevenell**, L., and Widmer, M., 2002. Geothermal reservoir volume estimation from gravity and aeromagnetic modeling of the Steamboat Hills geothermal area, Reno, Nevada. *Trans. GRC* 26: 443-448.

Skalbeck, J.D., L. **Shevenell**, and M. Widmer, 2002, Mixing of thermal and non-thermal waters in the Steamboat Hills area, Nevada. *Geothermics, v.* 31(1): 69-90.

Shevenell, L., Garside, L., Arehart, G., van Soest, M., and Kennedy, B.M., 2002. Geochemical sampling of thermal and non-thermal waters in Nevada to evaluate the potential for resource utilization. Transactions Geothermal Resources Council 26: 501-506.

Long, J.C.S., and **Shevenell**, L., 2001. The Potential of Geothermal Energy. Testimony prepared for the Secretaries of the Departments of Interior and Energy, presented on November 29, 2001, 6 p.

Shevenell, L., and Goff, F., 2000, Temporal geochemical variations in volatile emissions from Mount St. Helens, 1980-1994. J. Vol. Geoth. Res., 99(1-4): 123-138.

Shevenell, L., L. Garside, and R. Hess, 2000, Nevada geothermal resources. *Nevada Bureau of Mines and Geology Map* 126.

Shevenell, L., and Goff, F., 1996, In-situ tritium production and fluid mean residence times in the two subsystems of the Valles Caldera hydrothermal system, New Mexico, *New Mexico Geol. Soc. Guidebook*, 47th Field Conference, Jemez Mountains Region, p. 455-461.

Shevenell, L., and Goff, F., 1995, The use of ^3H in groundwaters to determine fluid mean residence times of Valles Caldera hydrothermal fluids, New Mexico. J. Vol. Geoth. Res., 67(1-3): 187-205.

Shevenell, L., and F. Goff, 1995, Evolution of geothermal waters at Mount St. Helens, Washington, U.S.A. J. Vol. Geoth. Res., 69(1/2): 73-93.

Shevenell, L., and F. Goff, 1993, Addition of magmatic volatiles into the hot spring waters of Loowit Canyon, Mount St. Helens, Washington, U.S.A. Bull. Vol., 55(7): 489-503.

Shevenell, L., 1991, Tritium in the thermal waters discharging in Loowit Canyon, Mount St. Helens, Washington, U.S.A. Chem. Geol. (Isotope Geoscience Section) 94: 123-135.

Shevenell, L., 1990, Chemical and Isotopic Investigation of the New Hydrothermal System at Mt. St. Helens, Washington: University of Nevada, Reno, 282 p.

Goff, F., **Shevenell**, L., Gardner, J.N., Vuataz, F.D., and Grigsby, C.O., 1988, The hydrothermal outflow plume of Valles caldera, New Mexico and a comparison with other outflow plumes: Journal of Geophysical Research, v. 93, no. B6, p. 6041–6058.

Shevenell, L., Goff, F., Grigsby, C.O., Janik, C.J., Trujillo, P.E., Jr., and Counce, D., 1987, Chemical and isotopic characteristics of thermal fluids in the Long Valley Caldera Lateral Flow System, California. Trans. Geoth. Res. Council 11: 195-202.

Goff, F., and **Shevenell**, L., 1987, Travertine deposits at Soda Dam, New Mexico and their implications for the age and evolution of the Valles Caldera hydrothermal system. Bull. Geol. Soc. of Am. 99: 292-302.

Shevenell, L., 1989, Preliminary evaluation of thermal and non-thermal waters at selected sites in Panama, Central America: *Los Alamos National laboratory Report* LA-11103-MS, 27 p.

Shevenell, L., Goff, F., and Grigsby, C.O., 1987, In-situ borehole fluid and gas sampling in high temperature environments, *in* Wellbore Sampling Workshop, (R. Traeger and B. Harding, eds.). SAND87-1918: 27-30.

Goff, F., and **Shevenell**, L., 1987, Travertine deposits at Soda Dam, New Mexico and their implications for the age and evolution of the Valles Caldera hydrothermal system. *Bull. Geol. Soc. of Am.* 99: 292-302.

Goff, F., **Shevenell**, L., Kelkar, S., Smith, D., Meert, J., Heiken, G., Bargar, K., Ramos, N., Truesdell, A.H., Stallard, M., Musgrave, J., 1987, Stratigraphy, temperature profiles, and flow test data from PLTG-1 and PLTG-2 coreholes, Platanares Geothermal System, Honduras: *Trans. GRC.*, v. 11, p. 253–259.

Shevenell, L., Grigsby, C.O., Goff, F., Jannik, N.O., and Phillips, F., 1986, Mixing and boiling of thermal fluids in Long Valley Caldera, California, *in* Proceedings of the Second Workshop on Hydrologic and Geochemical Monitoring in the Long Valley Caldera, LBL-22852: 36-39.