

## **FLUID CHEMISTRY SERVICES**

---

Geochemical studies and fluid chemistry management are an integral part of the GeothermEx approach to exploration, resource evaluation, resource development and operations. Company expertise includes:

- Exploration sampling of waters and gases for chemical and isotopic analysis
- Fluid sampling during well tests and production
- Downhole sampling
- Design and construction of equipment for sampling and gas/steam measurements
- Field analyses
- Design, purchasing and set-up of field laboratories, and training of sampling and analysis personnel
- Management of laboratory analysis programs
- Chemical database management, quality control and graphical representations
- Project design, specifications and cost estimates for chemical data collection and management
- Applications and interpretation of chemical geothermometers and mixing models
- Interpretation and integration of chemical data into hydrogeologic models
- Numerical modeling of fluid chemistry thermodynamics during production, injection, mixing, and scale deposition
- Prediction, definition and management of scale deposition and corrosion
- Chemical engineering studies and solutions for scaling problems in gathering systems, power plant turbines and associated facilities
- Chemical tracer tests, including design, management, analytical services, data reduction and interpretation

GeothermEx has performed geochemistry projects world-wide, both on a stand-alone basis, and as parts of larger projects of exploration, testing and/or resource evaluation. The countries we have worked in and the activities in each (typically in multiple field locations) include:

Reconnaissance and detailed exploration:

The Philippines, Honduras, Nicaragua, Panama, Costa Rica, USA (California, Nevada, Oregon and Idaho), Indonesia, Papua New Guinea (Lihir Island), Argentina, Kenya, Ethiopia, Iran, Portugal (the Azores), Canada (British Columbia)

Well test and production fluids sample collection:

USA (Steamboat Springs, Empire, Fish Lake, Coso, The Geysers, Bradys Hot Springs), Papua New Guinea (Lihir Island), Portugal (the Azores), Japan, Indonesia

Compilation of raw data, interpretation and integration with geological, geophysical, hydrological and well test data into hydrogeological models, many used as input for numerical simulations:

Japan, The Philippines, Costa Rica, Honduras, Guatemala, Yugoslavia, Mexico, Western USA, Italy, Kenya, Portugal (the Azores), Hawaii, Indonesia, St. Lucia, Tibet

Studies of scaling and scaling potential, evaluation of scale management options:

Japan, The Philippines, Portugal (the Azores), Papua New Guinea (Lihir Island), USA (Salton Sea, Roosevelt Hot Springs), Costa Rica, Indonesia, El Salvador

**Examples of Recent Major Projects Include:**

- São Miguel, Azores, Portugal, 1998 – 2008: Well test fluids sampling (waters, gases, isotopes); training of field and laboratory personnel; tracer test design, execution and oversight; calcite scale inhibitor testing, evaluation and oversight; reservoir modeling; database design at the Ribeira Grande - Pico Vermelho geothermal field.
- British Columbia, 2007 – 2008, and 2000 - 2001: Evaluation of reconnaissance-scale fluids chemistry data and detailed studies of selected geothermal prospects. Hydrochemical and geothermal model development for evaluation of the geothermal system at Meager Mountain.
- Iceland, 2006 – 2008: Evaluation of fluids chemistry program design (plans for supercritical fluids testing) at the Iceland Deep Drilling Project and evaluation of fluids chemistry, temperature and drilling data from four geothermal fields.

- Nevada, 2008: Ranking of proposals for five different geothermal projects for a major utility company, using integrated geologic, geochemical and geophysical data to establish potential reserves and project risk factors.
- Steamboat, Nevada, 2006 - 2007, and 2002 - 2003: Database design, compilation and evaluation for conceptual model and monitoring of groundwater in the outflow zone of the geothermal reservoir. Project management and detailed conceptual modeling to support numerical simulation of the geothermal reservoir.
- Turkey, 2007: Evaluation of fluids chemistry data and reservoir modeling to support numerical simulation for the Germencik geothermal field.
- New Zealand, 2006 – 2007: Conceptual hydrogeologic model (chemistry, geology, temperature distribution) and quantification of changes in response to exploitation of the Kawerau geothermal field.
- Kenya, 2006 – 2007: Fluids chemistry studies of the Olkaria geothermal field (Olkaria I, II, III, IV and Domes Projects) to develop and support conceptual and numerical reservoir models.
- Warner Valley, Oregon, 2006: Fluids chemistry sampling, conceptual modeling of resource and reserves evaluation of the Crump Geyser.
- São Miguel, Portuguese Azores, 2006: Comprehensive evaluations of the geothermal prospects of the islands of Faial, Pico and, using data from geochemical, geological and geophysical surveys.
- Siver Peak, Nevada USA, 2006: Establishing a conceptual model of the geothermal resource associated with lithium brine deposits.
- Jordan, 2006: Geochemistry and conceptual model of the thermal waters of central Jordan, for the Ministry of Energy and Mineral Resources.
- Cerro Prieto, Mexico, 1999, and 2005: Fluids chemistry, temperature and geologic models of the geothermal field, to develop and support numerical reservoir simulation.
- Surprise Valley, California 2005: Program management and resource studies (chemistry, geology, geophysics, temperature) for exploration program design and conceptual modeling at.
- Nevis, West Indies, 2005: Fluids sampling, geochemical and conceptual modeling of the geothermal resource for Organization of American States.

- Raft River, Idaho, 2004: Fluids sampling at tests of geothermal wells, conceptual modeling of the resource.
- North and Central America, 2002 – 2004: Conceptual modeling, energy reserves estimations, exploration and development costs estimations, design and implementation of comprehensive integrated database (MS-Access) for geotechnical and costs data, at nearly 100 producing and prospective geothermal systems in the western U.S.A. and Mexico – Central America.
- Mexico, 2003: Conceptual models and reserves valuations for numerical simulations of the Los Azufres, Los Humeros and Tres Virgenes geothermal fields, for Comisión Federal de Electricidad.
- California, 2002: Detailed hydrogeological, chemical and reservoir conceptual modeling, including mercury transport, at the geothermal system at Sulfur Bank Mercury Mine.
- Nicaragua, 2000 – 2001: Field sampling and analyses at springs, wells and fumaroles, data interpretation, project management, data compilation and management of over 2300 database records for master plan study of the geothermal resources.
- India, 2001 – 2002: Hydrochemical and geothermal model development for country-wide study and ranking of the geothermal resources.
- Costa Rica, 1999 – 2004: Hydrochemical and geothermal model development for pre-feasibility and feasibility evaluations of the geothermal systems at Rincón de la Vieja.
- Indonesia, 1999: Conceptual and geochemical modeling of the Karaha Bodas geothermal system.
- Japan, 1996 – 1997: Chemistry database software and chemical equilibrium thermodynamics software design, installation and training, for use by Akita Geothermal Energy Company in its operation of the Uenotai geothermal field.

## **Partial Bibliography of Studies Specific to Fluid Chemistry**

- 2007 "Advances in the Past 20 Years: Geochemistry in Geothermal Exploration, Resource Evaluation and Reservoir Management" *in* Transactions, Geothermal Resources Council, vol. 31, 2007.
- 2007 "Resource Exploitation at Steamboat, Nevada: What it takes to Document and Understand the Reservoir/Groundwater/Community Interaction" *in* Transactions, Geothermal Resources Council, vol. 31, 2007 *with* Stuart Johnson and Paul Spielman.

- 2002 "Updated numerical simulation of the Miravalles geothermal field, Costa Rica" *in* Transactions, Geothermal Resources Council, vol. 26, 2002.
- 2002 "A methodology for assessment of geothermal energy reserves associated with volcanic systems" *in* Transactions, Geothermal Resources Council, vol. 26, 2002.
- 2001 "Reactive chemical transport simulation to study geothermal production with mineral recovery and silica scaling" *in* Transactions, Geothermal Resources Council, vol. 25, 2001.
- 2001 "Reducing Cost and Environmental Impact of Geothermal Power Through Modeling of Chemical Processes in the Reservoir" *in* Proceedings, 26<sup>th</sup> Stanford Workshop on Geothermal Reservoir Engineering, Stanford, California, January 2001.
- 1995 "Management of Fluid Injection in Geothermal Wells to Avoid Silica Scaling at Low Levels of Silica Oversaturation" *in* Proceedings, World Geothermal Congress, Florence, Italy, May 1995.
- 1995 "Chemical Transients During Production of High Gas Wells at the Northern Geysers Steamfield, California" *in* Proceedings, World Geothermal Congress, Florence, Italy, May 1995.
- 1993 "Geochemical Methods for Monitoring Injection Effects" *presented at the* Workshop on Injection of Geothermal Fluids, Mexicali, Mexico, May 1993.
- 1993 "Solubility of Sphalerite (ZnS) in the Salton Sea Geothermal System, Imperial Valley, CA" *for* Cyprus Power Corporation.
- 1992 "Steam Chemistry in the NCPA Leasehold Trough 1990" *for* Northern California Power Agency.
- 1992 "Production of CO<sub>2</sub> from Geothermal Reservoirs and the History and Estimates of Future CO<sub>2</sub> Production from the COSO Geothermal Field, California" *for* California Energy Company, Inc.
- 1991 "Prediction and Prevention of Silica Scaling at Low Levels of Oversaturation: Case Studies and Calculations for Uenotai Geothermal Field, Akita Prefecture, Japan" *in* Proceedings, Sixteenth Workshop on Geothermal Reservoir Engineering, Stanford University.
- 1990 "Management of Non-condensable Gases Produced in the Steam at CEC Coso BLM Project Area Wells - An Interim Report" *for* Credit Suisse, NY USA.
- 1990 "Investigation of Chemical Scaling at the Uenotai Geothermal Field, Akita Prefecture, Japan" *for* Akita Geothermal Energy Company.

- 1989 "Thermal Fluids Geochemistry Database, Lihir Island, PNG" *for* Kennecott, Inc.
- 1989 "Probable Subsurface Temperature at Lake Magadi, Kenya, as Indicated by Hot Springs Geochemistry, and the Potential for the Development of Geothermal Electric Power" *for* Mission Energy.
- 1989 "Interpretation of Geochemical Monitoring and Pressure Interference Data, Ormat Geothermal Project, Steamboat Springs, Nevada" *for* ORMAT, Inc.
- 1989 "Effects of Condensate Injection on Steam Chemistry at The Geysers Field" *in* Transactions, Geothermal Resources Council.
- 1989 "Chemical Studies of the Geothermal Fluid at Okuaizu Geothermal Reservoir with Respect to Gas Concentrations and Scale Deposition" *for* Mitsui Mining and Smelting Company.
- 1988 "Well Flow Testing and Chemical Sampling" *for* Kennecott, Inc.
- 1988 "Steam Chemistry in NCPA Geysers Leasehold, February 1988" *for* Northern California Power Agency
- 1988 "Program for Monitoring Geochemistry of Natural Thermal Discharges in Lihir Caldera" *for* Kennecott, Inc.
- 1988 "Geochemistry of the Lihir Thermal System: Estimation of Gas Discharge Rates and Water Chemistry in the Minife Area, 1987" *for* Kennecott, Inc.
- 1988 "Explanation of the Use of Silica Geothermometry to Correct Well Flow Sample Analyses for 'Excess Steam'" *for* DEP.
- 1988 "Review and Recommendations for Geochemical Sampling and Analytical Methods" *for* Akita Geothermal Energy Company.
- 1988 "Chemical Effects of Seawater Injection and Proposal for Testing" *for* Kennecott, Inc.
- 1987 "Geochemistry of Thermal Waters & Gases on Lihir Island, 1986" *for* Kennecott, Inc.
- 1987 "Causes and Prevention of Stibnite Scale in the Steamboat Springs, Nevada Geothermal Binary Power Plant" *for* ORMAT, Inc.
- 1985 "Flow Test and Fluids Sampling at Well LADWP 66-6, Coso Geothermal Field, Inyo County, California (June 10-12, 1985)" *for* Los Angeles Department of Water and Power.

- 1985 "Short-Term Flow Test and Fluid Sampling at Well LADWP 43-7, Coso Geothermal Field, Inyo County, California (March 1-2, 1985)" *for* Los Angeles Department of Water and Power.
- 1985 "Calculation of Calcite and Anhydrite Scaling Potential in Geothermal Wells (Bacon-Manito, Philippines)" *in* Proceedings, 7th New Zealand Geothermal Workshop.
- 1985 "Analysis of the Recent Well Data and Investigation of the Superheat and Non-Condensable Gas Contents of Geothermal Steam from the Coldwater Creek Area, The Geysers Geothermal Field, California" *for* CCPA Roseville, CA USA.
- 1985 "An Investigation of Wellbore Scaling at the Miravalles Geothermal Field, Costa Rica" *in* Transactions, Geothermal Resources Council, Vol. 9.
- 1983 "Geochemistry of Oilfield Waters in the Bekasap Production Area and Surroundings" *for* CALTEX Petroleum Corporation.
- 1983 "Geochemical Assessment of the Mainit-Sadanga Geothermal Prospect, Mountain Province, Luzon, Philippines" *for* CALTEX Petroleum Corporation.
- 1982 "Geochemistry of Water Samples from Hole P-2, Castle Hot Springs Area, Yavapai County, Nevada" *for* Hunt Oil Company.
- 1982 "Findings and Recommendations for Geothermal Exploration, World Bank Mission to Panama, September 1982" *for* World Bank.
- 1982 "Chemical Analysis of Water Samples from HE #66-16 Pirouette Field, Dixie Valley, Nevada" *for* Hunt Energy Company.
- 1981 "Review of Hydrochemistry of the Animas, New Mexico Thermal Anomaly" *for* AMAX, Denver, CO USA.
- 1981 "Interpretation of Well Testing Results with Specific Reference to the Calciting Problem - Miravalles Geothermal Project, Costa Rica" *for* Instituto Costarricense del Electricidad.
- 1981 "Interim Summary of Groundwater Chemistry at the Tuscarora Prospect, Elko County, NV" *for* AMAX, Denver, CO USA.
- 1981 "Geochemistry of Ground Waters from Drill Holes at the Southern Big Smokey Prospect" *for* Hunt Oil Company.
- 1981 "Geochemistry of Fluid from Gradient Hole No.67, Spencer Hot Springs, Nevada" *for* Hunt Oil Company.

- 1981 "Chemical Analysis of Fluids Samples from Anadarko Salt Wells Federal 14-36 Drill Stem Test, April 21, 1981" *for* Anadarko Production Co., Houston TX USA.
- 1981 "An Analysis of Hydrochemical Data from the Cove Fort, Utah Geothermal Reservoir" *for* AMAX, Denver, CO USA.
- 1981 "A Review of the Geochemistry of Thermal Waters in the Bruneau-Grand View Area, Idaho" *for* AMAX, Denver, CO USA.
- 1981 "A Well Test Manual for The Geysers Geothermal Field" *for* EXTEX Petroleum, Inc.
- 1980 "Central American Energy Programme Phase II Reconnaissance Geochemical Survey and Interpretation of Thermal Spring Waters and Gases" *for* United Nations Department of Technical Cooperation for Development.
- 1979 "Interpretation of Groundwater Chemistry in the Thermal Areas Surrounding Volcan Miravalles, Guanacaste Province, Costa Rica" *for* Instituto Costarricense de Electricidad.