

FLUID CHEMISTRY SERVICES

Geochemical studies and fluid chemistry management are an integral part of GeothermEx's program of exploration, resource evaluation, resource development and production engineering design and evaluation. 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 computer graphics;
- CHMWORKS geothermal fluids chemistry database management system, designed and coded in MS Windows by GeothermEx;
- 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;

- WATCHWORKS fluid chemistry thermodynamics computer code, developed for MS Windows in association with Orkustofnun and the University of Iceland, Iceland;
- 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.

Geochemistry projects have been performed world-wide, both on a stand-alone basis, and as parts of larger projects of exploration, testing and/or resource evaluation. For example:

- Reconnaissance and detailed exploration:

The Philippines, Honduras, Nicaragua, Panama, Costa Rica, USA (California, Nevada, Oregon and Idaho), Indonesia, Papua New Guinea, Argentina, Kenya, Ethiopia, Former Imperial Government of Iran, Portugal (the Azores).

- Well test and production fluids sample collection:

Steamboat Springs USA, Empire USA, Fish Lake USA, Coso USA, The Geysers USA, Lihir Island PNG, Brady Hot Springs USA, 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), Lihir Island PNG, Salton Sea USA, Costa Rica, Indonesia, El Salvador, Roosevelt USA.

Examples of Recent Major Studies Include:

- Central Java, Indonesia: fluids chemistry sampling and analysis, database management, field lab design, set-up and personnel training, well test monitoring, hydrogeochemical modeling as part of major exploration and field development projects, Dieng, Patuha and Wayang Windu geothermal fields.
- The Geysers USA: monitoring of steam chemistry and stable isotopes in connection with new drilling, well-testing, reservoir modeling and production monitoring for power plant owner.
- Nevada USA: design, management and execution of complete chemical data collection program at new field development (over 12 wells drilled and tested); testing of calcite scale inhibitor; chemical dye tracer test including analytical services.
- Salton Sea, USA: numerical modeling of sphalerite solubility in hypersaline brines, 1993; review and modeling of reservoir zinc (Zn) concentrations, in association with planned extraction from produced brines.
- Northern Honshu, Japan: evaluation and descriptions of scaling mechanisms, thermodynamic and kinetic modeling of silica and calcite scaling, worldwide case studies, predictions for various production scenarios, predictions for scale suppression using gas mixing, recommendations for scale management, recommendations and design of system retrofits to eliminate turbine blade scale.
- Northern Honshu, Japan: thermodynamic modeling of reservoir gas concentrations and behavior; thermodynamic modeling of sulfide, silica and calcite, rhodochrosite and kutnahorite scale deposition, in relation to fluids composition and mixing during production from a heterogeneous reservoir.
- Lihir Island, Papua New Guinea: exploration and well test sampling and fluids analysis; calcite and anhydrite scaling potential of heating seawater and mixing seawater with thermal water, effects of unusual fluid composition on chemical geothermometers and fluid enthalpy, integration into hydrogeologic and numerical model of reservoir, various studies.
- Nevada USA: causes and prevention of stibnite scale at a binary power plant.

Partial Bibliography of Studies Specific to Fluid Chemistry

- 2001 "Reducing Cost and Environmental Impact of Geothermal Power Through Modeling of Chemical Processes in the Reservoir" *in* Proceedings, 26th Stanford Workshop on Geothermal Reservoir Engineering, Stanford, California, January 2001.
- 2000 "User-Oriented Software for Geothermal Applications: The Watchworks Program for Windows 95" *in* Proceedings, World Geothermal Congress, Beppu and Morioka, Japan, May 2000.
- 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 CO₂ from Geothermal Reservoirs and the History and Estimates of Future CO₂ 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.