GeothermEx
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EXPLORATION SERVICES

GeothermEx has been involved in worldwide reconnaissance and detailed exploration since it was founded in 1973. Of nearly 200 exploration efforts conducted by GeothermEx, several representative projects illustrating the range of our exploration experience are discussed in the paragraphs below. These typically include the design, management and execution of geologic, geochemical and geophysical surveys, shallow temperature gradient drilling, integrated data analyses and construction of detailed geothermal models, selection of drilling sites, and deep exploratory drilling.

Terceira, Azores (Portugal)

GeothermEx provides exploration services to Sociedade Geotérmica da Terceira (GeoTerceira) for its ongoing project to develop geothermal power for the island of Terceira in the Azores. To date, this work has included a complete review of previous studies; interpretation of the geologic and volcanic environment; development of and exploration plan and strategy; design, supervision and interpretation of audiomagnetotelluric (AMT) surveys; design, planning, supervision and interpretation of a deep (500 m) temperature-gradient drilling program; and drilling two deep exploratory wells. A high-temperature geothermal resource has been identified, and a 12 MW geothermal power development is planned.

Nevis Island (Federation of St. Kitts & Nevis)

On behalf of the Geo-Caraïbes project of the Organization of American States (OAS), GeothermEx undertook geological and geochemical surveys on Nevis as part of an evaluation of this Caribbean island's commercial geothermal potential. GeothermEx's work focused on the western side of the island, which hosts numerous thermal manifestations (soufrières, hot springs, warms springs and seeps, and thermally anomalous well waters and groundwaters) that were sampled and analyzed. Existing geologic mapping was supplemented by analysis of air photos and satellite imagery, as well as field checking and measurements of structural attitudes. Existing geophysical data were also evaluated, particularly those related to recent seismicity. Integration of this data set resulted in the development of a working conceptual model of the Nevis geothermal regime, which includes a deeper, thermally altered seawater system and a shallower, perched meteoric system, both at drillable depths. Nevis was therefore identified as a strong candidate for geothermal exploration and development, which has led to exploratory drilling by a private developer.

Nicaragua

As part of its geothermal master-plan study for the Republic of Nicaragua, GeothermEx carried out exploration at varying levels of detail in eight of the country's principal geothermal resource areas, including Volcán Casita, Volcán Telica, the Chiltepe Peninsula, and Volcán Mombacho. Activities included geologic mapping and collection and analysis

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of fluid samples (water and gases) in all areas; assessment of geologic hazards; interpretation of volcanic activity; and, in 4 selected areas, the design, supervision and interpretation of magnetotelluric (MT) surveys. Results were incorporated into integrated reports of individual resource areas that included estimates of potentially available geothermal energy reserves, as well as into a national map of the geothermal resources of Nicaragua.

Costa Rican Geothermal Fields

Together with Instituto Costarricense de Electricidad (ICE), GeothermEx designed and managed an exploration program that covered over 500 km2 of young volcanic terrain. Work included reconnaissance and detailed geologic mapping and photogeology, gravimetry, a hydrologic survey, fluid geochemistry and isotopy, extensive electrical resistivity soundings and traverses, and the drilling of over 40 temperature-observation holes (to 450 m depth). This program led to the siting and drilling of the initial three discovery wells of the Miravalles Field by GeothermEx and ICE. To date a total of 163 MW of generation capacity has been installed in the field, making Miravalles the largest geothermal development in Central America. At the Rincon de la Vieja geothermal field, GeothermEx has undertaken various exploration surveys, culminating first in a pre-feasibility study of the field, and later a feasibility-level analysis for the Las Pailas portion of the field, where a 35 MW development is in the planning stages.

Northwestern Iran (work conducted for the former Imperial Government of Iran)

On behalf of an agency of the former Imperial Government of Iran, GeothermEx provided five two-man geochemical field crews, field equipment, and a resident project manager for a project involving sampling of springs, fumaroles and streams for geochemical and isotopic analyses. More than 2,000 samples of water, gas and rock were collected in four areas totaling 18,000 km2; analyses were performed in the field for selected species, and complete laboratory analyses were performed in the United States under the supervision of GeothermEx.

Batong Buhay (The Philippines)

On behalf of a private client, GeothermEx performed detailed geologic, geochemical and geophysical surveys, plus the drilling of several heat-flow slim holes (to 375 m) in a volcanic-metamorphic terrain. In addition to the normal management requirements of such a project, GeothermEx was also required to coordinate activities of several independent groups: the client, the Philippine government, the Philippine army, local village governments, and hostile guerilla groups. Other problems that had to be overcome included remote and rugged terrain, and the very high temperature of the resource at very shallow depths. The project proved the presence of a major high-temperature geothermal resource through slim-hole drilling into the reservoir.

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Dixie Valley, Nevada (USA)

GeothermEx participated in the exploration, discovery and development of this major geothermal field from 1974 to 1984. Exploration work carried out for Sunoco Energy Development Co. and other companies by GeothermEx at Dixie Valley included geologic mapping, geochemistry and isotopy of hot springs, drill-site selection, drilling supervision and logging of over two dozen temperature-gradient holes (maximum depth 500 m), detailed gravimetry, analysis of historic seismicity, analysis of other geophysical survey data, modeling of the prospect, siting of the discovery well of the field, wellsite geology, and energy reserve estimation and field development design. A 60 MW geothermal power plant now exists on the site.

Salt Wells, Nevada (USA)

Exploration services provided by GeothermEx for a private client included detailed geologic mapping, analysis of historic seismicity, a hydrologic survey, geochemical sampling and modeling, drill-site selection, drilling supervision, and measurement of temperature gradients in more than 25 holes ranging in depth from 500 to 1,500 feet (150 to 460 m), location of a deep test well, and fluid sampling and analysis during flow testing.

Klamath Basin, Oregon (USA)

GeothermEx designed and managed an exploration program to cover an area of 20,000 km2 in south-central Oregon for Pacific Power and Light Company and Weyerhaeuser Company. This work included geologic mapping of selected areas at 1:62,500 and 1:24,000 scales, geochemical surveys of springs and wells, an isotope survey of selected waters, several electrical resistivity surveys of Schlumberger, VES and dipole-dipole configuration, a gravity survey, thermal infra-red imaging, and drilling, coring and logging of a deep (2,000 ft or 610 m) temperature-gradient well. The work resulted in the classification of more than 500,000 acres (200,000 hectares) of lands owned by Weyerhaeuser Company, for leasing and/or further development.

Bradys Hot Springs, Nevada (USA)

As part of a 20 MW power generation project, GeothermEx performed very detailed photo- and field geology (1:10,000), fluid chemistry and isotopy, an airborne infrared survey, detailed gravimetry, data synthesis, detailed geologic modeling, and well-site selection for production and injection wells. This led to the completion of the entire 20 MW project within a two-year period.

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OTHER INTERNATIONAL EXPLORATION ACTIVITIES

Argentina (Province of Mendoza)

- Reconnaissance geology
- Fluid geochemistry
- Design of detailed exploration program

The Azores (São Miguel, Terceira, and Faial)

- Reconnaissance geology and photogeology
- Fluid geochemistry and isotopy
- MT resistivity surveys
- Data analysis and modeling
- Well-site geology
- Reservoir geochemistry
- Reserves analysis

Djibouti (Asal Depression)

- Data analysis and modeling
- Interpretation of drilling logs
- Well-site selection

El Salvador (Chipilapa region)

- Well-log analysis
- Re-analysis of geophysical data
- Preparation of geologic models
- Drill-site selection

Ethiopia (Danakil Depression and southern Afar)

- Field and photogeology
- Fluid chemistry
- Synthesis of all exploration data
- Design of geophysical program

Mozambique

- Regional reconnaissance

Honduras

- Nationwide geochemical survey of springs and wells
- Reconnaissance geology
- Interpretation of drilling logs
- Design of detailed exploration program

Indonesia (western and central Java)

- Reconnaissance geology
- Fluid geochemistry and isotopy
- Design and management of TDEM and MT surveys
- Design and management of gravity surveys
- Analysis of exploration and well-log data
- Preparation of models
- Recommendation of drilling sites

Japan (Niseko, Hokkaido; Minami Aizu, Honshu; Kirishima, Kyushu)

- Regional reconnaissance
- Analysis of geologic, geophysical and geochemical data
- Preparation of field models
- Drill-site selection

Kenya (Lake Magadi; elsewhere in Rift Valley)

- Reconnaissance geologic mapping
- Fluid geochemistry
- Data analysis and modeling
- Design of detailed exploration programs
- Drill-site selection

Nicaragua

- Nationwide geochemical survey
- Regional gravimetry
- Geologic mapping
- Identification of drilling targets
- Nationwide Geothermal Master Plan
- Geophysical (MT/TDEM) surveys

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India

- Nationwide geothermal survey
- Site-specific pre-feasibility studies
- Development of exploration programs
- Feasbility study specifications

Vietnam

- Regional reconnaissance

Thailand

- Regional reconnaissance

Turkey

- Regional reconnaissance
- Evaluation of drilling targets

Uganda (Western Rift Zone)

- Regional reconnaissance
- Fluid geochemistry
- Data analysis
- Drill-site selection and well design

Yugoslavia (Kocani region)

- Detailed hydrologic surveys
- Analysis of prior geophysical data
- Modeling of geothermal system
- Recommendation of drilling sites

Other countries in which reconnaissance exploration and/or data review and analysis have been carried out include:

- Mexico
- Panama
- Chile
- St. Lucia
- Dominica
- Montserrat
- St. Vincent and the Grenadines
- Italy
- Armenia
- Serbia
- The Hashemite Kingdom of Jordan
- Yemen Arab Republic
- Madagascar
- China (Taiwan)

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OTHER AREAS OF GEOTHERMAL EXPLORATION IN THE UNITED STATES
Detailed Exploration

California

Big Valley

- field and photo geology
- fluid geochemistry
- gravimetry
- analysis of other geophysical data
- drilling of temperature-gradient holes

Lava Mountains - Randsburg

- permitting of drilling sites
- drilling of temperature-gradient holes
- modeling of system
- identification of deep drilling targets

The Geysers - Clear Lake

- geologic mapping
- fluid geochemistry and isotopy
- microseismic monitoring and analysis of natural and induced seismicity
- electrical resistivity surveys
- gravimetry (300 km^2 area)
- drilling of temperature-gradient holes to 750 m depth
- permitting of drilling sites
- siting and design of deep wells
- well-site geology and geophysical logging
- field-wide conceptual modeling
- field-wide numerical simulation

Hawaii

Puna District

- geologic mapping and photogeology
- seismicity analysis
- subsurface geology
- well-log analysis
- preparation of system models
- siting of exploration wells

Idaho

Bruneau - Grand View

- photogeology (3,000 km^2)
- fluid geochemistry and isotopy
- gravimetry
- temperature-gradient drilling to 900 m depth
- data synthesis and modeling

Nevada

Antelope Valley

- geologic mapping
- fluid geochemistry
- permitting of drilling sites
- temperature-gradient drilling

Fish Lake Valley

- geologic mapping and photogeology
- electrical resistivity survey
- drilling of temperature-gradient holes
- data analyses/ conceptual modeling
- data analyses/ conceptual modeling
- recommendation of deep drilling targets

Gerlach

- detailed field and photogeology
- fluid geochemistry
- detailed gravimetry
- data analysis and modeling
- drilling of temperature-gradient holes to 600 m

Leach Hot Springs

- geologic mapping
- fluid geochemistry
- interpretation of electrical resistivity and MT data
- drilling of temperature-gradient holes
- well-site geology

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Panther Canyon

- permitting of drilling sites
- temperature-gradient drilling

Reese River

- geologic analysis
- fluid geochemistry
- drilling of temperature-gradient holes
- slim hole drilling

Silver Peak

- fluid geochemistry
- geologic analysis
- design of exploratory drilling program

Sulphur

- geologic mapping
- fluid geochemistry
- gravimetric survey
- drilling of temperature-gradient hole

New Mexico

Kilbourne Hole

- geologic mapping
- fluid geochemistry
- drilling of temperature-gradient holes
- data analysis and interpretation

Oregon

Alvord Valley

- geologic mapping
- fluid geochemistry
- gravimetric survey (500 km^2 area)
- drilling of temperature-gradient holes to 500 m
- data analysis and interpretation

Bully Creek - Vale

- geologic mapping
- fluid geochemistry and isotopy
- electrical resistivity and MT surveys
- temperature-gradient drilling to 1,000 m depth

Santiam Pass

- permitting of drilling sites
- drilling of temperature-gradient holes

Ontario

- photogeologic mapping
- gravimetric survey
- seismic refraction survey
- fluid geochemistry
- temperature-gradient drilling
- data interpretation and modeling
- selection of drilling sites
- well-site geology and geophysical logging

Utah

Dog Valley

- geologic mapping
- fluid geochemistry and isotopy
- MT survey
- temperature-gradient drilling
- data analysis and interpretation
- well-site geology

Reconnaissance Exploration Projects

Alaska

- Unalaska Island

Arizona

- Clifton
- Castle Hot Springs
- Mojave Desert

California

- Calistoga
- Day-Big Bend
- Long Valley
- Medicine Lake
- Mount Lassen

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- Salton Trough
- Sierra Valley
- Sonoma Valley
- Surprise Valley
- Susanville
- Ukiah
- Wendel-Amedee

Colorado

- Mineral Hot Spring
- Mount Princeton-Hortense
- Ouray

Idaho

- Boise
- Camas Prairie
- Cleveland-Maple Grove
- Crane Creek
- Island Park
- Raft River Valley
- Weiser

Nevada

- Baltazor-McGee
- Beowawe
- Big Smoky Valley
- Fly Ranch
- Gerlach
- Grass Valley
- Jersey Valley
- Moapa Indian Reservation
- San Emidio Desert (Empire)
- Steamboat Springs - Reno
- Tuscarora - Hot Sulphur Springs
- Wabuska Hot Springs

New Mexico

- Animas Valley
- Jemez Springs
- Radium Springs
- Socorro Peak

Oregon

- Belknap
- Breitenbush
- Hot Lake
- Klamath Falls
- LaGrande
- Lakeview
- Malheur-Harney Basin
- Newberry Caldera

Utah

- Cedar City
- Cove Fort
- Little Mountain
- Minersville-Parowan
- Newcastle
- Pavant Butte
- Roosevelt Hot Springs
- Thermo

Washington

- Glacier Pass
- Indian Heaven
- Mt. St. Helens
- Snohomish County

Wyoming

- Cody
- Dubois
- Red Desert
- Thermopolis
- Washakie