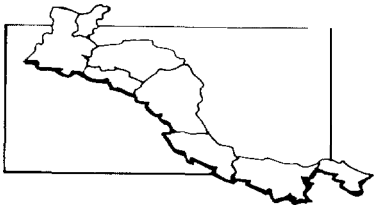
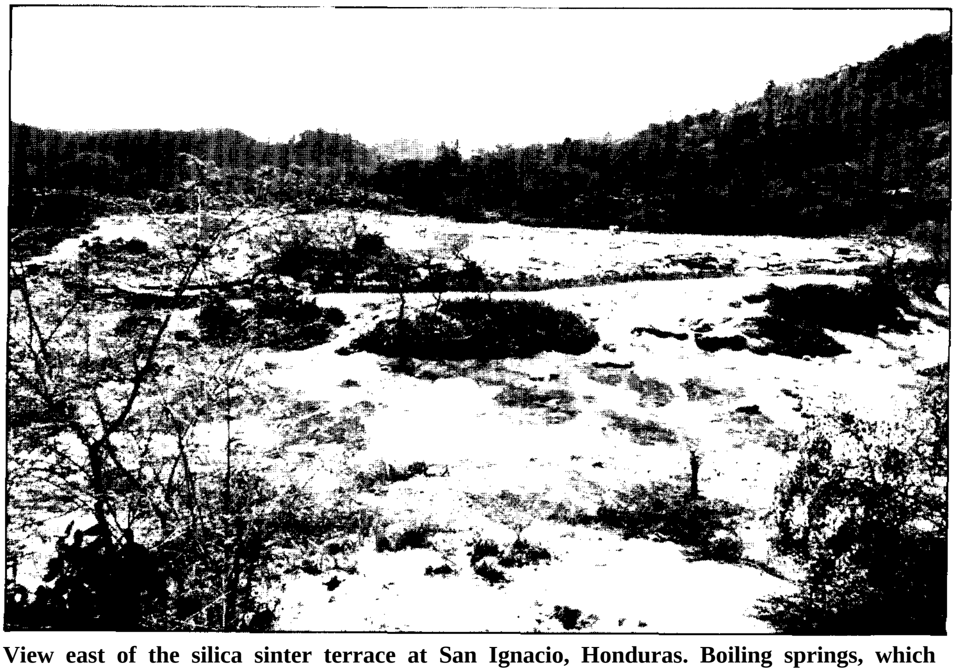


Geochemistry at Honduran Geothermal Sites

by Fraser Goff C. O. Grigsby, Lisa A. Shevenell, and J. Wilfred Gutierrez

In May 1985 a team from Los Alamos National Laboratory, the United States Geological Survey, and the Empresa Nacional de Energia Electrica (ENEE) earned out hydrogeochemical studies at six major hot-spring systems in the western half of Honduras. The locations of these systems are noted on the map in "Geology of Honduran Geothermal Sites." The team analyzed water samples for concentrations of major and trace elements, stable isotopes, and tritium, gas samples for concentrations of carbon dioxide, hydrogen sulfide, methane, and other gases, and rock samples for concentrations of carbon and oxygen isotopes. The results of the analyses were used to assess the suitability of the sites for geothermal development. The team also studied many cold springs throughout Honduras to obtain background information about the concentrations of deuterium, tritium, and oxygen-18 in Central American waters.



View east of the silica sinter terrace at San Ignacio, Honduras. Boiling springs, which are used for cooking, discharge all around the perimeter of the 100- by 150-meter terrace. (Photo by Fraser Goff.)

Table 1

Concentrations of silica, arsenic, lithium, boron, bromine, and ammonium in surface waters at six Honduran hot-spring sites and the temperatures of those surface waters. High surface concentrations of these species may indicate high temperatures in the underground reservoirs. Also listed, for comparison, are the concentrations found in a fluid sample from the Vanes Caldera geothermal site in New Mexico. This sample was collected at a depth of 1500 meters (at the entry to Baca well #13); the temperature of the fluid there, after being corrected for steam flash, is 278°C.

	Hot-Spring Temperature	Concentration (mg/1)					
Site	**(°C)**	SiO_2	**As**	**Li**	**B**	**Br**	NH_4
Azacualpa	115.4	211	0.07	0.94	1.59	<0.1	1.09
El Olivar	75.9	120	<0.05	1.38	8.02	0.3	10.00
Pavana	101.8	128	0.11	0.27	1.43	<0.1	0.17
Platanares	99.5	288	1.26	4.04	16.70	<0.1	10.40
Sambo Creek	99.5	133	<0.05	0.17	0.09	<0.1	0.12
San Ignacio	99.0	214	<0.05	1.44	3.81	<0,5	2.78
Vanes Caldera		488	1.16	17.20	14.90	5.3	1,52

The six sites studied were Azacualpa, El Olivar, Pavana, Platanares, Sambo Creek, and San Ignacio. Geologic evidence indicates that the hot-spring systems in Honduras are not associated with recent silicic volcanism, as is the case, for example, at Yellowstone National Park in Wyoming and the Vanes Caldera in New Mexico. Rather, the setting in Honduras resembles that of Nevada: water circulates deep into the earth, is heated conductively, and rises connectively along faults and fractures. In agreement with the geologic evidence, the surface waters were found not to be acid-sulfate in character, which is indicative of an origin in near-surface steam reservoirs, and to be instead neutral to alkaline-chloride in character, which is indicative of an origin in subsurface reservoirs. Boiling and/or superheated hot springs are present at all sites except El Olivar; the temperature of the springs there is less than 76°C. Several of the spring systems have deposited silica (SiO_2) as terraces or as gravel cements, a feature that usually indicates subsurface reservoir temperatures greater than 150°C.

The concentrations of certain chemical constituents in the surface waters at a geothermal site depend primarily on the subsurface reservoir temperature and the rock type and to a lesser extent on the amount of circulating water and the flow rate. Significant concentrations of silica, arsenic, lithium, boron, bromine, and ammonium, for example, usually indicate a high equilibrium temperature in the reservoir. Table 1 lists the concentrations of these constituents in typical water samples from the six Honduran sites and, for comparison, in a sample from a reservoir in the Vanes Caldera of New Mexico, which is known to contain high-temperature fluid. We use the Vanes Caldera for comparison because it is a classic geothermal system, well known among geologists, and its rock types are very similar to those found at the Honduran sites (primarily welded tuffs and ancient sedimentary rocks such as limestones, sandstones, and shales). Nevertheless, since the Vanes

Caldera fluid is generated in a volcanic environment and, in addition, the sample for that reservoir came from a very-high-temperature well, only qualitative conclusions can be drawn from such a comparison. The data suggest that the Platanares site is the hottest of the six Honduran sites but is not as hot as the Vanes Caldera reservoir.

A better way to assess equilibrium reservoir temperatures is to use chemical geothermometers. Table 2 lists, for the six Honduran sites and for the Vanes Caldera, the subsurface reservoir temperatures estimated with two widely used geothermometers, quartz and sodium-potassium-calcium. The quartz geothermometer relates quartz (SiO_2) concentration to temperature through the laboratory-measured solubility curve of this mineral. The volubility of quartz rises steeply between 100 and 300°C. Since precipitation is quite sluggish with falling temperature, the silica concentrations found in the surface waters are good indicators of the subsurface reservoir temperature. The sodium-potassium-calcium geothermometer, an empirical relation between relative concentrations of these elements in surface water and reservoir temperatures, is based on data gathered from many high-temperature geothermal systems around the world. The Platanares site again comes out ahead, but the temperatures of two other sites, San Ignacio and Azacualpa, are greater than 180°C, the minimum temperature required for economical generation of electric power.

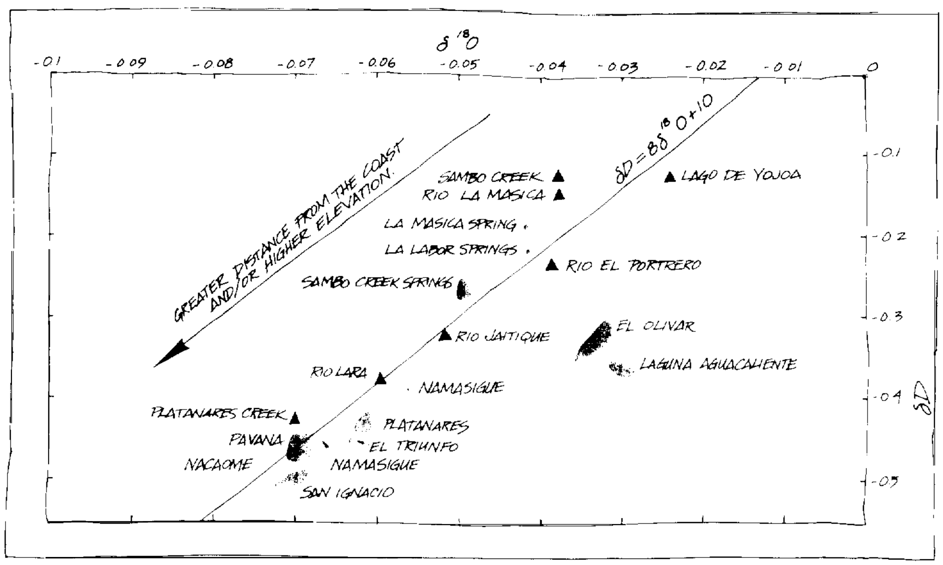
Our results from chemical geothermometry generally agree with those from gas geothermometry. One gas geothermometer uses the relative concentrations of carbon dioxide, hydrogen sulfide, methane, and hydrogen as an indicator of temperature. The relationship is empirical but has been supported by theoretical studies of equilibration among these gases at high temperature and by comparison with the gas chemistry of many explored geothermal fields.

Table 3 lists the minimum electric

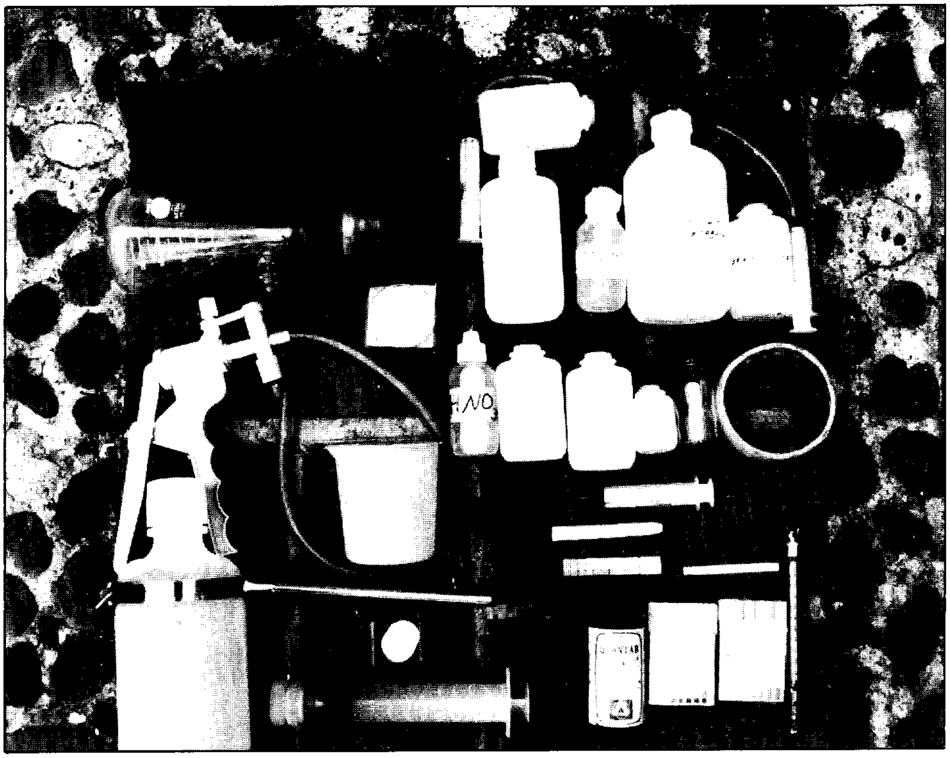
Table 2

Estimated temperatures of the underground reservoirs at six Honduran hot-spring sites. These estimates were obtained by using two chemical geothermometers, the quartz and the sodium-potassium-calcium geothermometers (see text). Also listed are similar estimates for the temperature of the underground reservoir at the Vanes Caldera geothermal site in New Mexico. The observed temperature of the Vanes Caldera fluid, measured at a depth of 1500 meters (at the entry to Baca well #13) and corrected for steam flash, is 278°C.

	Estimated Reservoir Temperature (°C)	
Site	**Quartz Geothermometer**	**Na-K-Ca Geothermometer**
Azacualpa	184	181
El Olivar	148	101
Pavana	151	138
Platanares	207	225
Sambo Creek	147	148
San Ignacio	185	208
Vanes Caldera	249	282



Results of isotopic analyses of water samples from hot springs (red) and lakes, rivers, and cold streams (black) in Honduras. Shown is a plot of $\delta D = (^2H/^1H)_{sample} - (^2H/^1H)_{SMOW}$ versus $\delta^{18}O = (^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{SMOW}$, where ^2H, ^1H, ^{18}O, and ^{16}O are isotopic concentrations and SMOW stands for standard mean ocean water. Data points for all surface waters worldwide are found to fall near the line $\delta D = 8\delta^{18}O + 10$. The distance along that line between the data point for SMOW and the data point for a sample is indicative of the distance from the ocean and the elevation of the sample's origin. These isotopic analyses indicate that the Honduran geothermal reservoirs contain recycled rainwater from the local area around each site.



Some of the lightweight, compact equipment used to collect samples of water from hot springs. Six samples are collected from a spring, one each for anion, cation, tritium, deuterium and oxygen-18 (as water), carbon-13, and oxygen-18 (as sulfate) analysis. The samples for anion and cation analysis are filtered through a 0.45-micrometer filter; the sample for cation analysis is acidified with $HN0_3$ to a pH less than 2; the sample for carbon-13 analysis is treated with saturated $SrCl_2$ and concentrated NH_40H to precipitate $SrCO_3$; and the sample for analysis of oxygen-18 as sulfate is treated with formaldehyde to preserve the sulfate. Conductivity, temperature, pH, and chloride are measured at the site. Gas sampling requires a different array of equipment.

Table 3

Estimates of thermal power and equivalent electrical power from surface discharges at six Honduran hot-spring sites. Also listed are values for the parameters involved in the estimates: the estimated surface discharge rates, the best available estimates for the temperatures of the underground reservoirs, and the ambient temperatures. The thermal power was approximated as the product of surface discharge rate and the difference between the heat content of the fluid at the temperature of the reservoir and at ambient temperature. An efficiency of 20 percent was assumed for the conversion of thermal power to electrical power, which is practical only if the reservoir temperature exceeds 180°C. The power potential of these sites may be much greater than these estimates of power from surface discharges.

Site	Estimated Surface Discharge (l/rein)	Estimated Reservoir Temperature (“c)	Ambient Temperature (“c’)	Thermal Power (MW)	Electrical Power (MW)
Platanares	3150	225	27	44.9	9
San Ignacio	1200	190	28	13.8	2.8
Azacualpa	1200	185	28	13.4	2.5
Pavana	I coo	145	30	8.1	---
Sambo Creek	2000	150	30	16.9	---
El Olivar	200	120	30	1.3	---

power potential of these sites based on the estimated reservoir temperatures and the estimated surface discharge rates. Here too, Platanares looks very promising.

Ratios of deuterium to hydrogen-1 concentrations and oxygen- 18 to oxygen-16 concentrations in a water sample provide information about the source of the water. Measured values of these isotopic ratios in samples of surface water from the Honduran geothermal sites indicate that recycled rainwater is feeding the reservoirs (see accompanying figure).

The tritium content of a geothermal fluid can be related to its age through equations describing the circulation of fluids in the geothermal system, The equations include the known input of tritium from the atmosphere as a function of time and location of the system. Analytical solution of the equations indicates that Honduran geothermal waters are between 34 and 7500 years old and are most likely several thousand years old. The better sites should therefore provide a stable, long-lasting source of geothermal power.

The ratio of carbon-l 3 to carbon-12 concentrations in a sample of surface water is an indicator of rock types through which the water flows. Measured values of this ratio in bicarbonate (HCO_3) from the Honduran hot springs indicate that the springs are flowing through sedimentary rocks and/or rocks containing hydrocarbons and other organic compounds.

By combining the information obtained from Geochemical and geologic studies, the temperature and flow dynamics of a site can be evaluated before the more expensive step of drilling begins. ■

The Geochemical work reported here was done by Dale Counce, Fraser Goff Chuck Grigsby, Wilfred Gutierrez, Lisa Shevenell, and Pat Trujillo of Los A1amos National Laboratory. Alfred Truesdell and Cathy Janik of the U.S. Geological Survey (Menlo Park), and Rodrigo Paredes of ENEE.