A GEOCHEMICAL RECONNAISSANCE OF THERMAL AND NONTHERMAL WATERS IN NICARAGUA

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ABSTRACT

Instituto Nacional Electricidad (INE), the Nicaraguan utility company, commissioned a Master Plan for Electrical Development in that country which included a Geothermal Resources Inventory. Geothermal exploration and evaluation integrated geological, geochemical, and geophysical surveys. The geochemical reconnaissance had a two-fold purpose: 1) to detect and define areas of regional geothermal potential, and 2) to support site-specific targets for exploration drilling suggested by the other surveys.

Two hundred thirty-five localities were sampled: 43 springs and 192 wells. Samples from cooler springs and wells were collected around thermal waters so that relative anomalies might be recognized. The area covered over 20,000 sq. km., in or bordering the Nicaraguan Depression.

Several geochemical anomalies were discovered, aligned along north-south or northwest-southeast trends. Geophysics has defined several deep, primary reservoirs. Thermal manifestations are usually absent at the surface but are present where secondary, shallower reservoirs occur.

INTRODUCTION

Three field crews worked in various, predetermined parts of the country. Sampling operations had originally been planned for the dry season but overlapped into the rainy season. The 1978 rainy season experienced the first normal rainfall after several years of less than average precipitation.

Field determinations of waters included temperature, pH, specific conductance, flow rate, chloride (Quantabs) and ammonia (Nessler Reagent in the field and Orion gas-sensitive electrode in the base office). Sample environmental descriptions and well conditions were noted. Laboratory determinations, by Amtech Laboratories (San Diego, California), included Na, Ca, K, Mg, SO_4, Cl, HCO_3 and CO_3, SiO_2, F, B, pH, and conductivity. Thermal waters were defined as having temperatures greater than 32°C. Eight areas showed geothermal geochemical anomalies of waters. Four areas are described in this paper.

PREVIOUS WORK

The first extensive work on thermal manifestations in (western) Nicaragua was performed by Texas Instruments under government contract in 1969 and 1970. That investigation led to a study of the Marabios Volcanic Range, including the San Jacinto and Momotombo areas, followed by development of the Momotombo site (located on the northwestern edge of Lake Managua). The latter area has been successively developed by the United Nations Development Program (1972-1973), Electroconsult (1974-1976), and California Energy Company (1975 to recent)--the latter two companies engaged chiefly in development drilling. IECO is presently monitoring some continuous-flow well tests at Momotombo.

CURRENT WORK

Sampling during the 1978 exploration program was conducted primarily in the Nicaraguan Depression, in the Marabios Range, and in the Tertiary Highlands to the east. The jungle area in eastern Nicaragua between the towns of Rama and Nueva Guinea show some isolated Recent volcanic centers (McBirney and Williams, 1965) and hot spring occurrences. A brief geologic and geochemical survey of this area was performed. More detailed geochemical work was conducted in areas where power requirements are highest.

The Nicaraguan Depression, about 30 to 45 km wide, is bounded on the east by the Tertiary Interior Highlands province and on the west by the Pacific coastal plain. The Depression and Marabios volcanic range trend northwest-southeast, with a number of transverse offsets. The Depression has the aspect of a graben but the structure is complicated and obscured by alluvial and volcanic fill. Current tectonism is evidenced by seismicity and volcanism.

The geochemical anomalies discovered during the Master Plan project are characterized by various combinations of 1) apparent high subsurface temperatures established by cation and silica mixing model geothermometers, 2) above-ambient temperatures of surface manifestations, and 3) anomalous concentrations of boron, ammonia, carbon dioxide, hydrogen sulfide, and chloride ions. These concentrations suggest magmatic degassing at depth and subsequent fractionating of volatiles into cooler groundwaters from ascending steam.

The water analyses suggest a hot water rather than a vapor phase as shown by the chemical constituents; the geophysical resistivity values also support this model (White, 1970; Ellis and Mahon, 1976).

Between the towns of Masaya and Nandaime, a major geophysical anomaly is present from a depth of 2000 to 4000 m and extends laterally for about 18 km. This anomaly is interpreted to represent the geothermal reservoir. From wells immediately above this anomaly, a total of eleven water samples were collected, taken from depths to 300 m. These samples indicate no mixing of thermal waters with shallow aquifer waters, leading to the conclusion that this possible reservoir is overlain by impermeable cap rock.

Among the questions asked of the chemical analyses of the thermal and nonthermal waters were (1) are there any indications of geothermal fluids? 2) can a reliable minimum temperature be assigned to the fluids at depth? 3) what is the degree of mixing between the deeper geothermal fluids and the cooler groundwaters? 4) through what local geologic conditions (connate waters, evaporite deposits, sulfide ore bodies, organic decay in sediments, rock-type) must fluids ascend that might produce false signatures? The answers require continued evaluation and study.

Even when the cation and silica geothermometers correspond, they must not be used dogmatically as evidence for subsurface temperatures. However, when chemical constituents show anomalous concentrations over background waters, the presence--on a regional level--of a geothermal reservoir may be inferred. Targeting a reservoir is based upon agreement of data from diverse geotechnical studies.

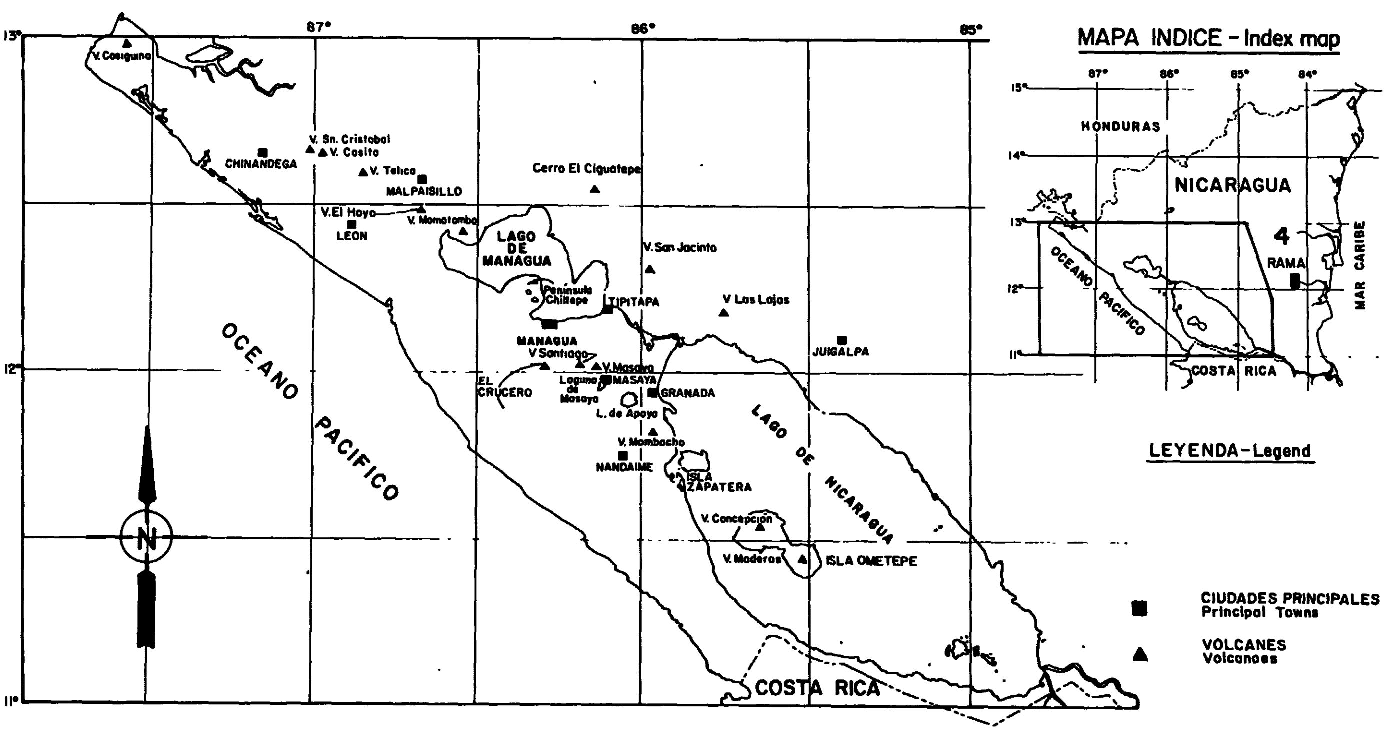
VOLCAN MOMBACHO AREA

Recharge of dilute Ca>Na-HCO_3 is being heated by rising steam (there are several fumeroles in the Mombacho crater) to produce a Ca-Na SO_4 water, which may mix with a boiling NaCl fluid. The silica mixing model suggests a deep fluid temperature of 210°C. However, the silica in solution may be controlled by chalcedony or volcanic glass rather than quartz. The high SO_4 and Mg content of the waters in this region indicates cooling by conduction and water-wall rock reactions during fluid ascent to the surface. The cation geothermometer for several samples is around 200°C.

Present in some samples are high boron and ammonia concentrations which may result from steam leakage from a deep thermal reservoir. A high conductance-low resistivity anomaly was revealed in a reconnaissance geophysical survey in the plains at the southwest edge of Volcan Mombacho. The area requires further geochemical and geophysical work to determine field potential.

THE VOLCAN SANTIAGO/MASAYA-TIPITAPA TREND

Anomalous waters occur along a series of en echelon normal faults striking north to northeast. There are relatively anomalous proportions of SiO_2, TDS, Cl, B, and NH_3 with some NaCl mixing, possibly revealing a deeper thermal fluid. A number of samples have cation geothermometers between 200°C and 215°C but they may be the result of high partial pressures of CO_2. Ratios of NH_3/Cl and B/Cl in some anomalous waters exhibit contradictory trends, suggesting a gas or steam component, NaCl geothermal brine at depth, or contribution of NH_3 from decaying organic debris in lake sediments, with Cl originating from different sources introduced by different waters. The waters nonetheless



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show a steam-heated component of undetermined origin. A reconnaissance geophysical survey shows a potential reservoir area about 10 km east of the anomalous trend, toward Lake Nicaragua. Structurally, it appears that these waters originate as recharge at the Volcan Santiago/Masaya complex (the Masaya crater currently has a small pool of incandescent lava) and flow northward along the faults which may form a graben. These faults possibly connect with a deeper geothermal reservoir.

Geophysical interpretation suggests several potential reservoir areas below 2000 meters. The lava lake at Volcan Masaya reveals the presence of a shallow magma chamber as a heat source. Self-sealing immediately above the system may explain the lack of direct surface thermal manifestations; leakage from such a reservoir may depend on complicated fault-fracture connections to the surface.

THE MALPAISILLO AREA

A number of well waters southeast and east of Malpaisillo show relative anomalous chemical components and temperatures above normal. Their general composition is Ca>Na- or Na>Ca- HCO_3. Several samples, aligned along a northwest-southeast trend, exhibit relatively high boron, ammonia, silica, and TDS. The cation geothermometer shows equilibrium temperatures below 100°C. The silica geothermometer, based on quartz solubility, is between 140° to 157°C; if controlled by dissolution of chalcedony, the temperature is between 120° and 133°C. The Malpaisillo geochemical anomaly is not as strong as the other trends present in western Nicaragua and requires further study to determine mixing amounts and geothermal significance. All samples in the area were well waters. No thermal springs are currently known.

VOLCAN TELICA/CASITA-VILLA SALVADORITA ANOMALY

Many warm springs and wells are found in the lowlands along the northeast fringe of the Marabios Range. Two anomalous trends are present, one running north of Volcan Telica and the other striking northwest-southeast from east of Volcan Casita toward Villa Salvadorita.

The northerly anomaly from Volcan Telica shows high Cl, B, SiO_2, NH_3, and TDS. The B and Cl anomalies are coincident, and B/Cl is independent of Cl in several samples, suggesting a common source for both elements, possibly volcanic gases. The cation geothermometer gives equilibrium temperatures of 60° to 90°C. Silica in the warm groundwaters is probably controlled by chalcedony or amorphous silica. The low geothermometer temperatures could be the result of cooling by conduction on ascent to the surface and chemical re-equilibration of fluids with the Recent volcanic sediments. The silica mixing model is complicated but suggests a 200°C component, with maximum steam loss before mixing. Various cation mixing models show a subsurface temperature range from 171° to 207°C.

The northwesterly Volcan Casita-Villa Salvadorita anomaly includes high B, B-B/Cl, and Cl high relative to surrounding cooler waters, and high SiO_2. The B-B/Cl anomaly is offset with respect to the chloride anomaly. This suggests that the B is produced by a source independent of the increased Cl content. It is possible different waters flowing through different subsurface conditions produce the anomaly offsets. Silica and cation mixing models for these waters yield various results. The geothermal geochemical indicators do suggest a fractionating of volatiles from subsurface boiling into the shallow groundwaters.

Both these anomalies are close to active volcanoes Telica and San Cristobal. A heat source at depth is indicated. Geophysical reconnaissance surveys show a high conductance zone circling Volcan Casita-San Cristobal on the north, east, and west sides. An increase of conductance to the north may be due to penetration of saline waters from the Gulf of Fonseca into permeable formations. A detailed geophysical survey will better define the geothermal resource potential in this area.

CONCLUSIONS

The occurrence of many geochemical geothermal indicators in the waters sampled during the reconnaissance program reveal the presence of several high-temperature geothermal reservoirs in western Nicaragua. Preliminary data--integrating geology, geophysics, and geochemistry--suggest that the probable reservoirs are sealed. Shallow ground waters are heated by rising steam from these reservoirs creating secondary reservoirs where tectonic stresses have made the overlying sediments more permeable and porous. The frequent occurrence of anomalous waters along the major regional structural trends, and the clustering of thermal manifestations over fault/fracture intersections tends to support the hypothesis that the geothermal reservoirs are deep. Geophysical data also support this probability. Hence, deep exploration drilling sites must be chosen carefully and should not necessarily be placed next to surface thermal manifestations. The complexities seen in the various mixing models are based on contributions of different waters flowing through heterogeneous subsurface conditions. Isotope analyses of the waters are necessary to define sources and hydrolodic regimes in the geothermal systems. More detailed work in all geotechnical areas is indicated. Temperature gradient holes must penetrate below the phreatic water level to obtain meaningful gradients.

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BIBLIOGRAPHY

Consorcio IECO-Lahmeyer, 1979, Plan maestro, v. 5, Geothermal Resources Inventory, 150 p.

Consorcio IECO-Lahmeyer, 1978, Geothermal Resources Inventory, v. 5-2, Geophysical Investigation: prepared by Electrodyne Surveys, Reno, Nevada.

Ellis, A. J., and Mahon, W. A. J., 1977, Chemistry and geothermal systems: N.Y., Academic Press, 391 p.

Fournier, R. O., 1977, Chemical geothermometers and mixing models for geothermal systems: Geothermics, v. 5, p. 41-50.

GeothermEx, Inc., 1978, Geothermal interpretation of groundwater geochemistry in the areas of Masaya, Managua, Northern Marabios Range, Juigalpa and Rama, Nicaragua, 29 p.

McBirney, A. R. and Williams, H., 1965, Volcanic history of Nicaragua: Berkeley, University of California Press, U. C. Publications in Geological Sciences, v. 55.

Thigpen, J. B., 1970, Final report, geothermal resources project, stage one, part 2, regional geology: thermal manifestations of western Nicaragua: Texas Instruments, Incorporated, unpublished report.

White, D. E., 1970, Geothermics (Spec. Issue 2), 1, 58 p.