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The Chalupas and Chachimbiro Geothermal Fields in Ecuador

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ABSTRACT

The geological setting as well as a preliminary geothermal model of two of the main geothermal areas of Ecuador are presented in this paper. The assessment is based only on surface exploration activities. It is likely that, because of the presence of abundant highly differentiated volcanic products of recent origin, both areas are good prospectors for further exploration.

Country Background

Ecuador covers an area of 284,000 km^2 which is divided into three distinct geographic zones (Figure 1). The western coastal lowlands (Costa), which extend from the Pacific Ocean to the Andes, corresponds to one-fourth of the country's total area and has about one-half of its population. Guayaquil is Ecuador's largest city and its most important port. The high Andean Mountains (Sierra), which run essentially north-south through the center of the country, have one-half of its population and includes Ecuador's capital, Quito. The third geographic zone is the low-lying eastern region (Oriente) which is covered by a tropical rainforest and is drained by tributaries of the Amazonas River, it holds nearly all of Ecuador's proven oil reserves. The "Oriente" constitutes about one half of the country's area, but has less than 4% of its population.

Ecuador's 1997 population was estimated in 11.46 million (52.9% urban), with a 2.5% growth rate for the 1982-1990 period.

Regional Geological Framework

The Ecuadorian active continental margin is characterized by the subduction of the Nazca Plate beneath the South America Plate under particular conditions because of the presence of the aseismic Carnegie Ridge, a structure generated by the movement of the Nazca plate over the Galapagos Hot Spot (Hey, 1977).

In Ecuador, the Andean Range was formed following several orogenic pulses since at least Cretaceous times. The Sierra geographic and physiographic zone corresponds to the core of the Ecuadorian Andes. It is characterized by two paralell mountain ranges or **Cordillera Occidental** (to the west) and the **Cordillera Real** (to the east) separated by a narrow valley, the **Interandean Depression,** which disappears towards the south.

The Ecuadorian Cordillera is mainly formed by basic and intermediate volcanic rocks emplaced in a submarine environment (Macuchi Formation), which are covered by a discontinuous turbiditic deposits of Cretaceous to Eocene age. The Cordillera Real consists of igneous and sedimentary rocks, deeply modified by a Paleozoic to Cretaceous metamorphic event. The Interandean Depression is an important extensional structure bounded by active fault scarps and partly filled by volcanic and volcano-sedimentary deposits that locally reach some thousands of meters in thickness.

The Ecuadorian Volcanic Belt extends north-south along the whole country, with an average width of about 80 km. The Quaternary activity, characterized by the building of a great number of huge stratovolcanoes, forming the highest peaks of the northern Andes, is restricted to the area north of 2°S. The products of stratovolcanoes cover a basal volcanic complex and form a thick lava pile with minor tuff intercalations and local ignimbritic cover. A thickness of at least 1000 m has been observed along the fault scarps of the Interandean Depression. This roughly tabular volcanic sequence is faulted and tilted (Barberi F. et al., 1988).

Geothermal exploration studies in the areas of Chalupas and Chachimbiro were carried out by the Ecuadorian Electrification Institute (INECEL) between 1983 ad 1986 using its own resources.

The Chalupas Geothermal Field

The Chalupas geothermal field is located in the Cordillera Real about 60 km southeast of Quito and 35 km northeast of Latacunga (Figure 1). The most important clement is a caldera, at the center of which there is the Quilindaña volcano (at 0°74'S and 78°20'W).

The caldera rim is about 5 km from the southeast flank of Cotopaxi volcano. In its immediate vicinity there are only a few scattered houses of workers from some large cattle ranches (haciendas). The Cotopaxi National Park is the closest neighbor of the Chalupas field.

The field can be reached by an about 50 km long gravel road which runs along the northern and eastern flanks of the Cotopaxi volcano and is connected to the Pan American highway near the town of Lasso. The 130 kV Pisayambo-Santa Rosa transmission line of the National Interconnected System, is about 25 km from the center of the field.

The topography of the area is irregular and it is influenced by the Quillindaña stratovolcano (Elev. 4,878 m). The bottom of the caldera is relatively flat, at an average elevation of 3,600 m. The lowest areas inside the caldera (Elev. 3,500 m.) are located at its northeastern and southeastern ends where the Tambo and Chalupas rivers run through the eastern rim, toward the lower lands at about 400 masl.

The area is covered by clouds and subjected to constant rain most of the time. The daily temperatures varies from 0 to 16° C with a mean of 4° C. Mean annual rainfall is about 1,200 mm. The period July-September is considered to be the dry season, with sunny but cold and windy days.

Summary of Performed Research

The Chalupas Caldera has an approximate elliptical shape (13 km x 16 km) and is defined morphologically by a series of periclinal lavas, clearly recognizable on the northern, western and southern caldera rims, covering the core of the Cordillera Real. The bottom is filled with fractured lavas and fragmentary materials from the paroxismical eruption and subsequent collapse of the Chalupas stratovolcano. Surface deposits are product of glacial, lacustrine and fluvial erosion.

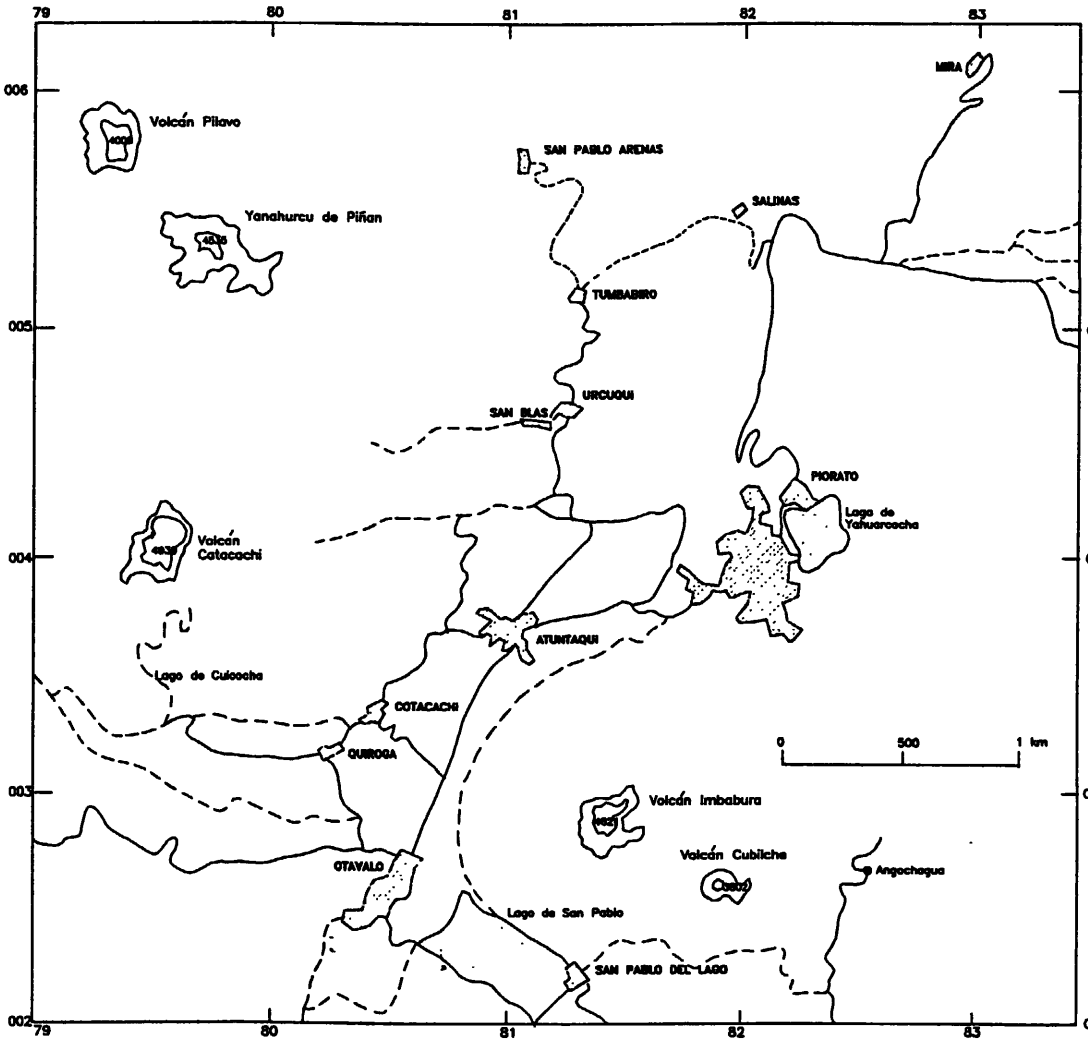

Figure 1. Location of the geothermal fields.

The evolution of volcanism in this area, has generated a series of differentiated volcanic caldera rocks that include basic, intermediate and acid products.

Three main faults systems have been identified. One is parallel to the dominant direction to the Andean Range (NNE-SSW) the other two are transversal to it (NW-SE and NE-SW) and displace the previous one. Apparently the NE-SW faults are the most recent ones.

The metamorphic core of the Cordillera Real forms an impervious basement on which a pile of Pliocene lavas have accumulated; it may reach very high values of secondary permeability by fracturing, as well as the lavas that formed the Chalupas stratovolcano, buried by the caldera collapse.

The pyroclastic products, morraine and lagunar deposits that fill the caldera, have low or zero primary permeability, and a plastic behavior that prevents them from acquiring secondary permeability by fracturing.

The geochemical studies included 45 surface and subsurface water sampling points outside and inside the caldera. Of these, 26 are thermal with temperatures ranging from 37° to 26°C. The most frequent chemical types are alkaline-earth and alkaline bicarbonate, within which subgroups based on their salinity and temperature have been defined.

Alkaline-earth bicarbonate waters are characteristic of shallower waters which interact with gases rich in CO_2. The alkaline bicarbonate waters indicate deeper flow regimes and interaction processes with acid rocks despite the fact that they always show a high grade of dilution due to the mixture with meteoric waters. Values of pH are generally between 6.1 and 6.8.

The ratio between CO_2 partial pressure and the temperature obtained for the manifestations could indicate a regional thermal anomaly. There are also traces of hot gases that contaminate the surface waters.

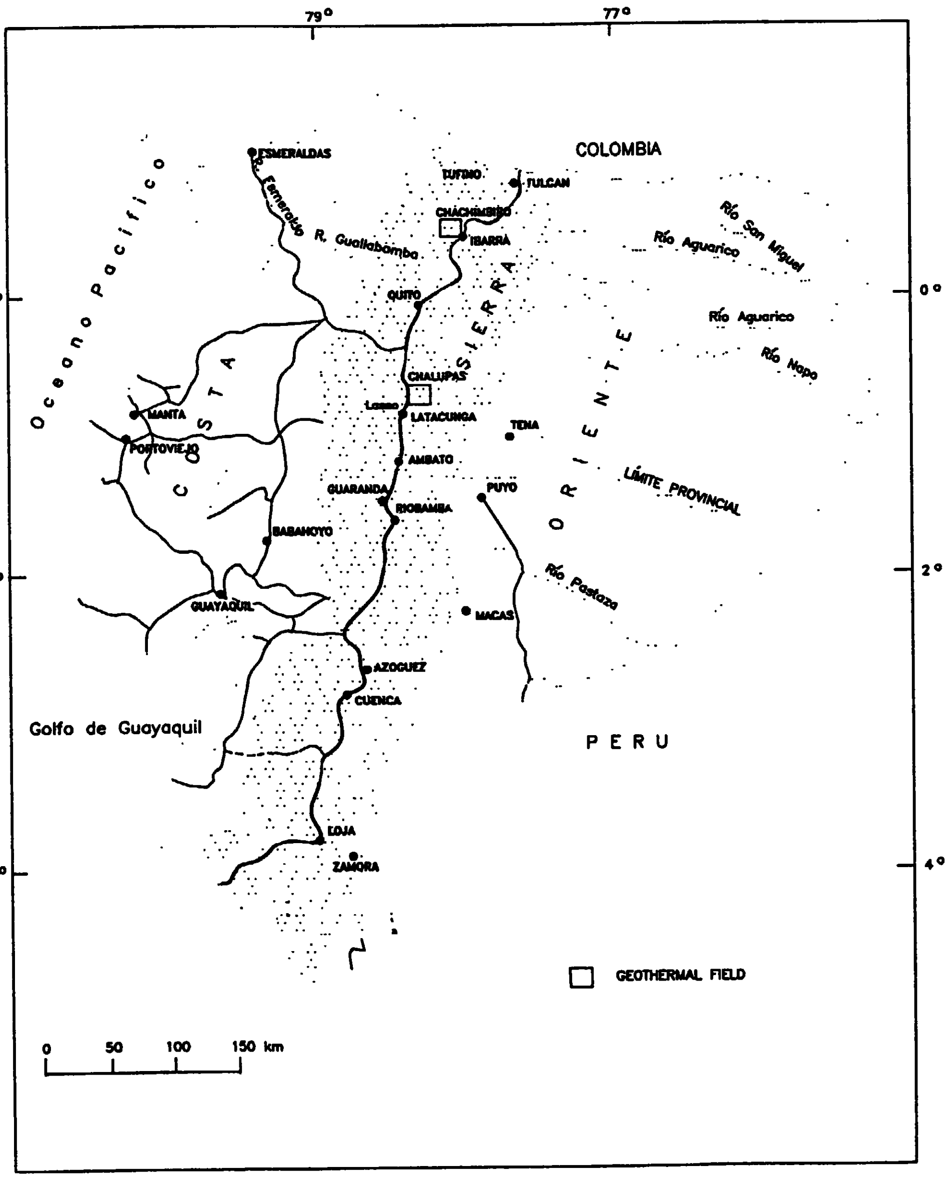

Figure 2. Schematic map of the Chachimbiro area.

North of the caldera, in a transversal fault zone sulfate water with ammonia and boron anomalies have been found. The latter might be manifestations of ascending fluids stemming from a convective steam system; their deep temperatures should exceed 180°C.

As for the isotopic composition, all the samples fall on the straight meteoric water line in a wide composition interval, which assumes extensive near surface circulation and confirms the impervious condition of the surface deposits filling the caldera. The variations in the isotopic contents correspond to different infiltration levels at elevations between 3,500 and 4,200 meters (Almeida et.al.,1992).

Based on a gravity survey supported by two bases and 282 stations inside the caldera, the simple Bouguer anomalies with no terrain corrections was determined. The first objective of the study was to define the collapse structures parallel to the caldera rim. It was determined that the prevailing structure in the area is the result of a combination of the caldera collapse and regional tectonic effects.

The measured values on the local anomaly have a difference of up to 30 mgals respect to the regional anomaly. The lowest values (258 mgals) are located under the Quilindaña Volcano, which reflects the largest depth of the substratum in the area.

The caldera is defined by a series of isogal curves, especially at its northeastern, eastern and southern rims. Toward the north and west, the isogal curves are defining a regional (SSW-NNE) fault which, along with the structure's collapse, constitute the caldera rim.

Preliminary Geothermal Model for Chalupas.

The heat source is inferred to be a large magma chamber, located at about 10 km depth which fed the Chalupas stratovolcano during the building of a big cone, and until the collapse that occurred after a violent explosive activity that emitted at least 100 km^3 of rhyolitic materials. After the caldera collapse phase, the volcanic activity continued inside the caldera and build the Quilindaña, Huahui and Plaza de Armas vents. The characteristics of the volcanic complex, which has remained active for more than one million years, are good indications of the existence of a magmatic chamber that created an important heat flow anomaly in the region.

It is assumed that the geothermal reservoir is formed by Pliocene volcanic rocks and lavas from the Chalupas Volcano, with a thickness between 1,000 and 2,000 meters. Both units would have a high secondary permeability owing to the fracturing caused by the caldera collapse.

Among the Buena Vista pyroclastic products, fragments of hydrothermally altered rocks have been determined. This might indicate the existence of a geothermal system inside the caldera. The thermal springs having ammonia, boron an temperature anomalies also suggest the presence of endogenous fluids from a convective system.

The cap rock is formed by a 200-500 meters thick pile of very impervious pyroclastic products, lake sediments, lahars and morraines. It is also feasible that there is a self sealing phenomenon, caused by the precipitation of minerals when hot fluids get in contact with cold recharge fluids.

Chachimbiro Geothermal Field

The geothermal area of Chachimbiro is located in the West Andean Range (Cordillera Occidental) about 70 km north-northeast of Quito and at 17 km northwest of Ibarra (Fig. 1). The center of the area of interest is at the 0°25'N and 78°17'W, inside the Cayapas-Cotacachi National Park.

The field can be reached from Ibarra by a 20 km paved road to the town of Ureuquí. Afterwards, one must take a gravel road for 10 kilometers toward the El Hospital, Ranch and finally, 10 km. by a private road to the ranch itself. To reach the Chachimbiro site, where the major thermal manifestations are located, one has to take the 18 km gravel road of Ureuquí – Tumbabiro – Chachimbiro (Fig. 2). The 130 kV Quito-Ibarra transmission line of the National Interconnected System is about 25 km from the center of the area.

The topography is uneven and is dominated by the stratovolcanoes of Cotacachi (4,944 m) and Yanahureu de Piñan (4,535 m). The Chachimbiro thermal manifestations area is at about 2,560 masl.

Summary of the Research Carried Out

The area of Chachimbiro is characterized by persistent volcanic activity that began during Pleistocene. This is reflected by a large concentration of volcanic vents such as: Cotacachi, Pilavo, Yanahureu de Piñan and Cerro Negro. These are part of the important Volcanic Complex of Huanguillaro, where a gravitational collapse event surely involving some explosive events, has been recognized. In the area there are also some vents of a lesser size and 17 acid domes.

The thermal manifestations are abundant despite the thick pyroclastic cover. The most frequent ones are of the alkali chloride type, with medium-to-high thermality (56°C) and flows of about 70 liters per minute. These thermal waters most likely represent the lateral outflow of an hydrothermal system.

According to Almeida (1992), thermal waters show an evident chemical evolution from bicarbonate waters up to chloride waters in which delta values of ^{18}O increases from −11 to +6 $\%_0$. The total dissolved solids also increase as heavy isotopes in solution increase. This suggests an enrichment process of the solutes owing to the boiling evaporation of the original meteoric water under anomalous thermal conditions or due to a mixture of saline thermal waters with colder waters. The temperatures at depth based on geothermometry are around 240°C.

Preliminary Geothermal Model

It is inferred that the heat source is comprised of a system of at least three magmatic chambers, that have fed the Chachimbiro Dome Complex since the Pliocene and the Huanguillaro Volcanic Complex. According to unpublished INECEL reports there is evidence that volcanism has persisted during the entire Pleistocene up to recent times, dating of a pyroclastic flow from one of the domes indicates an age less than 8,000 years. Volcanic rocks at Chachimbiro are highly differentiated from andesites to rhyodacites, with a considerable volume of pyroclastic products and magmatic liquid in the domes. This favors the possibility that there is an important heat flow anomaly induced by thermal conduction from continuously recharged magma chambers.

The inferred depth of the geothermal reservoir at Chachimbiro is between 1,000 and 2,000 meters in volcanic fractured rocks at the base of the pile of Pliocenic lavas.

The rock cap of the geothermal system is made of an accumulation of pyroclastic products, various hundred meters thick, and is characterized by selfsealing above the reservoir.

References

Almeida, E., 1988. Los Recursos Geotérmicos del Ecuador Continental. INECEL Unpublished Internal Report.

Almeida, E. et al., 1992. Modelo Geotérmico Preliminar de Areas Volcanicas del Ecuador a partir de Estudios Químicos e Isotópicos de Manifestaciones Termales. Geothermal Investigations with isotope and geochemical techniques in Latin America. Proceedings of a Final Research Co-ordination Meeting IAEA, pp. 219-235. Vienna, Austria.

Barberi, F. et al., 1988. Plio-Quaternary Volcanism in Ecuador. Geolog. Mag. 125 (I), 1988, pp. 1-14.

Hey, R., 1977. Tectonic Evolution of the Cocos-Nazca spreading center. Geolog. Soc. of America. Bull. 88, pp. 1404-20.

INECEL, 1983. Síntesis de los Estudios de Aprovechamiento de los Recursos Geotérmicos en el Area de Chalupas, Unpublished Internal Report, pp 1-12.