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Exploration for High-Temperature Geothermal Resources in the Andean Countries of South America

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ABSTRACT

The Andean countries of South America have very significant unexploited geothermal resources. During the decade of the 1960, geothermal exploration started in Colombia, Argentina and Chile with the aim to use this clean source of energy for electricity generation. Later on, there was some interest in developing geothermal in Ecuador, Peru and Bolivia. However, at present it has not been possible to develop this energy for electricity generation.

High-temperature geothermal resources in Colombia, Ecuador, Peru, Bolivia, Argentina and Chile are associated with Quaternary volcanic activity. On the other hand, low to medium temperature resources are found in eastern South America. All these countries have carried out geothermal exploration initiated by the respective governments, which have been supported by foreign institutions, such as UNDP, OLADE and others.

At present, interest in developing high-temperature geothermal resources for electricity purposes has been renewed in some of these Andean countries, with most of the exploration conducted by private geothermal developers . Furthermore, a risk mitigation fund is being prepared for geothermal development in those countries; the fund will be established by the Latin American Development Bank (CAF) and the German Development Bank (KfW).

1. INTRODUCTION.

The subduction of the oceanic Nazca Plate under South America has given origin to the uplifting of the Andes mountain chain and the associated volcanic and geothermal activity. The active volcanic segments are controlled by the morphology and the dip of the Benioff zone. Three main active volcanic segments are located where the subducting slab dips about 30°; the Northern Volcanic Zone(NVZ), the Central Volcanic Zone (CVZ); and the Southern Volcanic Zone (SVZ). Areas where the dip is nearly horizontal account for the volcanic gaps, like the ones between the NVZ and the CVZ (The Peruvian Flat Slab) and between the CVZ and the SVZ (The Pampean Flat Slab) (Ramos et al., 2002).

The high-temperature geothermal resources in Colombia, Ecuador, Peru, Bolivia, Argentina and Chile are associated with the Quaternary volcanic activity. Low to medium-temperature resources are found along the volcanic gaps and in the eastern part of the continent. All of the Andean countries are conducting geothermal exploration and interest in developing the geothermal resources for power generation has been renewed in some of these countries.

Due to the high investment cost and risks associated with the exploration phase, which represent significant barriers, the German development bank KfW together with the development bank of Latin America (CAF), have initiated the formation of a geothermal development facility (GDF) as a market incentive to facilitate the geothermal energy development in Bolivia, Colombia, Ecuador, Peru and Chile. The GDF will include a grant-based risk mitigation fund in order to help early stage development and therefore mitigate the largest barriers to the development of the technology (ThinkGeoEnergy, 2011).

Several estimations of South American's potential for electricity generation based on geothermal resources have been done. Gawell et. al.,(1999), estimated that it was between 3,970 and 8,610 MW; Lahsen, (1986) in a preliminary analysis of Chile assumes for this country a generation potential of 16,000 MW for 50 years from geothermal fluids with temperatures exceeding 150°C, obtained from within a depth of 3,000 m.

Based on available information and considering only traditional hydrothermal resources and present technology, it is possible to assume a total electricity generation potential of 30,000 MW, 15% of the world potential inferred by Stefansson, (2005). In spite of this enormous potential, the only geothermal power plant which has operated on the South American continent is the 670 kW binary unit in the Copahue geothermal field (Argentina), which was decommissioned in 1996 (Bertani, 2010). So far geothermal energy has been an unexploited energy source for electricity generation in South America, but it has the potential of providing reliable base load electricity, reducing greenhouse gas emissions, and reducing reliance on imported fossil fuels.

Figure 1: Quaternary volcanic zones of South America.

2. COLOMBIA

2.1 Geothermal Resources and Explorations Activities

Most of the high-temperature geothermal areas in Colombia are associated with active volcanoes of the northern part of the Northern Volcanic Zone of the Andes. In this zone there are 15 active volcanoes that lie at the triple junction of the oceanic Nazca and Caribbean plates with the South American Continental Plate. The major volcanoes are Nevados del Ruiz, Tolima, Huila and Galeras.

Geothermal reconnaissance studies in the country started in 1968 by the National Geological Survey at the Nevados del Ruiz complex. A well was drilled there in 1977, that did not reach the reservoir, but the geological information suggested a high-temperature system (Alfaro et al., 2005). Since then, several studies have also been done in some others areas of Colombia, including an MT survey in the Nereidas Valley (García et al., 2013).

Based on geological, geochemical and hydrogeological studies, nine areas of geothermal interest have been selected for exploration of high-enthalpy resources. The most promising ones are Chiles-Cerro Negro, Azufral, and Paipa (Fig. 2). In the Chiles volcanic area, gas geothermometry indicates a temperature of 230°C; resistivity data confirms a geothermal reservoir under the volcano (Alfaro, et al., 2010).

Figure 2: Geothermal areas of Colombia.

Presently, exploration studies including geology, geochemistry and geophysics are underway in the Azufral and Paipa-Iza geothermal areas where drilling of exploratory wells is being considered (Aguilera, 2013a.).

3. ECUADOR

3.1 Geothermal Resources and Exploration Activities

The Ecuadorian Andes consist of two parallel NNE striking mountain chains; i.e., the Cordillera Occidental to the west and the Cordillera Real to the east, separated by the Inter Andean Valley. Both Cordilleras are capped by late Tertiary volcanic rocks. The Quaternary volcanic arc covers both in their northern part extending it into Colombia.

The volcanic arc consists of more than 50 volcanoes; 30 of them are still active, most of which are spatially associated with high-temperature geothermal areas. The volcanic activity disappears south of 2°S latitude. South from the volcanic zone there are medium-temperature thermal areas.

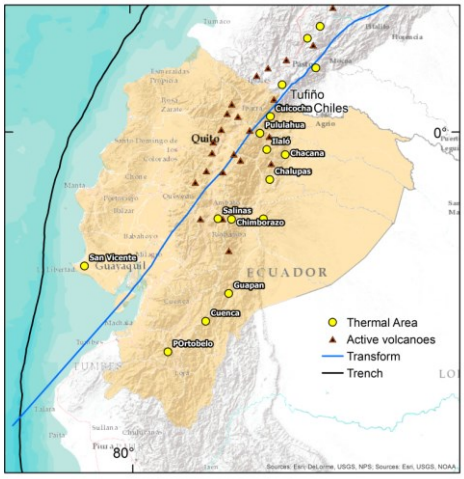

Figure 3: Geothermal areas of Ecuador.

Geothermal exploration in Ecuador has been perfomed by government institutions with foreign collaboration. A reconnaissance study carried out in 1979-1980 in the Tufiño, Chachimbiro and Chalupas areas defined these areas as high-temperature hydrothermal systems. Further studies indicated an electricity generation potential of 534 MW for the three prospects (Beate & Salgado, 2010) with a countrywide potential of around 3,000 MW (Lloret and Labus, 2014).

In 2008 the Ministry of Electricity and Renewable Energy (MEER) restarted geothermal exploration with the aim of developing one or more of the prospects. The first exploration well in the Tufiño area was completed in 2009. At Chachimbiro geophysical surveys have been undertaken along with studies for siting deep exploration wells. Prefeasibility studies have also been conducted at the Chacana and Chalpatan prospects (Lloret and Labus, 2014). At the Chalupas prospect a feasibility study has been conducted for a 50 MWe geothermal power plant (Beate and Salgado, 2010).

In 2012, the Governments of Colombia and Ecuador agreed to execute a joint geothermal project in the areas of the Chiles, Tufiño and Cerro Negro volcanoes, which are located at the boundary of the two countries. The aim of the project is to build a 150 MWe geothermal power plant (Aguilera, 2013c).

4. PERU

4.1 Geothermal Resources and Exploration Activities

Most of the high-temperature geothermal areas in Peru are found along the Eje Volcánico Sur, located in the northern part of the Central Volcanic Zone; this volcanic arc disappears north of 12°S latitude. The Eje Volcánico Sur includes more than 300 volcanic center where recent activity have been reported (e.g., at the Misti, Ubinas, Ticnasi, Sabancaya, Huaynaputina volcanoes).

Six geothermal regions have been identified in Peru: Cajamarca, Callejón de Huaylas, Churin, Central, Ejes Volcánico Sur and Cuzco-Puno (Figure 4). The hot springs located in the geothermal regions of Northern and Central Peru are controlled by the geothermal gradient and those of the southern part of the country are related to active volcanism (Vargas and Cruz, 2010).

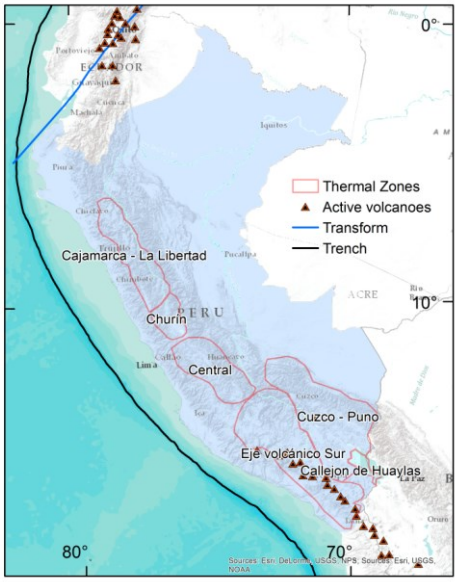

Figure 4: Geothermal areas of Peru.

In 1997 the Government approved the organic law of Geothermal Resources, under which the Ministry of Energy and Mines (MEM) has to propose regulations and apply them to geothermal energy policies. In 2010, the MEM enacted draft regulations for geothermal resources, and starting in 2011, five companies were authorized to explore 26 geothermal areas (Urzua-Monsalve et al., 2012; Muñoz et al., 2013).

A preliminary assessment of the exploitable geothermal energy potential of 3,000 MWe was reported by the MEM in 2011. The most promising geothermal areas on the basis of preliminary studies are Tutupaca, Calacoa, Laguna Salinas, Chachani and Chivay (Vargas and Cruz, 2010; Hiriart and Gutierrez, 2013).

5. BOLIVIA

5.1 Geothermal Resources and Exploration Activities

Most of the high-enthalpy geothermal resources in Bolivia have been discovered along the Cordillera Occidental on the border with Chile, an area characterized by late Tertiary and Quaternary volcanic activity. To the east extends the Altiplano, the Cordillera Central and the Cordillera Oriental, which is a fold and thrust belt that consists of a Paleozoic block.

More than 70 geothermal manifestation areas have been reported in Bolivia (Aliaga, 1984). These are found in the eastern slopes of the Cordillera Occidental, in the central part of the Altiplano and in the southern part of the Cordillera Oriental. Currently, there are not applicable regulations for geothermal licenses or concessions.

Between 1975 and 1985 the first exploration survey supported by UNDP established the existence of high enthalpy resources in the areas of Laguna Colorada, Salar de Empexa and Volcan Sajama (Figure 5). Feasibility surveys including drilling of six wells with an average depth of 1,500 m were made between 1990 and 2000 in the Laguna Colorada field (Delgadillo, 2000; Terceros, 2000). The total flow rate of these wells is about 360 ton/h, and the temperature of the produced fluids is between 250 and 270ºC: Reservoir engineering studies suggest a power potential of 350 MWe for this propect (Aguilera 2013b). The estimated power potential of exploitable geothermal energy resources in Bolivia is between 510 and 1,260 MW (Gawell et al., 1999).

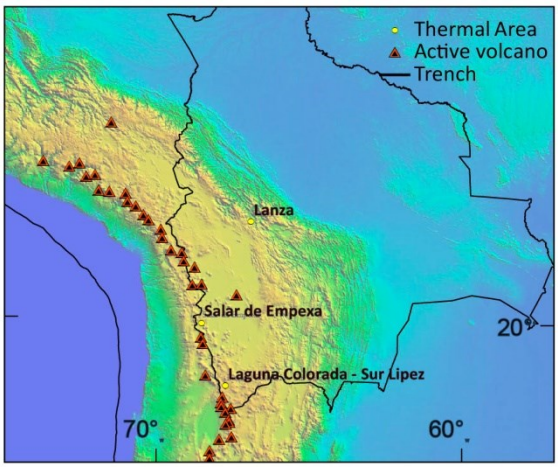

Figure 5: Geothermal areas of Bolivia.

A new feasibility study for the exploitation of the Laguna Colorada (Sol de la Mañana) geothermal field was completed in 2008. The main objective of this project is to build a 100 MW geothermal power plant through the installation of four generation units of 25 MWe (Aguilera 2013b).

6. ARGENTINA

6.1 Geothermal Resources and Exploration Activities

In Argentina high enthalpy geothermal resources are manly found in areas of active volcanism of the southern part of the Central and of the Southern Volcanic Zones of the Andes, which are separated by near horizontal subduction from 27°S to 32°S latitude. Low and medium-enthalpy resources are found in the central and eastern parts of the country.

According to Pesce (2010), the best known high-temperature geothermal areas in Argentina are Copahue, Domuyo and Tuzgle (Fig. 7).

At Copahue geothermal exploration studies together with data from three wells of about 1,200 m depth, indicate a 230-240°C vapor-dominated system. In 1968, a pilot 670 kW binary plant was installed, which currently is not operating (Bertani, 2010). The installation of a 30 MW power plant is being considered at this geothermal field.

At the Domuyo area geological, geochemical and geophysical explorations studies have been done; geothermometric data suggest a reservoir temperature between 178°C and 226°C. The most recent conceptual model suggest the presence of two geothermal reservoir; a shallow system at 700 to 800 m depth, and a deeper, hotter reservoir at 2-3 km depth (Pesce, 2013).

At the Tuzgle geothermal area geothermal exploration was undertaken in the 1980's and 1990's including volcanology, geochemistry, geophysics and gradient drilling; geothermometric data suggest a temperature between 133°C and 142°C. Currently, a private company has six geothermal concessions in the area. The same company has also six concessions in San Juan Province, near the border with Chile (http: //geotermiandina.com.ar).

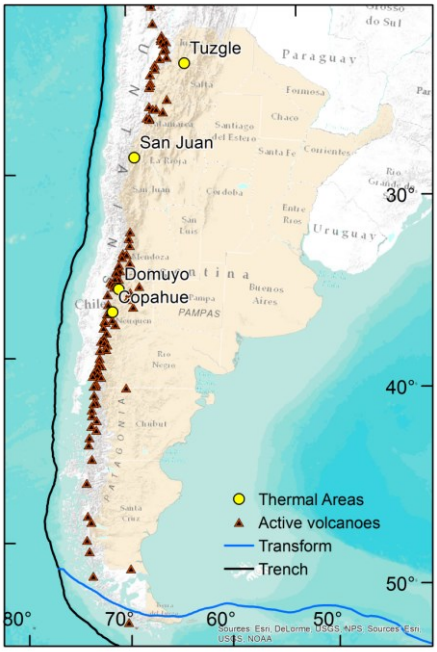

Figure 6: Geothermal areas of Argentina.

7. CHILE

7.1 Geothermal Resources and Exploration Activities

The high-temperature spring areas in Chile are located along the Andean Cordillera, associated with the Quaternary volcanic zones. The Northern Zone extends from 17° 30' to 28°S and the Central-Southern Zone from 33°S to 46°S. In areas where active volcanism is absent (i.e., between 28°S and 33°S latitude and between 46°S and 48°S latitude) and in the Coastal Range, thermal springs are scarce and their temperatures are usually lower than 30°C (Lahsen, 1976, 1988; Hauser, 1997).

During the last five years geothermal exploration in Chile has been very active due to the need for energy security. Chile has had to depend on imports to meet more than 75% of its energy requirements. At present, detailed exploration studies are being carried out by 14 private companies in 76 geothermal concession areas. The Northern Chile Geothermal Zone has about 90 hot-spring areas (Hauser, 1997) and 45 exploration concessions are being surveyed; the most advanced exploration programs have been conducted in the Colpitas, Apacheta, Pampa Lirima and El Tatio-La Torta geothermal prospects (e.g. Urzúa et al., 2002; Aguirre et al., 2011; Sofia and Clavero, 2010). Exploratory wells have been drilled in all of these areas, and the estimated combined power potential of exploitable geothermal energy of these four prospects is between 400 and 1,000 MWe. Exploitation concessions have been granted for the Apacheta and El Tatio geothermal fields, and the environmental assessment for the installation of a 50 MWe power plant has been approved for the Apacheta field; the exploitation concession at El Tatio recently has been canceled due to the company failing to comply with project's environmental and safety requirements.

In the Central-Southern Zone there are about 200 hot-spring areas (Hauser, 1997), and 31 exploration concessions have been granted; the most advanced exploration studies have been completed at the Tinguiririca, Calabozos, Laguna del Maule, Chillán and Tolhuaca geothermal areas (e.g., Clavero et al., 2011; Sofia and Clavero, 2010; Melosh et al., 2010, 2012; Hickson et al., 2011). Exploratory wells have been drilled in these prospects and the estimated combined power potential for the five areas ranges from 650 to 950 MWe. Exploitation concessions were granted for the Laguna del Maule (Mariposa) and Tolhuaca (San Gregorio) projects, where production size wells have been drilled. An environmental impact assessment was submitted to the authorities for the approval of the installation of a 70 MWe power plant in the Tolhuaca geothermal area, where well Tol-4 has an output of 12 MW.

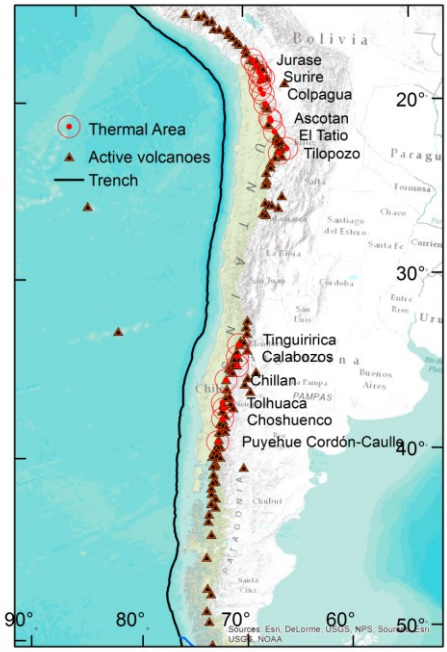

Figure 7: Geothermal areas of Chile.

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