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# GEOTHERMAL DEVELOPMENT IN ECUADOR: HISTORY, CURRENT STATUS AND FUTURE

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## ABSTRACT

Exploration of geothermal resources in Ecuador began in 1979. Three decades later, the high enthalpy geothermal projects of Chachimbiro, Chacana and Chalpatán have reached the advanced prefeasibility stage, while the Tufiño-Chiles-Cerro Negro and Chalupas projects are currently under research. The present exploitation of geothermal resources in Ecuador is restricted to bathing resorts, balneology and swimming pools. The total geothermal potential of the country is estimated at 3000 MWe. Nothing unusual, considering the fact that the country is traversed by more than 40 active volcanoes. The total installed capacity of geothermal energy for direct heat applications in 2009 was 5 MWt, with a slight increase over the last five years. Currently, a plan to carry out prefeasibility studies on twenty two undeveloped prospects is being discussed.

## 1. INTRODUCTION

Reconnaissance and exploration of geothermal resources in Ecuador is not relatively new. Nonetheless, the search for geothermal energy has found several obstacles that have inevitably delayed its exploitation. The dissolution of state entities that lead geothermal research activities along with the financial cutbacks and lack of specialists in geothermal engineering branches were some of the main drawbacks in the past. Consequently, they caused a slow development of research studies in the prospects with the most promising potential for electricity generation purposes. At the present, three prospects have reached a drilling point stage and at least one is expected to be operational within the next 5 years. Attention has also been put on developing mid and low temperature research projects for alternate uses such as fish hatchery, greenhouse heating, space heating and industrial applications. The following sections are intended to give a basic overview of historical geothermal activity and the state of geothermal development in the country.

## 2. BACKGROUND

### 2.1 Geothermal exploration in Ecuador 1979-2013

Reconnaissance studies for geothermal resources in Ecuador began in 1979. The "Geothermal Investigation Project" was the first of its kind carried out by the Latin American Energy Organization (OLADE), the Ecuadorian Institute of Electrification (INECEL), the Bureau de Recherches Geologiques et Mineres (BRGM) and the private company AQUATER. The objective was to select

areas suitable for geothermal exploration of high enthalpy resources for electricity generation purposes. The project was executed following the guidelines established by OLADE, to undertake a geothermal reconnaissance study (OLADE, 1978). The study comprised a two stage research. The first stage involved field surveys to study detailed geology, petrology and volcanology along the Ecuadorian Andes chain affected by a development of the Plio-Quaternary volcanic activity. This region is divided into 3 areas, shown in Figure 1: from the Columbian border to Cotopaxi, the area around the Chimborazo mount and the Cuenca-Azogues area.

Other geological areas of the country were not considered due to a lack of recent volcanic activity or constrained access. Preliminary reconnaissance activities which include air photos, field observation, laboratory analyses of rock samples, chemical elements in water and datings using different methodologies, were carried out. As a result, a geo-vulcanological report identified areas with the most favorable geothermal conditions in the country.

The second stage consisted of a hydrogeology analysis based on the reconstruction of the regional hydrogeological conditions along the country. Meteorological parameters were measured on site and cold/hot water sampling activities were performed where thermal manifestations were spotted. The final report pointed out the need to undertake a more detailed research (prefeasibility) to study permeability characteristics over the most promising geothermal prospects (Tufiño, Chachimbiro, Chalupas). A geochemistry campaign was recommended to determine the origin of the hot springs that were spotted.

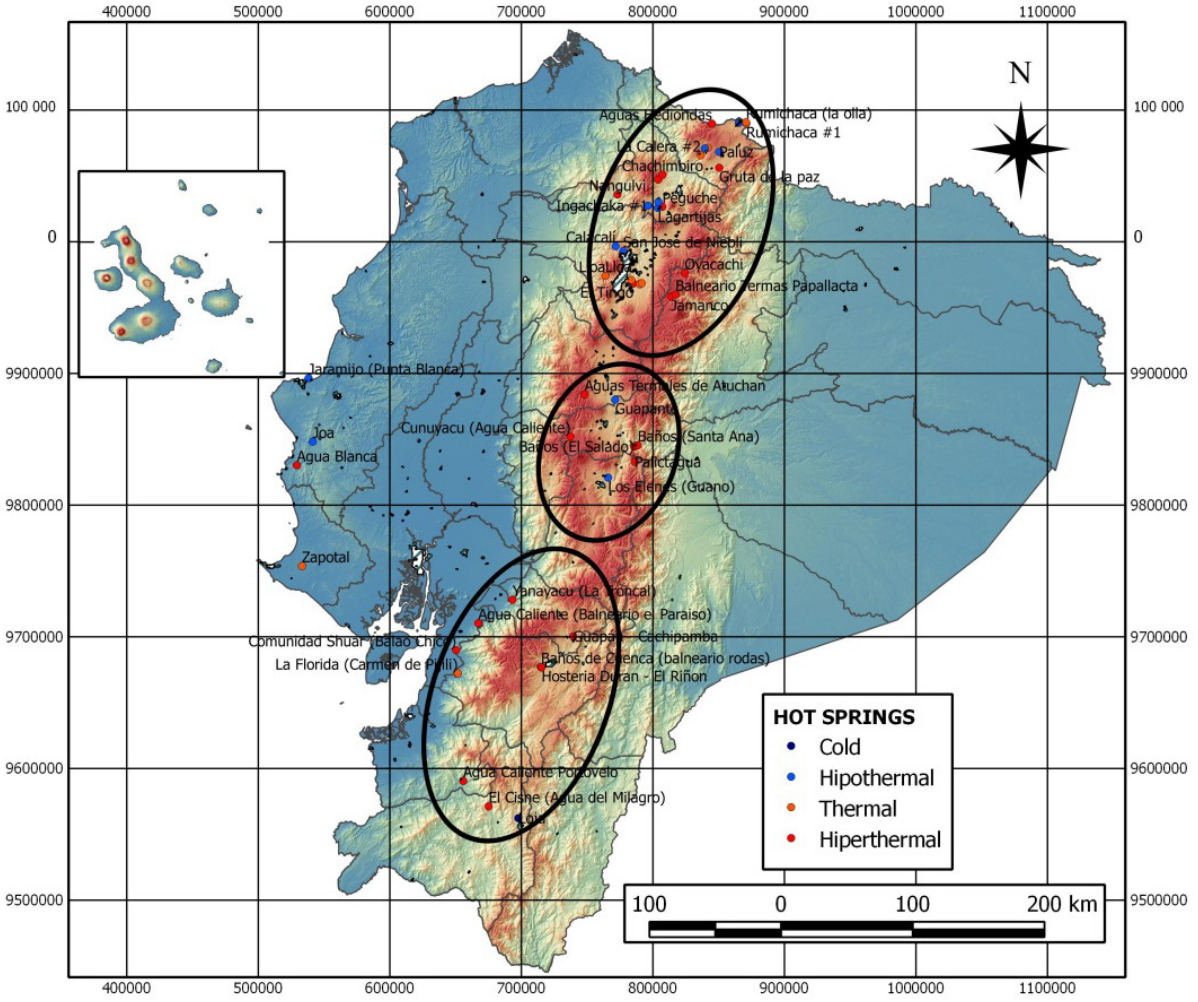


FIGURE 1: Areas analyzed in the reconnaissance study of 1979

## 2.2 Prefeasibility studies

In 1981, following the recommendations made in the reconnaissance study, a stage one prefeasibility study (geology, hydrogeology and geochemistry studies that end in a preliminary geothermal conceptual model before a geophysics campaign) was executed in Chachimbiro and Chalupas. For the Tufiño prospect, OLADE undertook a simultaneous campaign with INECEL and the Colombian Institute of Energy (ICEL) (OLADE, 1981). The purpose of this campaign was to further develop geothermal research activities in the area. As a result, Chiles-Cerro Negro (within the same area as the Tufiño prospect) was declared by the Colombian government an area of interest for geothermal development. This lead to a joint research agreement, signed between the two countries in 1982. Consequently, Ecuador and Colombia began the exploration phase as a bi-national project in a 250 $km^2$ area.

AQUATER and OLADE provided technical assistance to continue prefeasibility studies in the now renamed Tufiño-Chiles-Cerro Negro project from 1986 to 1987 (OLADE, 1987). Detailed geological, geochemical and geophysical activities were carried out. As a result, a preliminary high enthalpy resource model was developed. Followed suit, INECEL carried out 53 Vertical Electrical Resistivity Soundings (VES) in the area to identify hydrothermal activity, and to enhance surface data geology obtained in previous studies (Aguilera, 2010). Between 1983 and 1990, INECEL and the International Atomic Energy Agency (IAEA) also carried out geochemical studies in Chalupas and Chachimbiro to gather more information about their potential for generation purposes (INECEL, 1983).

Unfortunately, all scientific research related to geothermal reconnaissance and exploration ceased in 1993 due to political reasons and financial cutbacks. In 1996, the Economic Commission for Latin America and the Caribbean (CEPAL) and the European Union (EU) presented a project called "Development of Geothermal Resources in Latin America and the Caribbean". The project aimed to strengthen the institutional and legal capacity of government bodies to promote a sustainable exploitation of geothermal resources in Latin America. The project ended in 1998, resulting in more than one country being suitable for further studies. Nevertheless, Ecuador was surprisingly listed as first candidate due to its high resource potential, estimated at 534 MWe (Data provided by the Energy Economic Information System, OLADE). The government formally requested technical assistance from CEPAL to develop a strategy for future exploitation of geothermal resources in the country. This plan was finalized by a CEPAL consultant in 1999. Meanwhile, geochemical and isotopic studies were resumed in Chachimbiro and Tufiño, from 1999 to 2001 with the assistance of IAEA. The scope of this research also included other areas recommended in OLADE's reconnaissance study. The results of the geochemical and isotopic samples were discussed by Aguilera et al. (2005), in a scientific report published by Elsevier.

Geothermal exploration was interrupted again in 2002, when Ecuador went through an internal financial crisis. This had a collateral impact on scientific research funding, cutting the resources needed to conclude the studies currently underway. Five years later, in 2007, the need to diversify the country's energy matrix became a national policy. Consequently, attention was put again on geothermal energy due to its high capacity factor. In 2008, CONELEC hired a former INECEL researcher to deliver a project outline for the Chalupas prospect and an abridgment of all geothermal prospects from 1979 up to the present. The final report stated that Chalupas is currently at a prefeasibility stage, and further geophysics (mainly Magneto Telluric surveys) studies were required to estimate the resource's temperature (Beate, 2008). The study also displayed a list of twenty two areas of geothermal interest based on previous studies. One year later, the Ecuador Electric Corporation (CELEC EP) commissioned advanced reconnaissance studies for the Chacana prospect. Aguilera ( 2010) indicated an estimated potential of 1480 $MW_e$ divided into three areas within the caldera: Cachiyacu, Jamanco and Oyacachi. Later in the same year, the Ministry of Electricity and Renewable Energy (MEER) restarted exploration at the Tufiño-Chiles-Cerro Negro project. The first geothermal exploration slim hole in Ecuador was completed in May 2009, reaching a depth of 554 meters. Research activities continued with funding provided by the National Secretariat for Science

and Technology (SENACYT). In 2010, MEER requested a "Plan for the Development of Geothermal Resources", which was entrusted to the same experienced consultant that delivered the prefeasibility studies for the Chalupas prospect. This document had an emphasis on electricity generation purposes, and consequently, ended up ranking geothermal prospects in the country based on its highest potential, taken from previous prefeasibility studies. In 2012, the National Institute for Pre-investment Studies (INP) commissioned the study of the Chalpatán prospect to a private consulting firm (CGS) and CELEC. Prefeasibility studies concluded in 2013, with temperatures estimated to be below 120°C (CGS, 2013). Consequently, the project turned out to be insufficient in terms of electricity generation purposes. However, the location close to the city of Tulcán gives the possibility for direct use of this geothermal resource for industrial and agricultural purposes. Further studies involve drilling exploration wells to prove the resource's potential.

## 3. CURRENT STATUS OF GEOTHERMAL PROSPECTS IN ECUADOR

The current status of the geothermal prospects is presented in this section, providing a general overview of the most promising prospects and also addressing the prospects in which further development for direct use can be achieved.

### 3.1 Tufiño-Chiles-Cerro Negro

Many prefeasibility studies have been carried out in specific areas of the Tufiño-Chiles-Cerro Negro prospect, shown in Figure 2. Nevertheless, the prospect has not yet been studied integrally. Therefore, additional geological and geochemical studies are required to enhance the conceptual models of the prospect. Complementary magneto-tellurics (MT) and time-domain electromagnetics (TDEM) surveys will also provide a better understanding of the resistivity anomaly in the main area of the prospect. Re-analysis of geological, geochemical and geophysical surface exploration data was endorsed to a private consulting group which is currently executing field activities.

If these complementary studies are positive and a high temperature resource is proven, feasibility studies must be undertaken to prove the resource's production capacity. Beate (2010) states in his

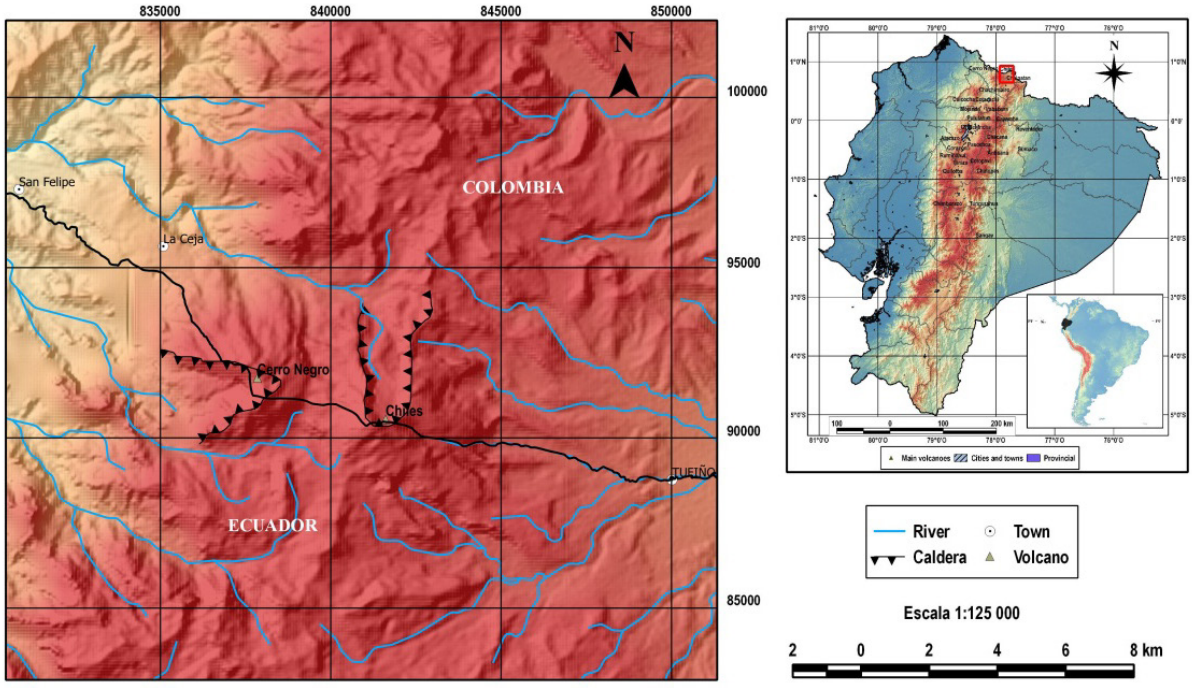


FIGURE 2: Location of the Tufiño-Chiles-Cerro Negro prospect

review an estimate of 138 MWe for the Tufiño prospect, based on surface data geology presented by Almeida (1990).

### 3.2 Chachimbiro

Preliminary feasibility studies in the Chachimbiro prospect (Figure 3) concluded in 2012. The assessment of risk factors, which include the reservoir temperature, permeability and fluid chemistry, indicate a probability of success of 65%. Drilling of shallow exploration wells will allow the quantification and evaluation of the geothermal reservoir. A low cost 1500 m depth slim hole is recommended to determine the sustainability of the resource for long term production. If the results from exploration wells are positive, advanced feasibility studies must be oriented to determine the suitability of the project for electricity generation purposes or for direct use. The project is currently undergoing environmental impact assessment. The Japan International Cooperation Agency (JICA) has showed interest in financing the feasibility stage. The geothermal potential of Chachimbiro is estimated to be 81 MWe.

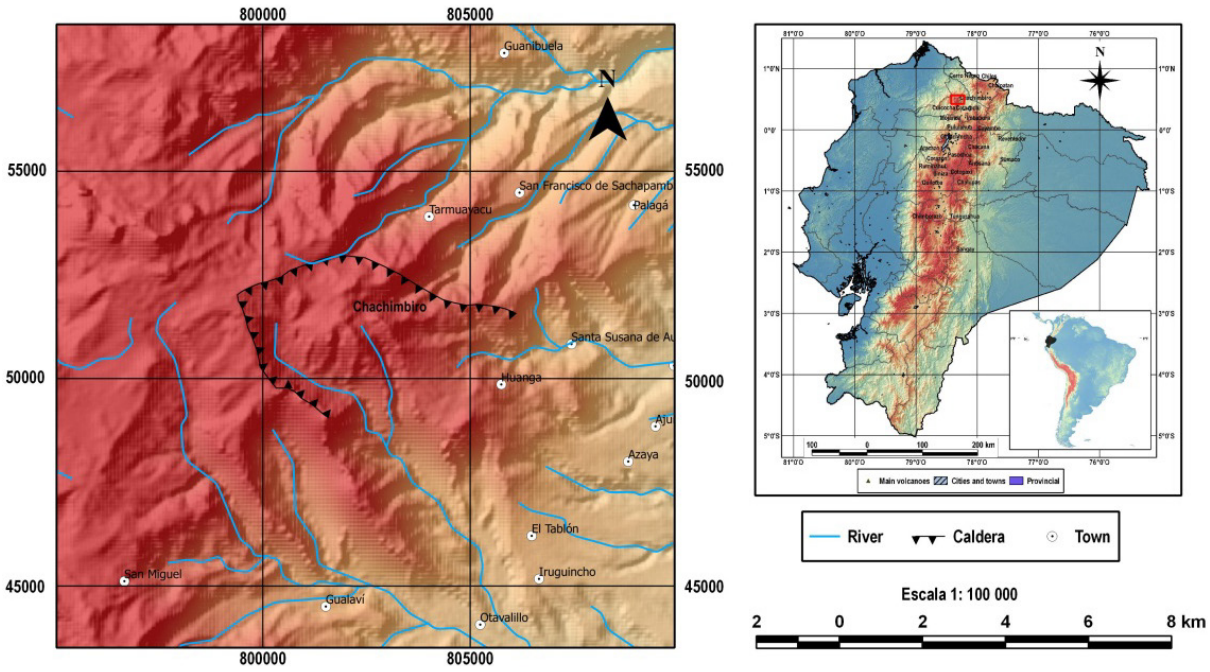


FIGURE 3: Location of the Chachimbiro prospect

### 3.3 Chacana

Chacana has a good potential for hosting a geothermal reservoir at a shallow depth due to the geological conditions and rhyolite volcanic properties, which are persistent in time. Previous geological, geochemical and geophysical studies resulted in three preliminary conceptual models (Villares, 2010). CELEC EP commissioned prefeasibility studies in the Chacana prospect (Figure 4) in 2011. The next stage consists of drilling two exploratory slim holes to depths of 600 m and 900 m. The purpose of these exploration wells is to intersect the main faults inside the caldera and to reach the reservoirs in Cachiyacu and Jamanco. Once the drilling stage is completed, reservoir temperatures and permeability can be properly verified. The project is currently undergoing environmental impact assessment. The potential expected in Jamanco is 13 MWe and of Cachiyacu is 39 MWe.

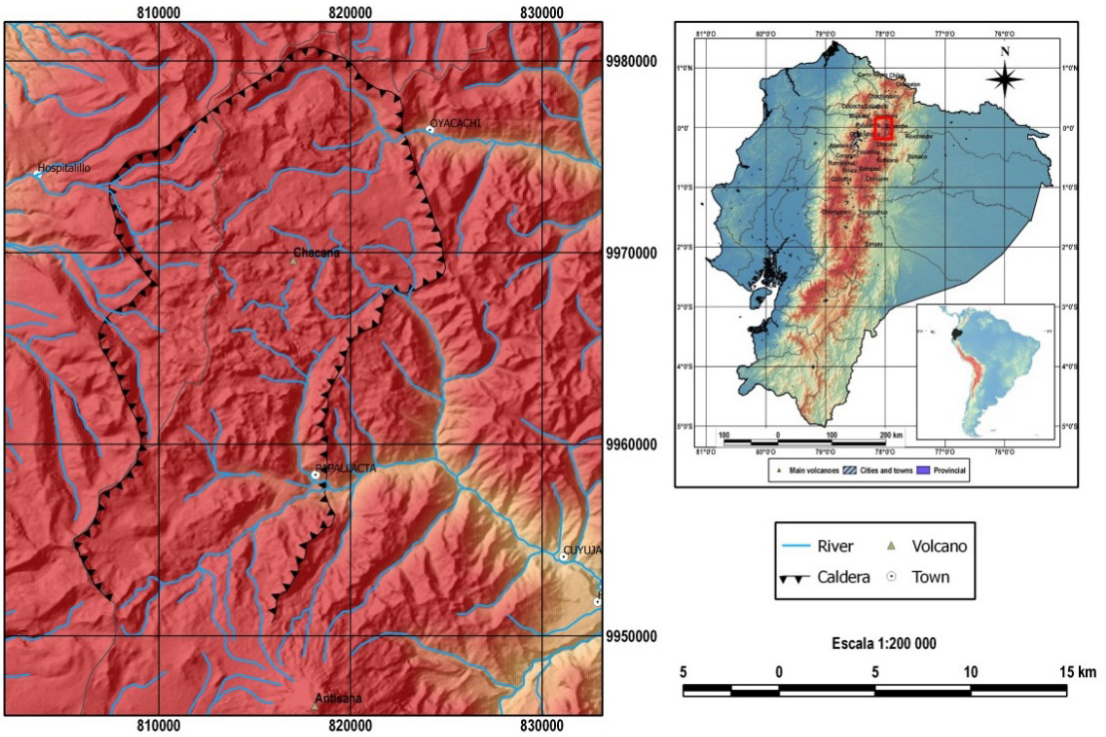


FIGURE 4: Location of the Chacana prospect

### 3.4 Chalpatán

Due to its proximity to Tufiño–Chiles-Cerro Negro, the Chalpatán caldera (Figure 5) was also studied by OLADE, INECEL and ICEL from 1982 to 1987. Prefeasibility studies were completed in 2013. These studies included the use of state of the art technologies, such as satellite and airborne infrared

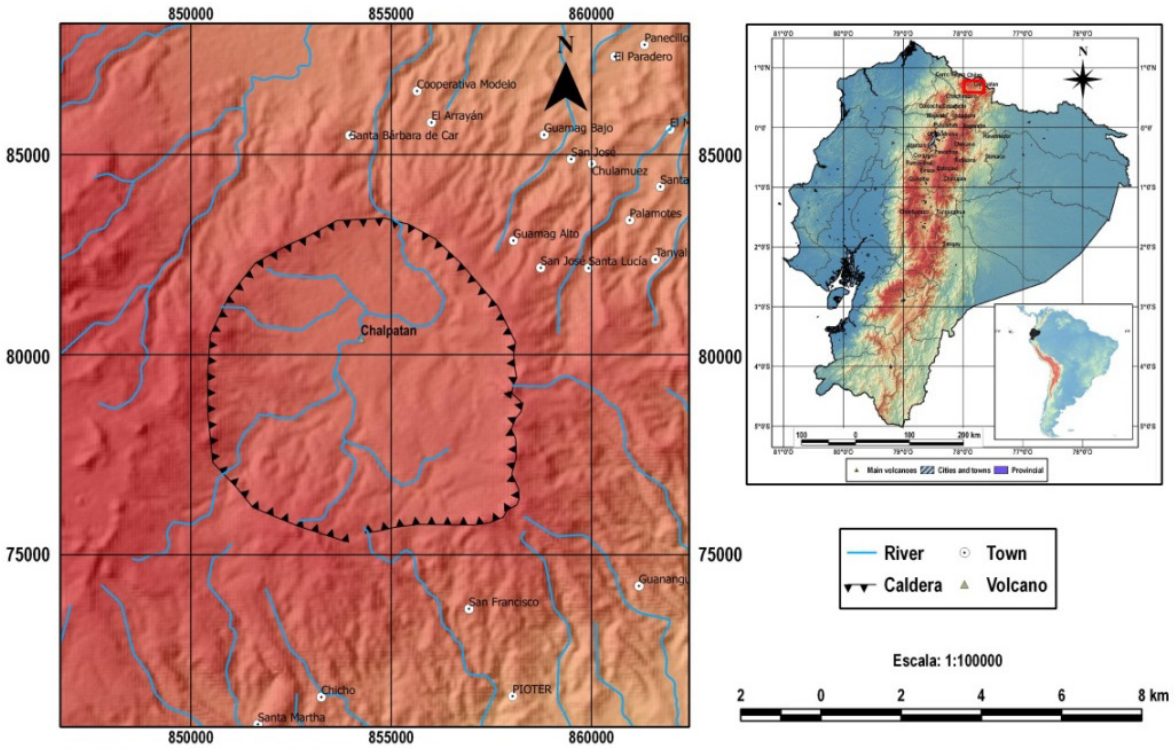


FIGURE 5: Location of Chalpatán prospect

thermal imagery, Audio Magneto Tellurics, and Magnetometry. Preliminary results indicate temperatures below 120°C and an estimated liquid reservoir of 1'850.000 $m^3$, suitable for industrial, agricultural and direct heat use. The National Institute for Energy Efficiency and Renewable Energy (INER) has showed interest in developing a low enthalpy research project in the area, once the exploratory wells are drilled. The Chalpatán caldera is located 20 km south-west of Tulcán city, with an extension of approximately 130 $km^2$. Only the caldera has been studied, leaving the El Angel ecological reserve outside the area of interest.

### 3.5 Chalupas

Although prefeasibility studies were carried out in Chalupas (Figure 6), additional research activities are required to complete the geothermal conceptual model presented by INECEL in 1983. Detailed geology, geochemistry and geophysics measurements must be performed using enhanced methodologies. Future work involves carrying out a Schlumberger resistivity survey with traversing (mapping) measurements at 500 m spacing (Beate and Salgado, 2010). The project has been temporarily delayed by CELEC EP, and will be resumed once the feasibility studies are finalized in Chachimbiro. Almeida (1990) determined an estimated potential of 283 $MW_e$, based on surface data geology.

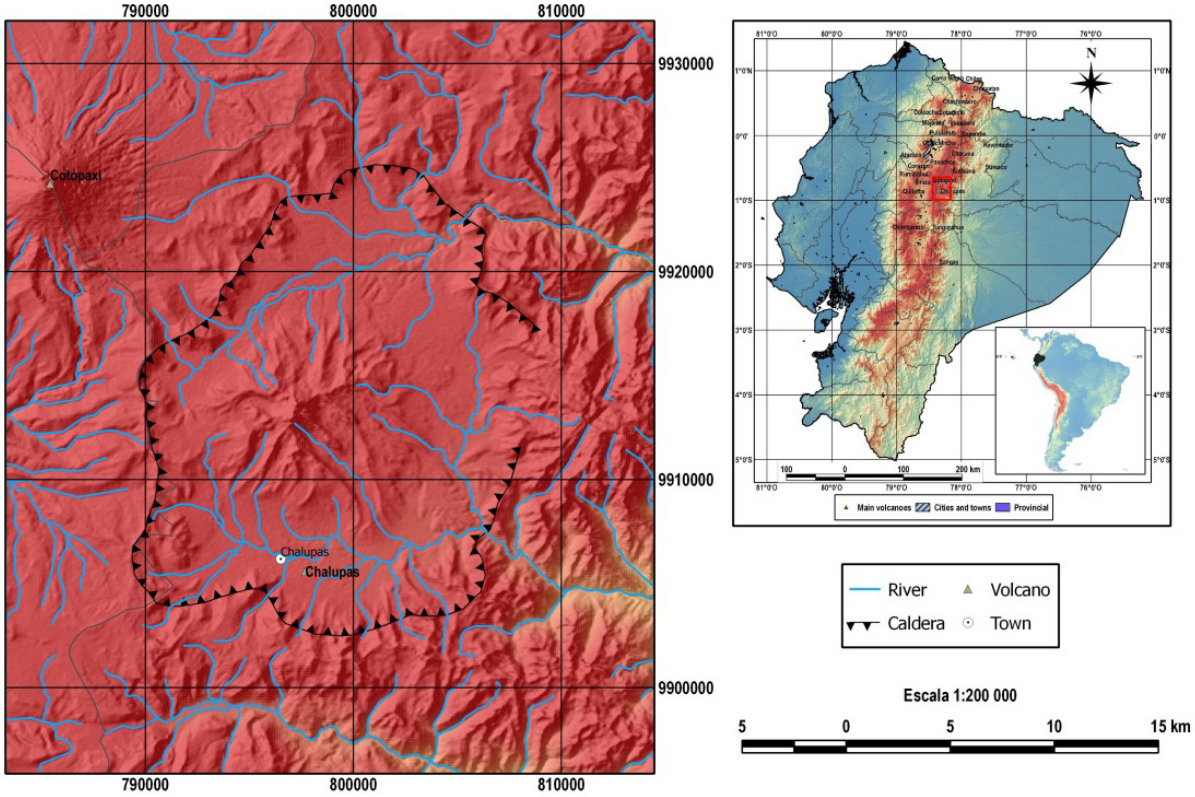


FIGURE 6: Location of the Chalupas prospect

## 4. UNDEVELOPED PROSPECTS

A study of the geochemical and isotopic characterization of volcanic and geothermal fluids discharged from the Ecuadorian volcanic arc was carried out by Inguaggiato et al. (2010). The authors identified sensible sites to start a systematic geochemical monitoring activity and complementary research for geothermal energy exploration. Beate (2010) also listed twenty one locations in Ecuador worthwhile for geothermal reconnaissance and exploration. Only five of these locations have been studied

(Tufiño-Chiles-Cerro Negro, Chachimbiro, Chacana, Chalpatán, and Chalupas), mostly due to their potential for electricity generation purposes. The following prospects highlighted in Figure 7 remain undeveloped with limited information available: Chimborazo, Baños de Cuenca, Guapán, Alcedo, Guagua Pichincha, Pululahua, Cayambe, Cuicocha, Tungurahua, Ilaló, Salinas de Bolivar, San Vicente, Portovelo, Iguán, Mojanda, and Soche.

A detailed geothermal reconnaissance study must be carried out in the sites that were pointed out by Beate and Inguaggiato (Inguaggiato et al., 2010). It is recommended that the guidelines established by OLADE are followed to assure a compatibility with the methodology used in previous studies. Activities include the assessment of existing data, followed by survey campaigns (detailed geology, hydrogeology, and geochemistry analyses).

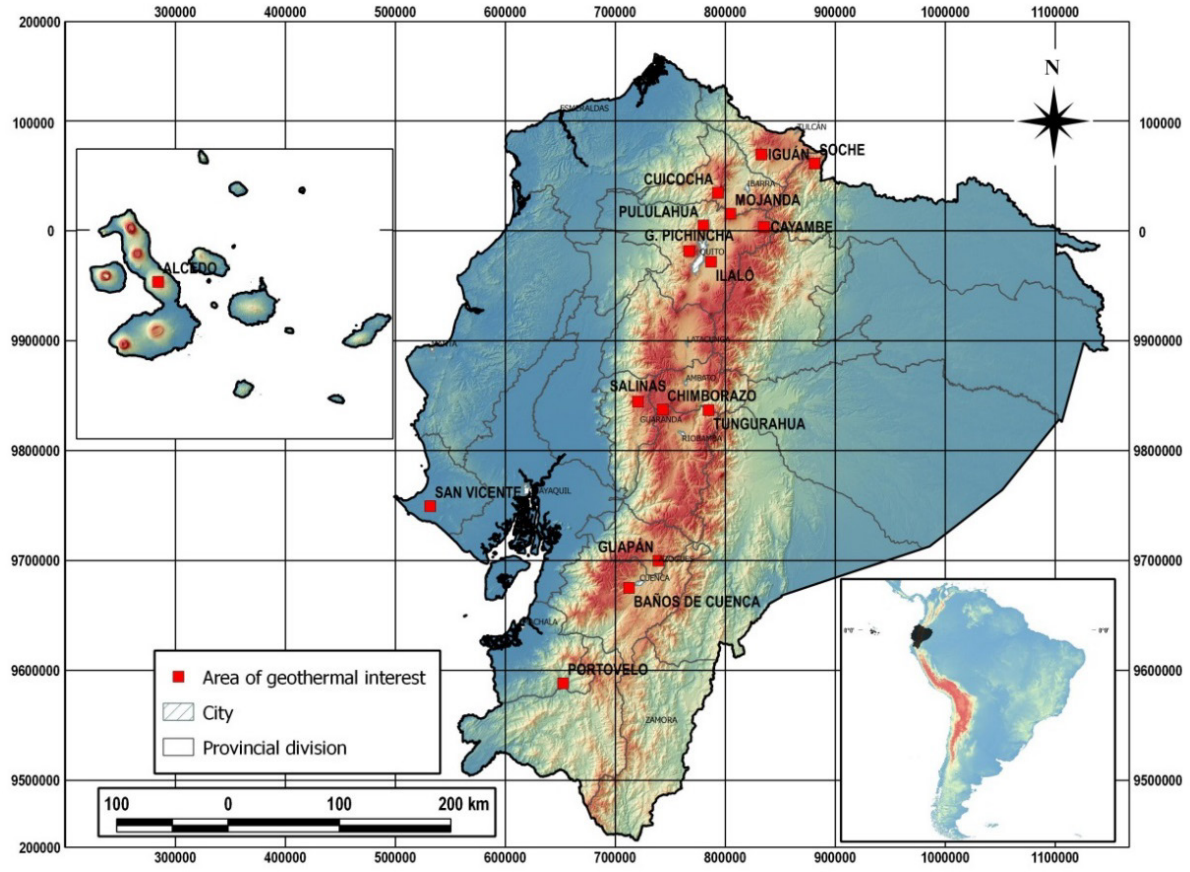


FIGURE 7: Locations of undeveloped prospects

## 5. OTHER GEOTHERMAL RELATED ACTIVITIES

### 5.1 Geothermal bilateral technical cooperation

Based on the expertise and experience that Iceland has in geothermal energy exploration and exploitation, the government of Ecuador, through the Ministry of Electricity and Renewable Energy, signed a Memorandum of Understanding with the Ministry of Industry and Tourism from Iceland in 2009. This agreement has the purpose of establishing the institutional relationship which will promote bilateral technical cooperation in matters of geothermal development between Ecuador and Iceland. In 2013, INER was officially designated by the Ministry of Electricity and Renewable Energy to execute the MoU.

### 5.2 Regulatory framework

The International Renewable Energy Agency (IRENA) and the OLADE have launched an initiative to improve access to geothermal energy in the Andean Region. This initiative, supported with expertise from Iceland, Mexico, New Zealand, France and the International Geothermal Organization (IGA) aims to contribute to the development of the vast geothermal potential in this region. Five countries are participating in this initiative: Bolivia, Chile, Colombia, Ecuador and Peru.

As a result of the workshop held in Iceland on March 4th-5th, 2013 and supported by country status reports, a potential area for further action has been identified as legal and regulatory frameworks for geothermal sector. On November 21st-22nd, a multistakeholder workshop organized by IRENA and OLADE entitled "Promoting the Enabling Environment for Geothermal Development in the Andean Countries – Legal and Regulatory Frameworks" was held in Lima, Peru. The event was designed to share the experiences of the countries that have had a long standing history in the geothermal sector with the Andean countries. The event brought together stakeholders from the governments, private sector and supporting institutions. In addition, links to possible synergies and areas of further support/collaboration derived during the workshop.

An Ecuadorian delegation integrated by members of the government's energy sector attended the workshop where the following commitments were agreed upon:

- Technical assistance from the Inter-American Development Bank (IDB) to develop a regulatory framework based on existing regulations;
- Legal assessment provided by the National Energy Authority of Iceland in the development of new policies and regulations for a geothermal law in Ecuador; and
- Assistance from IRENA to connect financial resources from bilateral and multilateral organizations to support the development of geothermal regulatory framework.

## 6. FUTURE DEVELOPMENTS

Currently, utilization of geothermal resources in Ecuador is restricted to bathing resorts, balneology and swimming pools. The total installed capacity of geothermal energy for direct heat applications in 2009 was 5 MWt (Beate & Salgado, 2005), with a slight increase over the last five years. Therapeutic benefits provided by medicinal mineral hot springs have been exploited in most resorts and spas all over Ecuador. However, significant alternate uses remain unknown by Ecuadorian society. Currently, a portfolio of projects for direct use in fish hatchery, greenhouse heating, space heating, and industrial applications is being researched by universities and public research institutions. One of the ongoing projects of INER focuses on development of new research lines for future implementation of low enthalpy geothermal projects. Research involves mainly the direct use of geothermal resources for diverse applications, such as greenhouses, space heating and cooling, industrial processes and tourism related activities. INER has started advanced studies in Baños de Cuenca, based on the highest temperature records and previous studies undertaken in this area by De Grys et all (1970) and Burbano et all (2013), in order to determine the origin of the geothermal system. Another of INER's research projects is undergoing in the city of Guayaquil, in collaboration with ESPOL University. The main objective of this project is to determine the soil thermal properties to be used as a heat sink to replace cooling towers and conventional air conditioning systems in commercial buildings with ground source heat pumps.

## 7. FINAL REMARKS

Geothermal resources represent an opportunity to meet energy needs with a clean, sustainable form of energy in South America. Not surprisingly, Ecuador is located in a privileged location along the

Andean Mountain Range and is traversed by more than 40 active volcanoes. The Geothermal Energy Association (Gawell et al., 1999) estimated the country's geothermal potential at 1700 MWe in 1999. However, it seems that the geothermal potential is much higher. Thus, Stefansson (2005) proposed an empirical relationship between the number of active volcanoes in a determined area and the geothermoelectric potential. Based on this relationship, if only 20 active volcanoes are considered within the Ecuadorian volcanic arc, the estimated potential could reach 3000 MWe (Beate, 2010), considering a 3 km depth. If rhyolitic calderas such as Chalupas and Chacana and their equivalent in andesitic magma are also considered, between 30 and 40 volcanoes could increase the overall theoretical potential up to 8000 MWe (Beate, 2010). This exceeds the current installed capacity of Ecuadorian interconnected system, equal to 4700 MWe (CONELEC, 2013).

INER has an active participation in the development of scientific research which contributes to the National Plan for Good Living (SENPLADES, 2013). One of the goals of the strategy is that renewable energies reach 6% share of total energy generation. The development of consolidated national geothermal map with participation of all state research institutes is currently being analyzed.

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