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Geothermal Country Update for Ecuador: 2010 - 2015

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ABSTRACT

Utilization of geothermal energy in Ecuador is still restricted to direct use in swimming pools (5.16 MWt and 102.4 TJ/yr for annual utilization), nevertheless, government policies aim to develop renewable energy resources including hydro, wind, solar, biomass and geothermal. Profound changes in both energy and production matrixes are underway to be completed in the next three years, mostly based on substantial increases of hydropower generation to lessen or even eliminate the use of fossil fuels. The current energy mix is dominated by hydro (50%) and fossil fuels (47%) and other (3%), with a total installed generation capacity of 4,797.94 MWe. This results in a gross electricity production of 21,638.00 GWh/yr (as of 2012) where 12,536.00 GWh are from renewable sources and 10,310.92 GWh from fossil fuels; the remainder of 238 GWh corresponds to imported energy from Colombia and Peru. The 2011/2012 increase in gross energy production was 11.21%. Electricity production from renewable energy sources other than hydro increased in the last years to about 129.90 MWe.

In this period 2010 – 2015, the geothermal situation in Ecuador has improved substantially compared with the previous decades, although no deep drilling has taken place yet. The geothermal plan launched by MEER in 2010 for electricity generation, based on available surface data, ranked 11 prospects for prefeasibility stage studies: Chachimbiro, Chalpatán, Chacana-Jamanco, Chalupas, Guapán, Chacana-Cachiyacu, Tufiño, Chimborazo, Chacana-Oyacachi, Baños de Cuenca and Alcedo. CELEC EP completed, in 2012, geological, geochemical, and geophysical surveys at pre-drilling stage, including comprehensive MT and TDEM measurements for the Chachimbiro, Chacana-Cachiyacu and Chacana.-Jamanco prospects. Data was integrated into multi-hypothesis conceptual models including risk assessment, likely generating capacity (based on power-density method, Grant, 2000), and location of deep exploration drill sites. A total compound mean of 133 MWe for the most optimistic alternative of these three prospects was established, although exploration risk remains high. Proposed deep exploration slim holes are planned to be drilled in 2014-2015 under CELEC EP, mainly to test temperature, in order to lessen the risk and proceed into appraisal drilling if results are positive. Chalpatán prospect completed prefeasibility surface surveys in 2013 and results indicate potential direct uses of the resource instead of electricity generation. A 1.85 km^3 fault-controlled hot water reservoir (70-120ºC) at 1,500 meters depth is likely to exist inside of the Chalpatán caldera. The Tufiño-Chiles geothermal prospect is a Bi-National Project located on the Ecuador-Colombia border and is subject to final prefeasibility scrutiny with complementary surface studies, mainly rock age dating, gas geochemistry and a comprehensive MT survey, to produce a geothermal model to target locations for deep exploration holes and to drill a first deep exploration hole to test the resource model and temperature. A follow-up geochemical survey, funded by INER, is underway at Baños de Cuenca to evaluate the origin of fluids and possibly deep temperatures and potential direct uses. The remaining prospects listed above wait on MEER funding to complete prefeasibility stage studies. Low- to medium- temperature resources are abundant along the volcanic arc, but are not confined to the volcanic highlands, since they are present also in the fore arc plains as well as in back-arc areas, mostly related to deep cutting basement faults. Finally, in Ecuador, geothermal energy is challenged to be cost-efficient in light of an abundant hydro resource, as well as to be environmentally safe.

1. INTRODUCTION

This paper is a follow up of the country update for the previous interval (Beate & Salgado, 2010). It summarizes geothermal activities in Ecuador for the period 2010-2015, nevertheless the history of exploration before 2010 and the description of underexplored areas or prospects hasn’t been included, since no changes have occurred; in this case, the reader is referred to the previous country update. Ecuador is a democratic republic, located on the equatorial edge of western South America; it has 14,483,499 inhabitants living in a territory of 256,370 km^2 (INEC, 2010); the official language is Spanish and the GNP was 66,879 MUSD for the year 2013 (Banco Central del Ecuador, 2014). Since the approval of the new Constitution in 2008, the government has steered towards a stronger participation of the state in exploration and development of the country’s energy and mineral resources. It is the aim of the government to change the energy matrix towards the substitution of the fossil fuels for power generation with indigenous, clean, renewable energy resources, mainly hydro, but also including wind, solar, geothermal and biomass.

The leading agencies for geothermal energy are MICSE (Ministry for the Coordination of Strategic Resources), MEER (Ministry of Electricity and Renewable Energy), CONELEC (National Council for Electricity – Regulatory issues); CELEC EP (Public Corporation for Electricity Generation) and INER (National Institute for Energy Efficiency and Renewable Energy), CNRH (National Council for Water Resources) and MAE (Ministry of the Environment). Public funding has been allocated already through MEER for geothermal exploration of both high and low temperature resources. In accordance to the Constitution (2008), which dictates that no energy concessions can be granted, joint ventures are favored in government to government agreements where the State of Ecuador owns at least 51 % interest.

The following pages include an overview of Ecuador's geological setting, a description of the best known geothermal resources and potential, together with the state of geothermal utilization and a discussion of the actual and future development.

2. OVERVIEW OF ECUADOR'S GEOLOGICAL SETTING

Geographically and geomorphologically, mainland Ecuador consists of three regions: the coastal plains or Costa, the Andes mountain chain or Sierra and the Amazon basin or Oriente. A fourth region comprises the Galapagos Islands, located about 1,000 km to the west of mainland Ecuador, in the Pacific Ocean (Figure 1).

The Andes are the backbone of the country. They were formed by multiple accretion since Jurassic times (Aspden and Litherland, 1992; Egüez and Aspden, 1993; Litherland et al., 1993), and consists of two parallel NNE striking mountain chains: a) the Cordillera Real (CR or Eastern Cordillera), which are sub-linear belts of metamorphic rocks intruded by both, S and I-type granitoids of early Mesozoic age; b) the Cordillera Occidental (CO or Western Cordillera) consists of late Mesozoic to Early-Cenozoic basalts and volcaniclastics, which represent accreted oceanic terrains (Hughes and Pilatasig, 2002), these rocks are intruded by I-type Tertiary granitoids. Both cordilleras have been uplifted and are capped by late Tertiary to Quaternary volcanics. Between the two Cordilleras, the Interandean Valley (IAV) is located, which is laterally bonded by active faults, mostly thrust faults. It comprises thick Late-Tertiary to Recent volcaniclastic and epiclastic sedimentary sequences. Covering both Cordilleras in its northern half, a well developed, broad, calk-alkaline volcanic arc extends northwards into Colombia (Barberi et al., 1988; Hall & Beate, 1991). This continental arc is of Quaternary age and consists of more than 50 volcanoes, of which at least 20 have been active during the Holocene (Hall, et al., 2008) and three are currently in eruption. It also implies the presence of a thick crust and evolution of magmas at the lower crust (Chiaradia, et al., 2009). The southern part of the Andes shows only extinct volcanic activity due to the flattening of the slab since late Miocene (Gutscher et al., 2000).

The Oriente is an extensive sedimentary basin, which overlies cratonic basement (Baldock, 1982). Older rocks include Jurassic batholiths and a Cretaceous carbonate platform, covered by Tertiary epiclastic sediments. Large thrust folds cut the sequence with a NS strike along the cordilleran foothills. Quaternary alkaline volcanoes are present along the central west margin of the basin in a back-arc setting.

The Costa is the flat region west of the Andes; it comprises a late-Cretaceous to Cenozoic fore-arc basin underlain by early Mesozoic oceanic crust. No active volcanism is present in this region. The Galápagos Islands represent, together with the submarine Carnegie Ridge, the Galapagos hot spot trace above the Nazca Plate. The islands consist of about fifteen basaltic shield volcanoes, increasing in age towards the East, hence most of the actual volcanic activity occurs on the westernmost islands of Fernandina, Isabela and Roca Redonda.

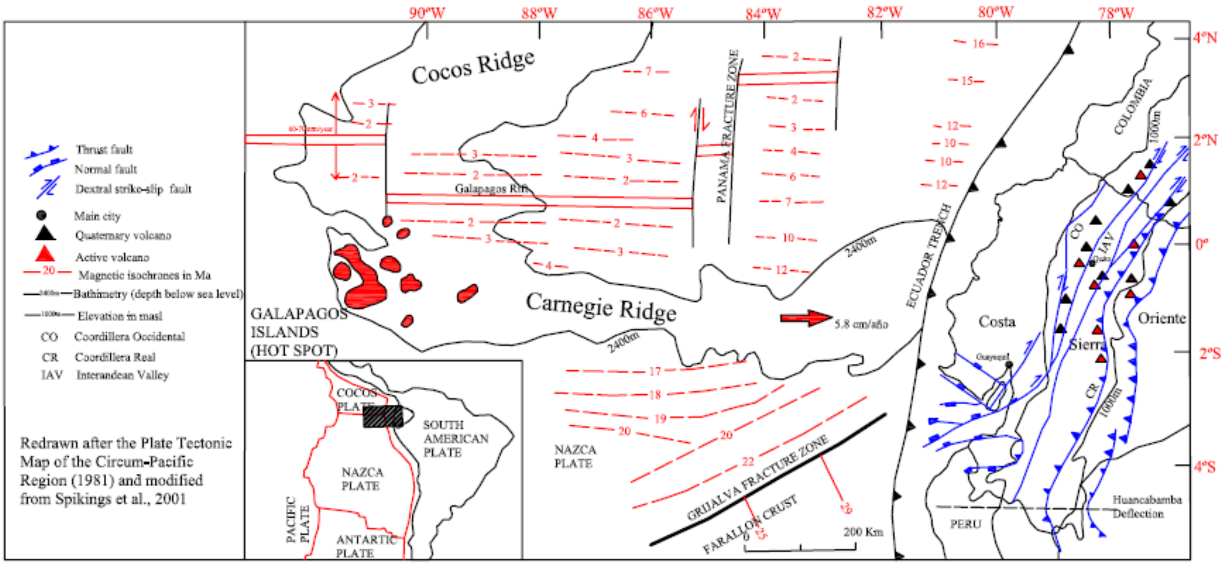

Figure 1. Geodynamic Setting of Ecuador, showing mainland Ecuador on South American plate and the Galapagos Islands on Nazca plate.

Geodynamic processes are controlled since Late Oligocene by the nearly orthogonal convergence between Nazca and Southamerican plates, which has generated regional uplift and crustal faulting and deformation as well as extensive volcanism (Lonsdale, 1978). The northern half of the country is part of the North Andean Block, which moves at 6-10 mm/yr in a NE direction along strike-slip faults entering the gulf of Guayaquil (Ego et al. 1993). This compressive regime formed several intramontane basins of pull-apart nature between the two cordilleras since Miocene. The IAV has been formed as a spindle shaped basin by displacement along a restraining bend in a transpressive regime since about 6 Ma due to an increase in the coupling of Carnegie ridge in the subduction zone (Spikings, 2001; Winkler, 2002; Villagomez, 2002). This setting, together with the extensive Quaternary volcanism, favors the presence of high heat-flow anomalies along the Ecuadorean Andes as well as in both the Galápagos hotspot and the nearby Galápagos spreading center; hence, the availability of heat sources for geothermal systems to exist are plenty in Ecuador.

3. GEOTHERMAL RESOURCES AND POTENTIAL

In 2008, the Ecuadorian government through MEER, re-starts geothermal exploration, aiming to develop the former INECEL (Instituto Ecuatoriano de Electrification) geothermal prospects for power generation. MEER (2010) launched the Geothermal Plan for electricity generation, which described and priorized – based on Bloomquist (1995) - 11 geothermal prospects countrywide. These prospect where: Chachimbiro, Chalpatán, Chacana-Jamanco, Chalupas, Guapán, Chacana-Cachiyacu, Tufiño, Chimborazo, Chacana-Oyacachi, Baños de Cuenca and Alcedo. The Plan included also technical files for each prospect, preliminary TORs on Prefeasibility Studies for the first five prospects and general aspects to be taken into account for a geothermal law. In 2010, MEER delegated to CELEC EP (the public company responsible for the generation and transmission of electricity), the research and development of Geothermal Projects in Ecuador.

During this period 2010 – 2015, the following actions did take place: Prefeasibility studies up to pre-drilling stage were bidded and contracted by CELEC EP for prospects Chachimbiro, Chacana-Jamanco and Chacana-Cachiyacu; the bids were won by the Ecuadorean company Servicios y Remediación S.A. (SYR) in early 2011 and final reports were handed in January 2012 for Chachimbiro and May 2012 for both the Chacana-Cachiyacu and Chacana-Jamanco prospects. A fourth geothermal prospect, Chalpatán, was given by INP (Instituto Nacional de Preinversión), under an agreement with CELEC EP and MEER to CGS, a Spanish consulting company, the final report of which was handed in April 2013. By the end of 2013, SYR won the bid to do complementary exploration work in the Bi-National Tufiño – Chiles Geothermal Project to establish a geothermal model and, eventually, drill the first deep exploration hole to culminate the prefeasibility stage of the project.

3.1 Description and Assessment of Geothermal Prospects

This assessment is a description of “what”, “where” (Figure 2) and the “characteristics of” the geothermal prospects regarding its resource and potential. It follows the Geothermal Plan (MEER, 2010) in respect to electrical uses, but is for overall interest as referred to direct uses. Of special interest are the results of state funded Geothermal Prefeasibility Studies carried out between 2011 and 2013 on the prospects Chachimbiro, Chacana-Jamanco, Chacana-Cachiyacu and Chalpatán, which put all four of them in the pre-drilling stage, including comprehensive geological, geochemical and geophysical surveys, conceptual models, risk assessment and location of first deep exploration drilling sites.

3.1.1 Chachimbiro geothermal prospect

This prospect is located on the east slopes of the CO, at about 20 km west of the city of Ibarra in the province of Imbabura. It is accessed by gravel and dirt roads. Climate is temperate and vegetation changes from forested to grassy on a rather rugged topography, varying from 2,800 to 4,000 masl. The area straddles the Cotacachi – Cayapas Ecological Reserve and land is used for agriculture at lower elevations. Nearest major load center is Ibarra. A high voltage transmission line, 20 km from the area, connects Colombia to the Ecuadorean grid. A potential of 113 MWe has been estimated by Almeida (1990) from interpretation of surface data using volumetric heat-in-place method (Muffler and Cataldi, 1978).

A comprehensive surface exploration work and resource evaluation of the Chachimbiro Geothermal Prospect was carried out by SYR- Quito from April to November 2011, on behalf of CELEC EP; the following paragraphs condense the results of the technical report (CELEC EP / SYR, 2012-a). The prospect is based on several mixed chloride-bicarbonate hot and warm springs (up to 61 ºC), located on the E and SE slopes of the Quaternary andesitic-dacitic Chachimbiro volcanic complex. It overlies a thin layer of late Tertiary volcanics and a folded and faulted late Cretaceous volcanic and sedimentary basement of accreted oceanic affinity. The Quaternary volcanic history indicates a long-lived and evolving magmatic heat source centered in dacitic Tumbatú (125 ka) and Hugá (ca. 40 ka) domes; this activity dates back 500 000 years with andesitic lava flows of Huanguillaro stratovolcano. The youngest activity is represented by the 5800 years old rhyodacitic satellite dome located at the volcano’s NE lower flanks. Thus, Chachimbiro’s magmatic system represents a viable candidate heat source for the development of a high temperature geothermal system. Several regional NE-SW trending dextral strike-slip faults extent through the area, providing both the conduit for the magmatic intrusion underlying Hugá dome (La Florida fault) as well as the pathways for the ascent of deep thermal fluids on the E flank (Azufral fault), along which cold gas seeps and recent, primarily argillic, hidrothermal alteration occurs. Nevertheless, smectite-chlorite haloes around advanced argillic alteration might indicate that the temperature of the thermal manifestations was higher in the past. On the other hand, fractures show an extensional component indicating that the structural regime could provide a favorable environment for the development of a high permeability fracture network.

The geochemistry of prospect waters and gas is complex and does not lead to a single interpretation. The hot spring waters show neutral alkali-chloride chemistry (up to 2250 ppm Cl) and stable isotope enrichment similar to waters from high temperature geothermal systems. Na-K geothermometry indicates temperatures of 225-235°C, but high calcium and magnesium concentrations lead to low (110°C) alkali geothermometer predictions. The silica geothermometer predicts 170°C, but spring waters are found to be in equilibrium with amorphous silica at their surface temperature, suggesting that the geothermometer has been reset near surface. Isotopic contents of helium and bicarbonate carbon show a faint magmatic signature, whereas that of sulphate sulphur suggests a marine origin. Gas from the Quebrada Azufral and Quebrada Pijumbí gas seeps is almost pure CO2 with very low content of hydrogen-bearing gases (H2, H2S, CH4 and NH3) common to hydrothermal systems. The N2/Ar ratio of these gases suggests either a crustal or magmatic source with little meteoric influence. The CO/CO2-CH4/CO2 gas geothermometer pair predicts 260°C but at slightly more oxidizing reservoir conditions than usual for hydrothermal systems. Various conceptual hydrologic models can be constructed to match with aspects of the geochemistry but no one model adequately explains them all, so multiple alternative models are proposed.

The geophysical program included 70 magnetotelluric (MT) stations, 35 time domain electromagnetic (TDEM) station, 700 gravity stations, 2400 magnetic stations and a four month microearthquake survey; all of the surveys are compatible with the existence of a geothermal reservoir. The MT survey resolves an extensive, low resistivity, smectite clay alteration zone consistent with the clay alteration that caps almost all developed geothermal reservoirs. The low resistivity cap is centered near the intersection of the two main hot spring and alteration trends and extends to a deeper clay zone typical of a reservoir margin. Although generally encouraging, the resistivity pattern suggests a potential connection of the high resistivity zone below the clay cap to a deeply incised adjacent valley, raising the possibility that the reservoir cap was abruptly breached by a landslide, potentially resulting in a loss of reservoir permeability. More significantly, when the interpretation of the low resistivity cap is integrated with the geochemistry, geology and hydrology, consistent conceptual models suggest that any permeable reservoir is several hundred meters below the base of the clay cap. Because the overall pattern differs from all developed field case histories considered as potential analogs, the geophysics is consistent with relatively high exploration risk.

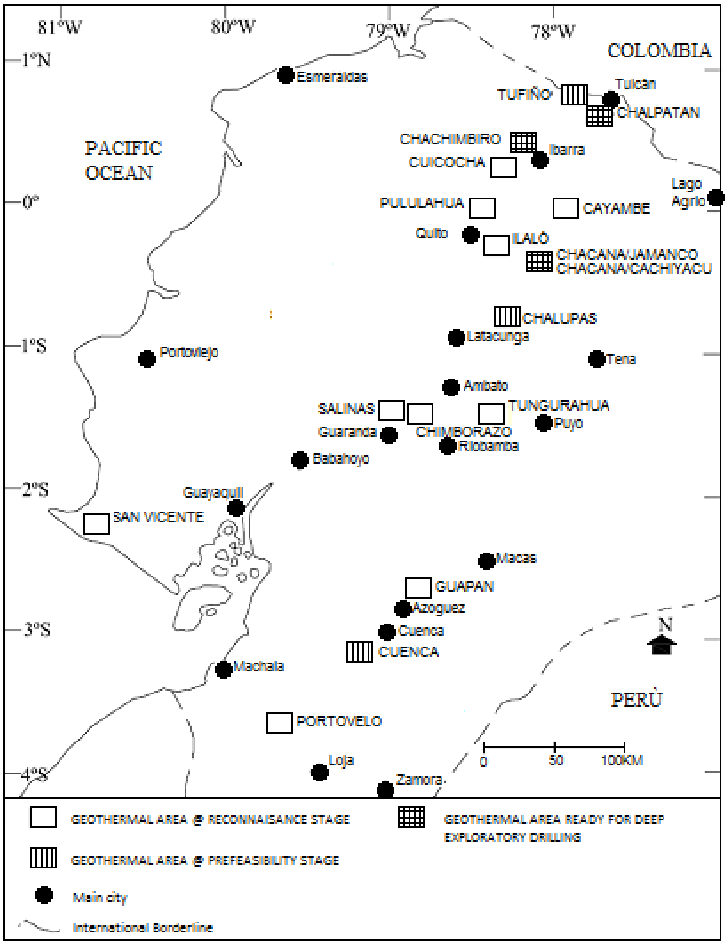

Figure 2: Location map for geothermal areas in mainland Ecuador. Modified from Almeida, E./INECEL, 1990.

Integration of the geology, fluid geochemistry and geophysics survey results yields three possible conceptual models for the resource. Model 1: moderate to high temperature geothermal resource associated with the Azufral fault zone. By including a second, deep cap rock near the boiling zone in the reservoir section, the model can account for cooling and chemistry of the low temperature gas manifestations and the hot springs at the surface. Based on this model, the most likely areal extent of the resource is approximately 4.5 sq. km based on an interpretation of the margins of the reservoir from the shape of the resistivity anomaly. An optimistic interpretation of the resistivity anomaly provides an upside areal extent of 12 sq. km. By applying a range of power densities from 10 to 20 MWe per sq. km, probabilistic assessments of resource capacity provide a range of 13 to 178 MWe with a mean resource size of 81 MWe. These results indicate that Chachimbiro could host a small to medium size geothermal reservoir. More pessimistic alternative models can also account for the reservoir features observed in the geological, geochemical, and geophysical data sets. Model 2: in which the high temperature system has peaked and is now in a cooling and waning phase. Model 3: the system is immature and the fluids have failed to achieve chemical equilibrium. The immature model is the most pessimistic and would imply that a commercial resource does not exist at Chachimbiro.

The assessment of the exploration risk factors, which include reservoir temperature, permeability, and chemistry, indicate that Chachimbiro is a fairly risky prospect, consequently to its pre-drilling stage. The main concerns are temperature and permeability risk, while fluid chemistry is considered to represent a small risk. It is recommended that exploration drilling start with a vertical 1500m slim-hole drilled to intersect the Azufral fault with the aim to reach the interpreted liquid reservoir and the zone of high resistivity alteration imaged by MT for a minimum of expenditure. At present, CELEC EP is preparing the TORs (Terms of Reference) and the tender documents to contract deep exploration drilling in Chachimbiro geothermal prospect.

3.1.2 Chacana geothermal prospect

This prospect is related to the silicic Chacana caldera (60 km east of Quito) on the CR in the province of Napo. Elevations range between 3,200 and 4,000 masl on ragged topography covered with grassland and few forested patches. Climate is wet and cold for most of the year. The main load center is Quito and a high voltage transmission line already runs through its southern half, as well as paved and gravel roads. The prospect is mostly located in environmentally sensitive territory, namely the Antisana and Cayambe-Coca ecological reserves.

Exploration studies carried out between July 2011 and April 2012, covered the southern half of the Chacana caldera and were conducted by the consulting firm Servicios y Remediación S.A. (SyR) under a contract with the Ecuadorian Electric Power Corporation - CELEC EP. The studies, condensed here from CELEC EP / SYR, (2012, b), encompassed a full scope of work in the areas of geology, geochemistry and geophysics and have culminated in the preparation of conceptual models of the geothermal resource in four areas of interest: Cachiyacu, Jamanco, Chimbaurcu and Plaza de Armas.

The study area is defined by three areas of hot springs known as Cachiyacu, Jamanco and Termas de Papallacta. The Chacana caldera is a major Late Pliocene to Quaternary active volcanic complex of calc-alkaline affinity and lies over a Paleozoic-Mesozoic metamorphic basement and Upper Tertiary volcanic rocks (Hall and Mothes, 2001). The magmatic history of the area involves the formation of the Chacana caldera and the initial fill of its depression by a large volume of siliceous tuff and breccias, the age of which fluctuates between 2.7 to 2.6 million years, followed by the frequent emission of lavas with an andesitic and dacitic composition until 1.5 million years ago. The total thickness of the caldera fill is estimated as some 2,000 meters. Subsequently, due to magma intrusions at depth, there was a period of resurgence and emplacement of dikes with a preferential N-S orientation, about 950,000 years ago followed by extensive propylithic hydrothermal alteration that affected the pre-existing rocks.

In response to the tectonic stress, five dextral transcurrent regional faults with NE-SW orientations cross the study area and surrounding areas; the main ones are the Tambo and Tumiguina faults. However, the main structural feature of the study area is the Chacana Rift, a large N-S fracture that has contributed eruption materials to a number of volcanic centers along its more than 50 km length, for over 200,000 years. The youngest activity in the study area is represented by two historical andesitic lava flows, much likely related to this rift. Also, a group of recent dacitic and rhyolitic domes are located in the Cachiyacu basin without showing signs of Late Pleistocene glacial erosion. The most favorable candidate for a reservoir would be the Late Tertiary volcanic and sedimentary rocks that lie over the metamorphic basement. Meanwhile, the rocks that constitute the caldera fill are in general of low permeability, but at the local level and especially close to the major fault zones, these rocks could have significant permeability. The fault zones, dikes, fractures and thick accumulations of breccias along the caldera edge should be reasonably permeable.

The geochemical data obtained from the water and gas samples taken from the hot springs in the Chacana study area are complex and do not yield a single interpretation. The isotope composition of the waters indicates a meteoric origin and belongs to the neutral alkaline – chloride type (up to 2,270 ppm of chloride), which is common in high-temperature geothermal systems; it is of intermediate salinity and its surface temperatures are as high as 72°C in Jamanco, 63°C in Cachiyacu and 58°C in Termas de Papallacta. The location of the hot springs seems to be controlled by faults running in a SW-NE direction. The first two belong to different geothermal systems, in light of the different deuterium content and CI/B values; the third, Termas, would belong to the Jamanco system because it has a similar deuterium value even though it would represent a minor water-rock interaction process. Three geochemical models are proposed to explain the data obtained for both Cachiyacu and Jamanco, given the disparity in the geothermometer results and the partial equilibrium in their waters. A first model predicts a moderate-to-high temperature system with values of 180°C to 240°C for Cachiyacu and 150°C to 180°C for Jamanco, based on Na/K geothermometer readings and equilibrium temperatures for alteration minerals. The Na/K/Ca geothermometer marks the lower limits for each case. This geothermal model is the most optimistic, and it has been used in preparing the conceptual models for Cachiyacu and Jamanco, representing a viable high-temperature convective geothermal system. A second geochemical model represents a convective geothermal system in a cooling or waning stage, based on silica and K/Mg geothermometers, with temperature readings of 140 to 170°C for Cachiyacu and about 140°C for Jamanco, and between 110 and 120°C for both prospects, respectively. A third geochemical model explains the high values for He and the partial pressure of CO_2 as part of an immature geothermal system generated by recent magmatic activity, whose fluids have not had enough time to reach equilibrium with the reservoir rock.

The geophysical survey of Chacana compiles results from 130 magnetotelluric (MT) stations, 50 time-domain electromagnetic method (TDEM) stations, 701 gravimetric stations, 800 magnetometric stations and 10 mobile seismic stations installed for a four-month period. The MT study detected five low-resistivity anomalies that were apparently produced by the hydrothermal alteration of volcanic rocks to clays and that would indicate the existence of a geothermal system at depth in four of them: Jamanco, Cachiyacu, Plaza de Armas and Chimbaurcu; a fifth anomaly is not related to a geothermal system. The MT survey also detected high resistivity values underneath the floor of the Chacana caldera, which in qualitative terms indicate that the metamorphic basement lies under the areas of Cachiyacu, Chimbaurcu and Plaza de Armas, at depths between 1,500 and 2,000 meters. This would suggest that, if a geothermal reservoir should exist, it would preferentially be located in the relatively permeable lower parts of the caldera fill instead of being in the basement. The gravimetric data provide significant support for the MT structural assessment, indicating less dense rocks in Cachiyacu, Plaza de Armas and the Jamanco-Papallacta corridor. The magnetometric survey yielded similar results, with magnetic lows in Cachiyacu, on the western edge of the caldera, and more weakly, in Jamanco. The microseismicity study indicates seismotectonic activity inside the caldera, in the south west half of the study area, more or less bounded by the Tambo and Tumiguina faults and by the caldera edge. This activity is consistent with the presence of fracture permeability at deep levels, including the basement, acting as a conduit for the ascent of the basal recharge (upflow) of geothermal fluids. This fact would favor the prospects of Cachiyacu and Plaza de Armas; and to a lesser extent, the prospects of Jamanco and Chimbaurcu.

The integration of data from geological, fluid geochemistry and geophysical studies has made it possible to prepare conceptual models for four geothermal areas of interest located inside the southern part of the Chacana caldera. These areas of interest are Cachiyacu, Jamanco, Chimbaurcu and Plaza de Armas. The models are based on the low-resistivity anomalies with typical geothermal characteristics obtained in the MT 3D survey, which has made it possible to define, with some certainty, the reservoir's central part (upflow), its most likely size and depth and the distribution of temperatures, based on the 150°C isotherm. Even though the optimistic conceptual model of the resource and its potential for finding suitable temperatures for a viable geothermal electricity project is considered first, it is important to mention that the results of the fluid geochemistry studies in the Cachiyacu and Jamanco prospects include the possibility of alternative models because there is no single interpretation for the data. These suggest the probability of finding, on the one hand, a system in a cooling stage with sub-economical temperatures and, on the other hand, an immature system with a high CO_2 content, restricted to the circulation of fluids in only one fault. Both alternative models represent a pessimistic option for finding a viable geothermal resource.

Based on the optimistic conceptual models for Cachiyacu and Jamanco, the probable size of the resource for these two prospects has been defined on the basis of the surface size of the resistivity anomaly. A probabilistic assessment of resource size indicates a resource power in the range of 3.3 to 26 MWe for Jamanco, with a mean of 13 MWe, applying power density ranges of 10 to 20 MWe/km^2. For Cachiyacu, the obtained power ranges are 7.6 to 83 MWe, with a mean of 39 MWe, which represents a small to medium-sized geothermal reservoir. In the case of Jamanco, it probably houses a small to moderate geothermal resource. Due to data availability, a resource assessment for Plaza de Armas and Chimbaurco geothermal prospects has not been attempted.

The evaluation of risk factors - including reservoir temperature, permeability and fluid chemistry -- indicates that both Jamanco and Cachiyacu are relatively risky prospects. The main risk factors are temperature and permeability in the case of Jamanco, while in Cachiyacu it is temperature. The significant resource risks that would merit a more in-depth investigation during the appraisal drilling phase are the potential entry of marginal cold water flows into the reservoir and the sustainability of the resource for long-term production. The key parameter to be verified in order to increase the probability of success at the lowest cost possible is to demonstrate the presence of economic temperatures at depth.

The optimal drilling strategy for Cachiyacu is to drill a small-diameter (slim-hole) exploratory well at a depth of 600 m, near the hot springs, and designed to intersect the Tambo Fault under the clay caprock. The objective is to reach the top of the high-temperature liquid reservoir in order to confirm, first of all, economical temperatures; and secondly, permeability. Given the lack of access to the drilling site and the fact that it is located in a protected area, the challenges will lie in obtaining the corresponding environmental permits and in transporting the drilling equipment by helicopter or overland. For Jamanco, the strategy is to drill a slim-hole exploratory well to a depth of 900 m, with the aim of intersecting the Jamanco Fault at the height of the base of the conductive rock and above the inferred site of the basal recharge (upflow), according to the conceptual model. The criteria for utilization of the well are the same as for Cachiyacu; however, the Jamanco drilling site is located outside protected areas and has excellent access roads, which enormously facilitates the logistics of the drilling process.

CELEC EP has plans for the near future to drill the proposed deep exploration slim holes in Jamanco (900 m) and Cachiyacu (600 m) to complete the advanced prefeasibility stage in order to commence appraisal drilling if results are encouraging.

A further study by Pilicita (2013), determined the total minimum surface heat discharge related to the Chacana Caldera is 274.62 TJ/year which is barely used in few swimming pools; he also figured out that about 600 tonnes of Arsenic have been deposited in lake Papallacta sediments in the last 250 years from hot springs draining into Tambo river, the main affluent to the lake, indicating active hot fluids circulation through the mineralized system in the south half of Chacana caldera (Villares, 2010).

3.1.3 CHALPATÁN Geothermal Prospect

This prospect is located at about 20 km south west of Tulcan city, province of Carchi, in northern most Ecuador and consists of several warm springs scattered inside the Chalpatán caldera. It was first explored by Inecel/Aquater/Olade (1987), according to Olade methodology (Olade, 1978) and follow up exploration work recommended to locate a low to moderate temperature resource hosted in the caldera structure. It is located in a benign environmental and social area at an average elevation of 3,200 masl. In 2012, INP-CELEC-MEER granted the bid-contract to CGS from Spain to do the prefeasibility studies on Chalpatán geothermal prospect in order to obtain a conceptual model and locate drill-hole sites for deep exploration with the aim to eventually tap geothermal fluids capable to generate electricity with binary technology. Funding took place through BID (Interamerican Development Bank IDB) under administration of INP (Instituto Nacional de Preinversión).

The CGS study (MEER/CELEC/INP/CGS, 2013) states that Chalpatán is an Early Pleistocene (2 – 1.2 Ma) collapse caldera, 8 km in diameter. The diameter halves at 1,200m depth and the floor is between 1,600 and 1,800 m depth, indicated by a resistive substratum. Post caldera lavas are andesites and dacites, about 1 Ma in age. The caldera floor is cut by a NNW-SSE fault and basement at the eastern block is uplifted as compared to the western block. Regional NNE faulting affects the caldera and has associated normal faults. Caldera fill is complex and consists of pyroclastic deposits, sediments and lavas, which are less compacted down to 1000 m, but compaction increases towards caldera floor at 1,600 m. The infill lavas reach a thickness of 500 m and are covered by a 10 to 80 m thick impermeable cover of volcanic ash and till.

About 12 warm springs (26 to 36ºC) of Na-Ca-bicarbonate water crop out inside the caldera. Waters are immature and don't seem to have a deep origin; no sulfur was detected and carbon isotopes indicate a mixed biogenic and endogenous origin. Calculated equilibrium temperatures vary from 74ºC to up to 137ºC and it is likely that the geothermal system in Chalpatán is heated by slightly higher than normal geothermal gradient of 33ºC/km. According to the theoretical steady state thermal model used by CGS, which assumes that thermal stability was reached at 700 ka, the 100ºC and 120ºC isotherms are located at 1,500 and 1,800 m respectively. Resource calculations indicate 1.85 km^3 of hot water at 70ºC, representing a potential energy resource of 484,000 GWh. Although the resource is not suited for commercial electricity production, the potential direct uses are readily applicable for greenhouses, fish farming, space heating, dairy industry and spas, among other uses, since the local community is demanding for it. CGS warns to keep away from gradient holes and recommends to drill two alternate deep exploration holes to 1,500 m depth, with a down-hole pump at 250 m depth. The prospect awaits funding to drill exploration holes and tap its geothermal energy.

3.1.4 Tufiño – Chiles geothermal prospect

This prospect is located in the CO (Cordillera Occidental or Western Cordillera), at 35 km west of the city of Tulcán, 7 km west of the villages of Tufiño and Chiles, in the province of Carchi (Ecuador) and Nariño department (Colombia). The development area lies across the Ecuador - Colombia border and comprises about 4,900 ha; likely drilling sites are on the south east slopes of Chiles volcano between 3,800 and 4,200 masl, where the climate is wet and cold most of the year and vegetation is grassy. Gravel roads give access to the area, where the main activities are agriculture and cattle farming. The cities of Tulcán and Ipiales are the main load centers.

Volcán Chiles, a moderate size, andesitic to dacitic, stratocone active in late Pleistocene, constitutes the main heat source, which is reinforced by Cerro Negro de Mayasquer, an active dacitic volcano adjacent to the west. These two volcanoes are built up on top of a thick pile of late Terciary volcanics (Pisayambo Fm.) overlying accreted oceanic crust of early-mid Cretaceous age (Pallatanga Terrain), with an associated island arc (Río Cala Fm.) and trench sediments (Natividad Fm.) of mid-late Cretaceous age. Reservoir rocks could be fractured Tertiary volcanic and vulcaniclastics, as well as Cretaceous volcanics and sediments, affected by the intersection of active NNE trending regional strike-slip faults with local E-W faults, which are likely to produce reasonable permeability.

Acid hot springs, up to 55°C (Table 1A), occur 2 – 3 km to the east of Volcan Chiles, along E-W faulting, with a strong H_2S smell. Bicarbonate springs are common several km to the east, close to the villages of Tufiño and Chiles. Fossil silica sinter terraces, about 1 km east of the acid springs, show that neutral chloride waters, indicative of a high temperature hydrothermal system, discharged at this site sometime in the past. Extensive areas of hydrothermally altered rocks are found 2.5 km north and 1.5 km south of Volcán Chiles. These are at ambient temperature, but show local emission of H_2S, and have been active in the Holocene; it is likely that the shallow part of the system has sealed up. Gas geothermometers indicate reservoir temperatures as high as 230°C. Location of acid springs and altered ground suggest considerable size of reservoir, mostly overlain by rugged glaciated terrain. Resistivity data (Schlumberger and MT soundings) suggest the existence of a geothermal reservoir under Volcán Chiles massif, with a fault-controlled eastwards lateral outflow on the east flank (INECEL-OLADE-AQUATER, 1987). Elevation of top of reservoir is below 3,100 masl with 100°C waters, but exploitable temperatures are 200 – 300 m deeper, indicating a drilling target for production at 1,000 to 1,500 m depth; this is indicated by the presence of a thick conductive layer, which is shallow (about 100 m) below the acid springs, but deepens 400 to 500 m towards the east (outflow).

The altered ground towards the south indicates a low temperature conductive layer associated with steam-heated rocks consisting of clays. Best sites for exploration-production drilling appear to be to the west of the acid springs, at about 3,800 – 4,000 masl, which would need the building of 1 – 3 km long access roads from the existing gravel roads. Water for drilling might be scarce in the dry season. Almeida (1990) gives an estimate of 138 MWe for the Tufiño prospect, based on surface data using the volumetric heat-in - place method.

In 2009, 1 MUSD of MEER funds was allocated to the Tufiño prospect at the Ecuadorean side to carry out 4 shallow (500 m), small diameter (NQ or 76 mm) gradient bore holes. The first hole, PGT 1, which is the very first geothermal hole to be drilled in Ecuador, reached a total depth of 554 m; this hole is located on the ESE lower flank of Volcán Chiles. Lithology of well PGT-1 down to 554 m comprises of till, lavas and thick sequence of rather low permeability volcaniclastics (microbreccias) and associated sediments as sandstone and siltstone. Low permeability would be expected along the upper conductive seal cap of the geothermal system. Shortly after, the exploration program was shut down and a temperature profile at PGT-1 was never measured.

In the last years the prospect regained its status of Bi-National Geothermal Project and is managed jointly by ISAGEN of Colombia and CELEC EP of Ecuador, being the former the operator. Public funding for geothermal exploration at Tufiño-Chiles is given at equal parts by each government. Reassessment of available geological, geochemical and geophysical information by ISAGEN – CELEC EP recommended complementary exploration surveys to proper locate the resource and its potential, for the case that a commercial resource might exist. Consequently, in mid 2013, ISAGEN – CELEC EP, did send the bid out for these complementary studies, comprising geology (mainly 40Ar/39Ar dating of rocks and defining alteration mineralogy), geochemistry (focused on gas analyses and isotope determination – D/18O, He, 13C and 34S) and geophysics based on about 100 MT/TDEM stations. This international contract was won by SYR in late 2013 and field work on geology and geochemistry started February 2014 on the Ecuadorean side.

3.1.5 Cuenca geothermal prospect

With a temperature of 75°C, the Baños de Cuenca hot springs are the hottest in mainland Ecuador (Table 1A). The springs are located 7 km southwest of the city of Cuenca (2,700 masl) in the province of Azuay. Topography is hilly to flat around the springs but becomes rugged towards the highlands. Vegetation is grassy with forested patches and land is used intensely for farming. Access is plenty along well maintained paved and gravel roads. The city of Cuenca, third in size in the country, is the main load center. Country rocks comprise thick Oligocene andesitic to rhyolitic volcanics of the Saraguro Formation, which are overlain by a sequence of Miocene sedimentary rocks of the Cuenca basin. Late Miocene ignimbrites of Tarqui Formation cover the area, being the Quimsacocha caldera, located 25 km southwest of Cuenca, one of its main vents. No Quaternary volcanism occurs in the area. Basement rocks comprise Jurassic meta-sediments overlain by late Cretaceous Yunguilla Formation, a carbonatic flysh. Major NE-trending faults cut the whole sequence and serve as primary channel ways for the deep fluids. One probable heat source is the mineralized Late Miocene-Pliocene Quimsacocha volcanic complex, located about 25 km southwest of Cuenca. It produced a cal-alcaline andesitic shield with lava flows and breccia, an extensive high sulfidation epithermal Au-Ag deposit, a caldera forming rhyolitic ignimbrite (Tarqui Fm.) at about 5 My and late intrusive and extrusive caldera - filling domes of dacite and rhyolite porphyries of adakitic signature at about 3.6 My (Beate, 2001); volcanic activity did not resumed after extrusion of the domes.

The hot spring waters are of the alkali chloride – bicarbonate type and deposit travertine along 8 m high and 200 m long ridges in the Baños de Cuenca area. A dozen of other hot and warm springs of the same nature are present to the north, south and west of Baños de Cuenca and indicate a structural control. Latest geological and geochemical studies undertaken by INER, with assistance of SYR, in the Baños de Cuenca prospect, indicate deep temperatures in the ranges of 100 to 140ºC, being the most likely heat source the normal geothermal gradient, although carbon isotopes show a magmatic signature (INER / SYR, 2014). Future work might consider geophysical surveys and the drilling of deep exploration holes to tap geothermal energy for direct uses, which have high demand in the area.

Table 1A. Chemical Composition of hot spring waters from several geothermal areas of mainland Ecuador (all values ppm)

Hot Spring	T°C	pH	Na	K	Ca	Mg	HCO3	Cl	SO4	Elevation (m)
Tufiño (Aguas Hediondas) *	52,5	4,6	201,2	40,3	91	48	---	123,7	809	3601
Tufiño 2 ****	53	5,9	149	34	100	70,6	350	110	550	3530
Tufiño 3 ****	40	6,2	134	3,1	104	70,7	670	74	2100	3260
Chachimbiro 1 *	51,2	6,9	969,9	117,7	86,6	44,2	250	1611,3	32,9	2531
Chachimbiro 2 (Pitzantzi) *	31,8	7,04	610,4	59	246,1	134,5	1615,9	854,1	10,5	2696
Chachimbiro 3 **	47,2	6,23	1329	117	102	54,9	861	2060	29,4	2580
Chacana 1 (Papallacta-Termas) *	58,9	6,82	540	10,2	312,4	3,6	79,3	973,5	526,2	3334
Chacana 2 (Papallacta-Jamanco) *	60,8	6,23	1136,4	42,6	294,2	8,1	454,3	1871,9	298,6	3518
Chacana 3 (Papallacta-Cachiyacu) *	64,6	6,39	915,7	79,8	106,4	33,1	672	1352,5	114,8	3910
Chacana 4 (Oyacachi) *	46,5	6,53	978,4	33,2	99	55,1	2012,2	653,4	84,3	3180
Chacana 5 (El Pisque) *	37	6,33	343,5	41,8	36,9	82,6	1155,5	173,7	22,4	2633
Ilaló 1 (La Merced) *	32,5	6,67	119,1	14,1	39,7	54,3	597,6	60,3	21,4	2586
Ilaló 2 (El Tingo) *	42,1	7	514,1	27,4	27,5	169,3	1756,1	295,3	52,9	2454
Ilaló 3 (Balneario Ilaló) *	37,7	6,48	209,9	26,2	58,1	81,3	902,4	107,8	73,3	2571
Ilaló 4 (Tolontag - Chacana) *	27,2	7,17	1123,5	53,6	244,5	52,9	1576,2	493,2	1297,1	3426
Palmira *	25,2	6,79	541,6	47,3	214,4	55,1	1695,1	406,3	0,5	2732
Pululahua *	25,4	---	393,4	6,3	326,3	143,2	2054,9	361,3	---	2610
Chalupas 1 ****	35	6,8	312	38	9,6	16	858	39	5	3740
Chalupas 2 ****	25	6,1	245	14	29	74	937	87	0,4	3520
Tungurahua 1 (La Virgen) *	52,7	6,43	500,5	77,8	205,2	403,8	1591,5	390,3	1518,1	1820
Tungurahua 2 (Salado) *	45,6	6,4	556,1	82,9	392,8	814	1561	800,9	3011,4	1927
Tungurahua 3 (Santa Ana) *	42,1	6,65	459,1	69,2	214,8	377,2	1597,6	350,6	1328,6	1751
Chimborazo (Cununyacu) *	47	8,37	640,7	7,8	299,4	1	61	1289,4	263,3	3670
Salinas de Bolivar *	19,4	7,55	911,8	143,9	26,7	15,1	115,9	1594,3	109,5	3511
San Vicente *	37,09	6,41	2381,1	15,2	2764,3	0,2	579,3	8368,7	---	70
Guapán 1 ***	45	6,7	5600	160	363	65	3090	5160	35	2660
Guapán 2 *****	46,9	6,79	3640,2	124,7	90,4	69,4	2524,4	572,6	62,9	2670
Baños Cuenca 1 (El Riñon) *	74,5	6,83	648,3	54,3	196	24,1	640,2	840,9	228,1	2704
Baños Cuenca 2 ****	56	6,6	743	59	152	24	890	861	227	2720
Portovelo *	52,4	7,94	438,4	13,7	152,9	0,1	27,4	789,5	247,1	661

* Inguaggiato et al., 2010
** Aguilera et al., 2005
*** De Grys et al., 1970
**** Almeida, 1992
***** IG/EPN - INGV, 2009

3.1.6 Guapán geothermal prospect.

Guapán is located 20 km NNE of Cuenca, very close to Azogues, in the province of Cañar. Several hot springs, with temperatures up to 49.6°C and high solute concentrations (TDS = 10,000 to 13,000, Table 1A), occur in Late Cretaceous and Miocene sediments on the east margin of the Cuenca Basin. No active or recent volcanism has been reported in the area, although shallow, late Tertiary intrusions are likely to exist at depth along regional faults. Thick, extensive travertine deposits are associated with the springs, which are fault controlled along a WNW-strike; these have been lately lowering its discharge due to carbonate self- sealing. Guapán is an interesting geothermal prospect, sited at a load center (the city of Azoguez), which should have high priority for exploration and development, although one foreseeable problem to overcome is carbonate scaling.

3.1.7 Chalupas geothermal prospect.

This prospect is located 70 km SSE from Quito, at the crest of the CR (Eastern Cordillera), in the province of Napo. It can be accessed from Latacunga city along gravel and dirt roads. Average elevation of prospect is 3,600 masl, climate is cold and wet for most of the year and vegetation is grassy. Topography is partly flat and partly hilly. The area of interest, the Chalupas caldera floor, is greater than 200 km^2. Latacunga is the nearest load center at a distance of 30 km.

The Chalupas caldera is 12 km in diameter and formed after the explosive eruption of about 100 km^3 of rhyolitic pumitic ash (Beate, 1985;), although this volume can be two or three times higher due to syngenetic filling of caldera. Hammersley (2003) obtained a 40Ar/39Ar age of 211 ka for the ash. Volcanic activity resumed after caldera collapse, building Quilindaña volcano inside it, which is andesitic to dacitic in composition; youngest intracaldera lava flows have a basaltic andesite composition and are affected by glacial erosion of the Younger Dryas Glacial advance, about 11 ka. The huge volume of erupted silicic magma as well as the persisting volcanic activity through time, warrants the presence of a heat source in the area. Due to the formation of the caldera by collapse, high permeability is expected at depth; regional NNE trending faults cross the caldera structure. The caldera collapse affected a thick pile of late Terciary intermediate volcanics (Pisayambo Fm.), which overly the Triassic-Jurassic metamorphic basement (blue qtz gneises of Tres Lagunas Granite).

The caldera has been eroded by glaciers and partly filled by cold water-saturated morraines; hence, only few low temperature springs, between 30 to 40°C (Table 1A), are found at the edges of the caldera structure, and are too diluted to give an estimate of the deep temperature. This may be also indicative of the absence of a shallow high-temperature system. Fault controlled hydrothermally altered rocks appear in the north and south caldera rims; christobalite is found at the west rim affecting pre-caldera lavas. Other alteration zones may be concealed underneath the morraine cover. A gravity survey shows the caldera structure, the geometry of the basement as well as the regionally north-trending Peltetec fault (Beate, 2001).

Future work should carry out a deep reaching MT/TDEM survey as to better define the caldera structure, its floor and any geothermal system hosted in it. About 450 MT stations at 1 km spacing and another 200 MT stations at 500 m spacing for fill-in would suffice to reach this goal. A complementary gravity survey should help to back up structural interpretation from MT survey. It is likely that the resource is deep-sitting, favoring the drilling of 1 to 1.5 km exploration slim holes to test temperature, instead of a program of shallow temperature gradient wells (400 to 500 m deep). Complementary geology studies focused on structure, as well as geochemical analyses of cold and warm springs together with gas sampling with emphasis on helium, carbon and sulfur isotopes would help to understand the hydrology and the origin of the fluids in Chalupas caldera.

Almeida (1990) estimates a potential of 283 MWe for the Chalupas prospect, from interpretation of surface data applying the volumetric heat-in-place method.

3.1.8 Chacana – Oyacachi

This prospect is located in the inner northwest edge of Chacana Caldera (60 km from capital city of Quito) and about 7 km west of the village of Oyacachi, at elevations ranging from 3,200 to 4,300 masl on a rather irregular topography. Vegetation is grassy and climate is cold and wet for most of the year. The area has a well maintained gravel road access on the mid and eastern portion and belongs to the Cayambe-Coca Protected Area. It is defined by several proximal hot springs of neutral chloride waters, now flooded by an artificial lake, few cold gas seeps with H_2S at higher elevation and by a series of hot springs of bicarbonate nature at 46.5ºC close to Oyacachi on the eastern edge of the caldera at a lower elevation. The heat source is likely related to post-caldera rhyolitic domes and obsidian flows of late Pleistocene age (Hall and Mothes, 2008). The nearest load centers are Oyacachi (7 km) and the city of Cayambe (25 km north). A deep-reaching MT/TDEM survey of about 130 stations should suffice to define the resource, which has to be proven by an exploratory slim hole reaching at least 1,000 m to measure deep temperatures and sample circulating fluids from an assumed reservoir in fractured basement rock and brecciated volcanic caldera infill. An estimate of 100 MWe has been given for the Oyacachi resource using volumetric heat-in-place method (Electroguayas, 2009).

3.1.9 Chimborazo geothermal prospect

This prospect is located 35 km northwest of Riobamba, at the crest of CO (Western Cordillera), in the province of Chimborazo. Elevations are in the range of 3,500 to 4,500 masl, vegetation is scarce and grassy at best, topography is hummocky and climate is cold throughout the whole year. Access is good along paved and gravel/dirt roads. The load centers are the cities of Ambato, Guaranda and Riobamba, situated inside a radius of 40 km. The development area is 4200 ha, situated on the NNW slope of Chimborazo volcano.

Chimborazo is a big composite stratovolcano, reaching 6,310 masl on its summit and starting at 4,000 m at its base. The composition of its products vary from basaltic andesites and andesites through dacites and rhyolites, being the later between 1 and 2 My old and the former between 5 and 10 ky old. Last eruption produced small phreato-magmatic (?) surges, only 1.7 ka in age. The whole edifice rests on Terciary vulcaniclastic sediments (Saquisilí Fm.) which overly accreted Early Cretaceous ocean crust (Pallatanga Fm.). Reservoir host rocks are likely to be composed of fractured volcanic rocks. Active faults cut the prospect area, but are concealed due to thick Pleistocene tephra cover. Only one hot spring exists in the area to the NNW foot of the volcano, with a temperature of 47°C and dilute neutral chloride chemistry (Table 1A). The fluids show water-rock equilibrium and indicate deep reservoir temperatures between 120 and 150°C. No geophysical survey has been done yet.

3.1.10 Alcedo geothermal prospect

It is located on Isabela Island, in the Galápagos Archipelago. It shows extensive hydrothermal alteration, numerous explosion craters (at least seven), strong geothermal fumaroles discharging vapor at 97°C (locally superheated at 130ºC) and a heat source related to a primary basaltic origin but also to shallow rhyolitic intrusions associated with explosive silicic volcanism of recent age (c.a. 120 ka, Geist, 1994) like obsidian flows and rhyolitic plinian tephra. The area is situated on the SSW structural rim of the caldera, which might indicate good permeability at depth, were a shallow high-temperature water-dominated geothermal system is present. Empirical gas geothermometry indicates temperatures of 260 to 320ºC for this intracaldera reservoir, which is probably capable of producing up to 150 MWe (Goff et al., 2000). This spectacular geothermal prospect is located inside the Galápagos National Park, and any intend to explore and exploit it must obey strict environmental regulations, if a geothermal permit is granted at all. Other limitations are the lack of any infrastructure, few distant power users without transmission line and scarce or no water for drilling. If power is tapped, it would imply the construction of submarine transmission lines to the load centers located in Isabela, Santa Cruz and San Cristóbal islands.

3.1.11 Other geothermal areas

Several geothermal areas like Cuicocha, Cayambe, Pululahua, Guagua Pichincha, Ilaló, Tungurahua, Salinas, San Vicente and Portovelo, remain unexplored and have not been included in this paper, but the reader can find its description in the previous update (Beate & Salgado, 2010).

4. GEOTHERMAL UTILIZATION

Today, utilization of geothermal resources in Ecuador is restricted to direct uses only, that is, for bathing resorts, balneology and swimming pools. The first use of space heating at private Termas Papallacta Spa Resort Hotel has been installed, but its use is irregular due to scaling problems. Pérez (2014) designed a heat exchanger (still has to be constructed) for the Papallacta resort using geothermal hot water from the hot springs. Also several projects for direct use in fish hatchery a wait funding for development. A summary of many, but not all, hot and warm springs used for swimming pools is shown in Standard Table 3, giving a total installed capacity of 5.157 MWt and an annual energy output of 102.401 TJ/yr, which is the same as for 2010 update.

5. DISCUSSION

Standard Tables 1 to 8 show clearly that conventional energy generation by hydro (50%) and fossil fuels (47%) dominates by far the Ecuadorean energy market, with a total installed capacity of 4,798 MWe and a gross production of 21,638 GWh/yr (CONELEC, 2014). They also show that, at present, other forms of energy production, i.e. nuclear and geothermal are non-existent and other renewables like biomass, wind and solar energy are still marginal (130 MWe). In the future, the general trend is to favor hydro, with an increase in renewables and a substantial decrease in fossil fuel, which in turn may favor geothermal energy development.

Standard Table 3 shows the utilization of geothermal energy for direct use, without changes since the 2010 update. This information has to be taken as a minimum estimate for hot spring waters used for swimming pools. Inlet-temperature is a safe parameter, but outlet-temperature has been arbitrarily assumed to be 35°C if temperature is above 40°C, 20°C if it is between 30 and 40°C and 15°C if it less than 20°C. The average flow rate has been assumed to be 63% of the maximum flow rate, which is also arbitrary. The maximum flow rate has been measured at the spring in most cases, but in others it has been estimated. This activity has been improving towards efficiency in the last years, but is difficult to assess due to lack of data and specific studies.

Because in Ecuador, there is no electricity production from geothermal and there are no heat pumps installed, Standard Tables 2 and 4 are not included. Standard Table 6 includes the first and only geothermal exploration well in Ecuador, a 554 m deep gradient hole completed in May 2009; although, a temperature profile was not measured. Some very shallow wells have been drilled in the last decades to obtain water for swimming pools, but data are scarce and wells are not included here as geothermal wells; most wells have been drilled to obtain water only for agricultural or industrial uses, without using any heat.

Allocated professional personnel to geothermal activities (Standard Table 7) has increased substantially in the last year, mainly from the side of the government with CELEC EP and INER and less so with MEER and universities in Quito (EPN and ESPE), although it is non-existent in the private industry and Foreign Aid Programs are in the making. The Geological Survey of Ecuador (INIGEMM) is considering seriously to participate and take care of geothermal exploration in the country.

Standard Table 8 shows that public investment has been allocated to geothermal activities in this last five year term (2010 to 2015 in the amount of 12 MUSD for research of the Tufiño, Chachimbiro and Chacana geothermal prospects, including the drilling of deep exploration slim holes. This has been possible due to the firm political decision of the present administration to explore and develop the geothermal resources in Ecuador.

General policies and planning regarding electrical energy are issued by the government through the MICSE, SEMPLADES (State's Planning Agency), Ministry of Electricity and Renewable Energy (MEER). The MEER coordinates the electric energy issues with CONELEC, which is in charge of the regulation of the sector, its electrification master plan, of supervising power generation projects, concessions/contracts for power generation, prices and environmental issues. One of the problems in the electricity market is the availability of energy, rather than the installed capacity, since the reservoirs for hydro generation are in some cases small and fossil fuels are expensive and not always at hand. This situation favors the demand of geothermal power as base load. The problem is temporarily solved by importing energy from Colombia and Peru (about 238.20 GWh/yr in 2012), but this tendency should reverse in the next 2 years, with the commissioning of the new hydro projects under construction.

Any project to generate electricity, including geothermal, needs a permit issued by CONELEC, which in turn demands a water-use permit from SENAGUA (National Agency for Water Issues) and an environmental permit from the Ministry of the Environment (MAE). According to the new Constitution 2008, energy in any form belongs to the state and its exploration and development is strictly regulated by the government, since energy is a strategic issue.

6. FUTURE DEVELOPMENT AND INSTALLATIONS

Since the government has taken the political decision to fund, explore and develop clean, indigenous, renewable energy resources, including geothermal energy, it is foreseeable that in the near future, say the next 5 to 10 years, Ecuador will have its first geothermal power plant. Direct uses will also be explored and developed, most probably by INIGEMM and INER, for the tourist, agribusiness, fish-hatching sectors among other applications.

Due to higher oil prices and to locally and regionally increasing energy demand, tapping of geothermal energy can become cost-efficient in relation to conventional hydro, oil and gas, and to other renewable energy forms. Public investment plays now a key role in funding future geothermal enterprises for both, electric and direct uses.

Several regions in the country remain unexplored for geothermal resources, namely the sedimentary basins in the Costa, the back-arc volcanic chain with recently active alkalic volcanoes and the sedimentary basins in the Oriente, as well as the Galapagos Archipelago at both, the hot spot and the nearby spreading center. This increases the exploration potential for geothermal resources in the country, in addition to the follow up exploration of the prospects cited above. Application of actual and future technology will allow to tap hidden resources, those where geothermal evidence at surface is nil (Duffield and Sass, 2003) and approach EGS technologies as well. A good start will be to re assess and update geothermal data nationwide and to produce both, the heat flow map and the geothermal map of Ecuador. INER is keen to produce a Geothermal Atlas of Ecuador in the following years. It is imperative to get the necessary funding (public and private) to drill the most promising prospects and tap geothermal power in Ecuador.

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STANDARD TABLES - NOTE: TABLES 2/8 AND 4/8 ARE NOT INCLUDED.

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2014			2.282,54	9.032,60	2.385,50	12.418,00			129,90	187,40	4.797,94	21.638,00
Under construction in December 2014			320,00	2.242,00	2.869,80	16.572,00					3.189,80	18.814,00
Funds committed, but not yet under construction in December 2014					933,70	5.237,00					933,70	5.237,00
Estimated total projected use by 2020	80,00	630,72	2.753,25	8.151,78	5.274,00	31.020,00			129,90	206,50	8.237,15	40.009,00

Note: import of 650 MW from Colombia and Perú is not include in this table.

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2014 (other than heat pumps)

1) I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish farming
K = Animal farming
S = Snow melting
H = Individual space heating (other than heat pumps)
D = District heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
O = Other (please specify by footnote)

2) Enthalpy information is given only if there is steam or two-phase flow

3) Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (^oC) - outlet temp. (^oC)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

4) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

5) Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

Locality	Type[1]	Maximum Utilization					Capacity[3]	Annual Utilization		
		Flow Rate	Temperature (^oC)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
Baños Cuenca	B	8.000	73.000	35.000	-----	-----	1.272	5.040	25.261	0.629
Baños Tungurahua- Virgen	B	5.120	53.000	35.000	-----	-----	0.386	3.226	7.659	0.629
El Salado	B	5.000	44.300	35.000	-----	-----	0.195	3.150	3.864	0.628
Palictahua	B	2.800	40.700	35.000	-----	-----	0.0067	1.764	1.326	0.627
Chachimbiro- Toma	B	1.500	58.000	35.000	-----	-----	0.144	0.945	2.867	0.631
Pitzantzi	B	0.950	40.800	35.000	-----	-----	0.023	0.599	0.458	0.631
Naugulvi	B	2.000	52.000	35.000	-----	-----	0.142	1.260	2.825	0.631
Cununyacu- Chimborazo	B	1.400	47.500	35.000	-----	-----	0.073	0.882	1.454	0.632
Guayllabamba- Chimborazo	B	5.000	40.000	35.000	-----	-----	0.105	3.150	2.077	0.627
Ilaló- Cununyacu	B	8.000	27.000	15.000	-----	-----	0.402	5.040	7.977	0.629
Tingo	B	1.200	32.000	20.000	-----	-----	0.060	0.756	1.197	0.633
San Antonio	B	12.000	35.500	20.000	-----	-----	0.778	7.560	15.456	0.630
Ushimana	B	1.000	19.000	15.000	-----	-----	0.017	0.630	0.332	0.619
Chunchi	B	2.000	29.500	15.000	-----	-----	0.121	1.260	2.410	0.632
Ilaló	B	5.000	35.000	20.000	-----	-----	0.314	3.150	6.232	0.629
Papallacta- Termas	B	1.100	53.000	35.000	-----	-----	0.083	0.693	1.645	0.628
El Tambo	B	1.000	50.000	35.000	-----	-----	0.063	0.630	1.246	0.627
Jamanco	B	2.000	66.000	35.000	-----	-----	0.259	1.260	5.152	0.631
Cachiyacu	B	1.200	68.000	35.000	-----	-----	0.166	2.756	3.291	0.629
Portovelo- Río Amarillo	B	1.200	57.000	35.000	-----	-----	0.110	0.756	2.194	0.632
Tufiño- Aguas Hed.	B	3.000	53.000	35.000	-----	-----	0.226	1.890	4.487	0.630
San Vicente	B	2.000	38.000	20.000	-----	-----	0.151	1.260	2.991	0.628
TOTAL		72.470					5.157	47.625	102.401	

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2014

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

2) Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

3) Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W
projects do not operate at 100% capacity all year

Note: please report all numbers to three significant figures.

Use	Installed Capacity1) (MWt)	Annual Energy Use2) (TJ/yr = 10^{12} J/yr)	Capacity Factor3)
Individual Space Heating4)			
District Heating 4)			
Air Conditioning (Cooling)			
Greenhouse Heating			
Fish Farming			
Animal Farming			
Agricultural Drying5)			
Industrial Process Heat6)			
Snow Melting			
Bathing and Swimming7)	5.157	102.401	0.629
Other Uses (specify)			
Subtotal	5.157	102.401	0.629
Geothermal Heat Pumps			
TOTAL	5.157	102.401	0.629

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2010 TO DECEMBER 31, 2014 (excluding heat pump wells)

1) Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration1)	(all)				1*	0.554
Production	>150° C					
	150-100° C					
	<100° C					
Injection	(all)					
Total					1	0.554

*geothermal gradient hole PGT-1 in Tufiño - Chiles geothermal prospect.

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Progran
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2010	-----	-----	2	-----	-----	-----
2011	-----	-----	-----	13	-----	-----
2012	1	-----	3	-----	-----	-----
2013	1	1	-----	1	-----	-----
2014	3	2	-----		-----	-----
Total	5	3	5	14	0	0

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2014) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	-----	-----	-----	-----	-----	----
2000-2004	-----	-----	-----	-----	-----	----
2005-2009	0,37	-----	-----	-----	-----	100
2010-2015	12,07	-----	-----	-----	-----	100