

Geothermal Map of Perú

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ABSTRACT

The Andes Cordillera resulted from the interaction of the Nazca Plate and the South American Plate. The subduction process occurring between both plates has controlled all geological evolution of such territory since Mesozoic to present time. In this context, magmatic and tectonic processes have allowed the development of geothermal environments with great resources to be evaluated and subsequently developed making a sustainable exploitation of them.

In consequence, Perú has a vast geothermal potential with many manifestations at the surface as hot springs, geysers, fumaroles, steam, etc., all over the country. The first geothermal studies began in the 70's with the first inventory of mineral and thermal springs.

In this work the Geothermal Map of Perú is presented in order to geographically define the zones of the country where geothermal resources are located. Currently six important geothermic regions have been identified: Cajamarca – La Libertad; Callejón de Huaylas; Churín; Central; Eje Volcánico Sur and Cuzco – Puno.

From the analysis of bibliographic information and field studies, it was concluded that in both, in northern and central Peru high temperature manifestations are the result of the geothermal gradient, in which the water flows across deep faults. Whereas in the southern part of the country the geothermal manifestations are related to active volcanism. In this zone the hot springs are of mixed origin, composed by meteoric and volcanic water.

Until now, most of the studies to characterize geothermal resources in Perú have been focused on the Eje Volcánico Sur zone, located in the southern part of the country where several zones with different geothermal importance have been recognized.

Group A: High importance: Tutupaca, Calacoa, Maure, Laguna Salinas, Chachani and Chivay.

Group B: Medium importance: Puquio, Parinacochas and Orcopampa.

Group C: Low importance: Catahuasi, Coropuna, Caylloma and Mazo Cruz.

Finally, it is important to mention that the present status of investigation of geothermal resources in Perú is in the exploration stage. At this point the geothermal map developed constitutes a tool to follow investigations that

contribute in the development of this environmentally friendly resource, for electric power generation and direct uses

1. INTRODUCTION

All over the world the major geothermal potential is associated to discontinuous chains of Plio-Pleistocene volcanic centers that take part of the Pacific Fire Belt, and Perú as a part of this, has a vast geothermal manifestation like hot springs, geysers, fumaroles etc.

The Peruvian Geological Survey - INGEMMET- has traditionally been the first institution devoted to perform geothermal studies that include the first mineral resources and thermal spring's inventory. The first geothermal studies were accomplished in the 70's starting with the first inventory of mineral and thermal springs (Zapata, 1973). The main purpose of those studies was the geochemical characterization of geothermal flows.

Because of the world energetic crisis that could affect Perú's economy, three years ago such objective was taken again as a priority. Firstly all the geothermal information was revised and analyzed in order to support further geothermal studies. In this context INGEMMET has evaluated some interesting areas and has defined other ones, trying to obtain a better background and assessing about our geothermal potential.

With all of this information together with field work we have elaborated a new geothermal map that intends to help in management decisions to be taken on possible investments in geothermic exploration/exploitation.

2. NEW GEOTHERMAL MAP

In order to update the Geothermal Map of Perú (Fig. 1) we used the geothermal map developed by Cossio and Vargas (1979), as a basis along with the INGEMMET Geological Map information at a 1:1,000,000 scale, which was updated in 1999. In addition the Thermal and Mineral springs Inventory Map updated in 2003 (using the information of Huamaní, 2000; Huamaní, 2001; Huamaní and Valenzuela, 2003; Steinmüller and Huamaní, 1998; Steinmüller and Nuñez, 1998; Steinmüller and Zavala, 2003) and the Volcanic Map of Perú developed in 1997 by Fidel *et. al.* (1997) were also considered.

With all these elements we re-defined the boundaries of six geothermal regions (Table 1), and their sub-divisions. Firstly we identified three sets in both Region 1 and Region 2. In Region 5 we have identified four sets and thirteen areas with different geothermal importance. The geothermal map will be in a useful tool to define high priority sites that could be most promissory while at the same time it will support the development of geothermal resources in Perú.

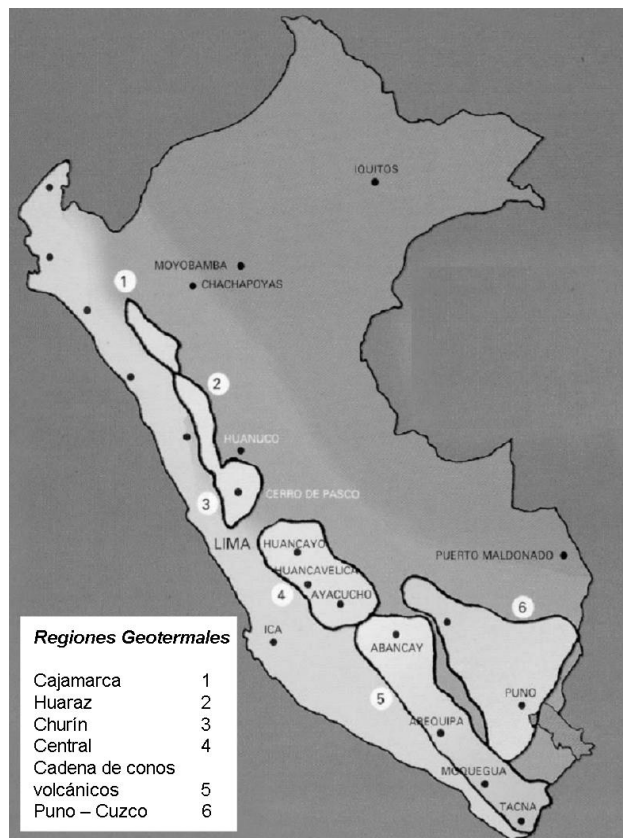


Figure 1: First Geothermal Map of Perú (Cossio and Vargas, 1979).

Table 1: Distribution of geothermal Regions, sets and areas in Perú.

Regions	Lots	Areas
1 Cajamarca – La Libertad	Cajamarca La Grama Otuzco	
2 Callejón de Huaylas	Huaraz Caraz Corongo	
3 Churín		
4 Central		
5 Eje Volcánico Sur	Arequipa Calacoa Tutupaca Challapalca	Cailloma Chivay Chachani Salinas Calacoa Tutupaca Río Maure Puquio Parinacochas Cotahuasi Coropuna Orcopampa Mazo Cruz
6 Cuzco – Puno		

3. GEOTHERMICAL REGIONS

The main tool to update the Geothermal Map of Perú (Fig. 2) has been the hot spring locations, all over the

country. In the last update was done by INGEMMET (1997 – 2003) more than 500 springs with temperatures higher than 20 °C were identified. Likewise these springs are controlled by typical geological structures and formations that also control their dynamics, recharge, storage and discharge.

The hot springs located in the northern and central Perú (Region 1, Region 2, Region 3, and Region 4) have a meteoric origin, where the high temperature manifestations are product of the geothermal gradients. In Region 5 and Region 6 geothermal manifestations are related to active volcanism and in some cases are of mixed origin, the water from precipitations infiltrates and it is heated by a heat source on depth.

3.1 Region 1: Cajamarca – La Libertad

This region has approximately 17,668 km², it is located in the southern part of Cajamarca and northern part of La Libertad. Here more than 30 hot geothermal manifestations have been inventoried. Based on geological issues we defined three geothermal sets called: Cajamarca, La Grama and Otuzco (Fig. 3).

This region is characterized by sedimentary rocks from Jurassic (Chicama formations) and Cretaceous (Goyllarisquiza group and their later carbonates facies). The most important hot spring comes from good porosity and permeability rocks constituted by quartz sandstones. Overlaying these phases and with an angular discordance, volcanic rocks from Calipuy group are founded. Yll these outcrops are strongly fractured because they are affected by Andean tectonics.

In this region no active volcanism seems to occur then hot springs are linked to deep faults where the temperature of water increases as a result of geothermal gradient (Fig. 4).

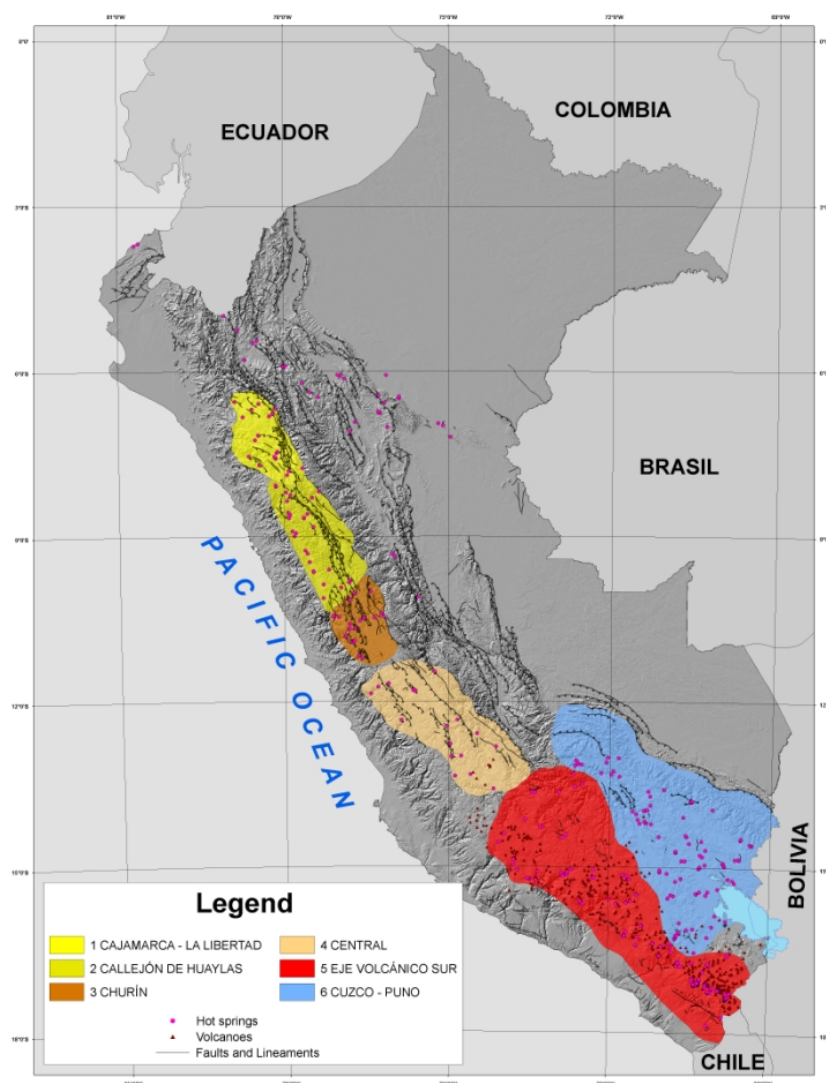


Figure 2: Updated Geothermal Map of Perú.

The temperatures are between 28 °C and 74 °C, values of electrical conductivity were determined to be between 0.01 and 0.49 S/m and pH between 5.9 and 8.1. The maximum flow rates recorded higher than 100 L/s (La Grama hot springs). Some hot springs like “Baños del Inca” emit H₂S and CO₂ steam. Hydrogeochemical classification shows that sodium-chlorided and calcium-bicarbonated are the main water families.

In the 80's geothermal explorations were focused on shallow wells in La Grama sets, but no important temperature anomalies; were found. The gradients observed were between 0.24 and 0.34 °C/10 m (CESEN, 1985).

Most of the geothermal manifestations are used in entertainment and balneology. This is an ancestral use that came from Inca's culture. In Baños del Inca hot spring Atahualpa Inca offered to Spanish conqueror Pizarro, treasures of gold and silver, asking for his freedom.

3.2 Region 2: Callejón de Huaylas

This region has an area of approximately of 27,057 km², is located in the southern mountains in La Libertad, Ancash, and Huánuco zones. Here there more than 40 geothermal manifestations have been found while there sets were defines as follow: Huaraz, Caraz, Corongo (Fig. 3).

In this region outcrops consist of very old rocks like those from Complejo del Marañón (Precambric), the sedimentary rocks from Mesozoic (Chicama and Oyón formations, Goyllarisquizga group) and the Cenozoic volcanic rocks (Calipuy group, Yungay formation) overlaying those with angular discordance. Finally intrusive rocks cut all the mentioned units. The Complejo del Marañón is controlled by an important fault system which is strongly folded forming a complex of large fractures. This configuration and mainly the size of the faults play an important role in the processes of conduction and outcrop of the geothermal manifestations. As in the last region, in this no active volcanism appears, so the thermal springs are associated to deep circulation of natural waters across regional faults, and the high temperature is as result of geothermal gradient in the zone.

The springs temperatures ranges from 24 °C to 60 °C, the electrical conductivity is between 0.01 and more than 0.50 S/m, the pH ranges between 3.2 to 9.7 while most of the springs are acidic. The maximum flow rate is higher than 15 L/s. Some springs emit steam like H₂S and CO₂. The predominant types of water are the sodium-chlorided and sodium-bicarbonated. In this region, many springs have not been discovered, yet. Most of the springs are used are used in therapy and balneology, and one of the most visited sites is called Tauripampa in Huánuco which is used as sauna since it emits.

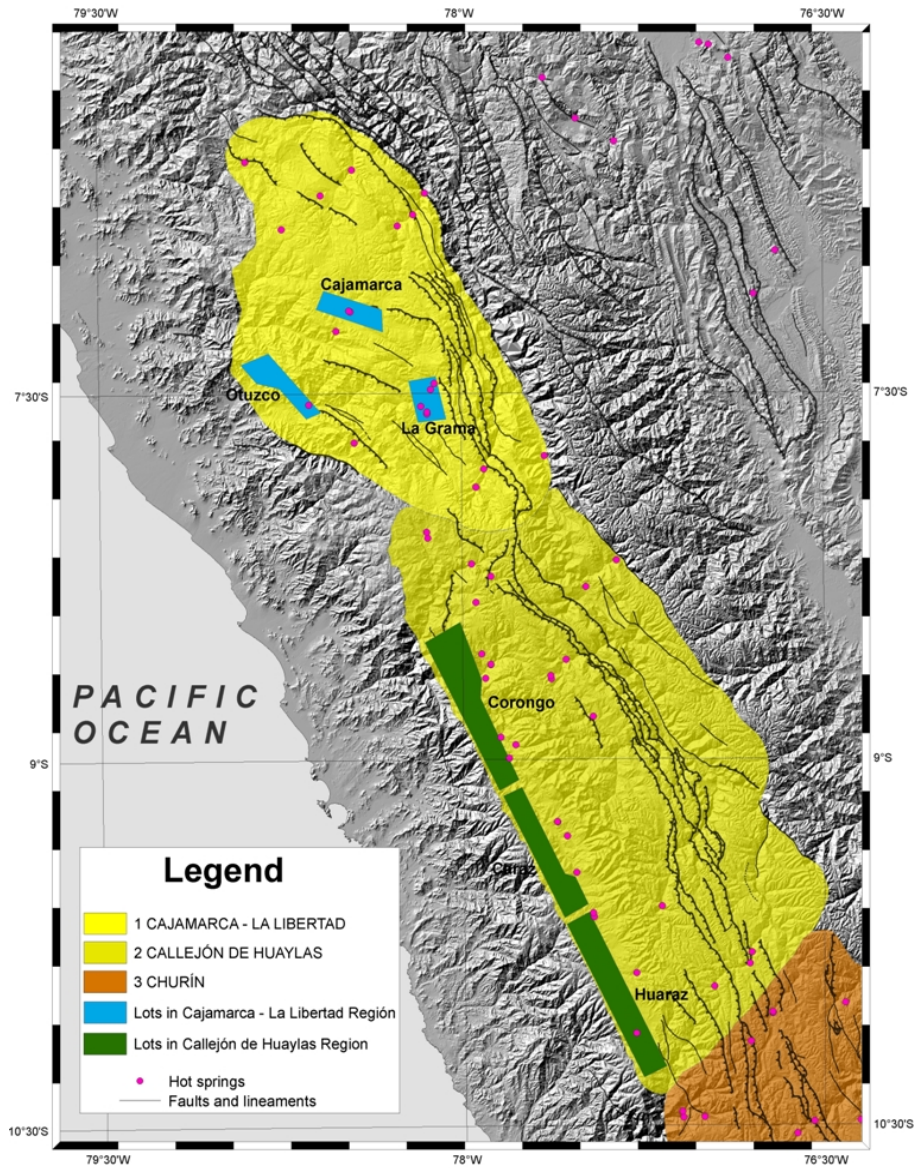


Figure 3: Place of Geothermics sets in Region 1 and Region 2.

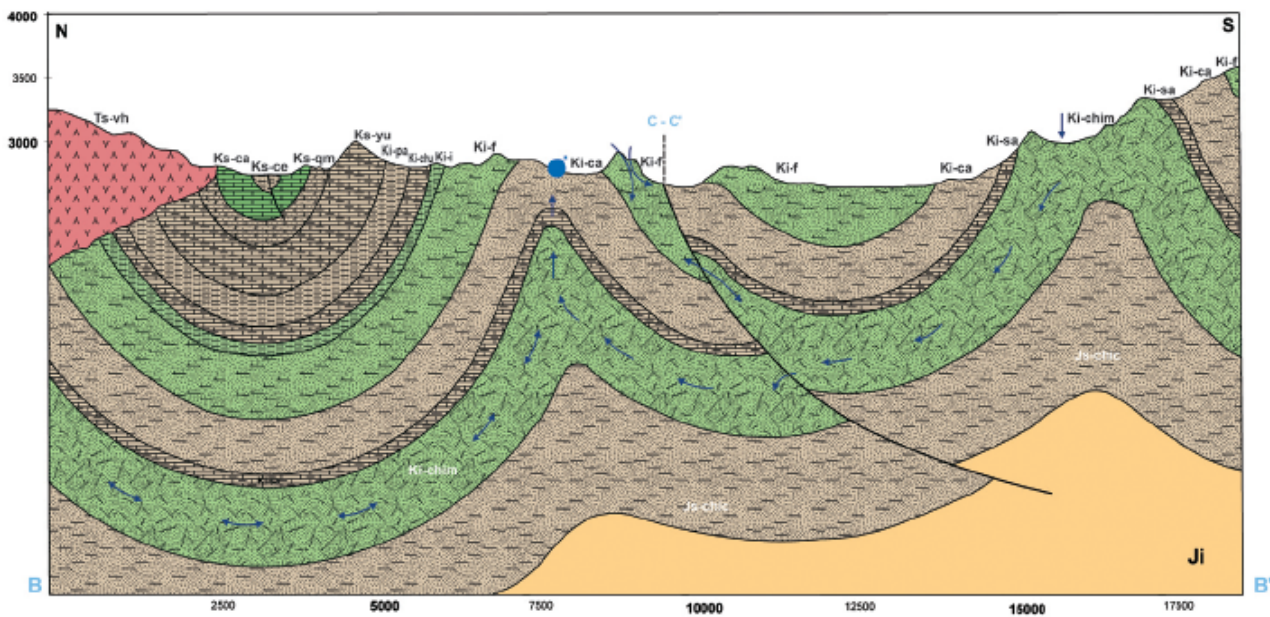


Figure 4: Hydrogeological section in Baños del Inca (Cajamarca) springs (AQUATEST, 2007).

3.3 Region 3: Churín

This region has a 15,392 km² of area and is located between Lima, Huánuco, Pasco and Junín. Here we have around 30 geothermal manifestations occur. Nowadays geothermal sets or areas are not defined yet.

The geological setting is characterized by sandstones, lutites and limestones from Cretaceous. These rocks are strongly fractured by some regional faults. The tectonic structures controlled most of the hot springs which are related to infiltration and movement of meteoric water to depth; here the groundwater increases the temperature as consequence of the geothermal gradient (Fig. 5).

The temperature ranges between 20 °C and 73 °C, the electrical conductivity between 0.03 and 0.39 S/m, the pH between 4.6 and 8.2. The flow rates registered are higher than 5 L/s. In 2006 INGEMMET and AQUATEST recorded the water flow and values of around 20 L/s in La Meseta hot springs were observed. One hot spring in this region emits steam as H₂S and CO₂. The waters are calcium-sulphated and sodium-chlorided types. At this zone no geothermal surveys have been undertaken.

Churín hot spring is well-known because people use this water in entertainment and balneology. In some hot springs mineral drinking water is naturally produced.

3.4 Region 4: Central

This geothermal region is located in Junín, Lima, Huancavelica and Ayacucho, and has an area of 45,858 km². In spite of here we have more than thirty geothermal manifestations occurring in this zone, geothermal sets or areas still have not been recognized.

The old rocks are the volcanosedimentary and metamorphic from Paleozoic (Excelsior, Ambo, Tarma, Copacabana and Mitu groups). Well-known are the marine limestones of Pucara group from Triassic-Jurassic, the sandstones of Goyllarisquizga group and the limestones, sandstones and lutites from Upper Cretaceous – Paleogene. This is a region with complicated tectonic characteristics, there are important and deep faults that control the geothermal gradient and determine the existence of several hot springs principally in sedimentary rocks.

The temperature of the hot springs has a range between 20 °C and 55 °C, the electrical conductivity has values higher than 0.50 S/m, and the pH is between 5.9 and 7.9. The flow rates registered are around 25 L/s. Some manifestations emit H₂S and CO₂ steams. The main waters are calcium and sodium-chlorided types. Some spring are used in balneology, entertainment and production of mineral drinking water.

In this region geothermal explorations have not been carried out.

3.5 Region 5: Eje Volcánico Sur

Considered as the most important geothermal region it has 104,498 km², and includes part of Ayacucho, Apurímac, Cuzco, Arequipa, Moquegua and Tacna. Here more than 300 geothermal manifestations as hot springs, fumaroles, geysers occur. But it is possible that there are a number of undiscovered sites with geothermal springs.

The stratigraphy of this region is dominated by volcanic rocks from Paleogene and specially Neogene, Barroso group; that evidence a recent volcanism. These rocks overlaying Cretaceous and Jurassic substratum (Chocolate formation and Yura group).

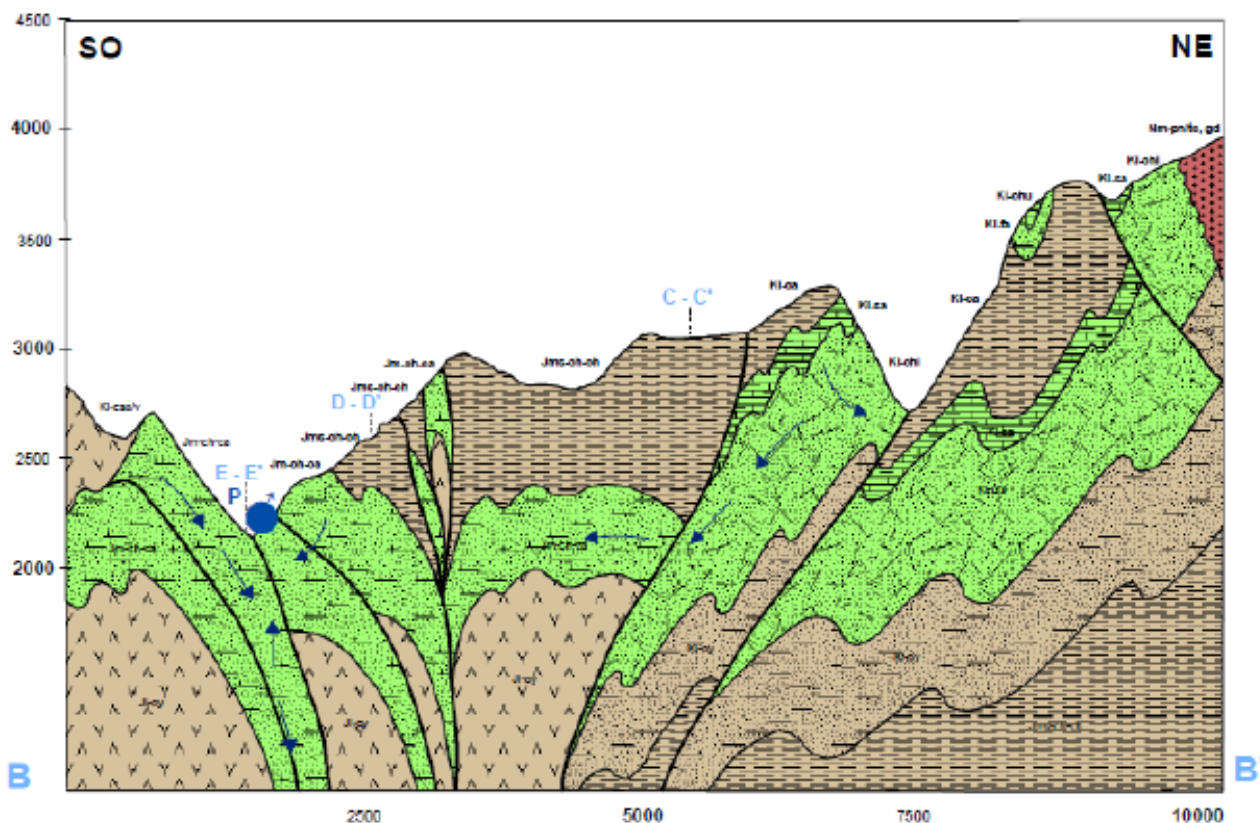


Figure 5: Hydrogeological section that shows a model of the aquifer and hot springs in Churín (AQUATEST, 2007).

In the Eje Volcánico Sur it has been registered the presence of more than 300 volcanic centers where recent activity has been noticed as follows Misti, Ubinas, Ticnasi, Sabancaya, Huaynaputina, Tutupaca and Yucamane.

All the volcanic and structural activity has caused strongly fractured volcanic rocks and the bed rock. This controls recharge, circulation and discharge of the geothermal fluids, in either deep or shallow zones.

The high temperatures registered are caused by the very many heat sources, like magmatic chambers, that are in contact with deep aquifers or by fractured or faulted zones lead the heat towards the shallow aquifers. Some of the hot springs in this region are of magmatic or volcanic origin.

In this region temperatures are between 20 °C and 90 °C, the electrical conductivity is higher than 0.70 S/m, and the pH is in between 1 to 9. Up to 95% of these waters are acidic. The maximum flow rates in individual hot springs are around 5 L/s, whereas a group of hot springs like those in Calientes valley values higher than 60 L/s have been measured. Most of the geothermal manifestations emit steam as H₂S and CO₂. The hydrogeochemical characterization indicates the sodium-chlorided and

sodium-sulfate waters. An impressive number of hot springs are used as tourist places (Pinchollo geyser in Arequipa), entertainment, balneology and drinking mineral water industry.

This is the region where several geothermal investigations have been carried out, and as a result of these surveys we can preliminarily recognized some interesting areas. The investigations made by Barragán *et. al.* (1996); Birkle *et. al.* (1996) and Torres *et. al.* (1997) have identified the following (Fig. 6):

Group A: High importance: Tutupaca, Calacoa, Maure, Laguna Salinas, Chachani and Chivay.

Group B: Medium importance: Puquio, Parinacochas and Orcopampa.

Group C: Low importance: Catahuasi, Coropuna, Caylloma and Mazo Cruz.

Nowadays this region is where some companies have started to development geothermal explorations projects, which are looking for an energetic alternative for this part of Perú.

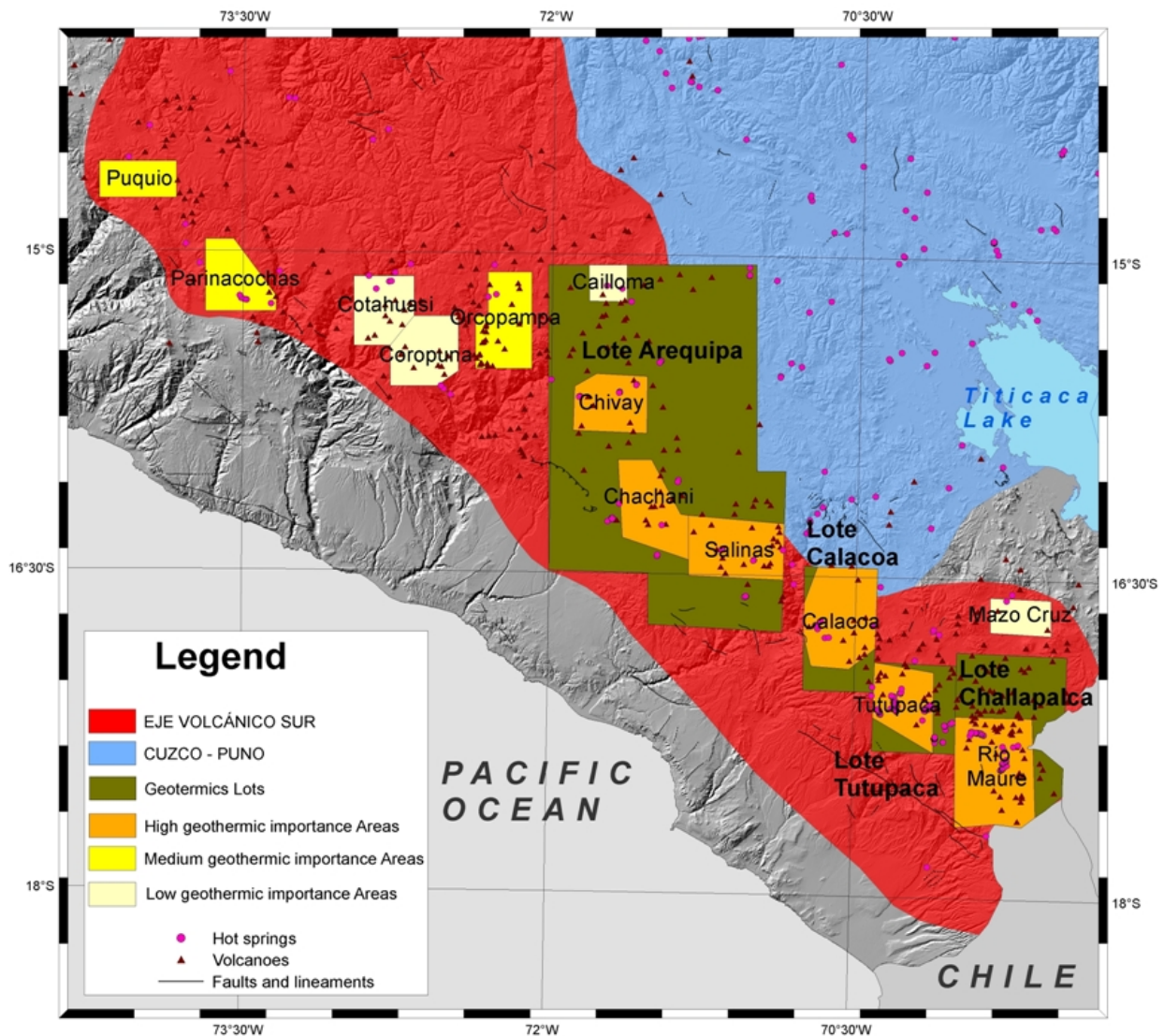


Figure 6: Location of the Geothermics sets areas in Region 5.

3.6 Region 6: Cuzco – Puno

This region has an area of 100,721 km², and is located in Cuzco, Puno and part of Madre de Dios zones. Here more than 90 geothermal manifestations occur, but promissory zones for geothermal investigations have not been recognized.

In this region outcrop shales and quartzites from Paleozoic; sandstones, limestones and volcanic rocks from Carboniferous and Permian – Triassic (Ambo, Copacabana and Mitu groups), followed by sandstones and lutites from Mesozoic and Cenozoic are found.

The geology is characteristic from Altiplano zone, this region is limited by deep faults with NW-SE direction, which control hydrothermal systems. It is recognized that under these deep faults a regional heat anomaly occurs. This seems to explain the high temperature of hot springs in this region.

The temperatures are between 24 °C and 88 °C, the electrical conductivity is between 0.01 and 0.52 S/m, the pH is between 4.5 and 9.8. The flow rates registered are higher than 20 L/s. Some hot springs emit steam as H₂S and CO₂. The waters are classified as sodium-chlorided and calcium-sulfate. Most of the hot springs are used for entertainment, balneology and production of mineral drinking water.

In 1960's a Japanese mission performed recognition activities in this region but there are no more information about this.

CONCLUSIONS

The new Map Geothermal of Perú is a tool that tries to be the starting point in the promotion of the geothermal energy in the country. It will support further studies tending to develop and exploit this resource in the benefit of the society. In spite of the great geothermal potential Perú has, no a complete recognition and exploration studies have been carried out. With this map, geological, tectonic, geophysical, hydrogeological, and geochemical information could be properly integrated.

There are two well defined zones of geothermal manifestations. The regions: 1, 2, 3 and 4 where the high temperature results from the geothermal gradient, where the water flows across deep faults. In regions 5 and 6 the geothermal manifestations are related to active volcanism, in these zones the hot springs are of mixed origin, composed of meteoric and volcanic water.

The potential and the several geothermal manifestations Perú has show us that geothermal development can be achieved to diverse scales and for different uses. The generation of electricity with high-rated projects but also industrial and urban heating and cooling. To achieve all these goals it is necessary to have a technical scientific basis in geothermal resources.

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