Proc. 10th New Zealand Geothermal Workshop 1988

"DEVELOPMENT OF GEOTHERMAL RESOURCES IN PERU"

0. VERASTEGUI

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Edif. La Torre - Of. 903
LIMA 1 - PERU

ABSTRACT

The peruvian territory by be located in relation to Collision Zone of the Continental Plate and Oceanic Plate, in agreement with the Plate Theory, offer good Geothermics possibilities.

Studies performed have identified the following zones of interest evidently priorited by ELECTROPERU S.A.: Callejón de Huaylas, Otuzco, La Grama, Cajalacoa, Tutupaca-Calientes and Challapalca.

The paper summarizes the most interesting aspects and the inssue obtained from the Geothermics investigations done up to date.

PROLOGUE

The energetical crisis around the world, generated by the uncontrolled increase of the cost of oil since 1973, has occasioned that in the Master Plan of Electricity it is considered the replacement of the energy obtained from those non-renewable resources by Hidroelectric Plants and the research of new energetical resources able to replace effectively these combustibles.

The study of new non-conventional fountains has considered the Geothermics, and its development according to the General Law of Electricity N° 23406, May 1982, is made by the statal enterprise ELECTROPERU S.A., which plans to increase the study and projections in order to achieve a rapid and extensive use of this natural resource in the peruvian territory.

CHRONOLOGICAL SYNTHESI OF DEVELOPED ACTIVITIES:

The activities made in Peru chronologically are the following:

1975.- The statal enterprise MINERO PERU S.A. made preliminary studies of geological exploration and geochemistry in the area of Calacoa, in Moquegua.

1976.- The Japanese enterprise Geothermal Energy Reserch and Development made studies of Geothermal acknowledgement in the surroundings of the towns of Sicuani, La Raya and Quisicollo in the region of Puno-Cuzco; the geothermometric results determined good perspectives in La Raya and Quisicollo.

1978.- The Instituto Geológico Minero y Metalúrgico (INGEMMET) made an inventary of the thermal activities known in the peruvian country and clustered them geographically in six (6) regions of interest called:

Region I	Cajamarca-La Libertad
Región II	Callejón de Huaylas
Region III	Churín
Region IV	Central
Región V	Cordillera Volcánica del Sur
Región VI	Puno-Cuzco

These regions are marked in the map N° 1.

1979 to 1980.- The italian enterprise AQUATER an INGEMMET of Peru, with the economical support of OLADE made a study of Geothermal acknowledgement that covered the Region V. The issues obtained have let it identify and prior those areas of interest that show all the favorable Geovolcanological and Hydrochemical conditions to find Geothermal systems; those areas *are* Tutupaca, Calacoa, Challapalca, Laguna Salinas, Chachani and Chivay, all of them marked in the map N° 2.

I980.- The american enterprise Geothermal Energy Systems Ltd. (GES) by order of a private enterprise made studies of Geothermal acknowledgement in the areas of Salinas, Calacoa and Tutupaca with good Geothermometrical issues.

1979 to 1983.- ELECTROPERU S.A. develops institutional activities such as: Participaton of three (3) of his engineers in the Geothermal specialization courses in Italy, Japan, Colombia and Mexico; efforts to archieve a permission in order to explore the areas of Calacoa, Tutupaca and Challapalca; elaboration of referencial terms for studies of possible new geothermal resources in these areas; efforts to get internatio - nal technical cooperation and establishmant of the Geothermal Investigations Unit.

1982 to 1986.- ELECTROPERU S.A. and the Centro Studi Renzo Tassel 1i (CESEN) from Italy, signed an agreement of Technical and Economical Cooperation in November 18th. 1982, in order to perform a study of Geothermal acknowledgement in the zones of Cajamarca-La Libertad, Callejón de Huaylas, Churfn and Central in an approximate area of 100,000 km2, which gives more priority to the areas of Callejón de Huaylas, 0tuco, La Grama, and Cajamarca (map N° 3). According to this agreement, in 1985 a first phase of study of Pre-Feasibiiity was held in La Grama, determining non-intereting temperature values inside the Reservoir for electric energy generation.

1983 to 1985.- INGEMMET and the Bristish Geological Survey (BES), according to a Technical Assistance Agreement, made a preliminary inventary of the Geothermal activities in the Region VI Cuzco-Puno, determining in some areas Reservoir temperatures of 160°C.

1986.- ELECTROPERU S.A. and the Organización Internacional de Energta Atómica (OIEA), according to the agreement made the year before, made Geochemical investigations in the Geothermal Region V. The prelirrn' nary issue shows excellent characteristics in Calacoa and Calientes with orders of marking some other determinations in other areas.

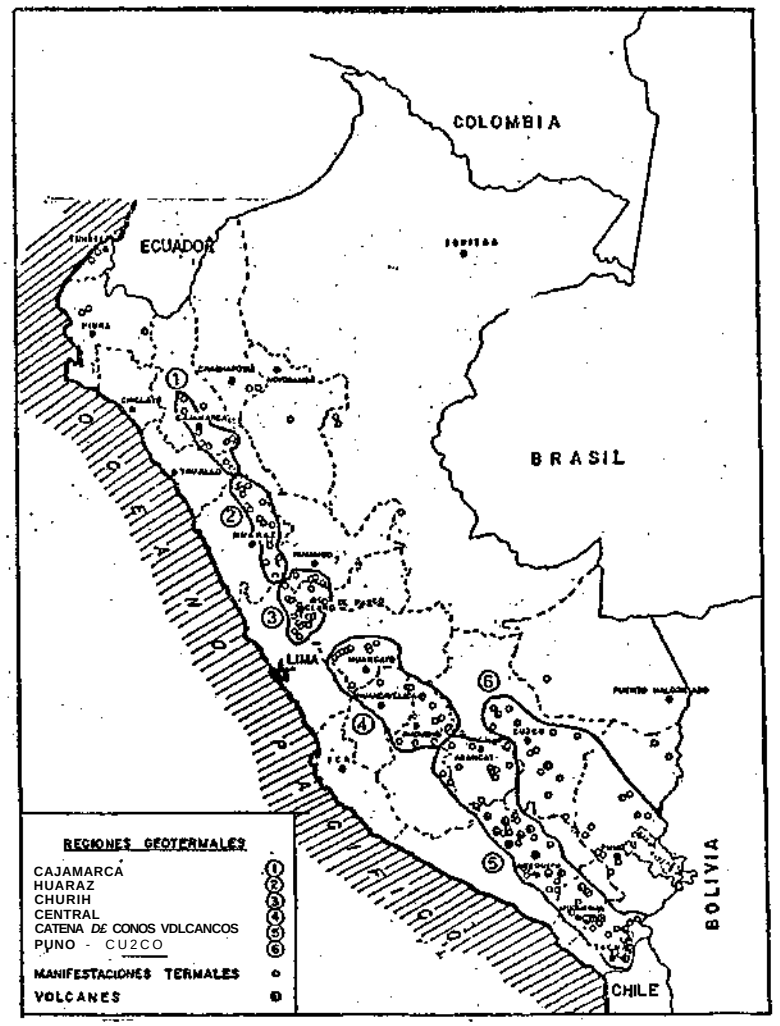


Fig. 1 : Map of Peru and Its six groups **of** Thermal **Springs on Geothermal** Regions.

ISSUES OBTAINED IN THE MOST INTERESTING AREAS:

According to the studies made, the most interes - ting areas have been determined and their characte - ristics are described very briefly in the following 1ines.

A.- GEOTHERMAL PROJECT CENTRO NORTE

- Area Callejón de Huaylas

Located in a prolonged area with approxima^- te N-S direction from the Cabana town in the North to the Chiquian town in the South, including the Rfo Santa valley,

The Stratigraphic sequence is constituted by sedimentary rocks, volcanic-sedimentaries, volca nic and intrusives, with an age between the Superior Jurassic and the Recent Jurassic.

The tectonic processes are related principa lly to the intrusion of the Batholit and appear with parallel fault systems in their borders, .specially on the occidental side, though there are some trans'- versal tectonic processes (North of Huaraz) that show certain activity that affects Quaternary grounds. In the South of Huaraz a system of active faults sub- parallel to the main Andean fault has been identified and its occidental blocks have suffered descents.

As a cosequence of the superior formations, Cretaceous and Tertiary, that are generally permea - ble and outcroping, the possible Geothermal goal (Re servoir rock) could be located under the Chicama fo7 mation (Basement with unknown structure) having it as a water-tight cover unit.

The possibilities of overloading would be given by the precipitations that reach an estimate of 700 mm./year and thaws filtration water, noticing that the theoric filtration average of the basin is of 250 mm./year.

The thermal activities are performed by springs (17) that reach emergency temperatures of 90° C and have two kinds of chemical structure principa- lly: sodium chloride and sodium bicarbonate with 3300 degrees of salinity and 600 mg/1 respectively.

The Geothermometers indicate base-temperatu_ res for Na/K 180°- 200°C and $Si0_2$ 120°- 200°C. The contents of Boron is medium-high of 15-180 ppm. with an increasing distribution from the North to the South.

The Heat fountain could be connected with a heat transmission towards an upper level caused by the remelting and rising of amazing quantities of magma and phenomenons related to the contribution of the Pacific Plate, Another cause could be the "Res_i_ dual Heat" as consequence of the long (from 112M.A. to 12 M.A.) and regularly continued activity intrusi- ve of the coastal Batholit. Besides we can suppose logically that the active and deeply developed faults along the Cordillera and to the West of the Santa river, work as heat transmission ways. The Batholit

of the Cordillera Blanca that shows signs of recent activity (Quaternary faults strong sismic activity) and which evolution has not finished yet and it is p£ ssible that its root keep a high temperature- could be another Heat fountain.

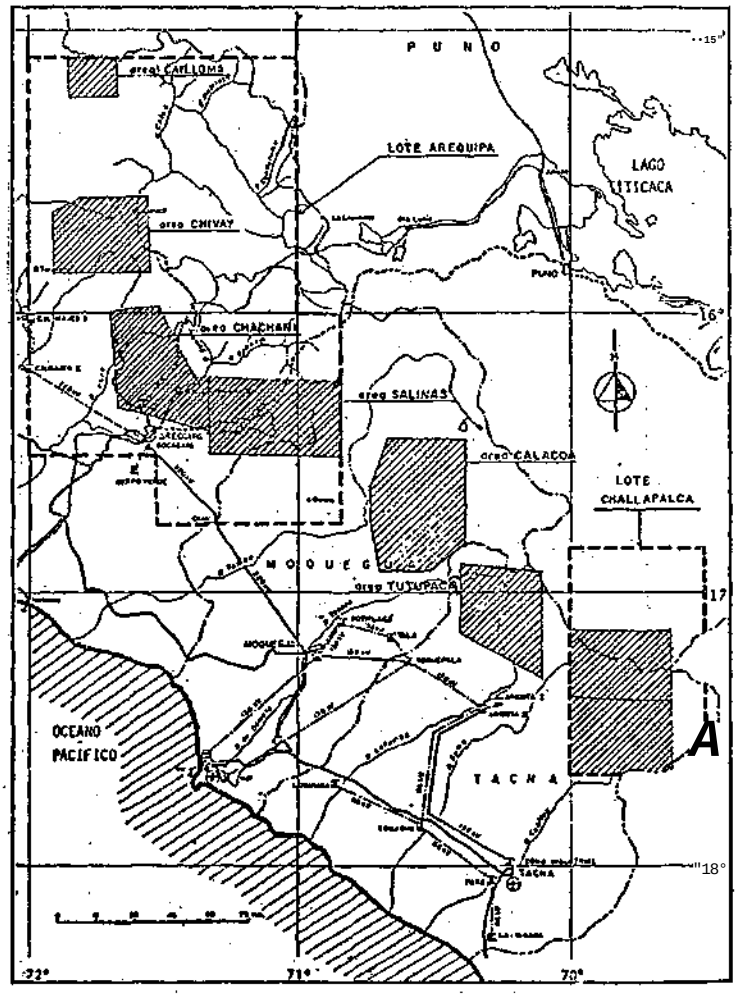


Fig. 2 : Map of Promising areas en the V Geothermal Region, Challapalca and Arequlpa sites.

- Area Otuzco

Area located along the northern side of the Chicama river-Huancay river covering an approximate surface of 600 Km2 between Ascope and the Hacienda Chuquizongo.

The Strat igraphic sequence is performed by sj2 dimentary units, volcanic-sed imentar ies and intrusi •? ves, which ages are from the Superior Jurassic to the Quaternary.

The zone is related to the Anticline of Lucma with NO-SE direction, in which nucleus crops out the shales of the Chicama formation; the faults and pleats in general follow the Andean lineament.

The Reservoir could be constituted by the Za- na formation, or the Pucará Group (Superior Triassic- Inferior Jurassic), which isn't determined yet, becaji se this zone would be the transition limit between both units. In any case the cover is constituted by the Chicama formation (Superior Jurassic).

The overloading is produced principally by the precipitations of about 200-500 mm/year.

The thermal fountains *(h)* emerge in the zone of contacts of the Chicama and Chimú formation and in correspondence to the transversal faults related to the Anticline structure with emergency temperatu- res that reach 7^°C and belong to the ffeld of the sodium chloride, have average salinity and good con- tents of Boron (10 mg/l), which makes it suppose that the come from a deep environment with a circulating time that lets interactions with the surrounding rocks.

The Geothermometrical indications of Na/K gi- ve values of temperature of about 23O°C; the Na/K/Ca of 190°C approximately, Na/Li of 250°C and SiO_2 corre ted 190°- 200°C. The correlations among isotopes show characteristics of meteoric water for the four samples.

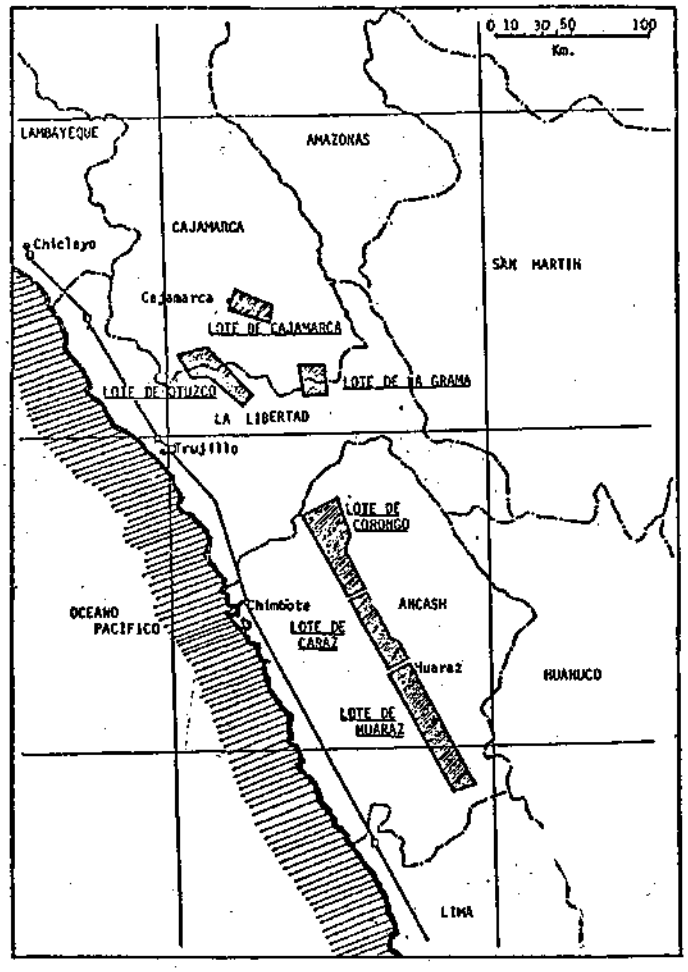
The heat fountain can be product of the most recent intrusives like Geodynamic phenomenons that still exist or the "Residual Heat" of the magmatic complex of the coastal batholit,

- Area La Grama.

Located between the provinces of San Marcos and Cajabamba (North and South respectively), from the department of Cajamarca, centralized in the con- fluence of the Cajamarca and Condebamba rivers, which union originates the Crisnejas river.

The stratigraphy of the zone is compound by sedimentary units with comprehensible ages between the Superior Jurassic and the Quaternary. The igneous are performed by sub-volcanic rocks that crop out in from of dikes in the surroundings of the thermal springs of Aguas Calientes and belong to the Tertic ry.

The area studied occupies the central part of a "Hingepoint" where the structures proceeding from the South plaited Andean direction get bran - ched off following in part the same northern direc- tion, which has caused an intense local tectonism with frequent sprains, faults in all directions and transversal deformations concerning to the structu- re axis.



F !g. 3 : Map of Promising areas fn the Geothermal Centro-Norte Project area.

The Reservoir will probably be constituded by the Pucará Group (Superior Triassic - Inferior Jurassic) that crops out 30 Km, at the western part of the area, having as cover the water-tight shales from the Chicama formation (Superior Jurassic).

The water samples belong to the sodium chloride and calcium bicarbonate kinds and show high contents of Boron and Lithium (Until 7.5 and 1 ppm respect ively).

The Geothermometers indicate the following temperatures: Na/K 200°- 220°C, Na/Li 2^0°- 260°C, Na/K/Ca— 180°C, S1O2 corrected~2^0°C. The isotopic analysis show that the water is principally of tectc nic origin.

It is possible that the thermality is caused by the superpositios of a regional geothermal anomaly correlated with the thermodynamic phenome - nons that still exist, or to the residual heat of the most recent episodes of the coastal Batholit.

The investigations of heat flux made as part of a 1st, phase of pre-feasibiiity studies determined non-interesting temperature values inside the Reservoir for electric energy generation. The Geophysics studies (insufficient) found a resistant basement at about 2000 m. of depth.

- Area of Cajamarca

It is located in the alluvial plain that surrounds Cajamarca city and its surroundings.

The formation units are constituted by sedimentary and volcanic rocks of ages comprehended between the Inferior Cretaceous and the Quaternary.

The zone of Cajamarca is considerably affected by effects of the pleats and faults as a consequence of the compression phases of the two latest cycles of the Andean Orogenies.

The Pucará Group (Superior Triassic - lnf£ rior Jurassic) probably constitutes the Resevoi.r, performing the Chicama formation (Superior Jurassic) as a coyer.

The chemical analysis made on the water sani pies (21) have determined two main families: bicarb£ nates (of persistent superficial circulation and low thermality) and sodium. Both of them with low salinity.

The Geothermometers have indicated the foll£ wing temperatures of depth: S102 110°C, Na/K 200° - 220°C, Na/Li 170°- 200°C and SiO_2 corrected 132°C. The samples according to the isotopic analysis show persistent characteristics of meteoric waters.

A heat fountain can be considered as a regi£ nal thermal anomaly related to the existence of Geodynamic phenomenons under the occidental edge of the country. Other causes can be more recent intrusions not confirmed and related to the activity of the coastal Batholit, The presence of active and deve - loped faults in depth could influence the thermal sj_ tuation as a circulation vehicle of the fluids and as a preferencial line of raising of magmas.

B,- SOUTH WEST GEOTHERMAL PROJECT,

- Area Calacoa.

Located in the sierra zone of the departa - ment of Moquegua, to a height of ^000 m.s.n.m.

The stratigraphic sequence is constituted by volcanic sedimentary rocks and sedimentary-volcanic whick ages are comprehended Between the Superior Jurassic and the recent.

The area is located in a volcanic complex formed in the intersection of three regional structjj ral systems; the Andean NO-SE; another NE-SO and posibly the oldest ENE-OSO. This complex belongs to a volcanic structure of explosive kind in which several Quaternary domes have been developed over a NNO-SSE alinement and in which one of them (Ticsani volcano) is of dacitic composition, with an age, determined by the K-Ar method, of 190,000 years, that places it in the Pleistocene.

The possible Reservoir could be constituted by permeable sedimentary rocks (Groups Puno and Yura from the Superior Jurassic, Inferior Cretaceous and Inferior Tertiary, respectively), and/or by the volcanic rocks strongly tectonized with secondary per - meability of the Tacaza Group of the Tertiary.

The thermal manifestations are principally springs, but there are fumaroles and geysers too, located in the valleys of the Chingane and Putina rivers, according to structures of faults of NE-SO direction. The highest emergency temperatures are comprehended between 5**°- 90°C.

The waters are principally of the sodium chloride kind, specially with the following chemical characteristics:

$$Na^{+} > Ca^{++} > K^{+} > Mg^{++}, \quad Cl^{-} > SO_4^{=} > HCO_3^{-}$$

The isotopic analysis have verified that the re are fluids with high temperature circulation.

The Geothermometers indicate the following temperature: SiO2 110°- 16O°C, Na/K 18O-19O°C, Na/K/Ca 179°- 186°C, Na/K/Ca/Mg 114°- 130°C, Na/Li 189°- 196°C, K/Mg 102°- 111°C, Chalcedony 250°- 298°C and amorphous silica 133°*" 17^°C.

- Area Tutupaca-Calientes

The area is located in the departament of Tacna and comprehends the oriental side of the 0ccj_ dental Cordillera and the peruvian Altiplano.

In this area the stratigraphic sequence is compound by sedimentary and volcanic rocks which ages vary from the Superior Jurassic to the recent.

Four structural systems have been identi fied: one very old with NE-SO direction, then ano - ther old N-S, the Andean NO-SE, and a recent one E-0.

The volcanism of PIio-Quaternary age is the most diffuse and is principally of central kind. At the beginning it was andesitic; through the time it has moved its emission centers to the NO folio - wing the andean structural trend and changing its composition to dacitic, so that the newest elements are located in the NO area, in the intersection of the structures of NO-SE and E-0 faults. The ages determined by the Ar-K method over acid domes is of 100,000 years.

The Reservoir can be constituted by perme£ ble sedimentary rocks (Yura Group of the Superior Jurassic - Inferior Cretaceous) or volcanic rocks with secondary permeability (Volcanic Huilacollo of the Tertiary medium).

The thermal activity is performed by fuma- roles, mud volcanoes and springs principally to the SE and 5 of the Tutupaca volcano and located in the structures of calderic collapse Ravines Azufre Gran de and Azufre Chico) in the crater made in the plaTn of Turun Turun and in the structure NO-SE that fo -r llows the Tacalaya river. The springs have an emergency temperature that reaches 87°C

The waters are principally sodium sulphate and calcium with acid pH.

According to the chemical composition of the gases, some samples of different Nitrogen con * tents can be considered as a product of a mixture bet ween a thermal fluid and different amounts of super- ficial waters that are initially balanced in the Atmosphere.

The SiO2 Geothermometers indicate tempera-tu res of 18O°C, the ones of Na/K until 2A0°C, Na/K/Ca 159°C - 190°C, Na/K/Ca/Mg 79°- 197°C, Na/Li~200°C, K/Mg 107°- 18**°C and the gas Geothermometers indicate temperatures of 235°- 325°C

- Area Challapalca

It is located in the departament of Tacna, to a height of ^,000 m.s.n.m,, in the morpho^structu ral unit called Altiplano, surrounded by positive forms that belong to volcanic elements, some of them compound, which age is calculated between the Miocene-Pliocene and the Quaternary.

Volcanic and sedimentary rocks which ages are comprehended between the Superior Jurassic-* Inferior Cretaceous and the Quaternary form the strati graphic sequence.

In the area four faults systems have been identified: the old NE-SO, the Andean NO-SE and two recent systems, one N-S that even has affected the Purupurini dome (of 100,000 years) and other E-0 in the Morocollo plain which seems to control partially the current of the Maure river, considering that the Andean tectonic has originated a faultment in blocks, producing a regional "Graben" kind structure.

The most recent volcanism is performed by the Purupurini domes of dacitic composition and which must be associated genetically to, structure crossing of the NO-SE Andean system and N^,The heat fountain must be related to this magmatiam.

The Reservoir can be constituted by sedimentary rocks of the Yura Group (Superior Jurassic - Iji ferior Cretaceous) or the volcanic rocks with secondary permeability of the volcanic Huilacollo (Tertia ry medium).

The thermal activity consists principally of springs which emergency temperature reach 87°C.

The waters are principally of sodium chloride kind, with high contents of Boron that oscillate bet* ween 1^12 and 8706 mol/1 $10^{\wedge 3}$.

The isotopic facts indicate that the thermal waters are product of a mixture in different percentages between fluids of deep origin and superficial waters.

The temperatures calculated according to the SiO2 Geothermometer reaches values of 192°C, while the Na/K/Ca one reaches values of 18^°- 212°C, Na/Li 20i*°T 2i*0°C, Na/K/Ca/Mg **3.5°- 179°C, K/Mg 87^{0}- 183°C, Na/K 182°* 232°C.