THERMAL MODEL OF THE LOW ENTHALPY RIO VALDEZ GEOTHERMAL FIELD TIERRA DEL FUEGO, ARGENTINA

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Key words: geothermal exploration, thermal waters, Tierra del Fuego, Argentina

ABSTRACT

The Isla Grande. in Tierra Del Fuego is located in the southernmost tip of South America. A low enthalpy thermal center is placed in its northern part, approximately at a longitude of 67° and a latitude of 54°. The main characteristics of the area will be discussed in this paper since it has been discovered recently and it has been not been mentioned in the international literature so far. These shows compromise hot springs and gaseous emanations distributed in thirsteen springs structurally controlled. The uprising of the fluids towards the surface is originated in the interception of transtensive structures (N20-25°) that tear the main external front of the Fueguina Cordillera. The thermal water originated as meteoric water, become an homogeneous group with a residence time longer than 20 years, they are bicarbonate zodiac with a ph between 7.8 and 8.2 and conductivity values from 631 to **658 µs/cm,** with a caudal of 65,200 l/h. The existence of a reservoir model following the intersection of structures joints and fractures within the metamorphic rocks where the fluids are accumulated at temperatures between 88 and 98°C.

INTRODUCTION

In April 1991 a survey of the south-east sector of the Fagnano Lake was carried out confirming the presence of the thermal shows in the area. Later a project of susesive studies was elaborated covering a wide range of scales, from regional to detailed surveys in order to select the location a study well.

At first, regional and detailed geological surveys, the geochemical analyses of the thermal and cold waters, the geothermometry, the tectonic of the area, and the mesoscopic characteristics of the geological structures, were carried out in order to establish the most interesting area from an economical viewpoint and to define a Preliminary Thermal Model. In the following stage, gravimetric and magnetoteluric surveys identifying the structures and the depth of the reservoir were carried out in the most important geothermal area that coincide with the most economically interesting area. At present, with all the data available a geoscientific synthesis is being conducted trying to determine the locations to drill the exploratory wells.

This project is aimed at evaluating the thermal potential of the area and to transfer the resource to private companies for its exploitation. This area could help to the economic development of the Tierra del Fuego Province. An international winter resort is planned based upon the availability of the thermal hotsprings and also the possibility of practicing winter and summer sports. Taking into account the climatological characteristics of Tierra del Fuego, with its long and cold winter, the geothermal energy could be used in a variety of applications.

The Rio Valdez hot springs are located over the northern base of the Fueguina Cordillera (Figure 1) 10 Km south from the eastern tip of the Fagnano Lake, in the Province of Tierra Del Fuego at 200 m a.s.l..

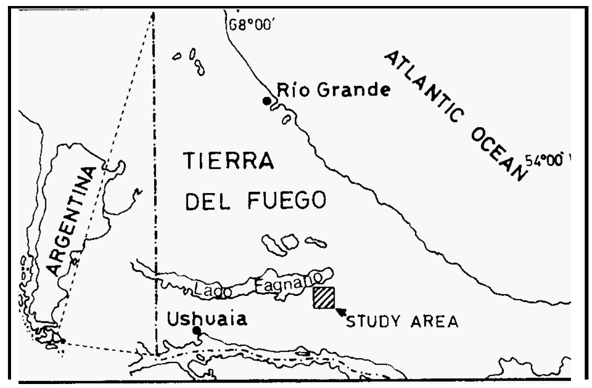

Fig. 1 Location map of Tierra del Fuego

The present work shows the results of the detailed geological, tectonical and water geochemistery surveys, and the preliminary geothermal modeling that constitute the first stage of the project.

ANALYSIS AND INTERPRETATION OF THE THERMAL CHARACTERISTICS

a. Geothermal Framework

The stratigraphy of the area is represented by the Lemarie Fm. (Borello, 1969, 1972) and the Yaghan Fm. (Krank, 1932) which constitute the main nuclei of the Fueguina Cordillera, the natural prolongation of the Patagonic Andes, and by Quaternary deposits (Figure 2).

The area of study is located at the base of the northern external front of the Fueguina Cordillera that made the volcanic and metasedimentary elements of Lemaire Fm. and the Yaghan Fm. to lay over the Neogene deposits of the foreland basin developed to the north. This fron part is dislocated by transversal structures (NNE) dividing the Fueguina Cordillera into a series of sierras developed sublatitudinally (Pesce, 1992). All these major stuctures are related temporal and geometrically to the senestral sublatitudinal transpresive Andes Tectonics, typical of the Fueguina Cordillera, being active since the Eocene (7) according to Dalziel and Palmer (1987), Cunningham (1993).

Lemaire Formation

The oldest unit is the Lemaire Fm. formed by solid beds of acid vulcanites and dynamo-metatnorphized piroclastics which transitionally becomes the Yaghan Fm.. At a Regional scale, their main components are lavas and ryolitic tuffs and dacites to ignimbrites, with tuffaceous, sandstones and conglomeradic intercalations (Caminos et al, 1981). The outcrops are composed, at the base by light grey rhyolitic porphyry, formed by quartz and felspar phenocrystals in a fine grain matrix. Quartz is the most abundant mineral, its phenocrystals are rounded. Felspars (Plagioclase and potasic plagioclase) are found in subordinated quantity. The alteration to epidote, sericite and chlorite is generally common and the beds are affected by dynamic metamorphism, with cleavage and pseudofluidality development.

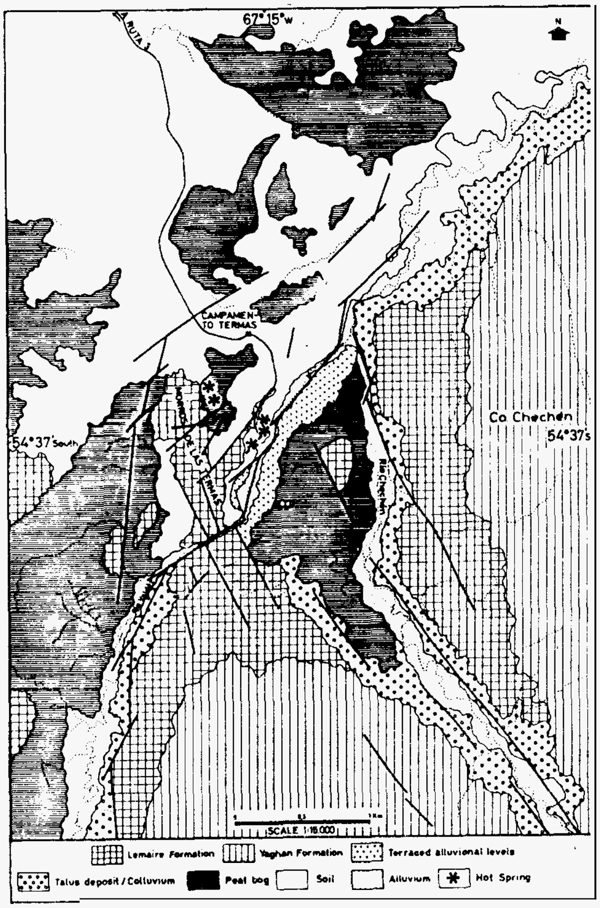

Fig. 2 Rock-statigraphic map with the main outline Río Valdez thermal area

This unit, dated early to upper Jurassic, crops out inthe study area and in the lower levels of the mountains by the Valdez and Checken rivers.

A sequence of crystaline tuffs of clastic textures formed by quartz crystaloclasts, sericited plagioclase and scarce biotite associated with vulcanic lithics. These rocks are folded and the micas tend to reorientate according to the S2 direction, coinciding with the axial plane of the fold.

Yaahan Formation

The yaghan Fm. consists of a regionally metamorphized marine sequence (metagraywacke phrenitic-pumpelliticfacies) formed by slates phyllites and carbonaceous shales with rythmic strtification and intercalations of beds of basic composition, crops out in the middle and upper parts of the area hills. Based upon the finding of Chondrites sp. Belemnites and ammonites Gender Favrella) the Yaghan Fm. was tentatively dated as Tithonian-Lower Cretaceous (Caminos et al, 1981).

The petrographic studies aliowedto interprete the outcropping metamorphics in the area of study as low degree micaceous quatzitic schists Formed by quartzitic levels and also micaceous levels (Muscovite) in some cases with granate and scarce lensitic levels of magnesian chlorite (Page et all, 1993). They are crossed by hydrothermal quartz veins (Mosaic texture). The fine laminationslates prevail in this units. They represent a low degree of metamorfism and a S1 cleavage developed through them, resulting in the orientation of the micaceous mineralsIt shows long wave foldswhich locally produce the reorientationof the micaceous minerals.

b. **Geology** of the Thermal Area

In the location where the most important economical area was delimited, the Lemaire Fm. is the basal geological unit and it is formed by rhyolitic and pyroclastic facies with quartz veins. Their rocks crop out in the Termas mounts (figure 3) together with terrace levels and pit bogs as follows:

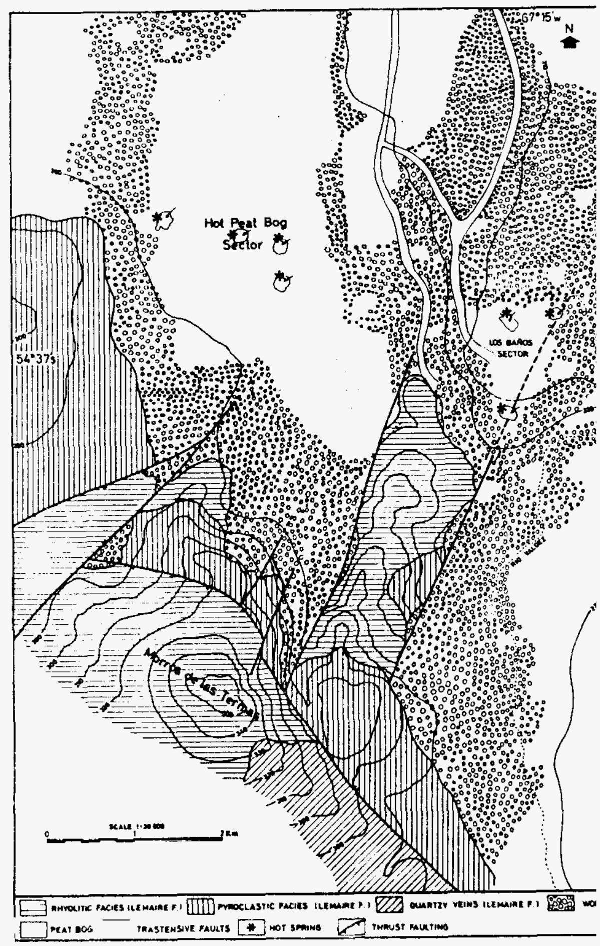

Fig. 3 Geological map of the area study showing distribution of stratigraphic units

Rhvolitic facies (Lemaire Fm.): It is represented by rhyolites (and/or dacites) with fine texture and sometimes by withish grey porphyres placed in the basal portion of the Baños mount. They are formed by phenoclasts of fragmented plagioclase (andesine-oligoclase) partialy replaced by albite scarce epidote and sericite and corroded quartz and scarce chloritized fringed biotite crystals. The groundmass has a multigranular texture formed mainly by acid plagioclase and quartz (Pesce, 1993). The minimum estimated thickness is 150 meters. Its contact with the tuffaceous member is transitional in a few meters, showing in during this period a prominent flaggy aspect. In these sectors, they develope a delicate milimetric foliation.

Pyroclastic facies (Lemaire Fm.): It is represented by wll stratified and laminated whitish pyroclastics located in the upper portion of the Los Baños mounts where they form compact and massive outcrops with grat milky quartz veins, having a clastic texture formed by crystaloclasts of potash felspar, weakly argilized. albitized and/or sericited individual crystals of potash plagioclaseand titanite cristaloclasts associated to very fine grain lithics. The micacitic matrix is abundant (50%) with evidence of recrystalization in two preferential orientations (Pesce, 1993). They crop out with a minimum thickness of 80 meters, and towards the summit the stratification controls gentle slopes of the relief insumed under the very vegetated plain developedto the southof the area.

Quartz veing: The rocks described before show milky siliceous venulations arrenged as irregular isolated veins or as sets of stepped fractures (gashes in echelon) or in anastomosed arrangements. Due to their spatial and temporal relationship with the dynamomethamorphized rocks containing them and the tectonic environment they are developed in, the fact that these venulations are produced by metamorphic mechanical segregation can be considered (Hodgson, 1989). Pre, sin and postgenetic veins can be recognized respect to the penetration cleavage (S1) and even related to the brittle stage (S3)as they enhance the discontinuitythey produced.

Terraced alluvional levelg: A first alluvional bed lays on the preceeding lithologies (Terrace 1) formed by holocenic psephitic, psamitic and pelitic levels (Caminos, 1980) originated by the redeposition of the material of glacial and fluvioglacial origin. They form groups roughly stratified in an horizontal way. The minimum thickness that can be estimated by the Río Valdez is 20 meters. The Río Valdez drains a presently narrow alluvional plain, running inside a canyon where it cuts the mountains fronts formed by the Lemaire Fm..Then, it widens until it loses its morfologycal identity in the downward slope formed by the coalescence of fluvial and colluvial fans that reach the Fagnano Lake.

Soils: Over the terraced levels a potsolized edaphic horizon full of organic matter developed on which the Austral forest (Notophagus sp.) is found. In flat sectors with a minimum drainage, peat bogs appear (Sphagnom sp.) developing at present that reach 2 meters of thickness.

c. Structure of the Thermal Area

The present estructure of Tierra Del Fuego Cordillera is the result of sussesive superimposed deformations episodes that gave the rocks a high degree of dynamic metamorphis. In the survey performed in the Termas mount a great quanti of fault planes, joint sets, strikes and dips of strata and fracture dips were measured, that associated with the microstructures make evident the complexity of the superposed systems.

But the most relevant feature with regard to this study is the present tectonic. This is shown in the modification of the geomorphologic characteristics of the relief are reflected in the displacement of streams, talus slope. Most of these structures correspondto the reactivation of old fractures that cut meanders, resent escarpments and produce the sinking of current lands.

The structural analysis made in the most important thermal sector (Figure 2) allowed to confirm that the thermal manifestations could be associated with the reactivation of old structures, probably conected to recent dislocation planes. The area Termas Mount is dislocated by a set of sublateral structures (N20-25°E) which are related to high angle direct faults. This set of deep structures would be associated with plane sets with a strike of N60°W and N45°W this fault sets have originated the upward way of the thermal fluids.

Structurally the area is placed on the external mounting that delimit the mountain front to the north (northeastern end of the Alvear Sierra, Sierra Thomas Bridge Sierra) oriented E-SE and the lineament of the Río Valdez (N20-25°) displecing the previous one with a senestra strike component. This lineament is enhanced in the area by the elongated disposition of the edges which form the Baños Mounts located inmediately to the South and East of the thermal emanations.

Mesostructuralobservationns

In order to make a better mesoscopic description of the structural features they will be ordered according to their relative age. In this way, a description of the different structures will be done, taking into account their space-time nad kinematic relations with respect to the lithologies they affect, as follows:

Primary structures (So)

They are represented by the stratification and/or lamination of the Pyroclastic Facies and with the volcanic flow of the Rhyolitic Facies. A grat number of them can be easily recognized in a homoclinal arrangement of N140/160° and 5/55°SW. Nevertheless, locally there have been recognized attitudes changing from sublatitudinal to submeridional, but always dipping to the west showing some foldings and/or subordinate bendings.

First staae of ductil deformation (S1)

This stage is represented by the penetrative cleavage oriented N110/120° and 60-70°SW that developed senestral shearing bands mainly in the Pyroclastic Facies (for details see Simpson and Shmid, 1983; Gapais, 1989, etc.). However, in the Rhyolitic Facies with pophiric textures, sigmoidal felspatic phenoclasts with retorted shape could be recognized, which allowed to visualize the univocally senestral shearing directions.

At an outcrop of Pyroclastic Facies it was recognized a prominent system of monoclinic symetry (Wilson, 1982) of gashes in echelon (Ramsay and Huber, 1983, 1987), kinematically related to these senestral shearing bands. It was determined by a set (80%) of senestral bands of 20 cm of thickness and oriented N110/115° and 80°NE and a minor set (20%) of 5cm. of thickness oriented N80/85°, 150/70° NW.

Second staqe of ductile deformation (S2)

This stage is better exposed in the Pyroclastic Facies, represented by shearing bands with or without mountings, oriented N110" and 30°SW transposition cleavages affecting S1 structures, accordine to subvertical N10/15° planes.

Moreover, centimetric kink bands developed from S1 forming fused monoclinic symetry systems (Wilson, 1982) were recognized. They are mainly formed by senestral sets (90%) oriented N10/15° and 80°SE and also subvertical dextral sets (10%) oriented N40°. The kink planes which are sometimes incompletely developedfrequently present some of their kink planes enhanced by thin shearing bands or by joints.

Brittle trenstensive Staae (S3)

This stage is represented by transtensive faults (with a normal component) and joints which are more developed in the Rhyolitic Facies and give form to the Rio Valdez lineament.

The senestral and normal faults, sometimes with developments higher than 15 meters, are more frequently oriented according to N24/25°, 78/80°SE, with estriations in fault planes dipping 10 in a N25° direction. The criterions of direction are given by steps with quartz crystalization protected by shoulders and minor second order faults (Ramsay and Huber, 1987).

The joints with developments exceed an extension 1 m^2 and sometimes enhanced by siliceous veins, can be grouped into two main sets oriented N13/16° and 50/90°SE and N52/70° and 80/90°SE.

Mesostructures syntesis

From a time and space viewpoint, the prresent mesostructures can be grouped into: 1- Primary structures (stration and volcanic flow: SO), 2- 1st Stage senestral transpresive ductile (penetrative cleavage: S1), 3- 2nd. Stage senestral trans presive ductile (Shearing bands, transposition cleavage, kink bands: S2), and 4- Brittle transtensive stage (Faulting and jointing: S3).

d. Geochemical Study of the Waters

The thermal manifestations in this area of study are arrenged into two sectors. One of them corresponding to Los Baños sector, located on the left margin of the Rio Valdez, in a reduced alluvional plain of the river and a first terraced level. In this sector a group of ten springs which are distributed in a surface of 120 m^2 are found. The other group of springs are formed by three manifestationswhich crop out at the structural depression located north of Los Baños Mount, in a reduced peat bog formed over the Quaternary lands (Figure 3).

Chermical characteristics of the waters

The water of all the thermal manifestations have the same chemical composition (Piper Diagram), including those of lower temperature. They are sodium bicarbonated waters, with a ph from 7,8 to 8,2 and conductivity between 613 and 658 µs/cm. The measured temperatures are 31 to 40°C, with a general average of 38,5°C and a total volume of aproximately 65,213 l/h.

The use of the Piper Diagram was complemented with the DAmore, Scandiffio and Panichi diagrams (1987) in which 6 parameters were calculated from the 7 main chemical components of the water in order to distiguish groups of waters based on the geological characteristics of the principal reservoirs crossed by them.

In the *case* of hot springs waters samples of the Rio Valdez, the similarity in its chemical composition show that they would come from the same aquafer, without different mixtures preocesses in its way to the emergency point.

In the comparison of the diagram "standards" presented by DAmore a similarity can be found with the one corresponding to the waters which have circulate through metamorphic rocks of low degree of the shales, slates and schists types.

Isotopic analysis (oxygen 18, deuterium and tritium), both from the cold and hot springs samples, indicate that the hot springs waters samples form an homogeneous group, according to the chemical composition, they have a similar origin and no changes in their trace up to the point where they emerge.

Cold waters have a higher content of deuterium and O_{18} than those from hot spring waters, this means they were heavier waters because they have camed greater content of the atmospheric elements, characterists which would indicate that the overcharge is local. Whereas hot spring waters while presenting fewer contents of deutereium and O_{18} would indicate that the area of overcharge is higher, characterists that supports the hypothesis that the area of reservoir overcharge would be in the Fueguina mountain renge basin headwaters.

Taking into consideration the tritium contents in the cold waters samples, compared to its absence in the hot waters samples, the conclusion that hot spring waters have a residence time longer than 20 years was reached.

	GEOTHERMOMETRE(t°C)						
SAMPLES	TQC	TCH	TNK	TNKCA	TKMG	TMGLI	TNALI
RVC1	116.7	88.0	120.2	98.5	84.8	147.8	104.1
RVC2	123.8	96.7	119.1	97.5	88.9	155.5	104.6
RVC3	118.9	90.4	118.7	95.9	86.3	152.2	105.7
RVC4	119.6	91.2	118.4	97.6	81.4	144.3	105.2
RVC5	119.6	91.2	116.8	95.0	95.6	152.2	105.2
RVC6	117.5	88.8	119.0	95.3	79.5	140.9	105.5
RVC7	117.5	88.8	118.0	80.4	95.4	150.8	104.8
RVC8	118.2	89.6	117.9	96.4	85.6	152.2	106.5
RVC9	117.5	88.8	117.5	87.0	80.4	142.8	104.6
RVC10	116.7	88.0	117.1	96.0	85.3	152.0	105.8
RVC11	122.4	94.2	119.5	96.6	86.8	152.0	105.0

second ones as antithetical of the senestral sublatitudinal transpresive structures.

The rising of the hot springs waters and gaseous emanations of the Rio Valdez (fig. 3) are structurally controlled by the transtensive structures (N20-25") which tear the main external Fueguino mountain range, associated with fracture sets with a strike of N120° and N145° which allows the rising fluids to reach the surface.

The hot springs waters were originated by the slow descension of the meteoric underground waters that precipitate in the highest areas of the Fueguina Cordillera, they are heated due to the effect of the thermal conductivity and emerge through the structures (fig. 4). They form an homogeneous group which does not experiment any different **process** through its path up to the point of emergency, with a residence time which would be higher than 20 years.

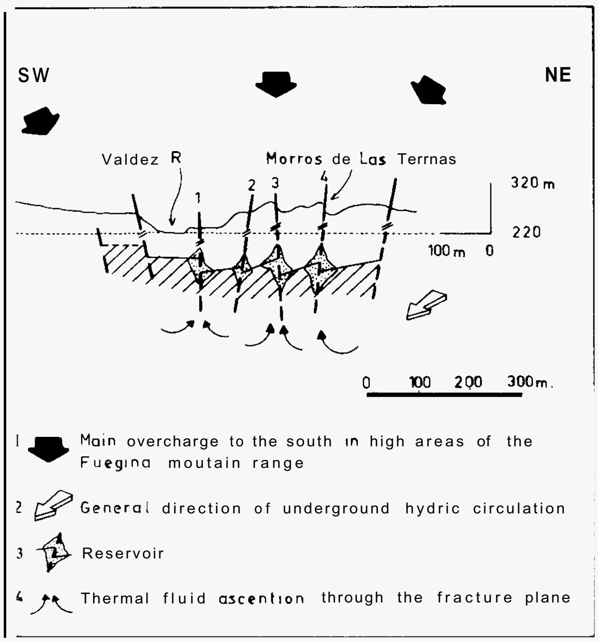

Fig. 4 Thermal model of geothermal field Rio Valdez

These waters and gases are hosted in the metamorphites fractures and joints forming the thermal reservoir at temperatures among 88 and 98°C. They are composed of sodium bicarbonated waters with ph among 7,8 and 8,2 and conductivity between 631 and 658 µs/cm which rise to the upper levels with an approximate volume of 65,200 l/h.

The existence of a reservoir model is interpreted. This follows the structures, joints and cracks and their intersections among the different structural systems inside the metamorphites, therefore the greater dimensions would be in the vertical direction.

ACKNOWLEDGEMENTS

I want do thank Dr. E. Iglesias for the critical reviews and suggestions.

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