GEOTHERMAL RESOURCES IN SOUTHWESTERN SOUTH AMERICA (ARGENTINA, CHILE)

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1. INTRODUCTION

In the Andean region of Argentina and Chile anomalous high heat flow and temperature gradients have been inferred in several areas, most of them located near active volcanoes. Also, high electrical conductivity zones have been observed in northern Chile and western Argentina. Even if these observations could mean the existence of resources for geothermal exploitation, only for some areas in Argentina a geothermal project has been established. In northern Chile, the area of El Tatio is the most explored geothermal field, and only recently the interest for a further assessment of this area has been revived.

Here, a brief summary of results concerning heat flow, radiogenic heat production and high conductivity zones will be presented. Also, some observations regarding the geochemical thermometry of some hot springs areas will be forwarded. The purpose of this note is to encourage the geothermal exploration in Argentina and Chile.

2. HEAT FLOW

Conventional heat flow measurements in Argentina and Chile (Uyeda et al., 1978a,b) are not significant as regards the thermal structure of the whole Andean region. A large number of the heat flow sites are located in a anomalous area of the Andean Range where there is not volcanic activity. In Argentina two heat flow measurements yield values of 21 mWm^{-2} and 26 mWm^{-2} (Fig. 1), and in Chile heat flow is between 10.0 and 41.9 mWm^{-2} in the area of the volcanic gap. A higher heat flow (78.7 mWm^{-2}) is observed in Central Chile (Santiago Basin), corresponding to some hot springs encountered in this area. Other high heat flow values were obtained in the middle slope of the Andes at about 26.2°S and in Tierra del Fuego (Fig. 1).

Empirical estimators enable to estimate the heat flow when actual measurements are not available. The analysis of the global heat flow data set carried out by Pollack et al. (1993) shows that in the Andean regions of Argentina and Chile heat flow may lie in the range between 60 and 120 mWm^{-2}. Higher estimates are for the central-southern areas in Chile and western Argentina. The spherical harmonic representation of global heat flow (Pollack et al., 1993) does not show the areas of thermal anomalies in the northern region, which probably are the consequence of local processes in the Andes.

Radiogenic heat production for Central Chile (33°-34°S) ranges between 1.45 and 2.09 μWm^{-3}, and between 0.44 and 2.09 μW^{-3} in the Lake Region (39°-41°S) -Muñoz (in prep.). Only these values of radiogenic heat production are known for Argentina and Chile. The higher values correspond to the Andean batholith of Central Chile, and to the Miocene granitoids of the volcanic zone in the Lake Region. Geotherms computed by assuming conductive transport of heat and an exponential model of distribution of radiogenic elements show that crustal gradients do not exceed the value of 30°C km^{-1}. Temperatures in the upper 5 km of the crust are lower than 150°C (Muñoz, in prep.). Crustal thermal heterogeneities are not well identified.

3. GEOELECTROMAGNETIC SOUNDINGS

Magnetotelluric and geomagnetic deep soundings have been carried out in Argentina, Bolivia and Chile. High electrical conductivity zones (HCZs) are encountered in the crust and uppermost mantle. The total conductance S (in 10^3 Siemens) is shown for several areas in Fig. 1. Here, we briefly comment about soundings in Argentina and Chile. Results for the Subandean Ranges and the Chaco of northewestern Argentina are not shown in Fig. 1. $\bar{S}$ designates the conductance in the most anomalous HCZ. $\bar{S}_c$ denotes high conductance in crustal layers. Subscripts denote the depth extent to which conductance is calculated.

Crustal HCZs are encountered at latitudes between 22' and 24°S. (Schwarz et al., 1984, 1994). This is a region with strong surface geothermal activity, and which comprises the El Tatio geothermal field. The HCZ beneath El Tatio may correspond to a magmatic intrusion at 5-7 km depth. Hydrothermal convection evolves within 1 km of the intrusion upper contact (Muiioz and Hamza, 1993). As observed by Schwarz et al. (1994), the measured electrical conductivities for the crust and upper mantle of this region are all higher than those in a 'normal' geological setting almost everywhere.

In western Argentina at about 26°S (Tucumán, Santiago del Estero, Pipanaco) there are HCZs in the crust an upper mantle (Baldis et al., 1983; Muiioz et al., 1992). Seismic activity at different depth ranges is not observed in this area; in the north and south directions there are clusters of seismicity (Barazangi and Isacks, 1976; Cahill and Isacks, 1992). In the area of HCZs the temperature gradient in water wells can generally be extrapolated to about 100°C km^{-1}. Crustal HCZs are found beneath the middle part of the sounding area shown in Fig. 1 (between the areas of Taco Ralo and Monteagudo).

HCZs between 33' and 34°S in Argentina (Fig. 1) are found mainly in the lower crust and upper mantle. The depths to the HCZs are of about 16 km, 34 km and 80 km; in the southern area of the anomaly, the depth to the second HCZ is shallower (Borzotta et al., 1993). In the upper crust (0-5 km), HCZs are found beneath Uspallata (32.7°S; 69°W), Titarelli (33°S; 68.5°W) and Beazley (33.8°S; 66.7°W - not shown in Fig. 1). The conductance of the upper layers in these areas amount to about 1-3 (10^3 Siemens).

At nearly 35.5°S in Argentina (Los Molles area), HCZs are found throughout the crust (Fig. 1). Basaltic products and eroded volcanic cones are observed in this area; also, gypsum formations are abundant. In some parts, the conductivity of the upper layers is of about 1-2 $mhom^{-1}$ (Fournier et al., 1993); the anomaly may be interrupted by a less conducting structure near the middle part of this area. Geothermometry yields a temperature of about 140°C, and higher temperature estimates are given westward and eastward of the profile (230°C and 215°C, respectively - Isaura Exploraciones y Sondeos, 1989). Near to this area, in the Llancanelo volcanic field (to the east of Los Molles), there are about 200 basaltic eruptive centres, and also strong hydroclastic eruptions in the geological history of the region have been described in the literature (Bermúdez and Delpino, 1989). Some characteristics of this region have suggested to designate it as a "hawaiian" environment, in what touches the relief position previous to the development of the volcanic field and the regime of extensional stress which dominated in the area (Delpino, 1992).

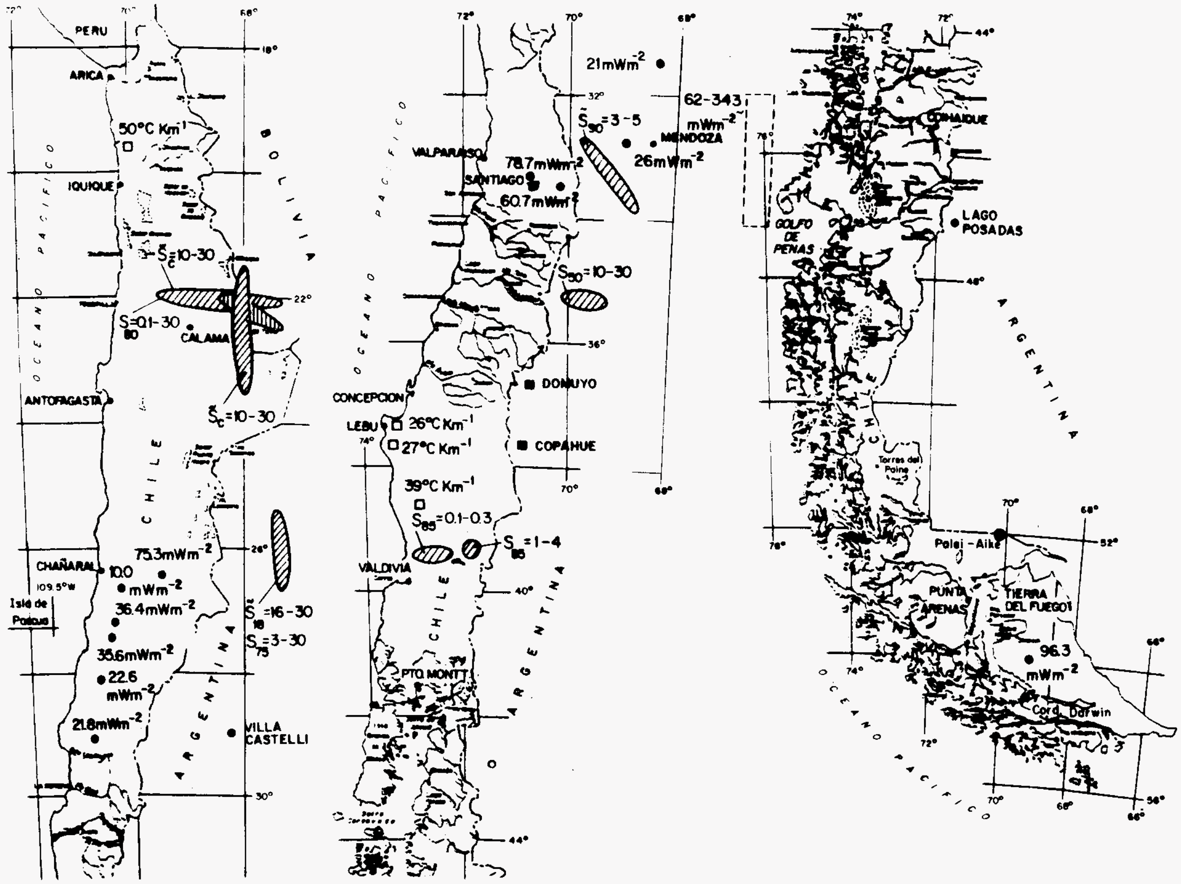

Fig.1. Geothermal and magnetotelluric observations in Argentina and Chile. Also some observations in Bolivia are shown. **S** is the electrical conductance in 10^3 Siemens; subscripts denote the depth extent (in km) to which conductance is calculated. $\tilde{S}$ is the conductance in the most anomalous high conducting zones. $\tilde{S}_C$ denotes high conductance in crustal layers (Heat flow values in the ocean are from Cande et al., 1987; for the other data, see the references in the text.)

In the Lake Region of Chile, at about 39.5°S, HCZs are encountered only in the area of the south volcanic zone (Villarrica volcano). Towards the Coast Range the conductance decreases, and no HCZs are there observed to depths of about 85 km (Muiioz et al., 1990, 1992).

HCZs in the lithosphere may be caused by different sources: partially molten rocks, fluids and volatiles, conducting minerals. As regards the former areas in Argentina and Chile, it could be said that the HCZs are mainly caused by crustal fluids and melts in the crust and upper mantle.

4. GEOTHERMOMETRY

The most developed geothermal projects correspond to the areas of Domuyo and Copahue in the Province of NeuquCn (Argentina). Geothermometry yields values higher than 200 °C in many zones within these fields. Copahue is a vapor-dominated geothermal field with reservoir temperature as high as 230°C (Esteves and Sierra, 1985). In Domuyo, the zones of vapor-dominated type may also be at high temperature; the temperature of the zones of water-vapor-mixed type is between 214°C and 233°C; the zones of water-dominated type are at about 166°C - 188°C and 135°C - 174°C (Esteves et al., 1985). Also, geothermal exploration has been carried out in the Puna, North Cordillera, Central Cordillera, Subandean Ranges and the Sierras Pampeanas. Similar temperature estimates are found in the area at nearly 35.5°S (Isaura Exploraciones y Sondeos, 1989).

For El Tatio geothermal field (Chile: 22.3°S; 68°W), the higher equilibrium temperature is found to be 285°C in a zone where good producers wells have been established (James, 1974; Muiioz and Hamza, 1993). A detailed study concerning the fluid-rock interaction in the El Tatio geothermal field is presented in Youngman (1984). Other geothermal areas in northern Chile where geothermometry indicates temperatures higher than 200°C are Puchuldiza (19.3°S; 69°W) and Suriri (19°S; 69°W). In these two areas, it seems that a fluid-rock equilibrium has not been attained. Geochemical estimates generally yield lower temperatures for the central-southern geothermal areas in Chile (see a compilation in Muiioz and Hamza, 1993). In this region, the area of San Pedro (35.1°S; 70.5°W) shows the highest degree of partial equilibrium with temperatures between 195°C and 245°C. Low-enthalpy fluids are indicated for the Santiago Basin (33°S; 70.5°W).

5. CONCLUSIONS

Geoelectromagnetic soundings and geochemical thermometers are both indicating that high-enthalpy geothermal fields are mainly located in some areas of northern Chile and in several localities along western Argentina. Hot-spring areas in central-southern Chile are generally associated to zones nearby active volcanoes, and no extended area showing surface thermal activity is encountered in this region. Along western Argentina, and in northern Chile, besides the extrusive type of magmatic activity, it is possible to distinguish a developed intrusive type generating large molten zones in the crust. In these regions fluids circulate over longer horizontal paths, with transit times of several years or decades: 15-17 years for El Tatio (Cusicanqui et al., 1975), 40 years for Los Molles (Isaura Exploraciones y Sondeos, 1989). Low-enthalpy geothermal areas are probably located in several places in Argentina and Chile; the Santiago Basin -which involves surface geothermal activity- is a prospective area for the assessment of low-enthalpy geothermal resources.

The thermal structure of Argentina and Chile is not well known. It is not possible to specify whether the high conductivity zones are involving hydrothermal activity in every case, or if in some areas only partially molten rocks are producing the high conductances. Geoelectromagnetic, thermal and chemical studies have to be continued for to better understand the thermal structure and the transport of heat in the upper crust.

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