ADVANCES IN GEOTHERMAL RESEARCH IN CHILE

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RESUMEN: Los geoindicadores Na, K, Mg and Ca indican un mayor grado de equilibrio fluido-roca en áreas termales del Norte de Chile que en las del Centro-Sur. Por otra parte, se presentan resultados de la producción radiogénica de calor y de la estructura termal en Chile Central, y su relación con la derivación magmática de granitoides.

KEY WORDS: Chile: Mature/Immature Fluids; Heat Production; Thermal Structure of the Crust.

FLUID-ROCK EQUILIBRIUM IN GEOTHERMAL AREAS

Evaluation of fluid-rock equilibrium in 33 geothermal areas and in the Santiago Basin was carried out by means of the relative Na, K, Mg and Ca contents of waters, and following the method established by Giggenbach (1988). In northern Chile only in two of eight geothermal areas fluids have attained a partial or a full equilibrium with both K-Na and K-Mg mineral systems; a partial equilibrium is also indicated for seven of twenty hot springs waters in central-south Chile (Table 1). Other geothermal areas correspond to immature waters which are generally unsuitable for the evaluation of K/Na and K/Mg equilibrium temperature; in these cases also CO_2-fugacities cannot be obtained.

TABLE 1. Full equilibrium or partial equilibrium temperatures in geothermal areas of Chile as indicated by the K/Mg and K/Na geothermometers.

Area	Latitude Longitude	T(K/Mg) (°C)	T(K/Na) (°C)
Northern Chile			
Puchuldiza	19°08'S 68°58'W	135-195	192-235
El Tatio (springs)	22°20'S 68°01'W	145-245	180-250

Area	Latitude Longitude	T(K/Mg) (°C)	T(K/Na) (°C)
El Tatio (wells)	22°20'S 68°01'S	165-285	165-285
Central-South Chile			
Apoquindo	33°25'S 70°25'W	80	140
Baños de Colina	33°48'S 70°00'W	120	180
Baños Morales	33°50'S 70°03'W	100	140
Vegas del Flaco	34°57'S 70°28'S	150	245
San Pedro	35°08'S 70°27'W	195	245
Campanario	35°56'S 70°33'W	125	195
Pemehue	38°03'S 71°44'W	115	180

Correlation between molecular Cl/B ratio and Na-K-Ca temperature (Youngman, 1984) is generally consistent with indications of fluid-rock equilibrium in different aquifers of El Tatio. Isotopic analysis of El Tatio waters and results from magnetotelluric soundings in the area -studies carried out by other workers- have been also used to reexamine the length of fluids circulation path by considering the *transparency* of magma (Lachenbruch and Sass, 1977) through hydrothermal convection; the actual distance travelled by the water may be estimated to be 20 Km, at a rate of about 1.3 Km/year.

Chillán (36°57'S; 71°33'W) and Río Blanco (38°35'S; 71°42'W) plot as immature waters; these are acid sulphate waters characterized by high temperatures at depth (170°C-240°C). In the Santiago Basin -in areas at about 33°20'S; 70°50'W- evaluation of fluid-rock equilibrium indicates that waters are immature; if K/Mg temperatures were still valid, deeper equilibrium temperatures may be of about 80°C.

HEAT PRODUCTION AND THERMAL STRUCTURE OF THE CRUST

The radiogenic surface heat production has been preliminary determined in the three tectonic units of Central Chile (33°S), ranging from the Coastal Range to the Andes Cordillera (Table 2).

TABLE 2. Preliminary thermal parameters in Central Chile batholiths. Q: surface heat flow; N: number of samples for heat production measurements; A_0 : mean surface heat production; A_0*: mean surface heat production of the uneroded crust; D: depth parameter of distribution of radiogenic elements. (Q value in brackets is an assumed value)

	Age (10^6 years)	Q (mWm^{-2})	N	$A_0 \pm \sigma$ (μWm^{-3})	A_0* (μWm^{-3})	D (Km)
Coastal Batholith	336	(63.0)	7	1.45±0.74	6.56	17.4
Central Batholith	101	78.7	4	1.20±0.62	7.04	26.2
Andean Batholith	41	60.7	6	1.87±0.36	7.16	13.0

Because of the few number of measurements depth parameter D is not well determined. Particularly, low mean radiogenic heat production in the Central Batholith and high measured heat flow allows for a very great value of D. The crustal temperatures of Central Chile were determined by considering the one dimensional heat conduction equation and assuming steady state conditions, and making use of the values given in Table 2. Some of the temperature distributions encountered show the possibility of partial fusion at the Moho level. The highest degree of partial fusion is shown for the Central Batholith; also, preliminary seismic velocity models of this region are showing low velocities in the lower crust, and increasing towards the Andes Cordillera.

It is not possible to fit a trend between SiO_2 contents and surface heat production in the case of Central Chile batholiths. This is similar to what has been observed in data of Sierra Nevada - United States (Tilling et al., 1970). Eastward variations in chemical composition and distribution of rare earth elements indicate that if Central Chile granitoids are derived from magmas of andesitic composition they are also not genetically related to the subducted Nazca plate tholeiitic basalts (Lόpez-Escobar, 1974). Similar conclusions have been put forward also for the Sierra Nevada igneous rocks which should envolve derivation from lower crustal and continental upper mantle sources.

The west to east migration of magmatic foci with time and the derivation of granitoids in Central Chile may be related to the change of subduction topology, the rate of tectonic erosion and to the thermal state of the crust. Erosion rates resulting from radiogenic heat production (Table 2) are shown in Table 3, and compared with rates inferred by Scholl et al. (1970) found by considering similar terranes and climates elsewhere in the world and for the last 25 million years -larger denudation rates correspond to glacial periods.

TABLE 3. Erosion rates - Central Chile batholiths.

	(from Heat Production) (cm/10^3y)	(from Scholl et al. (1970) (cm/10^3y)
Coastal batholith	7.8	1-5
Central batholith	45.9	
Andean batholith	42.7	2-10-80

CONCLUSIONS

Degree of fluid-rock equilibrium is higher for some areas in northern Chile than in the central-south region. In northern Chile, besides the extrusive type of magmatic activity, it is possible to distinguish a developed intrusive type -like in El Tatio- leading to the genesis of larger geothermal areas with fluids circulating through longer horizontal paths in the crust.

In Central Chile (33°S), in zones of the Central and Andean batholiths, the lower crust may be in a state of partial fusion. Distribution of radiogenic elements, changes in the topology of subduction and tectonic erosion rates are important to establish the derivation of granitoids and the geological history of arc magmatism. Thermal stresses due to temperature differences at different levels in the crust from the Coastal Range to the Andes Cordillera may produce seismic activity with foci in the crust.

REFERENCES

GIGGENBACH, W.F., 1988. Geochim. Cosmochim. Acta, **52**:2749-2765.

LACHENBRUCH, A.H. and SASS, J.H., 1977. In: J.G. Heacock (Editor), The Earth's Crust. AGU Geophys. Monogr., **20**: pp. 626-675.

LOPEZ-ESCOBAR, L., 1974. Plutonic and Volcanic Rocks from Central Chile (33°-42°S): Geochemical evidence regarding their petrogenesis. Ph.D Thesis, MIT, 270 pp.

SCHOLL, D.W., CHRISTENSEN, M.N., VON HUENE, R. and MARLOW, M.S., 1970. Geol. Soc. Amer. Bull., **81**, 1339-1360.

TILLING, R.I., GOTTFRIED, D. and DODGE, F.C.W., 1970. Geol. Soc. Amer. Bull., **81**, 1447-1462.

YOUNGMAN, K. J., 1984. Hydrothermal Alteration and Fluid-Rock Interaction in the El Tatio Geothermal Field, Antofagasta Province, Chile. Ms. Sc. Thesis, University of Auckland, 123 pp.