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GEOTHERMAL RESOURCE EXPLORATION IN NORTHERN CHILE: CONSTRAINTS FROM ORGANIC AND INORGANIC GAS COMPOSITION

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1. INTRODUCTION

Fluid geochemistry can be regarded as a useful tool for exploring and exploiting geothermal resources, being able to provide important insights on the chemical–physical conditions of the reservoirs and the thermodynamic processes acting at depth in geothermal fields (e.g. Nicholson, 1993; Arnorsson, 2001). In northern Chile, several promising geothermal systems have been recognized: Surire (4,300 m a.s.l.) 250 km NE the city of Iquique (Lahsen, 1976), Puchuldiza (4,200 m a.s.l.), located 200 km NE the city of Iquique (Lahsen, 1975, 1976), Apacheta (5,100 m a.s.l.) 120 km NE the city of Calama (Urzua *et al.*, 2002), El Tatio (4,300 m a.s.l.), 100 km NE the city of Calama (e.g. Lahsen, 1976; Lahsen and Trujillo, 1976), La Torta (4,900 m a.s.l.) 90 km NE the city of Calama (Urzua *et al.*, 2002). In the present work the chemical features of the thermal fluid discharges from Puchuldiza, Apacheta and El Tatio geothermal systems are presented in order to: i) assess the origin of the gas compounds, and ii) evaluate the physical–chemical conditions of the geothermal reservoirs.

2. GEOLOGICAL SETTING

The Central Volcanic Zone (CVZ) is part of the Andes Range and lies along southern Peru, northern Chile, western Bolivia and western Argentina. The CVZ, hosting several active volcanoes

(Stern, 2004), is mainly constituted by Late Oligocene and Quaternary volcanic and sedimentary rocks, Miocene–Pliocene andesitic to rhyolitic lava flows, lavadomes and ignimbrites, breccias and sandstones (Lahsen, 1976; Ramirez and Huete, 1981). The main tectonic features of this volcanic range are a series of NNW–SSE trending grabens (Francis and Rundle, 1976; Lahsen, 1976), where the main Chilean geothermal fields are hosted.

3. RESULTS

Thermal fluid discharges of Puchuldiza, El Tatio and Apacheta geothermal systems have outlet temperatures varying between 43 and 92 °C. The chemical composition of gases is dominated by the presence of CO_2 (10,018–992,830 μmol/mol) and H_2O (2,221–992,830 μmol/mol). Among acid gases, H_2S is generally present in considerable amounts (25–4261 μmol/mol), while HF, HCl and SO_2 are virtually absent (<0.1 μmol/mol), with the only exception of the Apacheta thermal discharges, where significant concentrations of HCl (6.07–6.34 μmol/mol) and SO_2 (1.19–1.53 μmol/mol) were detected. Among residual gases, N_2, H_2 and CH_4 show highly variable concentrations (108–33,048, 0.7–245 and 0.04–2,344 μmol/mol, respectively), while Ar and O_2 show relevant contents only at Puchuldiza (up to 717 and 207 μmol/mol, respectively). Helium and Ne are present only in minor amounts, and CO contents are below the detection limit (0.01 μmol/mol), likely due to its complete dissolution into shallow aquifers. Concerning the organic gas fraction, the composition of light hydrocarbons is marked by a high speciation, a feature that has been commonly observed in fluids of worldwide geothermal areas (e.g. Capaccioni *et al.*, 2004; Tassi *et al.*, 2005). Gas species pertaining to the alkanes group are generally the most abundant ones, although at Apacheta the light alkenes contents prevail over those of their homologue alkanes.

4. DISCUSSION AND CONCLUSIONS

The origin of the thermal fluid discharges of Puchuldiza, El Tatio and Apacheta areas is mainly related to the contribution of at least three different sources: 1) a low–temperature atmospheric–rich, 2) a medium–temperature hydrothermal, and 2) a high–temperature magmatic–related component. At Puchuldiza the thermal fluids have the highest contents of low–temperature gas species (CH_4, light alkanes, Ar and O_2), although gas composition maintains clues of medium–to–high entalphy processes acting at depth. On the contrary, at Apacheta the highly acidic gases (SO_2 and HCl), coupled with the particularly low contents of hydrocarbons, mainly composed by alkenes, suggest a strong contribution of a high–temperature component (Capaccioni *et al.*, 1995; Giggenbach, 1996). At El Tatio the chemical characteristics of the thermal fluids seems to indicate the presence of a relatively large and well–developed geothermal system, with minimum contents of atmospheric–related species.

Reservoir temperatures, calculated on the basis of the H_2/Ar geothermometer (Chiodini *et al.*, 2001), for Puchuldiza (136–176°C) geothermal system, are consistent with both those directly measured at the bottom of the 600–900 m deep exploration wells (164°C) (Araya *et al.*, 1979), and those indicated by the organic gas geothermometers (Capaccioni and Mangani, 2001; Tassi *et al.*, 2005). Differently, at El Tatio the thermodynamic equilibrium of the reactions among the light hydrocarbons, which are characterized by a relatively slow kinetics, seems to be established at temperature significantly higher than that (265°C) measured at depth (Lahsen and Trujillo, 1976) and those calculated by using the inorganic geothermometers (220–250°C). This suggests that i) the deeper levels of this geothermal system are characterized by relatively high temperatures (~300°C), and ii) the thick hydrothermal aquifer feeding the thermal discharges is able to buffer the high-temperature chemicals and the heat flux. Finally, at Apacheta, the calculated temperatures of both the organic and the inorganic gas geothermometers are particularly high (>330°C), not common for geothermal fluids, possibly in relation to the presence of a magmatic system still active in the area, as also indicated by the relatively high contents of light alkenes, HCl and SO_2.

Further important constraints on the reservoir conditions and the origin of thermal fluid discharges of northern Chile are expected to be obtained from a detailed geochemical survey to be carried out in the forthcoming years by the Chilean–Italian research group, mainly aimed to generate a regional framework for geothermal fields of the Andean Central Volcanic Zone.

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REFERENCES

Araya, C., Bravo, R., Solar, T., 1979. Control pozos 2 al 5 Campo Geotermico de Puchuldiza. CORFO, unpublished Report, 54 pp.

Arnorsson, S., 2001. Isotopic and chemical techniques in geothermal exploration, development and use: sampling methods, data handling, interpretation. IAEA publ., 359 pp.

Capaccioni, B., Mangani, F., 2001. Monitoring of active but quiescent volcanoes using light hydrocarbon distribution in volcanic gases: the results of 4 years of discontinuous monitoring in the Campi Flegrei (Italy). Earth Planet. Sci. Lett., 188, 543-555.

Capaccioni, B., Martini, M., Mangani, F., 1995. Light hydrocarbons in hydrothermal and magmatic fumaroles: hints of catalytic and thermal reactions. Bull. Volcanol. 56, 593–600.

Capaccioni, B., Taran, Y., Tassi, F., Vaselli, O., Mangani, F., Macias, J.L., 2004. Source conditions and degradation processes of light hydrocarbons in volcanic gases: an example from the Chichon Volcano (Chiapas State, Mexico). Chem. Geol. 206, 81-96.

Chiodini, G., Marini, L., Russo, M., 2001. Geochemical evidence for the existence of high-temperature hydrothermal brines at Vesuvio Volcano, Italy. Geochim. Cosmochim. Acta, 65, 2129-2147.

Francis, P., Rundle, C., 1976. Rates of production of the main magma types in the Central Andes. Geol. Soc. Am. Bull., 87, 474–480

Giggenbach, W., 1996. Chemical composition of volcanic gases. Monitoring and mitigation of Volcano Hazards. Springer–Verlag, Berlin, 222–256

Lahsen, A., 1975. Evaluación preliminar sistema geotérmico Puchuldiza. CORFO, unpublished report, 23 pp.

Lahsen, A., 1976. La actividad geotermal y sus relaciones con la tectónica y el volcanismo en el Norte de Chile. 1° Cong. Geol. Chileno, B105–B127

Lahsen, A., Trujillo, P., 1976. El campo geotermico El Tatio, Chile. CORFO, unpublished Report, 21 pp.

Nicholson, K., 1993. Geothermal fluids: chemistry and exploration techniques. Springer–Verlag, Berlin, 268 pp.

Ramírez, C., Huete, C., 1981. Carta Geológica de Chile, Hoja Ollagüe, Escala 1:250,000. Inst. Invest. Geol., Carta Nº 40

Stern, C., 2004. Active Andean volcanism: its geologic and tectonic setting. Rev. Geol. Chile, 31, 161–206

Tassi, F., Martínez, C., Vaselli, O., Capaccioni, B., Viramonte, J., 2005. The light lydrocarbons as a new geoindicator for temperature and redox conditions of geothermal fields: Evidence from the El Tatio (Northern Chile). App. Geochem., 20, 2049–2062

Urzua, L., Powell, T., Cumming, W., Dobson, P., 2002. Apacheta, a New Geothermal Prospect in Northern Chile. Geoth. Res. Coun. Tran., 26, 65–6