Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Geothermics 36 (2007) 389–420
GEOTHERMICS
www.elsevier.com/locate/geothermics

# Gas geochemistry of the Cordón Caulle geothermal system, Southern Chile

Fabián Sepúlveda [a,*], Alfredo Lahsen [b], Thomas Powell [c]

[a] *SGGES, University of Auckland, Private Bag 92019, Auckland, New Zealand*
[b] *Department of Geology, University of Chile, P.O. Box 13518 (21), Santiago, Chile*
[c] *Mighty River Power, P.O. Box 445, Hamilton, New Zealand*

Received 15 August 2005; accepted 15 May 2007
Available online 12 July 2007

**Abstract**

The Cordón Caulle geothermal system is located in a NW-trending volcano-tectonic depression of the Southern Andean Volcanic Zone of Chile. Outflows of low chloride water were previously interpreted as the surface expression of a shallow steam-heated aquifer, with subsurface temperatures of 150–170 °C. Gas data from fumaroles and hot springs have been used to assess the nature and temperature of the deeper, underlying geothermal reservoir. Fumaroles at the northeastern border of Cordón Caulle have $^3He/^4He$ ratios typical of subduction margins (6–7 $R_A$) and $N_2/Ar$ ratios of about 40, indicating deep convection of air-saturated groundwater. Fumaroles at the southwestern border have $N_2/Ar$ ratios >300, suggesting the presence of a deep volcanic component. Gas ratios of fumarole discharges yield equilibration temperatures >300 °C, whereas those of hot spring waters suggest temperatures of about 160 °C. Based on these data, and comparisons with well documented liquid and vapor-dominated geothermal systems, a model is proposed of a boiling liquid-dominated geothermal system overlain by a secondary steam-heated aquifer.


*Keywords:* Geothermal; Steam-heated: Geochemistry; Gas ratio grid; Redox relationship; Cordón Caulle; Chile

## 1. Introduction

The geothermal resources of the Andean region of Chile occur in close spatial relationship with active volcanism. Volcanic-geothermal activity is primarily controlled by the convergence of the Nazca and South America Plates. At present, the Andean volcanic-geothermal arc represents

* Corresponding author. Tel.: +64 9 373 7599; fax: +64 9 373 7435.
*E-mail address:* f.sepulveda@auckland.ac.nz (F. Sepúlveda).

0375-6505/$30.00 © 2007 CNR. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.geothermics.2007.05.001

**Nomenclature**

| | |
|---|---|
| ASW | air-saturated groundwater |
| $B$ | gas distribution coefficient |
| $C$ | concentration (refers either to $X$ or $r$) |
| $D$ | He/Ne ratio |
| $f$ | fugacity (bar) |
| $K_{CC}$ | equilibrium constant for reaction involving CO and $CO_2$ |
| $K_{MC}$ | equilibrium constant for reaction involving $CH_4$ and $CO_2$ |
| $P$ | pressure (bar) |
| $r$ | molar ratio (μmol/mol or any other gas concentration unit) |
| $r_{f,V}$ | final molar ratio in vapor |
| $r_{i,V}$ | initial molar ratio in vapor |
| $R$ | $^3He/^4He$ ratio |
| $R_A$ | $R$ for air |
| $R_C$ | corrected $^3He/^4He$ ratio |
| $R_H$ | $\log(f_{H_2}/f_{H_2O})$ |
| $R_{H,EMP}$ | $R_H$ for empirical redox state |
| $R_{H,FH}$ | $R_H$ for fayalite–hematite redox state |
| $R_{H,FM}$ | $R_H$ for quartz–fayalite–magnetite redox state |
| $R_{H,MH}$ | $R_H$ for magnetite–hematite redox state |
| $R_M$ | measured $^3He/^4He$ ratio |
| $T$ | temperature (°C) |
| $x$ | condensed fraction (% by mass) |
| $X$ | molar fraction (%) |
| $y$ | steam fraction (% by mass) |
| $y_A$ | percent air (by volume) |
| $z$ | steam compressibility factor |

*Subscripts*

| | |
|---|---|
| atm | atmospheric |
| (g) | gas |
| L | liquid |
| M | mixture |
| $T_C$ | condensation temperature |
| $T_R$ | reservoir temperature |
| $T_S$ | separation temperature |
| $V$ | vapor |
| $V_{SEP}$ | separated vapor |

one of the largest undeveloped geothermal provinces of the world. Two main margin-parallel volcanic zones can be distinguished within the Chilean Andes: the Northern Volcanic Zone (NVZ; 17°S–28°S) and the Southern Volcanic Zone (SVZ; 33°S–46°S). Among the geothermal systems of the SVZ is Cordón Caulle (40.5°S; Fig. 1), whose thermal manifestations account for a minimum natural thermal discharge of 40 MW (Sepúlveda et al., 2004). Based on chemical and isotopic data