Chemical Geology 266 (2009) 38–49

Contents lists available at ScienceDirect

Chemical Geology

journal homepage: www.elsevier.com/locate/chemgeo

The effects of volatile recycling, degassing and crustal contamination on the helium and carbon geochemistry of hydrothermal fluids from the Southern Volcanic Zone of Chile

Mary C. Ray [a,1], David R. Hilton [a,*], Jorge Muñoz [b], Tobias P. Fischer [c], Alison M. Shaw [d,2]

[a] Fluids and Volatiles Laboratory, Geosciences Research Division, Scripps Institution of Oceanography, UCSD, La Jolla, California 92093-0244, USA
[b] Servicio Nacional de Geología y Minería (Chilean Geological and Mining Survey), Puerto Varas Regional Office, La Paz 406, Puerto Varas, Chile
[c] Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131-1116, USA
[d] Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington DC, 20015 USA

ARTICLE INFO

Article history:
Accepted 18 December 2008

Keywords:
Volatile recycling
Crustal contamination
South America
$CO_2/^3He$
Helium isotopes
Carbon isotopes

ABSTRACT

We report new helium and carbon isotope ($^3He/^4He$, $\delta^{13}C$) and relative abundance ($CO_2/^3He$) characteristics of a suite of hydrothermal gases and fluids (fumaroles, hot springs, geothermal wells) from 18 localities in the Central Southern Volcanic Zone (CSVZ) of Chile. The CSVZ is characterized by a wide range of $^3He/^4He$ ratios, from 1.50 to 6.47 R_A (where R_A = air $^3He/^4He$), $\delta^{13}C$ (CO_2) values, from −2.9 to −17.7‰ (vs. PDB), and $CO_2/^3He$ ratios, which vary over 5 orders of magnitude (3.1×10^5 to 2.3×10^{11}). One hydrothermal locality, Aguas Calientes, has combined He–CO_2 characteristics remarkably similar to other arc-related systems worldwide implying that the underlying subduction zone complex (and mantle wedge) supplies volatiles to the volcanic front with little or no modification en route to the surface. The mechanism controlling helium isotope ratios of other hydrothermal systems appears to be mixing between mantle-derived helium and a radiogenic component derived from ^4He-rich country rock. The variable He–CO_2 elemental relationships and $\delta^{13}C$ (CO_2) values at these localities are consistent with gas separation (gas samples) or temperature-dependent calcite precipitation (water samples) in shallow-level hydrothermal systems. Both processes result in CO_2 loss which exacerbates the effects of contamination by crustal gases. Whereas the Aguas Calientes locality is useful for understanding the role of the underlying mantle wedge and subducting slab in supplying volatiles to the Andean volcanic front, the value of the majority of hydrothermal samples in the present study lies with discerning the potentially complicating effects of degassing and/or crustal contamination on the resulting He–CO_2 record.

1. Introduction

Coupling helium to CO_2 in arc-related studies has proven useful in a number of respects. For example, estimated fluxes of various volcanic gases to the atmosphere (including ^3He and CO_2) are often based on $CO_2/^3He$ values (usually measured on hydrothermal fluids) coupled with various combinations of ^3He, CO_2 and/or magma flux estimates (Marty et al., 1989; Allard, 1992; Marty and LeCloarec, 1992; Varekamp et al., 1992; Sano and Williams, 1996). Related work has targeted He and CO_2 (isotopes and relative abundances) to recognize crustal inputs to arc-related magmas, and their influence on petrogenetic processes (e.g. van Soest et al., 1998; Jaffe et al., 2004). More recently, interest has focused on the subject of volatile mass balance at subduction zones, with He and CO_2 being used to evaluate the efficiency of volatile recycling between the trench and volcanic arc (e.g., Hilton et al., 2002; Shaw et al., 2003; De Leeuw et al., 2007).

A theme common to all these studies is the need to distinguish between He–CO_2 variations which are diagnostic of underlying mantle sources, and variations related to crustal and/or hydrothermal effects which can act to disturb He–CO_2 relationships. A key region likely to be influenced by both mantle- and crustal-derived volatiles is the Southern Volcanic Zone (SVZ) of Chile where prior work (Hilton et al., 1993) has identified some hydrothermal localities characterized by $^3He/^4He$ typical of arc-related volcanism and others with large inputs of radiogenic (crustal) helium. Because the SVZ has abundant hydrothermal activity occurring in close proximity to recent volcanic activity, it provides an ideal setting to consider details of both mantle volatile recycling through the Andean subduction factory and the potentially complicating effects of crustal contamination and/or degassing imprints on the He–CO_2 systematics. To this end, we report new data coupling He and CO_2 (relative abundances and isotope

* Corresponding author. Tel.: +1 858 822 0639; fax: +1 858 822 3310.
E-mail address: drhilton@ucsd.edu (D.R. Hilton).
[1] Now at: U.S. Geological Survey, California Water Science Center, 4165 Spruance Road, Suite 200, San Diego, CA 92101, USA.
[2] Now at: Dept. Geology & Geophysics, Woods Hole Oceanographic Institution, Woods Hole, MA 02543 USA.

0009-2541/$ – see front matter
doi:10.1016/j.chemgeo.2008.12.026

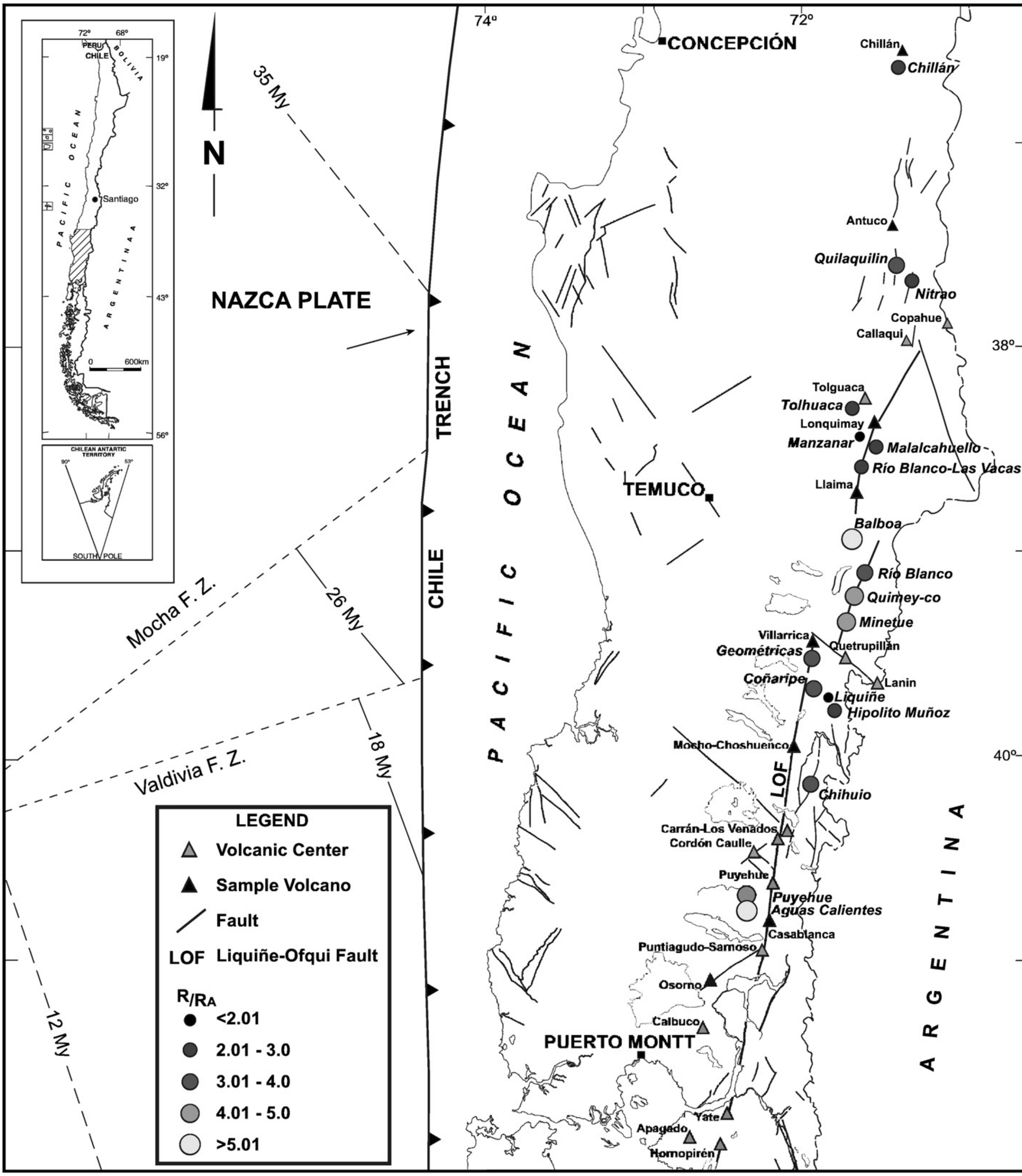

Fig. 1. Map of sample localities in the Central Southern Volcanic Zone of Chile together with range of air-corrected $^3He/^4He$ values (R_C/R_A notation).

characterisitics) of hydrothermal fluids from 18 individual geothermal systems in the central section of the SVZ.

2. Geological background

The Southern Volcanic Zone (SVZ) of central Chile lies between 33°S and 46°S and is one of four active arc segments that comprise the Andes (Thorpe et al., 1982; Parada et al., 2007). Subduction of the Nazca Plate beneath the South America Plate occurs at 7 to 9 cm/yr adjacent to all parts of this segment giving rise to ~60 historically and recently-active volcanic centers as well as three giant silicic caldera systems (Stern, 2004). In addition, there are numerous monogenetic cones (López-Escobar et al., 1995). The Liquiñe–Ofqui fault system is located in the central and southern portion of the SVZ and runs north-