



Origin of components in Chilean thermal waters

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ABSTRACT

Thermal waters of northern (18°–27°S) and southern (37°–45°S) Chile occur in two very different climatic, geologic and hydrologic environments: arid closed basins with abundant evaporites in the north; humid climate and well drained valleys in the south. The origin and behavior of the main components of the two groups of waters are examined and compared to each other. The modeling of the alteration of volcanic rocks leads to water compositions very different from those observed both in the north and south. In addition to hydrothermal alteration and deep emanations, the Cl/Br ratio reveals a major contribution of saline waters to the two groups: infiltrating brines from salt lakes in the north; seawater in the south.

In the north, concentrations of Cl, Br, Na, K, Ca, SO₄, Li, B, Si result from the mixing of alteration waters with recycled brines. Hydrothermal alteration is obscured by this massive saline input, except for Mg. δ³⁴S values are consistent with an origin of sulfate from salar brines, which are themselves derived from deep Tertiary gypsum. In the south, two processes account for the composition of thermal waters: mixing of alteration waters with seawater and deep magmatic contribution. The mixing process controls the concentration of Cl, Br, Na, Alk, Si, K, Ca, Mg. Magmatic inputs are detectable for SO₄, Li and B. δ³⁴S suggests that sulfate stems from the mixing of alteration waters with either marine SO₄ in coastal waters or with deep SO₂ in inland waters. In both the north and south, the Mg concentration is drastically lowered (<1 μmol/L) by the probable formation of a chlorite-type mineral. In the south, very small amounts of seawater (<1% in volume) are sufficient to imprint a clear signature on thermal waters. Not only coastal springs are affected by seawater mixing, but also remote inland springs, as far as 150 km from the sea. Subduction of marine sediments in the accretive margin could be the source of the marine imprint in thermal waters of southern Chile. Seawater may be expelled from the subducted lithosphere and incorporated into the mantle source.

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1. Introduction

The objective of this study is to determine the origin of the main components in thermal waters of Chilean Andes (Fig. 1). We will focus on two specific sections of the Cordillera: northern Chile (18°–27°S, 1000 km) and southern Chile (37°–45°S, 1000 km). Each one presents a geographic, climatic and geologic homogeneity. Both are mainly volcanic, but the northern Cordillera is an elevated patchwork of arid closed basins, while the southern Cordillera is a set of generally parallel valleys in a humid marine climate. The central Cordillera shows a large heterogeneity and absence of volcanoes between 27° and 33°S.

As a general rule, dissolved components in thermal waters have two main origins: magmatic fluids and hydrothermal alteration of

host rocks. In Chile, a major difference between the northern and the southern Cordillera is the presence of deep evaporites below the volcanic formations in the north, while they are completely lacking in the south. Salts and brines have a major impact on the composition of subsurface waters in northern Chile, which may obscure the origin of their dissolved components. One objective is to compare the composition of thermal waters in the two volcanic sections of the Cordillera in order to evaluate the extent of evaporite contribution.

This study is based on a large set of 104 analyses of thermal waters, which amounts to one third of all thermal waters known in Chile (Hauser, 1997). It is divided into three main parts: First we examine the behavior of the two most conservative components Cl and Br; then we model the alteration of volcanic rocks and compare the composition of the calculated solutions with the real ones; finally we try to unravel the origin of dissolved sulfate with the help of sulfur isotopes.

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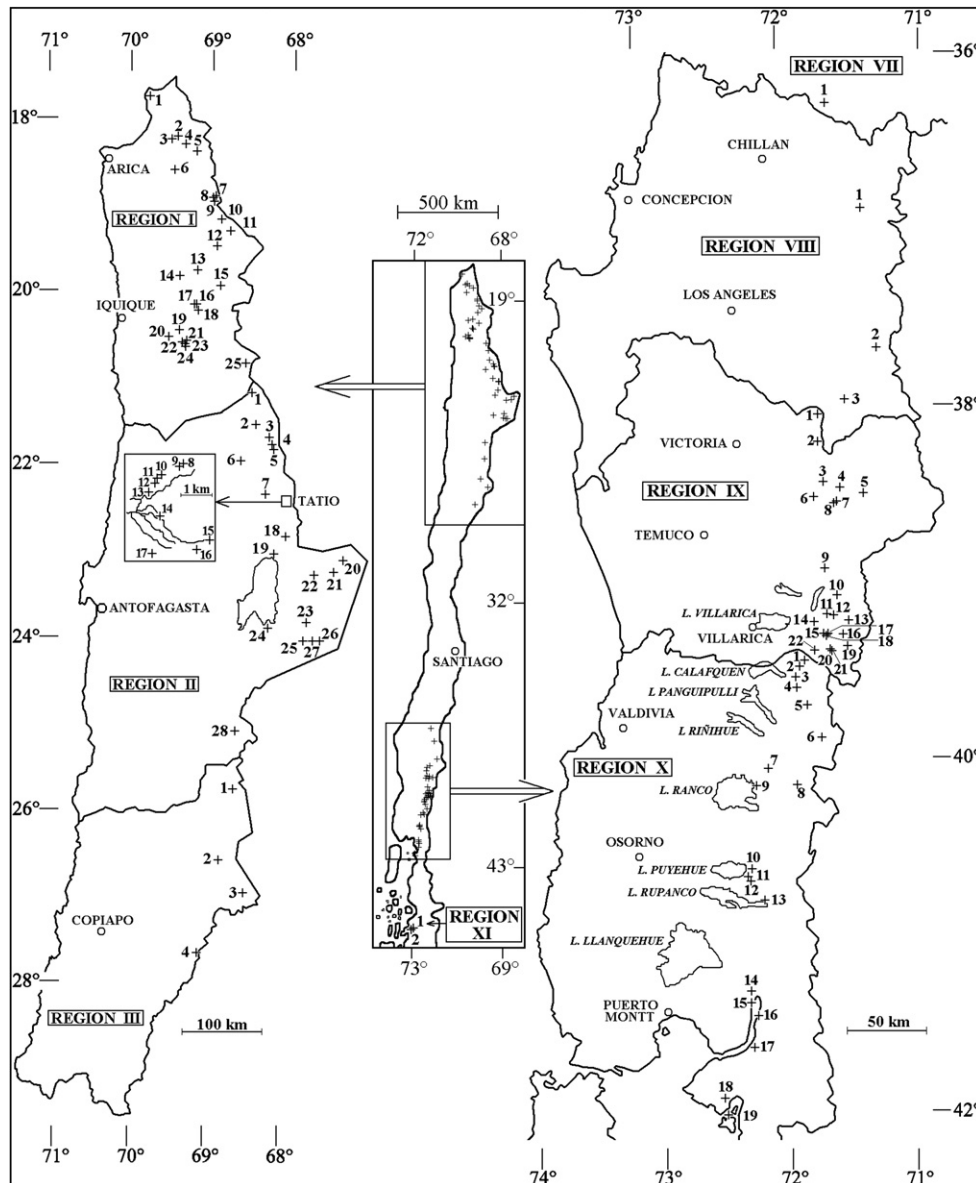


Fig. 1. Location map of Chilean thermal springs.

2. Previous studies

Previous studies are of two kinds: inventory studies covering wide areas and geochemical studies restricted to small thermal fields. Early global studies were done by Lahsen (1976a, 1976b, 1988), especially in northern Chile. Hauser (1997) realized an exhaustive inventory of thermal springs in whole Chile. Pérez (1999) described and analyzed most of the southern thermal springs in the latitude range between 39° and 42°S. Aguilera et al. (2006) and Tassi et al. (2008) surveyed the geothermal resources of northern Chile. Recently, Ray et al. (2009) published a geochemical study on gas geochemistry of hydrothermal fluids covering a large area of southern Chile. More specific studies focus on the largest geothermal field in South America: El Tatio (Cusicanqui et al., 1975; Giggenbach, 1978; Fernandez-Turiel et al., 2005; Tassi et al., 2005; Cortecci et al., 2005). Specific studies in other areas are scarce. Mahon and Cusicanqui (1980) described a small geothermal field in northern

Chile. Sepúlveda et al. (2004) and Sepúlveda et al. (2007) examined one of the largest active geothermal systems of Southern Chile.

3. Sampling and analyses

Water samples were filtered through a 0.45 µm membrane and stored in polyethylene bottles. Temperature and pH were measured as close as possible to the emergence point. Cations were analyzed by atomic absorption spectrometry. Cl and SO₄ were determined by ion chromatography and alkalinity by electrometric titration. Si and B were determined by automatic colorimetry. Bromide was analyzed by ICP–MS and ion chromatography. The detection limit of Br by ICP–MS is 0.04 µmol/L (3 µg/L). Very low concentrations of Mg and B were analyzed by ICP–MS. The error for all components is in the range ±2 to ±5% depending on the dilution steps and the detection limit. δ³⁴S was determined by elemental analyzer-isotopic ratio mass spectrometer (EA-IRMS) after precipitation of

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