Geochemical processes and mechanisms for cesium enrichment in a hot-spring system

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ABSTRACT

Geothermal systems in Tibet, a crucial geothermal region in China, belong to the Mediterranean-Himalayan geothermal belt and are characterized by a broad distribution of cesium (Cs) bearing geyserite deposits. Targejia, one of the largest Cs-bearing geyserites in southern-western Tibet, contains 1.446 × 10^4 tons of Cs. The highest ore grade reaches 2.89 wt%, and the ore-forming process can be subdivided into mineralization stages I to V. Cs is heterogeneously distributed in geyserites. Herein, two Cs-bearing ores are investigated, with distinct characteristics of (1) low-Cs-bearing ore (amorphous silica opal-A and opal-CT type) with low Cs (average of ~0.2 wt%), Na, K, Al, and Ca contents, and (2) high-Cs-bearing ore (clay type) with high-Cs (average of ~1.40 wt%), -Na, -K, -Al, and -Ca contents. It is reported for the first time that Cs primarily exists in clay rather than in amorphous silica opal. The Cs-enrichment mechanisms are different for the above two Cs-bearing geyserite types: (1) The deprotonated –OH, surrounded by water molecules, controls the amount of Cs absorbed on the geyserite surface (Si–OH) in the low-Cs-bearing ore. (2) The variable Cs content depends on the Al content because Al substitutes Si, yielding more negative charges to absorb Cs in the high-Cs-bearing ore. Geothermal fluid loading-mass elements, such as Cs and SiO_2, precipitate as amorphous silica (opal) with clay minerals. Mineral saturation index modeling was used to predict the most applicable physical parameters for ore formation. The results confirm that the ore forms at ~85 °C and a pH of ~8.5 in the Na-Cl system at stage V. The degree of Cs enrichment reduces from the latest stage V (0–4 ka) to the early stage IV (4–17 ka), and is controlled by clay dissolution, which might further relate to the climate change in Tibet’s Holocene. Fluid-rock interaction modeling shows that dissolution–reprecipitation induces a higher order of amorphous silica formation and clay dissolution at >40 °C and pH of 5–9 at stages V and III, excluding Cs from the ore.

Keywords: Cs, enrichment mechanism, amorphous silica, clay

INTRODUCTION

Owing to its excellent optoelectronic properties and strong chemical activity, cesium (Cs) is a critical metal widely used in vacuum devices and phototube manufacturing. So far, Cs deposits can be divided into granite-pegmatite (Černý 1978) and hot-spring types (Guo et al. 2008). Hot-spring deposits closely relate to geothermal systems because sinter deposits precipitated from geothermal fluids contain many ore elements (i.e., Au, Ag, Li, B, As, Mo, Hg, Cu, Pb, Sb, and W) (Fig. 1a) (Rui and Shen 1992; Lynne et al. 2007). Sinters represent a rare situation among low-epithermal hydrothermal systems because metal mineralization occurs in subaerial siliceous sinters (Lynne et al. 2007).

The Yunnan-Tibet geothermal belt (YTGB), part of the Himalayan geothermal belt, is in the primary collision zone with intense tectonic deformation between the Indian and Eurasian plates, where intense modern geothermal activities are developed (Tong and Zhang 1981). Geothermal systems, including geothermal fluids and their sediments, have been used as tracers for recording the changes in external surroundings and climate, which reflect the tectonic–thermal events in the plateau’s rapid uplifting process in recent several million years or several hundred-thousand years (Hou et al. 2001). Along the YTGB, large-scale silica sinters (opal-A, opal-CT, and opal-C) form as discharging thermal fluids cool at the surface below 100 °C (Guidry and Chafetz 2002).

In Tibet, China, a new type of Cs-bearing geyserite was found in 1986. Geothermal fluids have high-Cs contents (up to ~50 μg/mL), and parts of Cs-bearing geyserites constitute large-scale Cs deposits (Zheng et al. 1995). The Targejia hot-spring Cs deposit is one of the largest Cs deposits in Tibet and represents the focus of an ongoing exploration program for high-grade Cs ore (Zheng et al. 1995; Zhao et al. 2006a, 2006b, 2008). The Cs potential resources in the area yield 1.446 × 10^4 t (ore grade up to 1.55 wt%) (Zheng et al. 1995).

The Cs enrichment in geothermal fluids can be attributed to the partial melting of the Qinghai–Tibet Plateau’s crust, magma evolution, and fluid-rock interaction (Li et al. 2006). The collision between India and Asia is one crucial factor in partial melting (Li et al. 2006). When geothermal fluids loading high-Cs, high-H_2SiO_3, high-Na, high-B, and high-Li contents ascend...