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Geothermal constraints on enrichment of boron and lithium in salt lakes: An example from a river-salt lake system on the northern slope of the eastern Kunlun Mountains, China

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ABSTRACT

Some rivers on the northern slope of the eastern Kunlun Mountains in the Qaidam Basin, China, show very high concentrations of boron and lithium. Correspondingly, the salt lakes fed by these rivers show an unusual enrichment of boron and lithium, and become an important economic resource. The origin of boron and lithium has long been debated. The aim of this study is to analyze the water chemistry and hydrogen and oxygen isotopic composition of river water to understand the unusual enrichment of boron and lithium in the salt lakes of the Qaidam Basin. Oxygen and hydrogen isotope data show that the source of river water in the winter and summer originates from the Kunlun Mountain ice and snow melt water, respectively. The water chemistry shows that boron and lithium contents are high but little variable with seasons in the Nalenggele River and Wutumeiren River waters. By contrast, other rivers have much lower lithium and boron contents. Moreover, the contents of B^{3+} and Li^{+} in the river loads or bed sands show little difference amongst the rivers. This indicates that removal by adsorption or input by surface rock weathering is not the main controlling factor of the B^{3+} and Li^{+} variation in the rivers. Rivers with high B^{3+} and Li^{+} content are chemically similar to geothermal waters in the Tibetan Plateau. In addition, the source area of the Nalenggele River is located in a collision zone of the Kunlun Mountains and Altun Mountains. Large and deep faults can serve as conduits for geothermal fluids. Thus, deep geothermal waters in the source area can easily migrate to the surface and discharge as springs feeding the rivers. They are an important source of B^{3+} and Li^{+} to the rivers. The abnormally high contents of B^{3+} and Li^{+} in the Nalenggele and Wutumeiren Rivers also suggest that the geothermal source area may be a future target for boron and lithium resources.

1. Introduction

Salt lakes fed by rivers from the northern slope of the eastern Kunlun Mountains, Qaidam Basin, China, have unusually high concentrations of lithium and boron, and are important economic resources. This is a particularly important considering the current world shortage of lithium. However, it is unclear whether this resource is renewable, so it is important to understand whether the potential exists to maintain these resources after exploitation.

Our recent chemical analysis of rivers sourced from the eastern Kunlun Mountains shows that some rivers on the northern slopes have very high boron and lithium contents, with corresponding enrichment in the salt lakes fed by these rivers. Clearly, the boron and lithium resources in the salt lakes have a relation to recharge from the rivers. An important question is why, with similar types of rocks and chemical weathering conditions, some rivers are enriched in boron and lithium, but others have very low boron and lithium contents. Previous work reported that geothermal waters always show an unusually high concentration of lithium (Campbell, 2009), and the content of lithium in rivers is often used as an exploration indicator for hydrothermal systems (Fouillac and Michard, 1981; Brondi et al., 1970; Trompetter et al., 1999). It has been suggested that hydrothermal systems may be used to satisfy the international market demand for lithium. Investigations at Salar de Uyuni and the nearby salars (salt pans) of Coipasa and Empexa in the southern part of the Bolivian Altiplano were found to have widespread lithium-rich brines sourced from thermal springs associated with rhyolitic volcanic rocks of Quaternary age, which is thought to have been a major source of the lithium in the brines (Campbell, 2009; Shcherbakov and Dvorov, 1970; Ericksen et al., 1978). Vengosh et al. (1991) used B and Li isotopes to constrain boron and lithium sources in the Dead Sea, showing that they are mainly sourced from hot spring waters. Grimaud et al. (1985)

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studied about 300 thermal springs in Tibet in detail and found that many geothermal fields produce boron, lithium and cesium-rich waters. Zhen et al. (1989) has studied Tibetan salt lakes, also showing that boron and lithium may originate from geothermal waters. These high boron and lithium content waters likely originate from magma evolution. Boron isotopic data in Qaidam Basin also shows that the $\delta^{11}B$ of Nalengele River (−1.0‰) and Wutumeiren River (−0.7‰) are much lower than that of the Qaidam River (6.8‰). This suggests that the boron sources for these rivers are different (Xiao et al., 1999). Based on the geological setting and remote sensing images, Zhu et al. (1989) found that the magmatic-hydrothermal activity on the binding margin of the eastern Kunlun Mountains and Altun Mountains was frequent, possibly providing a constant source of B and Li to the geothermal water.

Due to the difficult terrain, it is impossible to investigate the source area or collect geothermal spring samples of the Nalenggele River. The objective of this study is to analyze the water chemistry and hydrogen and oxygen isotopic composition of the river water of the eastern Kunlun Mountains over several seasons in order to understand the dominant source of boron and lithium enrichment in rivers and the salt lakes that they feed.

2. Geological and hydrological setting

The Qaidam Basin is a large intermontane basin at the northeastern corner of the Tibetan Plateau. This rhombic-shaped basin is situated at a compressional right-step of two major sinistral fault systems, the Altun deep fault to the north and the Kunlun deep fault to the south (Fig. 1). The northeastern and southwestern edges of the basin are bounded by the Qilian and Kunlun Mountain belts, respectively. Before the Hercynian orogeny, the Qaidam area was still a part of ancient Tethys. Since then, it has undergone several orogenic movements, and the embryonic form of the Qaidam Basin occurred after the Indosinian movement since the Mesozoic (Fig. 1).

Restricted by terrain and the new tectonic activity, the surface water system in the Qaidam Basin is characterized by a centripetal radiation distribution (Fig. 1). All large rivers are found on the northern slope of the eastern Kunlun Mountains, and melt water is the main recharge component. Generally, the small rivers and tributaries disappear in gravel and sand deposits recharging groundwater down slope of the mountains. Some larger rivers can survive to the inland basin and so are sources for the salt lakes in low-lying areas. The Nalenggele River and Golmud River are the first and second largest rivers, respectively, in the Qaidam Basin. They originate from the eastern Kunlun Mountains and the average annual runoff is $10.351 \times 10^8\ m^3/y$ and $7.98 \times 10^8\ m^3/y$, respectively (Yang and Zhang, 1996). The Golmud River is mainly fed by two large tributaries, the Kunlun River and Xueshui River. Wutumeiren River, adjacent to the Nalenggele River, is sourced from marsh and spring water and constantly receives recharge from springs as it flows from west to east, finally becoming a large river with average discharge of $0.84 \times 10^8\ m^3/y$. It can be also regarded as a tributary of the lower reaches of the Nalenggele River. The Qaidam River, with runoff of $3.96 \times 10^8\ m^3/y$, and the Qrhanwusu River, with runoff of $1.37 \times 10^8\ m^3/y$, are also large rivers in the southern Qaidam Basin. Yiliping playa and, Xitai and Dongtai salt lakes are fed by the Nalenggele River, while Senie salt lake is fed by the Wutumeiren River, and Dabson salt lake is fed by the Golmud River. Surface or intercrystalline brines of the Yiliping playa, and Xitai and Dongtai salt lakes are a world famous resource for boron and lithium. The concentration of lithium is one of the highest found in brine resources in the world.

The dominant type of rocks in the source area of the rivers is generally granodiorite, plagioclase granite, and quartz diorite. Away from the mountains, the lithology changes to alluvial and pluvial sands, gravels, and sandy clay. Near the lake area, the lithology is mainly clay, salts, and gypsum-dominated evaporites.

3. Sampling and analysis

River and spring water samples were collected during three site visits in December 2008, July 2009 and January 2010 (Fig. 1). Generally, all rivers in the research area have the largest runoff in early summer, while they keep a base flow in late winter. Hence, many of the sites were sampled repeatedly to provide data on seasonal variations. In addition to samples from the Nalenggele, Wutumeiren, Kunlun, Xueshui, Golmud, Qaidam and Qrhanwusu Rivers, some

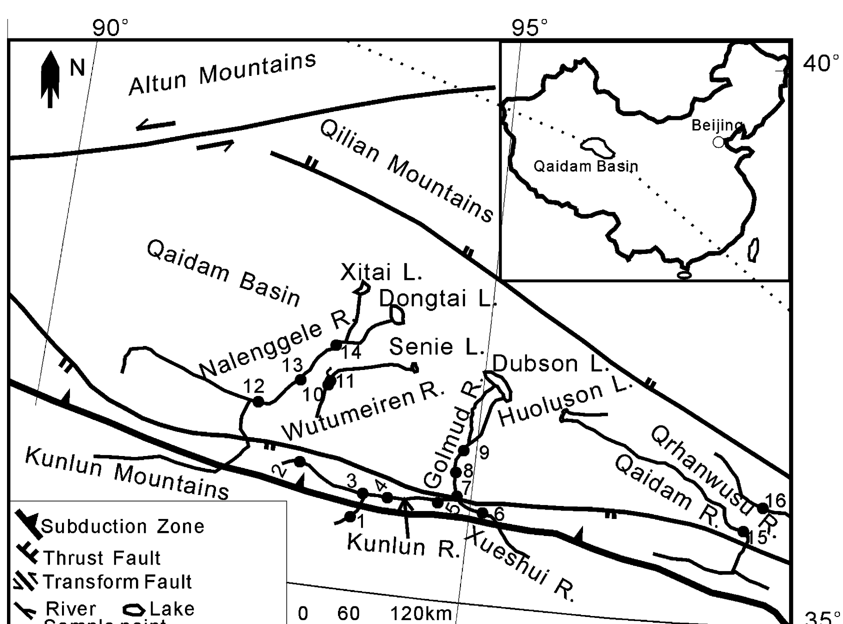

Fig. 1. The tectonic background of Qaidam Basin and location of the main rivers sourced from the northern slope of the eastern Kunlun Mountains. Location of river water sample sites are also displayed in the diagram. The sample numbers are corresponding to Fig. 2 and also Tables 1–3.