Sedimentary Geology 322 (2015) 34–42

Contents lists available at ScienceDirect

Sedimentary Geology

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

Boron occurrence in halite and boron isotope geochemistry of halite in the Qarhan Salt Lake, western China

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ARTICLE INFO

Article history:
Received 5 January 2015
Received in revised form 30 March 2015
Accepted 31 March 2015
Available online 9 April 2015

Editor: B. Jones

Keywords:
B isotope composition
Halite
Qarhan Salt Lake
Qaidam Basin
Western China

ABSTRACT

Previous studies have investigated boron (B) isotope composition of salt lake brines in the Qaidam Basin, western China. However, the research on B isotope geochemistry of halite from a sediment core in a typical sedimentary basin has been very limited. In this study, a 102-m-long drill core (ISL1A) was recovered from Qarhan Salt Lake in eastern Qaidam Basin. Forty-three halite samples from upper 44.0 m in ISL1A were collected and analyzed for chemical compositions (K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, Sr^{2+} and B^{3+}) and B isotopes in order to investigate their relationships, and B isotope fractionation between halite and brines in the Qarhan Salt Lake. The results show that: (1) more B^{3+} and Mg^{2+} values in halite are low concentrations and more concentrated, and low B^{3+} concentrations have a strong correlation with low Mg^{2+} in halite, which imply that they might be the same source; (2) low Mg^{2+} values in halite from ISL1A have a similar trend with $^{m}Mg^{2+}$ (molarity) of fluid inclusion brines from two sediment cores (east to ISL1A about 50 km) in the study area, suggesting that low B^{3+} and Mg^{2+} concentrations should derive from fluid inclusions in halite based on X-ray diffraction results in ISL1A that no borate and small amount of magnesium salts were deposited; (3) $\delta^{11}B$ values of halite in ISL1A range from −0.35 to +5.84‰, which are in the range of those of river water and brines (−1.0 to +9.6‰), and almost overlapped with those of brines (+2.9 to +7.5‰) in the Qarhan Salt Lake. These results suggest that no or minor B isotope fractionation between halite and brine occurred.

1. Introduction

The high geochemical reactivity of boron (B) and the large relative mass difference between ^{10}B and ^{11}B lead to significant B isotope fractionation in nature (Xiao et al., 2013). So far the concentrations of B and its different isotope components are important tracers for mass transfer processes in terrestrial systems (e.g. Casanova et al., 2005; Chetelat et al., 2005; Kasemann et al., 2009; Kaliwoda et al., 2011; Zhao et al., 2011; Anagnostou et al., 2012; Sakata et al., 2013). Consequently, B isotope composition of evaporites and brines have been used to trace paleosalinities and to reconstruct marine or non-marine depositional environments (Palmer and Slack, 1989; Qi et al., 1989; Vengosh et al., 1991, 1992, 1995; Xiao et al., 1992; Palmer and Swihart, 1996; Jiang, 2000; Liu et al., 2000; Kloppnam et al., 2001; Paris et al., 2010; Tan et al., 2010; Zhang et al., 2013).

Over the past two decades, significant research efforts have been invested to reconstruct the origin and geochemical processing of brines, groundwater, hot springs and sediments using B isotopes and elemental ratios (Vengosh et al., 1991, 1995, 1998, 1999; Xiao et al., 1992; Li et al., 2013; Lv et al., 2014). Similarly, the origin and evolution of different fluids and water–rock interaction have also been evaluated based on multiple isotopic and geochemical tracers (such as H, O, Sr, B isotopes, and Na/Cl, B/Cl, Br/Cl, B/Li, Mg/Ca ratios) (Vengosh et al., 2002, 2007). At the salt lakes in the arid region, some studies have focused on B isotope compositions of brines from different salt lakes in Inner Mongolia, Qinghai, Xinjiang and Tibet Provinces in western China, and reported that these values vary in different regions (Qi et al., 1993), and even in different salt lakes in the Qaidam Basin, Qinghai Province (Fig. 1) (Xiao et al., 1992, 1999, 2000; Vengosh et al., 1995; Liu et al., 2000). The result suggests that $\delta^{11}B$ values of brines in different salt lakes are probably influenced by evaporation conditions and surrounding supply of water (Xiao et al., 1992, 1999, 2000; Vengosh et al., 1995), and indicates that $\delta^{11}B$ values of brines in different salt lakes can be used to trace the source of saline lakes. Other studies on the relationship between ionic concentrations and B isotope compositions of brines from salt lakes in the Qaidam Basin indicate that the $\delta^{11}B$ values are uncorrelated with Na/Cl, Mg/Cl and K/Cl ratios, while they have a moderate correlation with Ca/Cl ratio in brines (Liu et al., 1999; Xiao et al., 1999).

However, the research on B isotope compositions of salt minerals in Qaidam Basin has been limited (Xiao et al., 1992; Liu et al., 2000; Wei et al., 2014). For example, Xiao et al. (1992) determined $\delta^{11}B$ values of brines, lake sediments and borate minerals in Da Qaidam Salt Lake in central-north Qaidam Basin, and discussed the mechanism of B isotope fractionation between brines and borate minerals in typical boron-rich

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http://dx.doi.org/10.1016/j.sedgeo.2015.03.012

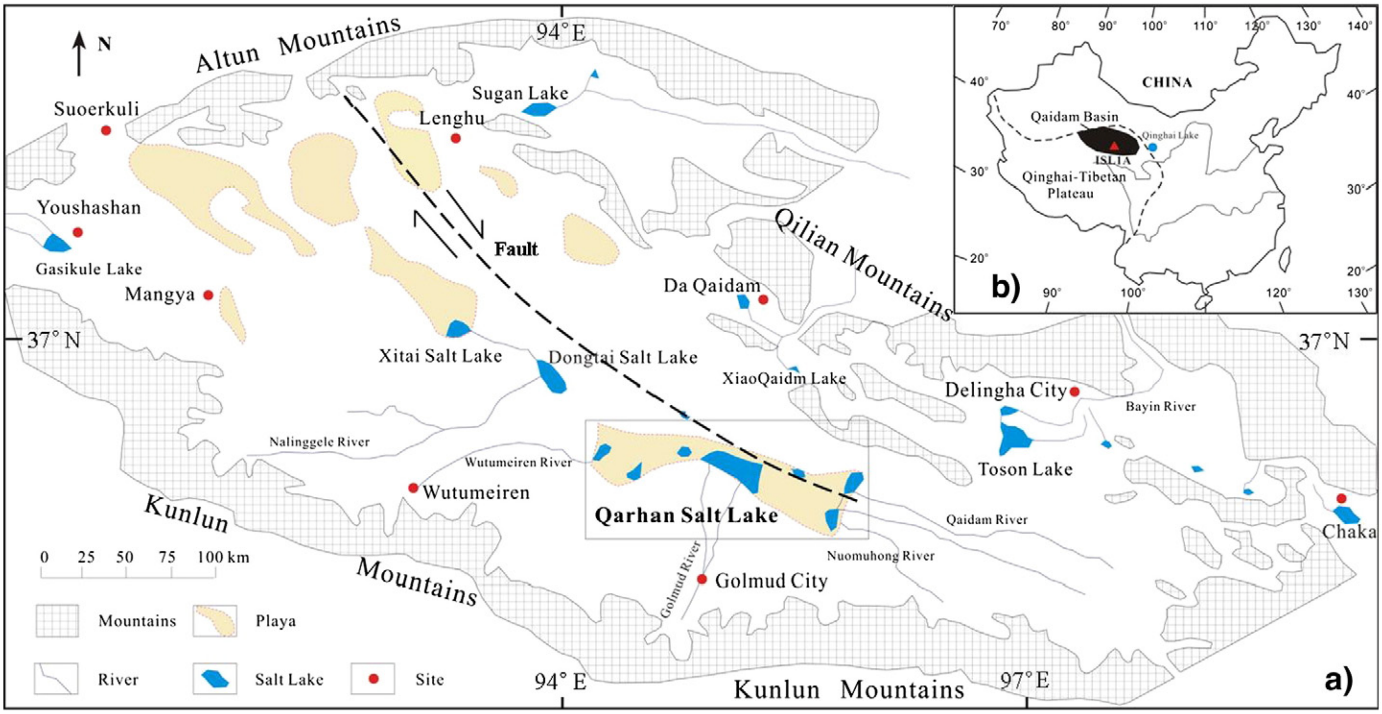

Fig. 1. Map showing the location of drilling cores and salt lakes in the Qaidam Basin. (a) Map showing the location of Qaidam Basin on the northeastern Qinghai–Tibetan Plateau. (b) Map showing the location of ISL1A in the Qarhan Salt Lake and other salt lakes in the Qaidam Basin.

salt lake. Liu et al. (2000) determined B concentrations, pH values and $\delta^{11}B$ values of halite and coexisting brines from seven salt lakes in the Qaidam Basin. The results indicate that $\delta^{11}B$ values of halite are similar to those of brines, and those values are decreasing with increasing B concentrations and pH values in the brines. Wei et al. (2014) carried out a study on chemical compositions and B isotope geochemistry of salt sediments from Dongtai Salt Lake in central Qaidam Basin (Fig. 1), and deciphered the origin of B and lithium resources in the salt lake.

Until today, the research on $\delta^{11}B$ of salt minerals, especially halite, in a sediment core is relatively less. Therefore, further investigations are required in order to (1) compare the relationship between chemical concentrations and B isotope compositions of halite from a sediment core in salt lakes; (2) discuss the mechanism of B removal from brine into halite; and (3) compare the variation in B isotopes and its isotope fractionation between halite and brines in a typical sedimentary basin. Consequently, B isotope geochemistry of halite will be discussed based on a 102-m-long Qarhan sediment core (ISL1A) collected from the eastern Qaidam Basin. Here we present K^+, Na^+, Ca^{2+}· Mg^{2+}, SO_4^{2-}, Cl^-, Sr^{2+} and B^{3+} concentrations as well as stable B isotope compositions of halite from the upper 44.0 m of the ISL1A core.

2. Description of the study area

Qarhan Salt Lake (36°37′36″ ~ 37°12′33″N, 94°42′36″ ~ 96°14′35″E) is the largest playa in the eastern Qaidam Basin (Fig. 1). It extends west to east for about 168 km and north to south by 20–40 km, covering an area of 5856 km^2 (Huang and Han, 2007). It contains ten shallow perennial and ephemeral saline lakes, including Seni Lake, Dabiele Lake, Xiaobiele Lake, Dabuxun Lake, Tuanjie Lake, Xiezuo Lake and Huobuxun Lake and so on (Fig. 2). The Dabuxun Lake is the largest saline lake in the Qarhan playa and layered potash salt, carnallite minerals ($MgCl_2 \cdot KCl \cdot 6H_2O$), are deposited along its north shores (Zhang, 1987).

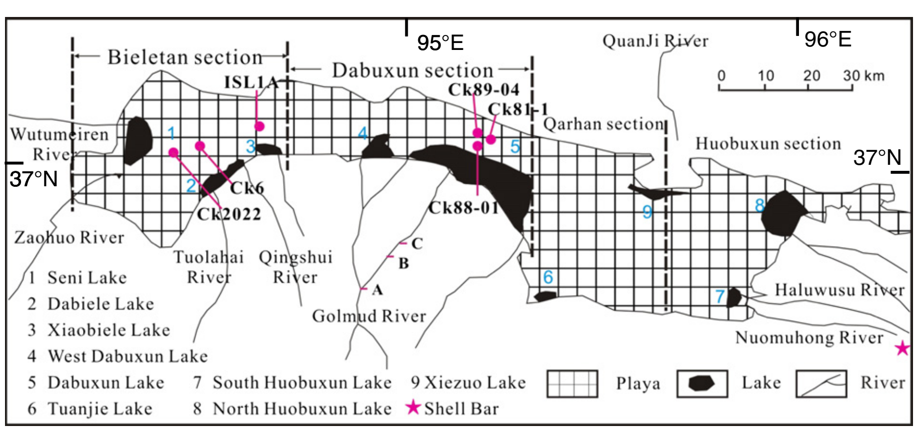

Fig. 2. Map of the drilling cores and the salt lakes in the Qarhan Salt Lake area. The symbols A, B, and C indicate the sampling sites of the Golmud River water reported by Vengosh et al. (1995).