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Variation of gypsum morphology along deep core SG-1, western Qaidam Basin (northeastern Tibetan Plateau) and its implication to depositional environments

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A B S T R A C T

The Qaidam Basin is an arid, closed, intermontane basin located on the northern margins of the Tibetan Plateau in China. A 938.5 m-long core (SG-1), dated between ~2.8 Ma–0.1 Ma, was obtained from the western Qaidam Basin. Gypsum is one of major evaporative minerals in the core. A total of 201 gypsum samples were selected and their crystal morphologies were carefully investigated. The crystal habits are lenticular, prismatic, tabular, twinned, stubby, and aggregate. Prismatic crystals occur in the upper 723 m, while lenticular crystals exist almost entirely in the upper 523 m. Tabular crystals are the most common morphology. The total abundance of gypsum crystal (including tabular, lenticular, and prismatic forms) tends to increase with decreasing depth. The relationship between crystal habits and depositional environments is complex, because same morphology can appear in different environments, and different morphologies can also occur in the same depositional environment. However, the occurrence of different morphologies can be attributed to the variable growth rates caused by the inhibition effect of additional cations (e.g. Mg^{2+}, Na^{+}, K^{+} and Sr^{2+}) on particular lattice parameters and the variation in precipitation experiments.

The lattice parameters of the unit cell of gypsum, measured by X-ray diffraction method, are: $a = 5.854$–12.57 Å; $b = 9.654$–16.231 Å; and $c = 5.163$–14.024 Å; $\beta = 113.54$–$119.88°$; Volume $= 601.55$–712.65 Å^3. The substitution of K^{+}, Na^{+} and Mg^{2+} for Ca^{2+} can reduce *c*-axis, while Sr^{2+} can reduce *a* and *b* axes. a/c, b/c, a/b tend to increase with K^{+}, Na^{+} and Mg^{2+} and decrease with Sr^{2+}. The Mg^{2+}, Na^{+}, K^{+} and Sr^{2+} contents in gypsum show significant variability, with K/Ca molar ratios varying from 1.03×10^{-4} to 32.08×10^{-4}, Mg/Ca molar ratios from 0.0023 to 0.1629, Na/Ca molar ratios from 0.031 to 0.575, and Sr/Ca molar ratios from 5.59×10^{-4} to 19.67×10^{-4}. Sr^{2+}, Mg^{2+}, Na^{+}, and K^{+} concentrations in gypsum mainly depend on growth rate and brine concentration.

1. Introduction

Evaporite minerals are important indicators for the paleoclimate and paleodepositional environments because they can reflect the hydrogeochemical conditions at the time of their precipitation (Yang et al., 1995; Playà et al., 2007; Li et al., 2010, 2013; Smykatz-Kloss and Roy, 2010; Bahadori et al., 2011; Dill et al., 2012; Tangestani and Validabadi, 2014). Gypsum ($CaSO_4 \cdot 2H_2O$), one of the most abundant evaporite minerals occurring as a syndepositional

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evaporite, carries information about brines from which they precipitate. The structure of gypsum can be described as repeating units of Ca and SO_4 layers parallel to the *b* axis, with every SO_4^{2-} group bound by four Ca atoms to form a tetrahedron (Fan and Teng, 2007). Each water molecule links adjacent Ca–SO_4 layers through weak hydrogen bonding (Atoji and Rundle, 1958; Pedersen and Semmingsen, 1982). The crystal habit of different gypsum crystals precipitated in continental environments can be used to identify the depositional environment and compare the relative importance of synsedimentary and diagenetic processes (Cody and Cody, 1988; Magee, 1991; Magee et al., 1995; Mees et al., 2012).

Trace elements are incorporated into the structure of gypsum during precipitation as a result of several processes (McIntire, 1963): (1) surface adsorption due to electrostatic attraction; (2) solid and fluid inclusions; and (3) solid-solution formation; and (4) defects in minerals. They affect the morphology, crystal size and the lattice parameters (Edinger, 1973; Ichikuni and Musha, 1978; Kushnir, 1980; McCaffrey et al., 1987; Franchini-Angela and Rinaudo, 1989; Guan et al., 2010; Rossi et al., 2011; Otalora and Garcia-Ruiz, 2014). These behaviors form a basis for utilizing trace element concentrations as geochemical indicators to decipher the depositional environment of the gypsum, evaluate paleosalinity, differentiate brine origin, and study the diagenetic history (Kushnir, 1980, 1981; Ullman and McLeod, 1986; Lu et al., 1997, 2002).

Since gypsum is formed in a complex lacustrine environment controlled by changes in climate, the relationship amongst crystal morphology, trace elements incorporated, lattice parameters and the depositional environment is complex. Most previous studies have been based on experiments performed under specific lab-controlled conditions; here we present a case study to investigate aforementioned relationships on gypsum occurring naturally.

The Qaidam Basin, located on the northern margins of the Tibetan Plateau (TP), is filled with Cenozoic sediments down to 12,000 m. During the Pliocene–Quaternary, lacustrine evaporites become more common upward through the geologic section (Chen and Bowler, 1986; Xia et al., 2001; Wang et al., 2012). In 2008, a continuous 938.5 m-long core with a high core recovery rate (95%) (SG-1; N38°24′35.3″, E92°30′32.6″) was obtained from the Qahansilatu sub-basin, western Qaidam Basin (Fig. 1). The age of the entire SG-1 core, dated by magnetostratigraphy and optically stimulated luminescence (OSL), is between ~2.8 Ma and ~0.1 Ma (Zhang et al., 2012a). In general, the sedimentary sequence consists of calcareous clay, clay–silt, and siltstone, intercalated with evaporite mineral layers (mainly halite) and scattered gypsum crystals, all of which indicate depositional cycles of clay/silt and halite/marl (Wang et al., 2012). Halite (NaCl) and gypsum ($CaSO_4 \cdot 2H_2O$) make up the majority of the evaporate minerals. Carbonates consist mainly of calcite ($CaCO_3$), aragonite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). Clays (including illite and chlorite), quartz, albite, orthoclase, and traces of talc and amphibole are also found. The different morphological characteristics of gypsum and their formation have been analyzed (Li et al., 2010), providing an opportunity to study the crystal morphologies of gypsum and their formation mechanisms. This study thus aims to: (1) study the variation of crystal morphologies in deep core SG-1, western Qaidam Basin (northeastern Tibetan Plateau); (2) elucidate the factors affecting the coprecipitated ions and lattice parameters in the gypsum; and (3) interpret the relationship amongst crystal morphology, coprecipitated ions, lattice parameters and the depositional environment.

2. Geological setting

The Qaidam Basin covers an area of ~120,000 km^2 along the northern margins of the TP (Fig. 1). It is surrounded by the Kunlun Mountains to the south, the Qilian Mountains to the northeast, and the Arjin Mountains to the northwest. The mean elevation of the

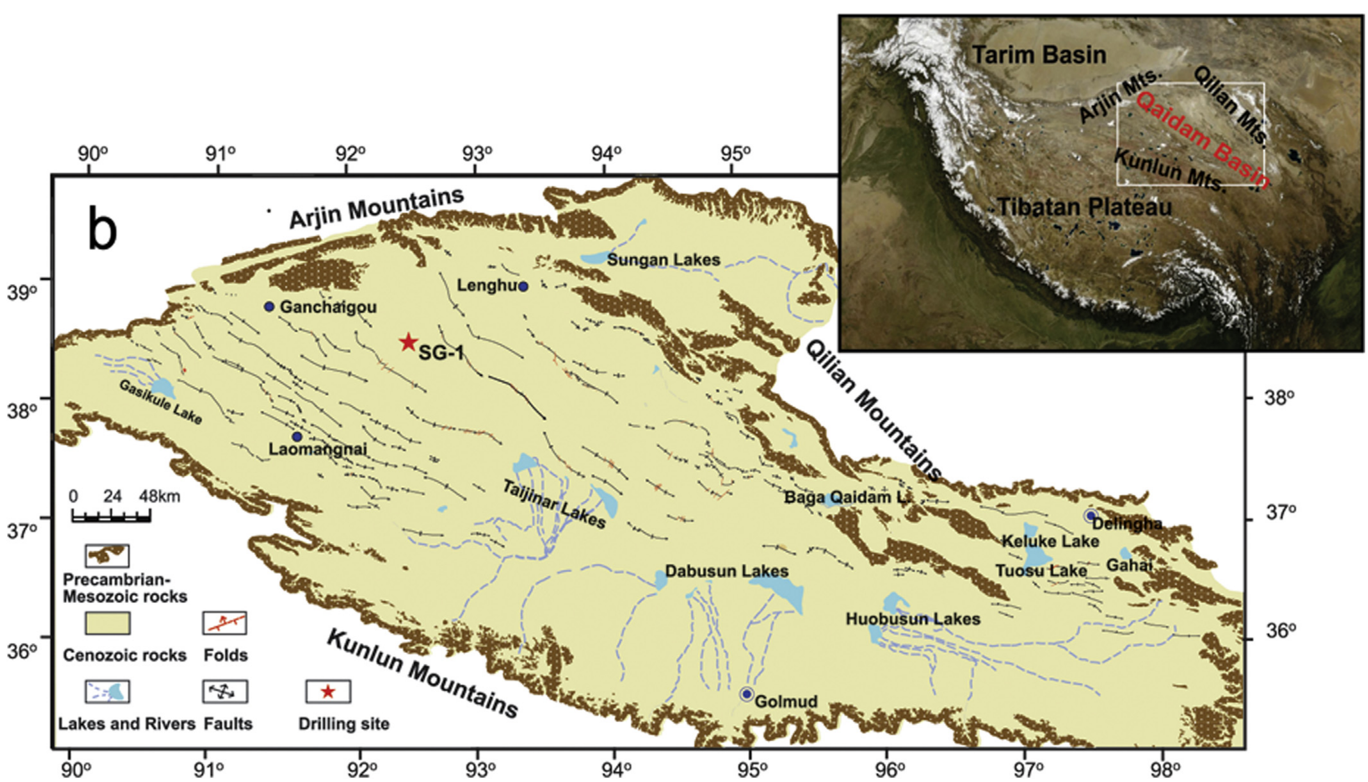

Fig. 1. Map of the Qaidam Basin and adjacent regions showing surrounding mountains, major structures, and the location of the SG-1 Core (modified from Yang et al., 2014).

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