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Genesis of the late Eocene bedded halite in the Qaidam Basin and its implication for paleoclimate in East Asia

Pei Guo[a,*], Chiyang Liu[a,*], Lei Huang[a], Peng Wang[b], Ke Wang[b], Haili Yuan[b], Chongkai Xu[a], Yiyin Zhang[a]

[a] State Key Laboratory of Continental Dynamics/Department of Geology, Northwest University, Xi'an, Shaanxi 710069, China
[b] Qinghai Oilfield Company, PetroChina, Dunhuang, Gansu 736202, China

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ABSTRACT

It has long been suggested that the Eocene climate in East Asia was characterized by three latitudinally distributed zones, one middle arid zone and two humid zones to its north and south. The middle arid zone was firstly proposed based on the widespread red beds and evaporites in a NWW-trending zone of China. However, this long-standing model has recently been challenged by increasing doubts about the effectiveness of these arid-climate indicators. The Qaidam Basin, as one of the Eocene evaporites-bearing basins in China, can be studied to test whether the bedded evaporites can validly indicate arid climate. Over 300-m halite beds have been found in the late Eocene Upper Xiaganchaigou (UXG) Formation in a local saline center (Shizigou area) of the Qaidam Basin. Its coexistence with source rocks and limited distribution, together with the absence of red beds, make it difficult to explain the halite genesis with the conventional climatic-controlled playa model. Based on stratigraphic correlation, lithological and mineralogical observation, and oxygen, carbon and chlorine isotopic analysis, we identify several characteristics about the Shizigou saline center: (1) undulated lake floor; (2) shallow water; (3) limited hydrothermal impact; (4) evaporation-induced precipitation; (5) high eolian influence; and (6) fluctuated climate background. According to these investigations, we suggest a new model for the genesis of the bedded halite in the Qaidam Basin, the tectonic-climatic model. The key point for this model is that the undulated topography caused by tectonic activity and the fluctuated climate together leaded to the hydrological isolation of the Shizigou area. The Shizigou area was isolated from the larger brackish Qaidam paleolake for independent evaporation during arid climate stage while connected with it during humid climate stage, causing alternatively water influx and evaporation and inducing the occurrence of interbedded halite and source rocks. Thus, the widespread bedded halite in the Eocene strata over China may indicate fluctuated rather than arid climate in East Asia.

1. Introduction

A number of hydrocarbon-rich continental basins developed during the Eocene in China, including the Bohai Bay Basin, Jianghan Basin, Qaidam Basin and so on, some of which bear the famous "small-in-size but rich-in hydrocarbon" sags in China (Fig. 1A) (Liu et al., 2014). These basins were confined in a NWW-trending zone of China (Fig. 1A). Noticeably, lake water in these nonmarine basins was all saline during the development of their major source rocks (Sun et al., 1997; Jiang et al., 2004; Quan et al., 2014), resulting in the interbedded relationship between source rocks and thick-bedded halite. Considering the widespread red beds and evaporites in this zone, some researchers proposed a latitudinal middle arid zone across East Asia during the Eocene to explain the occurrence of this saline phenomenon (e.g. Liu, 1997; Wang et al., 1999; Guo et al., 2008; Zhang et al., 2012; Wang et al., 2013). However, other researchers argued against this viewpoint; instead, they suggested a seasonal/monsoonal climate for Eocene China via petrological, sedimentological and paleontological evidence (Tong et al., 2002; Shi et al., 2008; Sun et al., 2009; Quan et al., 2011, 2012, 2014; Ma et al., 2012). The key for this controversy is whether the red beds and evaporites in this zone can effectively indicate arid climate (Quan et al., 2014). Numerous studies have strongly opposed the exclusive sedimentary indication of red beds for arid climates, because red beds simply indicate oxidizing conditions (e.g. van Houten, 1973; Turner, 1980; Sheldon, 2005). Therefore, the genesis of evaporites is very important for understanding the Eocene climate of China and checking whether there existed a middle arid zone during the Eocene in East Asia.

* Corresponding authors.
E-mail addresses: guopei@stumail.nwu.edu.cn (P. Guo), lcy@nwu.edu.cn (C. Liu).

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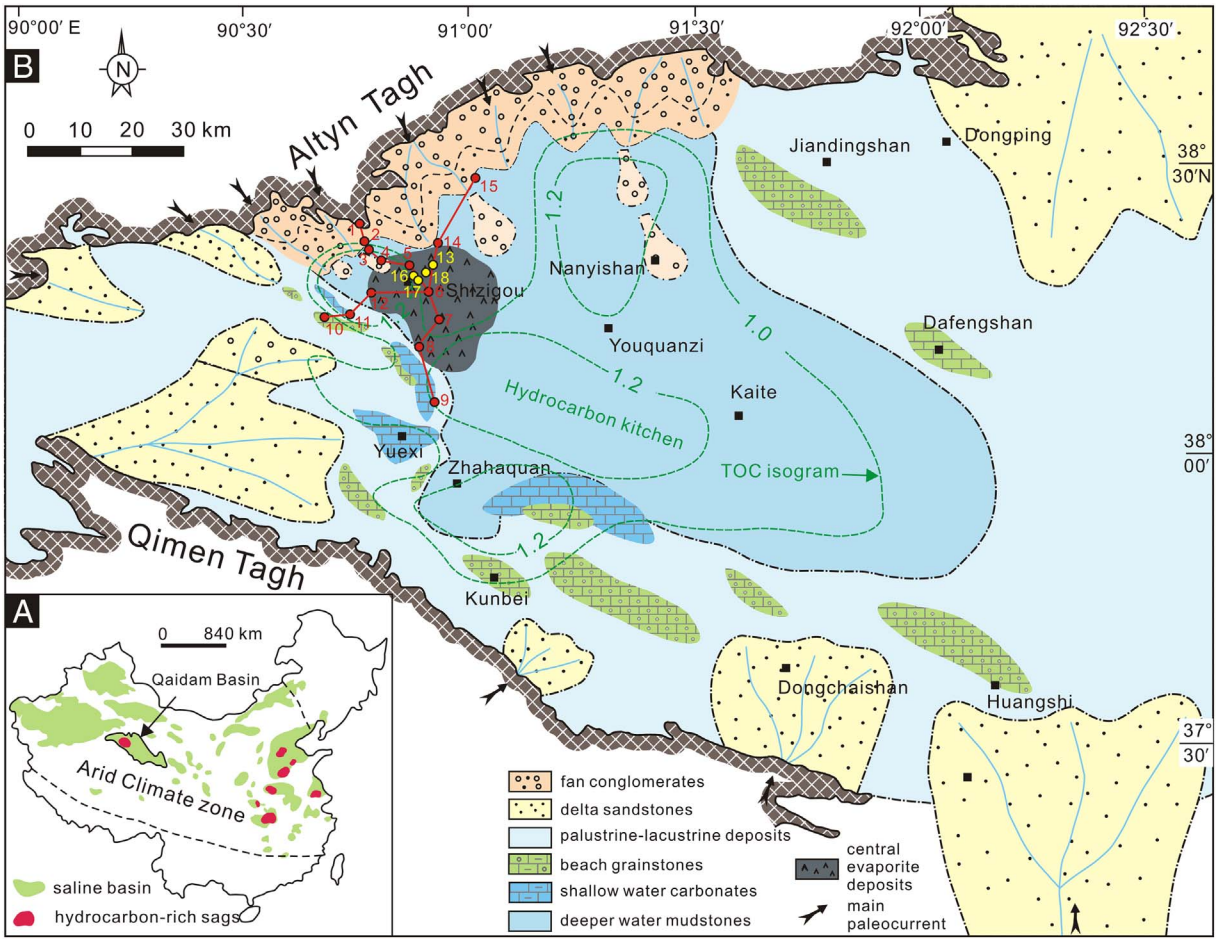

Fig. 1. (A) Location of the Qaidam Basin in the so-called Eocene arid climate zone of China (modified from Jiang et al., 2004 and Quan et al., 2014). (B) The location of Shizigou saline center in the late Eocene Qaidam paleolake. The paleogeographic map of the southwestern Qaidam Basin is recovered based on thousands of data from cores, outcrops, and heavy minerals (adapted from Wang et al., 2014). The hydrocarbon kitchens sketched by green dotted lines are adapted from Su et al., 2006. The wells marked by yellow circles are important wells for core observation and sample tests. Wells: 13-Shi 43, 16-Shi 37, 17-Shi 23, 18-Shi 40. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Thick-bedded evaporites, especially the soluble halite, are widespread around the world (Warren, 2016). Their existence has attracted continuous interests of geologists over the last fifty years (e.g. Hsü et al., 1972, 1977; Hardie and Lowenstein, 2004; Christeleit et al., 2015). Especially, evaporites closely associated with source rocks in sedimentary basins were widely investigated (Kirkland and Evans, 1981; Warren, 1986; Hussain and Warren, 1991; Quan et al., 2014). Nevertheless, due to the absence of modern counterparts, the genesis and depositional environment of these thick-bedded evaporites still remain uncertain (Warren, 2016); three models about this have been proposed so far: the deep-water model (e.g. Desborough, 1978; Johnson, 1981), shallow-water model (Lundell and Surdam, 1975; Moncure and Surdam, 1980), and frequent water-level changing model (e.g. Smith et al., 2008; Davis et al., 2009). The latter two models emphasized the climatic control on the formation of halite, while the first model focused more on the tectonic control (Hardie, 1990).

The Qaidam Basin, as one of the Paleogene saline basins in China, is situated on the northeastern margin of the Tibetan Plateau (Fig. 1A). During the late Eocene, ca. 300-m thick-bedded halite was deposited in a local sag (i.e., Shizigou area) in this basin (Fig. 1B). These halite beds co-existed with the major source rocks (Su et al., 2006), and the whole halite-bearing strata are integrally in (dark) grey tint. These characteristics are obviously distinct from the lithological associations of climate-based evaporative models, in which red beds spread widely in surrounding mudflats (Benison and Goldstein, 2001; Salvany et al., 2007). So far, two different models have been proposed to explain the genesis of thick-bedded evaporates in the Qaidam Basin, climate-controlled evaporation (arid) and tectonic-controlled hydrothermal origins (humid) (Yuan et al., 1983; Jin and Cha, 2000; Xia et al., 2017). Until now no consensus about this issue has been reached, leading to the poor understanding on the early Cenozoic climate of the Tibetan Plateau (Ye et al., 2016).

The main aim of this work is to study the genesis of the late Eocene bedded halite in the Qaidam Basin and then figure out whether the bedded halite can effectively indicate the existence of the middle arid zone in East Asia. Based on the detailed stratigraphic correlation, mineralogical analysis, textural description, and isotopic analysis of halite and carbonates, the water depth, halite origin, tectonic and climatic settings have all been studied to propose a mechanism model. This model emphasizes the importance of active tectonics and fluctuated climate for the formation of thick-bedded halite, which has potential to explain the genesis of the coeval halite in East China. This model also disagrees with the existence of the Eocene NWW-trending arid climate zone in East Asia.

2. Geological setting and stratigraphy

The Qaidam Basin is the largest intracontinental sedimentary basin on the NE Tibetan Plateau. It is filled with an unusually thick Mesozoic to Cenozoic sedimentary sequence of 3–16 km, averaging 8 km. This basin is now bounded by three large mountain ranges with elevations of 4000 to 5000 m, including the Altyn Tagh to the northwest, the Qimen