Quaternary Science Reviews 78 (2013) 53–64

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Magnetostratigraphic and radiometric constraints on salt formation in the Qaidam Basin, NE Tibetan Plateau

Jiuyi Wang [a,*], Xiaomin Fang [a,b], Erwin Appel [c], Weilin Zhang [a,c]

[a] Key Laboratory of Continental Collision and Plateau Uplift, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100101, China
[b] School of Earth Sciences & Key Laboratory of Western China's Environmental Systems (MOE), Lanzhou University, Lanzhou 730000, China
[c] Department of Geosciences, University Tübingen, Hölderlinstr. 12, 72074 Tübingen, Germany

ARTICLE INFO

Article history:
Received 20 September 2012
Received in revised form
4 July 2013
Accepted 16 July 2013
Available online 25 August 2013

Keywords:
Magnetostratigraphy
Radiometric geochronology
Pliocene–Quaternary
Salt formation
Qaidam Basin

ABSTRACT

The Qaidam Basin is the largest Cenozoic intermontane basin within the northeast (NE) Tibetan Plateau. It contains large amounts of nonmarine evaporite deposits formed during the Pliocene–Quaternary. Even at present, extensive salt deposits dominated by halite and potash are formed by solar-driven concentration of brine water in the basin interior, making it the most important industrial base for potash exploitation in China. The formation of salt required an arid climatic, appropriate hydrological and tectonic setting through geologic times and will do so in the future. Studying the salt formation in the Qaidam Basin will enhance our understanding of processes driven by saline lake evolution, regional climate change, and tectonic movements, not only for the setting of the Tibetan Plateau. Reliable dating is crucial for assessing the time of salt formation in Qaidam Basin and the accumulation process, yet no comprehensive scientific studies have been reported on this important issue until now. In this paper, we critically review and compile magnetostratigraphic and radiometric studies of the salt-bearing strata within seven depressions of the basin. We find that the ages of salt formation are very different in these depressions: for the Dalangtan, Yiliping, Chahansilatu, and Kunteyi depressions, first salt deposits occurred at >3.90 ± 0.02 Ma, 2.88 ± 0.04 Ma, 2.24 ± 0.01 Ma and 1.18 ± 0.02 Ma, respectively. For the Mahai, Gasikule, and Qarhan, the ages of earliest salt formation are much younger i.e., 302 ± 56 ka, 608 ± 38 ka, and 54–24 ka, respectively. However, the result from Mahai has to be considered with caution.

The variability of ages suggests an older salt-forming stage in the center of the western basin and a younger salt accumulation period along the basin margin. In a regional view, previous results from stratigraphy, sedimentology, geomorphology, and tectonic history allow us to conclude that the salt formation in the Qaidam Basin was probably controlled by pulsed intrabasinal tectonic movements and the distribution and migration of paleo-rivers during the Pliocene–Quaternary. However, the climatic shift towards drier and colder conditions in the Asian interior during this time also promoted salt formation.

1. Introduction

During late Pliocene to Quaternary times, large amounts of salts accumulated in continental inland basins (e.g., Death Valley in California, Searles Lake in western America, Pliocene Sedom Lagoon in the Dead Sea basin, Eyre Lake in western Australia, Qaidam Basin in western China). Reliable age determination for salt deposits is critical for assessing the patterns of paleo-saline lake evolution, regional climate change and tectonic movements. Thus, timing of salt formation in continental hydrologically closed basins in different regions of the world is a topic of common interest (Singh et al., 1972; Chen and Bowler, 1986; Luo and Ku, 1991; Lowenstein et al., 2003; Warren, 2010). Dating of saliferous lacustrine sediments by magnetostratigraphy and radiometric methods has proved to be very useful in establishing a temporal control of salt-bearing strata (Huang et al., 1983; Bowler et al., 1986; Phillips et al., 1993; Shen et al., 1993; Lowenstein et al., 2003; Qin et al., 2012; Zhang et al., 2012).

Since the Pliocene, abundant salt deposits have formed in the lacustrine strata of the Qaidam Basin (Chen and Bowler, 1986; Zhang, 1987). In the past three decades, magnetostratigraphic and radiometric dating was performed on drill cores from major

* Corresponding author. Tel.: +86 10 8409 7090; fax: +86 10 8409 7079.
E-mail address: wangjy@itpcas.ac.cn (J. Wang).

0277-3791/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.quascirev.2013.07.017

saliferous depressions of this basin, which delivered a series of valuable age estimates for salts formation in this region (Huang et al., 1983; Bowler et al., 1986; Phillips et al., 1993; Shen et al., 1993; Huang et al., 1997; Qin et al., 2012; Zhang et al., 2012). The purpose of this paper is to review developments provided by magnetostratigraphic and radiometric dating investigations of Pliocene–Quaternary salt bearing deposits in seven saliferous depressions of the Qaidam Basin and to compile these results. The seven sites follow along a west–east transect from the Gasikule, Dalangtan, Chahansilatu, Yiliping, and Kunteyi in northwestern part to the Mahai and Qarhan in the southeastern Qaidam (Fig. 1a).

2. Geological setting

The Qaidam Basin is situated at the northern margin of the Tibetan Plateau (Fig. 1a). Bounded by the Kunlun Mountains to the south, the Altun Mountains to the northwest, the Qilian Mountains to the northeast, and the Ela Mountains to the east, this hydrologically closed basin covers a large area of 120,000 km^2. The thickness of the Cenozoic basin fill ranges from 6000 m at the basin margin to 13,400 m in the depocenter (Chen and Bowler, 1986; Zhang, 1987; Wang and Coward, 1990; Xia et al., 2001). The mean elevation of the basin interior is about 2800 m above sea level, while the surrounding mountains reach elevations of 4000–5000 m (Zhang, 1987). Rain shadows caused by the surrounding mountains make the Qaidam Basin one of the driest regions in central Asia. The mean annual precipitation is less than 100 mm with a minimum of 25–40 mm in basin center, while the potential mean annual evaporation is more than about twenty times higher than precipitation (Chen and Bowler, 1986). Minor surface runoff supplied by snowmelt and rainfall contributes to groundwater recharge in summers and occasionally cause flooding events. Due to the hyper-arid climate only minor desert vegetation and hypersaline lakes occur in the basin. The modern inland plain of the Qaidam Basin is largely covered by dry salt playas, while only few shallow saline lakes are scattered across its surface (Fig. 1a). The dry salt playas are constrained in several depressions between low anticlinal ridges that strike in northwest–southeast direction. From the west to east, these depressions distribute in a spatial order of the Gasikule, Dalangtan, Chahansilatu, Yiliping, Kunteyi, Mahai, and the Qarhan (Fig. 1a).

Seismic reflection profiles in conjunction with drilling investigations and sedimentological studies have revealed that the Qaidam Basin has accumulated alluvial–fluviolacustrine sediments since the Paleocene–Eocene. The movements of surrounding fault systems (i.e., Kunlun, Altyn Tagh, and Qilian faults) (Fig. 1a) controlled the migration of the basin depocenter, and hence the evolutionary history of the paleolake. In the Paleocene–Eocene, the depocenter was situated in the western part of the basin, while the eastern part was still exposed to erosion. Since the Oligocene, the western basin underwent strong compression and uplift due to the movements of the Kunlun and Altyn Tagh faults, causing a progressive eastward migration of the depocenter and a basinward propagation of faults (Meyer et al., 1998; Wang et al., 2006; Fang et al., 2007). Seismostratigraphic studies (Gu et al., 1990; Huang et al., 1996; Xia et al., 2001) have demonstrated that the basin was completely enclosed since the Oligocene, forming a huge lake around the depocenter. From the late Miocene to Pliocene, stronger mountain uplift and compression caused an accelerated eastward migration of the depocenter, accompanied by basinward propagation of thrusts and folds formation. This process disassembled the former uniform larger lake into several depressions and lakes (Bally et al., 1986; Gu et al., 1990; Huang et al., 1996; Xia et al., 2001; Wang et al., 2006; Fang et al., 2007) (Fig. 1a). Since then, due to unique geological and geographical characteristics such as locality, source of inflow water as with climate became more arid, the lakes in separated depressions experienced differing hydrological and geochemical processes, and became saline lakes at differing times. Accordingly, these saline lakes formed salt formation at various time intervals and finally turned into playas with salt crusts in most areas of the Qaidam Basin.

This review focuses on published results of magnetostratigraphic and radiometric dating of drill cores in the seven saliferous depressions of the Qaidam Basin. The drill cores are ZK2605 in Gasikule (Fig. 1b), ZK402 in Dalangtan (Fig. 1c), SG-1 in Chahansilatu (Fig. 1c), ZK701 + 801 in Yiliping (Fig. 1d), ZK3208 in Kunteyi (Fig. 1c), ZK4012 in Mahai (Fig. 1e) and six subsurface cores in Qarhan (Fig. 1f).

3. Dating methods

Magnetostratigraphy combined with radiometric dating appears to be a useful approach for establishing chronology of salt formation. In order to obtain a reliable age framework, it's ideal to use dating techniques that can directly be applied to the salt samples themselves. Radiometric dating methods, such as ^{14}C, ^{230}Th/^{234}U disequilibrium and ^{36}Cl dating could be directly applied to salt materials and produce relatively accurate chronology. However, these methods have limited dating ranges. Radiocarbon dating is effective for materials that formed less than about 40 ka, and the dating range of the ^{230}Th/^{234}U disequilibrium method falls between ca 10 ka and 350 ka (Luo and Ku, 1991; Ku et al., 1998; Ku, 2000). Magnetostratigraphic analysis on salt-bearing lacustrine sediments can extend the dating range to older ages of million years being most effective in determining age markers at polarity boundaries of the Earth magnetic field. Thus, magnetostratigraphic and radiometric dating methods can complement each other for establishing an accurate chronology for the salt formation in Qaidam Basin reaching back to at least Pliocene (Zhang, 1987).

Previous studies have reported many useful age datasets from drill cores in the above mentioned seven saliferous depressions of the Qaidam Basin (Zhang, 1987; Luo and Ku, 1991; Phillips et al., 1993; Shen et al., 1993; Shi et al., 2010; Zhang et al., 2012). Before compiling them and discussing the chronologic implications, we summarize the measurement methods and analytical processing used by these authors.

3.1. Magnetostratigraphic dating

Paleomagnetic analysis has proven to be useful in dating late Cenozoic lacustrine outcrop sections near the basin margin and in anticlines (Sun et al., 2005; Fang et al., 2007; Lu and Xiong, 2009). However, outcrops of late Pliocene and Quaternary strata are absent and can be only studied by drill cores in depressions of the Qaidam Basin. During the last three decades, a series of drill cores have been collected in the depressions for exploitation of mineral resources or investigations of climate change. Magnetostratigraphic studies have been widely used for dating these cores and for defining a stratigraphic framework (Wang et al., 1986; Shen et al., 1993; Liu et al., 1998b; Shi et al., 2010; Qin et al., 2012; Zhang et al., 2012).

The paleomagnetic data of the selected cores in this review are adapted from several studies published at different times. In order to estimate accurate ages deduced from magnetostratigraphy it is necessary to evaluate the data reliability. We here summarize the acquisition technique and analytical processing of these data used by the original authors, and also present the paleomagnetic results of cores ZK2605, ZK402, SG-1, ZK701 + 801, ZK3208, and ZK4012 in the Supplementary Figs. S1–6.