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Research paper

Early–middle Miocene topographic growth of the northern Tibetan Plateau: Stable isotope and sedimentation evidence from the southwestern Qaidam basin

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ABSTRACT

This study presents facies analysis and carbonate stable isotopic records of a 4435-m-thick Oligocene–middle Miocene (~30 to ~11 Ma) stratigraphic section from the southwestern Qaidam basin, which place constraints on the interplay between topographic growth and climatic/hydrologic changes in the northern Tibetan Plateau. Three types of carbonate, including marl/limestone, pedogenic carbonate and carbonate cement, were collected and went through detailed screening for diagenesis. Carbonate cements are primary early diagenetic carbonates formed in shallow ground water setting. The majority of marls/limestones and pedogenic carbonates are primary micritic carbonates, whereas a few of them showing alterations were sub-sampled to avoid diagenetic phases. A negative shift in the $\delta^{18}O$ values of marls/limestones and depositional environment change from palustrine to shallow lacustrine associated with paleohydrological change at ~20 Ma are likely caused by tectonic activity in adjacent ranges. Around 15–14 Ma, a decrease of ~1.5‰ in the most negative $\delta^{18}O$ values of carbonate cements is interpreted to reflect the topographic growth of surrounding mountain ranges (i.e., Altun Shan, East Kunlun Range). This inference is supported by the sedimentary facies change from marginal lacustrine to fluvial that was accompanied by an abrupt increase in sedimentation rate. Finally, a ~1.5‰ positive shift in the most negative $\delta^{18}O$ values of carbonate cements and pedogenic carbonates, enriched $\delta^{13}C$ values of pedogenic carbonates, as well as sedimentary environment change from fluvial to braided river/alluvial fan at 13–12 Ma, most likely reflect a regional aridification event observed over a large area of the Central Asia. This aridification event may have been associated with continued topographic growth of the northern Tibetan Plateau to a critical elevation to block moisture (e.g., Westerlies) from penetrating the interior of Central Asia.

1. Introduction

Numerical climate simulations have shown that the topographic growth of the Tibetan Plateau exerts significant influence on the climate of Asia (Liu and Yin, 2002; Prell and Kutzbach, 1992; Roe et al., 2016; Ruddiman and Kutzbach, 1989; Zhang et al., 2007b), resulting in the intensification of Asian summer monsoons in the southern and eastern Tibetan Plateau, as well as aridification in the northern and western Plateau (An et al., 2001). The topographic growth itself and associated climatic changes (e.g., changes in moisture sources, rain shadow/moisture blocking effects, enhanced sub-cloud evaporation and/or surface water recycling; Blisniuk and Stern, 2005) influence the stable isotopic values of precipitation and hence soil, lake and fluvial waters, as well as authigenic carbonates that precipitate from those waters. In addition to topographic growth, retreat of the Para-Tethys seaway from the Tarim basin (Bosboom et al., 2014; Harzhauser and Piller, 2007; Rögl, 1998) would greatly influence the source of moisture to the interior of Central Asia (Fluteau et al., 1999; Ramstein et al., 1997; Zhang et al., 2007a). Likewise, Cenozoic global cooling would result in a temperature decrease and a change toward more arid condition (Dupont-Nivet et al., 2007; Ge et al., 2013; Kraatz and Geisler, 2010; Lu et al., 2010; Miao et al., 2012). These factors could also result in isotopic changes in authigenic carbonates and should be carefully evaluated.

Multiple studies have used the stable isotopic variations of sedimentary carbonates to reveal the paleoclimate and topographic evolution of the northern Tibetan Plateau (Dettman et al., 2003; Fan et al., 2007; Graham et al., 2005; Hough et al., 2014; Hough et al., 2011; Kent-Corson et al., 2009; Rieser et al., 2009; Zhuang et al., 2011a). Most of the studies infer topographic growth of surrounding ranges since 15–14 Ma (Hough et al., 2014; Hough et al., 2011; Zhuang et al., 2014) or later (e.g., 12 Ma; Dettman et al., 2003; Zhuang et al., 2011a).

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However, evidence from other proxies (e.g., low temperature thermochronology, magnetostratigraphy) suggests there were active tectonic phases associated with exhumation in the northern Plateau during the latest Oligocene–earliest Miocene (e.g., 24–20 Ma; Hough et al., 2014; Lease et al., 2012; Sobel and Dumitru, 1997; Wang et al., 2003; Yuan et al., 2006), as well as much earlier in the middle Eocene (Clark et al., 2010; Duvall et al., 2013; Yin et al., 2008). Kent-Corson et al. (2009) reported negative $\delta^{18}O$ shifts of carbonate rocks in several sedimentary sections in the Qaidam and Tarim basins during the Paleogene and attributed these to topographic growth of the northern Tibetan Plateau, although the timing was loosely confined.

Qaidam basin is the largest Cenozoic basin in the northern Tibetan Plateau (Fig. 1B) and records abundant regional tectonic information from Paleogene to Neogene time (Zhuang et al., 2011b). Previous stable isotopic studies in the Qaidam basin either reflect a short temporal range (e.g., <15 Ma; Zhuang et al., 2011a), or limited age constraints (Graham et al., 2005; Kent-Corson et al., 2009), or poor sampling resolution (Rieser et al., 2009). This study presents new stable isotopic data from a 4435-m-thick sedimentary section in the southwestern Qaidam Basin (Fig. 1C). With age constraints that extend from the Oligocene to middle Miocene (~31 to ~11 Ma; Chang et al., 2015), as well as detailed sedimentary facies analysis, we provide new insights into the climatic/hydrologic and topographic evolution of the northern Tibetan Plateau.

2. Geological setting, stratigraphy and age constraints

The studied Huatugou section lies in the southwestern Qaidam basin (Fig. 1B), which is a large (~120,000 km^2) intermontane basin located near the northern edge of the Tibetan Plateau (Fig. 1A). With elevations between 2600 and 3000 m, the Qaidam basin is surrounded on all sides by 4000–6000 m high mountain ranges, which are also bounded by large fault systems. The basin is bounded by the Altun Shan ("Shan" in Chinese means mountain) and Altyn Tagh fault to the northwest, the East Kunlun Range and Kunlun fault/Qimen Tagh thrusts to the south, and the Qilian Shan and north Qaidam thrusts to the northeast (Fig. 1B). Tectonic activity in the mountain ranges and fault systems of the Altyn Tagh and Qimen Tagh provided the majority of detritus and controlled sedimentary evolution in the western Qaidam basin (Cheng et al., 2015a; Rieser et al., 2005; Wang et al., 2006).

The depositional center of the Qaidam basin initially lay close to the Altyn Tagh fault and then migrated to the east, probably due to the uplift of the Altun Shan and intra-basinal deformation (Meng and Fang, 2008; Yin et al., 2008). Deformation within the Qaidam basin, manifested as northwest–southeast trending folds, such as the Youshashan anticline (Fig. 1C), initiated during the late Miocene, and continued through the Quaternary (Meng and Fang, 2008; Yin et al., 2008).

Cenozoic strata with a total thickness of ~6–7 km have filled the Qaidam basin (Huang et al., 1996). The Cenozoic strata, composed mainly of terrestrial alluvial-fluvial to lacustrine deposits, have been divided into seven formations, the ages of which were constrained by magnetostratigraphy (Chang et al., 2015; Fang et al., 2007; Lu and Xiong, 2009; Song et al., 2013; Sun et al., 2005b; Zhang, 2006; Zhang et al., 2014). From old to young, these seven formations are: Lulehe (early–middle Eocene), Xiaganchaigou (middle–late Eocene), Shangganchaigou (Oligocene), Xiayoushashan (early–middle Miocene), Shangyoushashan (middle–late Miocene), Shizigou (late Miocene–Pliocene) and Qigequan (Pleistocene).

Using magnetostratigraphy, Chang et al. (2015) determined ages for most of the Huatugou section (Fig. 2), which has a total stratigraphic thickness of 4435 m. They correlated strata between 1200 and 4100 m to 20.7–11.6 Ma of Geomagnetic Polarity Time Scale (GPTS; Gradstein et al., 2012). For the lower part of the section between 0 and 1200 m, however, they suggested two possible correlations. One designates ~28–20.7 Ma, and the other suggests an age range of ~31–20.7 Ma (Fig. 2). This second correlation accords with another magnetostratigraphic study in the same area (within hundreds of meters distance away), which correlates to ~31 Ma for the bottom of the Cenozoic strata in the Huatugou area (Zhang, 2006). Regardless of which correlation for the lower part is used, there is no impact on the ages for the isotopic changes that we discuss, because all the significant isotopic shifts are above 1200 m.

3. Methods

3.1. Stratigraphic study

The Huatugou section crops out along the steep southern limb of the Youshashan anticline in the southwestern Qaidam basin (Fig. 1C). This section includes the upper part of the Xiaganchaigou (0–470 m, Fig. 2), the Shangganchaigou (470–1940 m), Xiayoushashan (1940–3100 m) and Shangyoushashan (3100–4360 m) formations. The uppermost ~80 m of thick conglomerate (4360–4435 m) belongs to the Shizigou Formation. Detailed lithology, primary sedimentary structure, grain size, bedding thickness, bedding boundaries and lateral extent were recorded in the field.

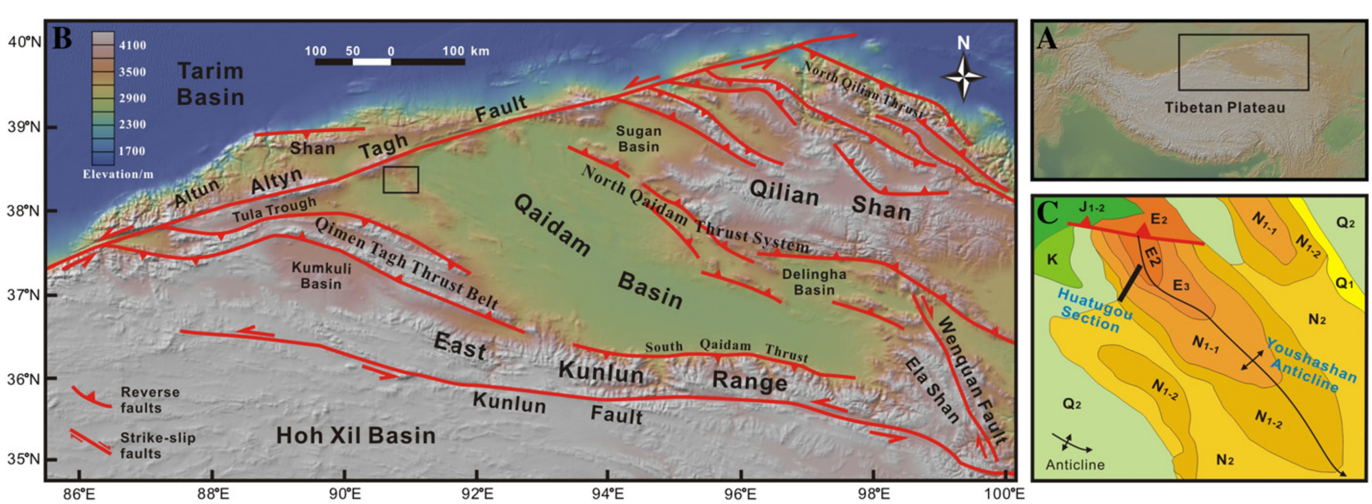

Fig. 1. A: Topographic map of the Tibetan Plateau, with box showing the location of 1B. B: Tectonic and topographic map of the Qaidam basin and surrounding regions, showing major faults. Box shows the location of 1C. C: Geological map of studied area. Legend: Q2, Holocene; Q1, Pleistocene; N2, late Miocene–Pliocene (Shizigou Formation); N1–2, middle–late Miocene (Shangyoushashan Formation); N1–1, early–middle Miocene (Xiayoushashan Formation); E3, Oligocene (Shangganchaigou Formation); E2, middle–late Eocene (Xiaganchaigou Formation); K, Cretaceous; J1–2, Early–Middle Jurassic.