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Provenance of Tertiary sandstone in the northern Qaidam basin, northeastern Tibetan Plateau: Integration of framework petrography, heavy mineral analysis and mineral chemistry

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ABSTRACT

An exceptionally thick Cenozoic sedimentary succession has developed in the Qaidam basin of the northeastern Tibetan Plateau. The provenance remains enigmatic; thus, more precise investigations are needed. An integrated study of sandstone framework petrography, heavy mineral analysis and mineral chemistry was adopted to perform provenance analysis of the Tertiary sandstones in the northern Qaidam basin.

No individual method exists that can provide comprehensive provenance interpretations on spatial and temporal variations. Based on three types of data, three depositional areas can be distinguished. Sandstones of Area A exhibit relatively high abundances of quartz, garnet and zircon, as well as relatively high textural maturity, implying long-distance sources. Multi-composition garnets and tourmalines reveal derivations of metasedimentary rocks and intermediate-acidic igneous rocks. Sandstones of Area B are rich in metamorphic lithic fragments, epidote and garnet. A dominance of Fe-rich garnets with low Mg, low Mn and variable Ca contents and dravites demonstrates predominant derivation of metasedimentary rocks. Therefore, the North Qaidam and South Qilian terranes are potential source areas for these two depositional areas. Additionally, high metamorphic heavy mineral abundances in the upper formations imply increasing contributions of these two metamorphic belts during the Tertiary tectonic uplift. However, sandstones of Area C are characterized by relatively high abundances of feldspar, igneous heavy minerals and high-Fe + Mn garnet, which suggest a main source of igneous rocks. The Altun and Qilian Mountains are potential source regions. Furthermore, increasing amounts of feldspar and igneous heavy minerals in the upper formations indicate a significant presence of igneous parent rocks, which are most likely a response to the multi-stage uplift events in the Altun Mountains since the early Eocene.

1. Introduction

The Qaidam basin is the largest continental basin in the northeastern Tibetan Plateau. It contains an exceptionally thick Tertiary sedimentary succession, with an average thickness up to 6 km (Hanson et al., 2001). This thick and continuous sedimentary record preserves substantial information about the tectonic settings of provenance and source rock lithology, as well as the tectonic evolution of the northeastern Tibetan Plateau. All clastic materials in the Qaidam basin are derived from source areas via drainage systems. Due to the immense volume of Tertiary sediments (Wang et al., 2006), it must be considered whether the source rocks experienced significant spatial and temporal changes. Moreover, the sediment provenance interpretation of the Qaidam basin can also provide helpful data regarding the tectonic uplift, exhumation and unroofing history of orogens in the northeastern Tibetan Plateau.

Previous studies primarily focused on the surrounding mountains and emphasized the mineralogy, petrology and geochronology of the current source rocks of the basin (e.g., Mattinson et al., 2007; Song et al., 2007a,b; Zhang et al., 2008a). Some studies discussed the tectonic history and climatic evolution of the Qaidam basin (e.g., Liu et al., 1998; Wang et al., 1999; Yin et al., 2002; Rieser et al., 2009; Zhuang et al., 2011). However, detailed provenance interpretations of sediments in the Qaidam basin are relatively scarce, and the parent rocks and their spatial and temporal distributions in the source regions remain unclear. Through paleocurrent measurements and sandstone petrography, Ritts and Biffi (2001) proposed that Jurassic and Cretaceous sediments in the northeastern Qaidam have a derivation from the Qilian Shan. Based on petrography and geochemistry, Rieser et al. (2005) reported that only a slight variation occurred in the compositions of Cenozoic sandstones in the northwest sector of the Qaidam basin. They also reported numerous $^{40}Ar/^{39}Ar$ ages of detrital white mica from Cenozoic sediments, and suggested a northern (Altun Mountains) and/or southern (Qimantagh–Kunlun Mountains)

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provenance for the western Qaidam basin (Rieser et al., 2006a). The data of detrital mica from the Lulehe Section in the eastern Qaidam basin revealed a uniform Permian source (Rieser et al., 2006b). Additional research, such as precise provenance analysis based on sensitive approaches, is needed to acquire a greater understanding of the provenance of sandstones in the northern Qaidam basin.

Sandstone provenance can be determined by a variety of methods, including framework grain composition analysis, heavy mineral analysis, whole-rock geochemistry, mineral chemistry and radiometric dating (Weltje and von Eynatten, 2004; Najman, 2006). Sedimentary petrography is a classical and standard method in provenance studies. Data collected by point counting in sandstone thin sections often provide initial insight for provenance determination. Discrimination diagrams have been constructed from well known tectonic settings and provenances to interpret clastic deposits for a particular time, setting and location on earth (Dickinson and Suczek, 1979; Ingersoll and Suczek, 1979; Ingersoll et al., 1984; Dickinson, 1985; Zuffa, 1985). Heavy mineral analysis is one of the most sensitive and effective tools for sandstone provenance discrimination. Many minerals have very specific geneses that can provide crucial provenance information (Morton, 1985; Morton and Hallsworth, 1994, 1999). To overcome the influences of alteration during the entire sedimentation and diagenesis cycle, Morton and Hallsworth (1994) proposed a number of provenance-sensitive heavy mineral ratios (e.g., apatite–tourmaline index (ATi), garnet–zircon index (GZi)), most of which are widely applied in sandstone provenance analysis (e.g., Hallsworth et al., 2000; Morton et al., 2004, 2005; Hallsworth and Chisholm, 2008). Currently, mineral chemistry of a single mineral group is readily applied in many provenance studies. Detrital garnet and tourmaline, which are comparatively abundant and stable in sandstones, are frequently used as provenance indicators (e.g., Sabeen et al., 2002; Morton et al., 2004, 2005; Mange and Morton, 2007; Win et al., 2007; Hallsworth and Chisholm, 2008; Takeuchi et al., 2008; Morton et al., 2009; Meinhold et al., 2010).

However, in some case studies, a single technique is insufficient for solving a provenance problem; significant detail is lost when only one technique is applied. Morton et al. (2012) advocated the importance of adopting an integrated approach, to overcome the limitations associated with individual approaches. An integrated approach can also establish a more comprehensive representation of source area characteristics.

This paper aims to provide the results and provenance interpretations of the Tertiary sandstones in the northern Qaidam basin by combining detrital framework grain composition, heavy mineral data and mineral chemical data. The purpose of the paper is twofold: the first objective is to reconstruct the source parent rock types and their spatial and temporal distributions; the second objective is to provide additional data regarding tectonic history of the northern Tibetan Plateau.

2. Geologic setting and samples

2.1. Geologic setting

The rhomb-shaped Qaidam basin is a large intracontinental sedimentary basin that is located on the northeastern corner of the Tibetan Plateau in northwestern China (Fig. 1a). The area of the basin is approximately 120,000 km^2. It is situated approximately 2.7–3.0 km above sea level and has developed a thick Mesozoic to Cenozoic sedimentary succession of 3–16 km, with an average of 8 km. The basin is bounded by three large mountain ranges. The Kunlun Mountains are located to the south, the Qilian Mountains are along the east, and the Altun Mountains are located to the northwest (Fig. 1a).

The formation of the Qaidam basin is considered the result of the convergent system at the northern margin of the Tibetan Plateau (Tapponnier et al., 2001). It is closely related to the India–Asia collision, and is associated with the rise, thickening, shortening and lateral extrusion of the Tibetan Plateau (Harrison et al., 1992; Tapponnier et al., 2001; Yin et al., 2002; Yue et al., 2003). Consequently, a series of thrust fold belts in the northwest-southeast direction in the basin and reverse faults along the Kunlun Mountains and Qilian Mountains developed.

The northern Qaidam basin is approximately 30,000 km^2. It extends approximately 200 km from west to east and extends approximately 150 km from north to south (Fig. 1b). The northern Qaidam basin can be divided into many sections based on internal deformation. To simplify the discussion of the depositional areas in the study, it is divided into three fold belts, namely the Lenghu, Maxian, Eboliang fold belts and five depressions, namely the Yiliping, Kunteyi, Qianxi, Yuka and Suganhu depressions. The Lenghu fold belt is divided into five units: No. 3, No. 4, No. 5, No. 6 and No. 7 Lenghu fold belts. The Maxian fold belt is divided into three units: the Mahai, Beilingqiu and Nanbaxian fold belts.

The North Qaidam, South Qilian terranes and the southern flanks of the Altun Mountains are the adjacent source regions of the northern Qaidam basin. The North Qaidam terrane, which extends in the northwest direction between the Qaidam basin and Qilian block, is represented by a Paleozoic metamorphic belt with exhumed rocks dominated by shallow-marine strata, mélange and granite, as well as granitic and pelitic gneisses with lesser amounts of eclogite and garnet peridotite (Gehrels et al., 2003; Song et al., 2003a,b, 2005; Mattinson et al., 2006; Song et al., 2006; Yang et al., 2006; Mattinson et al., 2007; Song et al., 2007a,b; Zhang et al., 2008a; Mattinson et al., 2009; Menold et al., 2009). The South Qilian terrane is a metamorphic belt with Upper Proterozoic–Lower Paleozoic metamorphic rocks (Gehrels et al., 2003). To the west, the southern flanks of the Altun Mountains consist of granites, metamorphic complexes, Jurassic rocks and Ordovician rocks; whereas to the east, the Altun mountains consist of Paleozoic and Mesozoic granites and a few diorites predominate with metamorphic rocks of different grades from the Proterozoic Dakendaban Group (Gehrels et al., 2003; Yang et al., 2006; Mattinson et al., 2007).

2.2. Stratigraphy of Qaidam basin

Cenozoic sedimentary strata in the Qaidam basin consist of continental sedimentary facies. The sedimentary succession was deposited mainly in a fluvial–lacustrine environment, including the alluvial fans (mainly conglomerates) along the basin margins, and fluvial, delta and lake sediments (sandstones, siltstones and mudstones), which are widespread throughout the basin fill. Lake sediments are divided into near-shore and deep-water sediments with many thin layers of carbonates. Various evaporites (gypsum and halite) formed during regressive phases of lake development, primarily in the Late Miocene to Pleistocene (Unpublished data).

Based on the basin-wide lithostratigraphic framework, the microfossil studies, magnetostratigraphy and isotope geochronology (Ye et al., 1993; Sun et al., 2005; Wang et al., 2007), the Cenozoic strata of the Qaidam basin can be divided into 7 stratigraphic units (Fig. 2) compared with distinct seismic reflectors (T_0–T_5 in Fig. 2). These units are listed as follows (in ascending order, Fig. 2): (1) Lulehe Formation (Paleocene to early Eocene, ?–~45 Ma); (2) Xia Ganchaigou Formation (middle to late Eocene, ~45–~35.5 Ma); (3) Shang Ganchaigou Formation (late Eocene to Oligocene, ~35.5–~22 Ma); (4) Xia Youshashan Formation (early to middle Miocene, ~22–~15 Ma); (5) Shang Youshashan Formation (middle to late Miocene, ~15–~8 Ma); (6) Shizigou Formation (late Miocene to Pliocene, ~8–2.8 Ma); and (7) Qigequan Formation (Quaternary, 2.8 Ma–present). Based on field outcrop and core drilling investigation in the northern Qaidam basin, Lulehe Formation strata are predominantly composed of alluvial fan deposits. Fluvial, delta and lake sediments are widely distributed from the Xia Ganchaigou Formation to the Shang Youshashan Formation. The strata from the upper Shang Youshashan Formation to the Qigequan Formation are composed of alluvial fan facies.