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Stable isotope characterization of pedogenic and lacustrine carbonates from the Chinese Tian Shan: Constraints on the Mesozoic–Lower Cenozoic palaeoenvironmental evolution

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ABSTRACT

In the Mesozoic–Cenozoic continental deposits of the Tian Shan area, two main levels containing pedogenic carbonates have been identified on both the southern and northern foothills of the range: one in the Upper Jurassic series and one in the Upper Cretaceous–Lower Palaeocene series. In order to reconstruct the palaeoenvironmental and palaeotopographic characteristics of the Tian Shan area during these two periods, we measured the oxygen and carbon isotope composition of these pedogenic carbonates (calcrete and nodules). The stable isotope compositions are homogeneous: most $\delta^{18}O$ values are between 21 and 25‰ and most $\delta^{13}C$ values are between −4 and −6‰. No distinction can be made between the calcrete and nodule isotopic compositions. The constancy of isotopic values across the Tian Shan is evidence of a development of these calcification features in similar palaeoenvironmental conditions. The main inference is that no significant relief existed in that area at the Cretaceous−Palaeogene boundary, implying that most of the present relief developed later, during the Cenozoic. In addition to the pedogenic carbonates, few beds of limestones interstratified in the Jurassic series of the southern foothills display oxygen and carbon isotope compositions typical of lacustrine carbonates, ruling out brackish water incursion at that period in the region.

1. Introduction

Calcification is a ubiquitous phenomenon that occurs in a large variety of geological settings including limestone diagenesis and continental weathering. In continental environments, under semi-arid conditions, the interaction between meteoric waters or groundwaters and sedimentary rocks commonly leads to pedogenic calcification (e.g. Wright and Tucker, 1991; Alonso-Zarza, 2003; Hasiotis et al., 2007). The resulting calcareous features correspond to the so-called calcretes and occur as isolated nodules or rather continuous levels of carbonates (Retallack, 1997; Wright, 2008). The oxygen and carbon isotope composition of such neoformed carbonates provides information on the palaeoenvironments within which they precipitated (e.g. Alonso-Zarza, 2003). Indeed, while the oxygen isotope composition of these carbonates depends on processes taking place in the soil–ground water system, such as evaporation, it is also function of the composition of the meteoric water. The latter depends on the palaeolatitude and the palaeoaltitude of the area, as well as on the distance to the ocean from which the atmospheric masses are derived. In a specific region, any variation in the $\delta^{18}O$ value of the carbonates through time may thus be, for example, a consequence of the climatic evolution. At a specific stratigraphic level, geographic variations of $\delta^{18}O$ may relate to the existence of a significant palaeotopography (e.g. Garzione et al., 2000). In a similar way, the carbon isotope composition of continental neoformed carbonates depends on the source of the carbon in the region, which relates to the relative abundance of carbon-bearing rocks (e.g. marine carbonates) over available organic carbon. The former have $\delta^{13}C$ values close to 0‰, whereas the second source has very negative values, close to −25‰ for carbon derived from C3-type plants and −15‰ from C4-type ones. The $\delta^{13}C$ signal can thus potentially be related to the geology of the area, the palaeoflora itself partially controlled by the palaeoclimate (e.g. Pustovoytov, 2002).

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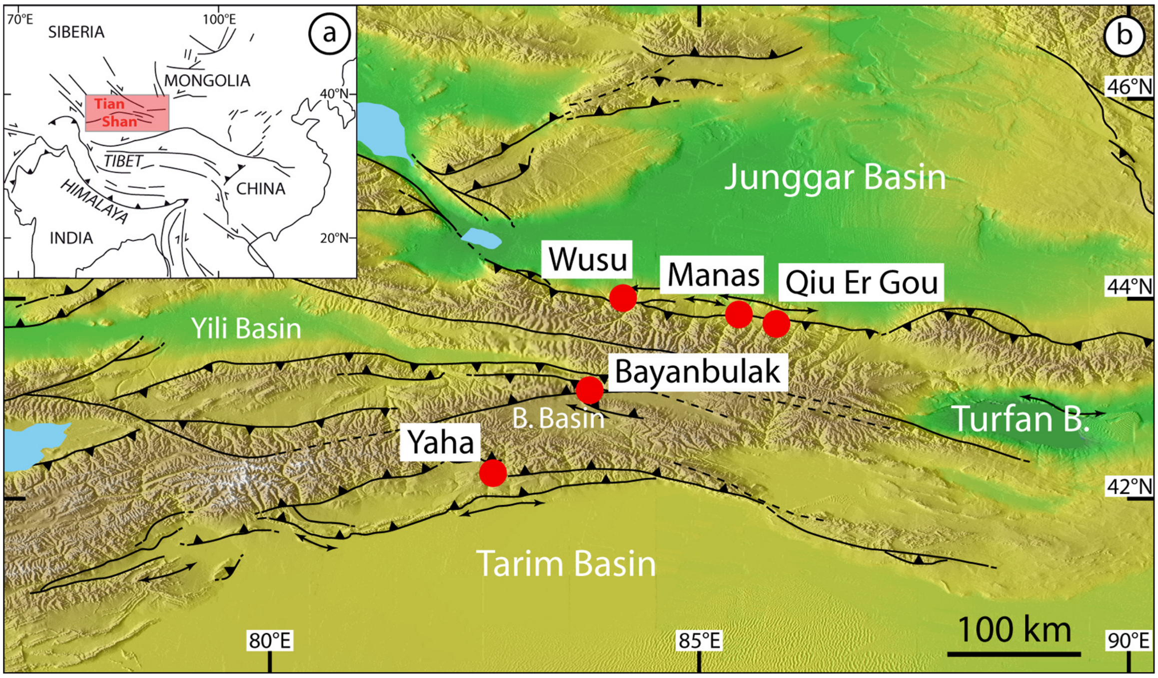

Fig. 1. (a) Schematic tectonic map of Asia and location of the Tian Shan Range in Central Asia. (b) Map of the Tian Shan area (DEM, G-TOPO-30, Mercator projection) showing the five sampling sites: the Wusu, Manas and Qiu Er Gou sections on the northern foothills, the Bayanbulak section in the Bayanbulak intramontane basin and the Yaha section on the southern foothills of the range. Section location and GPS coordinates are given in Table 1.

In North-West China, the intracontinental, east-west-oriented Tian Shan Range (Fig. 1) provides spectacular outcrops of Mesozoic–Cenozoic clastic sediment series. During fieldwork, we recognized several occurrences of calcretes and nodules throughout these series, especially in the Upper Mesozoic and Lower Cenozoic deposits. A strong aridification occurred during Late Jurassic, following the progressive appearance of dry seasons since the late Early Jurassic (e.g. Allen et al., 1991; Hendrix et al., 1992; Eberth et al., 2001; Li et al., 2004; Ashraf et al., 2010; Pan et al., 2013). Since this period, arid-to-semi-arid climate has been predominant in the Tian Shan area (e.g. Allen et al., 1991; Hendrix et al., 1992; Li et al., 2004; Sun and Wang, 2005; Jiang et al., 2008).

Since the late 1970s, the Cenozoic tectonic development of the range and its foreland basins have been widely studied (e.g. Tapponnier and Molnar, 1979; Windley et al., 1990; Allen et al., 1991; Hendrix et al., 1994; Charreau et al., 2005, 2009, 2012; Jolivet et al., 2014). In contrast, the Mesozoic evolution of the Tian Shan area is still largely debated (Jolivet et al., 2013), despite some efforts to reconstruct the sedimentary depositional environments (e.g. Hendrix et al., 1992; Eberth et al., 2001; Vincent and Allen, 2001; Li et al., 2004; Sha et al., 2011), the palaeotopographic evolution (Dumitru et al., 2001; Jolivet et al., 2010; Liu et al., 2013a; Yang et al., 2013, 2014) and the palaeoclimate (e.g. Hendrix et al., 1992, 1994; Hendrix, 2000; Eberth et al., 2001; Li et al., 2004; Ashraf et al., 2010; Bian et al., 2010). In this paper, we provide new isotopic data on pedogenic carbonates (calcrete and nodules) and limestone beds in order to improve our understanding of the general evolution of the area from Late Jurassic to Early Palaeogene.

2. Geological setting

The Tian Shan is a large mountain belt extending in Central Asia through Kyrgyzstan, Kazakhstan and North-West China (Fig. 1a). This range is surrounded by several basins, among which the Junggar Basin to the north and the Tarim Basin to the south (Fig. 1b). In the central part of the Tian Shan, several intramontane basins are preserved such as the Yili, Bayanbulak and Turfan basins (Figs. 1 and 2). The Tian Shan Range is limited by large crustal thrusts verging northward in the north and southward in the south towards the Junggar and Tarim Basins, respectively (Fig. 1b). During the Palaeozoic, several accretion events gave rise to an important topography that was progressively eroded from Middle Triassic to Middle Jurassic (e.g. Dumitru et al., 2001; Li et al., 2004; Jolivet et al., 2010, 2013; Liu et al., 2013b; Yang et al., 2013). The present-day topography formed later, mostly through the Cenozoic reactivation of Late Palaeozoic tectonic structures, driven by the far-field effects of the India–Asia collision event (e.g. Tapponnier and Molnar, 1979; Windley et al., 1990; Allen et al., 1991; Hendrix et al., 1994; Glorie et al., 2010; De Grave et al., 2011, 2013). Whereas the present-day topography is believed to have developed since Late Oligocene–Miocene (e.g. Charreau et al., 2005, 2009, 2012), uncertainties remain about the topographic evolution of the range during the Jurassic–Early Palaeogene period. For example, while low-thermochronology data suggest a long tectonic quiescence during most of the Mesozoic, leading to very slow and constant exhumation within the range (Dumitru et al., 2001; Jolivet et al., 2010, 2013), Upper Jurassic alluvial fan deposits exposed in the foothills are interpreted as the consequence of a compressive reactivation of the range (Hendrix et al., 1992; Li et al., 2004). In this context, the present study on calcretes and nodules provides independent information on the palaeotopographic evolution of the area.

3. Field work and samples

3.1. Field description

Throughout the area, we recognized several calcareous features (calcretes and nodules) at distinct stratigraphic levels (Fig. 2). Very few age data are available due to the lack of clear marine deposits, the scarcity of interbedded volcanic levels and the very limited available palynological and faunistic data (e.g. Wang and Gao, 2012; Yang et al., 2013). Nevertheless, regional stratigraphic correlations