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Climate-induced changes in sediment supply revealed by surface exposure dating of Sijiquan River terraces, northeastern Tibet

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ABSTRACT

In this paper, we report cosmogenic isotope evidence for dramatic changes in sediment supply during glacial–interglacial climatic cycles in the Late Quaternary. Previous work on fluvio-glacial processes in cold environments has qualitatively revealed that significant increases in debris production occurred in glacial periods, due typically to accelerated glacial and periglacial processes on high-relief slopes, resulting in river aggradation (accumulation) in the drainage. In interglacial periods, rivers behave in the opposite way, forming incised valleys. However, little has been studied on climatically controlled production-and-reworking processes with radiometric evidence. The evidence presented here is from the northeastern margin of the Tibetan Plateau, where lateral growth of the plateau is now ongoing. Reconstructions of fluvial response to Quaternary glacial fluctuations are crucial also to better understand the active tectonic process in the region using geomorphological information. The Sijiquan River drainage basin on the north of the East Kunlun Mountains was investigated. Detailed geomorphological mapping of fluvio-glacial landforms indicates two phases of aggradation, each of which was followed by valley incision. ^{10}Be and ^{26}Al concentrations in fluvial terrace deposits suggest that these two aggradational phases correspond most likely to the penultimate and last glacial periods, assuming a low rate of surface erosion on the terraces and zero inherited concentration. On the other hand, present-day river gravel has higher concentrations in amalgamated samples of ^{10}Be and ^{26}Al than the terrace deposits. Surface-exposure and burial analyses based on grain-by-grain measurements of both ^{10}Be and ^{26}Al indicate that the present-day river gravel consists mostly of reworked grains from terrace deposits and underlying fluvio-lacustrine rocks in the drainage basin. It is concluded that significant changes in clastic sediment supply occur in cold environments in response to glacial–interglacial cycles; clastic sediments are transported from mountain slopes much more directly in glacial periods than in interglacial periods. This violates the common assumption for surface exposure dating that the inherited cosmogenic isotope concentration is constant through time.

1. Introduction

The Tibetan Plateau has been growing laterally during the Late Cenozoic by including stable forelands surrounding it (Tapponnier et al., 2001; Mulch and Chamberlain, 2006; Rohrmann et al., 2011). The lateral growth is most spectacular and is now ongoing along the northeastern margin of the plateau (Tapponnier et al., 2001; Yin et al., 2007, 2008), and therefore dating tectonically deformed geomorphic surfaces in this area is a key to quantifying the tectonic processes of this orogen. Because this region is mostly arid and hence lacks organic matter preserved in sediments, geomorphological age estimation mainly by using satellite images or elevation data has been widely employed instead of conventional radiocarbon dating (e.g. Peltzer et al., 1989; Avouac and Peltzer, 1993; Zhang et al., 1995). Recent progress in surface exposure dating using cosmogenic radionuclides (CRNs) makes it possible to measure absolute dates of geomorphic surfaces in such an arid region. CRN dating has been used in the last few decades for dating tectonically deformed surfaces (e.g. van der Woerd et al., 2002; Mériaux et al., 2004; Hetzel, 2013). However, frequent discrepancies exist between geomorphologically-estimated ages and surface exposure dates, possibly because changes in debris production process associated

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with Quaternary climatic fluctuations in the upper reaches of a drainage basin would significantly affect inherited CRN concentrations in terrace deposits in the lower reaches (Anderson et al., 1996; Gosse and Phillips, 2001).

Previous works on fluvio-glacial processes in cold environments have qualitatively revealed: (1) that significant increase of debris production occurs in glacial periods due typically to accelerated glacial and periglacial processes acting on high-relief slopes in a drainage basin, resulting in river aggradation (accumulation) in the lower reaches of the drainage basin; and (2) that, in interglacial periods, rivers behave in the opposite way due primarily to decrease in river load, forming incised valleys (Dury, 1959; Budel, 1982; Personius et al., 1993; Bridgland, 2000; Maddy et al., 2001; Starkel, 2003). Geomorphological age estimation is based on a basic assumption that debris supply is controlled by climate, and therefore degradation–aggradation cycles are correlated to global climatic fluctuations. On the other hand, common CRN dating relies on an assumption that inherited CRN concentration is constant through time, although this assumption is often ignored or implicit. The assumptions underlying these two methods contradict with each other, and hence should be tested independently. However, little has been studied quantitatively on changes in debris production with the support of radiometric evidence (e.g., Fuller et al., 2009).

In this paper, cosmogenic isotope evidence is reported for changes in sediment supply during glacial–interglacial climatic cycles in the Late Quaternary. The study area is the Kumkol Basin on the north of the East Kunlun Mountains (Fig. 1), which is little-studied due to its inaccessibility despite being critical to studying active tectonic processes of the Tibetan Plateau. This basin encloses a large-scale active anticlinorium, which would provide a quantitative constraint on the lateral growth of the plateau if we could properly date tectonically deformed landforms. The study area has the advantages of: 1) evidence for two or more aggradation–degradation cycles which are well preserved owing to the arid climate; and 2) strong cosmic ray radiation due to high elevations (~4000 m above the sea level) and lack of shielding by soil, loess or vegetation.

2. Geological setting

The Kumkol Basin occupies the southwesternmost portion of the Qaidam Basin. The floor of the Kumkol Basin is about 4000 m above sea level (a.s.l.), forming a transition zone between the Qaidam Basin (c. 3000 m a.s.l.) and the Tibetan Plateau (c. 5000 m a.s.l.) (Fig. 1a). Along the margins of the Qaidam Basin are active tectonic elements, such as the Kunlun fault (KF), Altyn Tagh fault (ATF), and numerous active faults and folds in between (e.g.,Tapponnier et al., 2001; Yin et al., 2008). These faults and folds are thought to have been formed in association with the lateral growth of the Tibetan Plateau in Late Cenozoic time (e.g., Yin and Harrison, 2000; Tapponnier et al., 2001). A key to quantitatively understanding the growth mechanism of the plateau is tectonically-deformed fluvial and glacial landforms in the Qaidam Basin. If properly dated, they would provide quantitative constraints on the rate of crustal deformation.

The Kumkol Basin is shaped in the form of a triangle, and is bordered by the Altyn Shan ("Shan" means "mountain" in Chinese) on the northwest, the Qimen Tagh on the north, and the Arka Tagh on the south (Fig. 1b). The Qimen Tagh is a fault-related structure bordered by the dominantly north-dipping Qimen Tagh Thrust System. The southernmost thrust in the thrust system is referred to as the Ayakkum Thrust, forming a boundary thrust fault between the Qimen Tagh and the Kumkol Basin (Yin et al., 2007). The Altyn Shan is bordered on its south by the ATF, from which many left-slip and reverse faults branch. Some of these branch faults seem to continue eastward and eventually transform to the Qimen Tagh Thrust System, accommodating part of

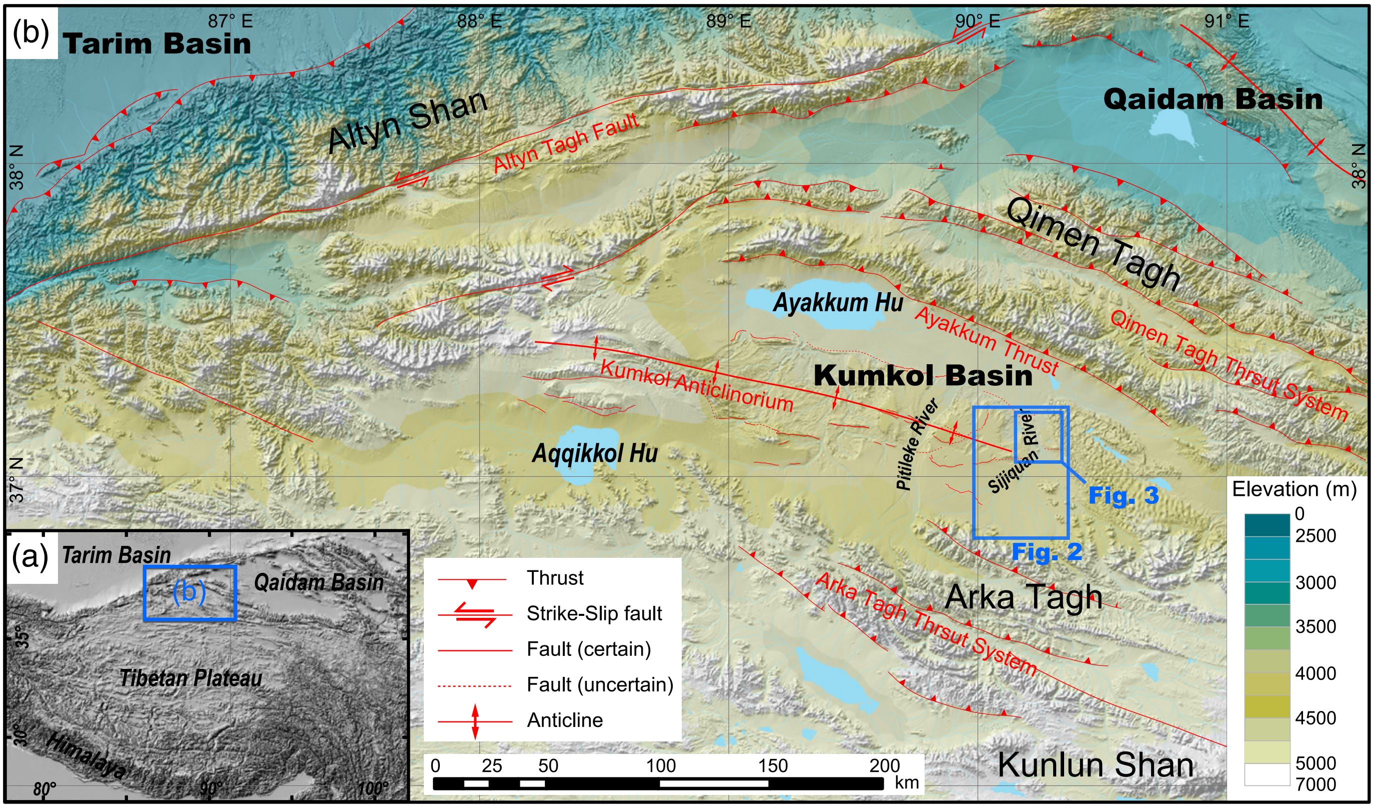

Fig. 1. Topography of (a) Tibetan Plateau and (b) Kumkol Basin shown by the SRTM3 digital elevation model. Major thrusts and folds are shown (after Meyer et al., 1998; Yin et al., 2008). Boxes show the locations of Figs. 2 and 3.