Palaeogeography, Palaeoclimatology, Palaeoecology 461 (2016) 418–431

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

Plateau uplift forcing climate change around 8.6 Ma on the northeastern Tibetan Plateau: Evidence from an integrated sedimentary Sr record

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ARTICLE INFO

Article history:
Received 11 May 2016
Received in revised form 28 August 2016
Accepted 4 September 2016
Available online 5 september 2016

Keywords:
Strontium
Chemical weathering
Sedimentary sorting
Paleosol
Tectonic uplift
Tibetan Plateau

ABSTRACT

The uplift of the northern Tibetan Plateau (TP) has long been regarded as one of major factors accounting for both the enhanced process of aridification recorded in central Asia and the shifts in the Asian monsoonal circulations that are known to have occurred at approximately 8 Ma. Until now, there have been few sedimentary records reported on which can directly, and in an integrated fashion, shed light on the region's tectonic and climate regimes. This can be largely attributed to the fact that the influence exerted by the presence of source materials and subsequent sedimentary sorting in this tectonically active region would be likely to bias significantly any paleoclimatic interpretation of silicate-derived proxies. Based on detailed investigations of strontium (Sr) distributions revealed by multi-step leaching in a fluvial sequence from the Linxia Basin which includes paleosols, we reconstructed the long-term late Miocene regional climatic and environmental changes likely to have occurred on the northeastern TP from 12.1 to 5.2 Ma. We investigated Sr-related proxies in two typical paleosol profiles to constrain Sr mobility in paleosol weathering, and, thus, to further prompt the interpretation of Sr-related proxies along the whole section. We would suggest that carbonate-derived Sr concentrations and Sr/Ca ratios are suitable proxies for tracing regional climate change associated with weathering and pedogenesis; together, they exhibit weakened chemical weathering intensity and pedogenesis at ~8.6 Ma. The concomitant appearance of immature sediments through poor sedimentary sorting revealed by silicate-derived Rb/Sr, $^{87}Sr/^{86}Sr$ and Eu anomaly (Eu/Eu*) alongside a sharp increase in sedimentation rates noted at this time suggests that it was indeed tectonic uplift that principally controlled the dramatic climatic and environmental changes. This multi-proxy record of concomitant tectonic uplift and climate change in the Linxia Basin provides direct geological evidence for uplift driven climate change in the northeastern TP region.

1. Introduction

The uplift of the northern margin of the Tibetan Plateau (TP) is generally regarded as one of the major factors contributing to late Cenozoic central Asian aridification and Asian atmospheric circulations reorganization (Manabe and Terpstra, 1974; Ruddiman and Kutzbach, 1989; Kutzbach et al., 1993; An et al., 2001; Guo et al., 2002; Li et al., 2014; Liu et al., 2015; Li et al., 2016). The onset of eolian red clay accumulation in the Chinese Loess Plateau region (CLP; Ding et al., 2001; An et al., 2001; Song et al., 2001; Qiang et al., 2001), and the remarkable increase in eolian sedimentation to the west of the CLP and in the North Pacific (Rea et al., 1998; Guo et al., 2002) at ~8 Ma record the enhancement of the arid conditions experienced by the central Asian interior, as well as the shifts in the Asian winter monsoonal system. Numerous tectonic and sedimentary records suggest that tectonic uplift at ~8 Ma occurred across the northern TP (Chen et al., 2002; Fang et al., 2005; Molnar, 2005; Zheng et al., 2006; Li et al., 2014). Although modeling work has emphasized the role played by a phased uplift of the northern TP in the development of Asian monsoonal systems and the aridification of the central Asian interior (Liu and Yin, 2002; Liu et al., 2015; Zhang et al., 2015), the temporally concurrent but spatially separated tectonic and climatic evidence exerts poor constraints on revealing the exact mechanisms and processes behind such tectonic forcing. Until now, few sedimentary records directly integrating regional tectonic and climatic developments have been available.

The materials which have accumulated in the sedimentary basins around the northern TP represent a useful archive for documenting late Cenozoic regional landforms and climatic evolution. It has been considered likely that a combination of changes in the provenance of

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http://dx.doi.org/10.1016/j.palaeo.2016.09.002
0031-0182/

source materials, hydrographic patterns and progressive tectonic uplift might well bias the accuracy of any reconstruction of paleoclimatic evolution, especially when using coarse, clastic sediments as a foundation for such a reconstruction (Argast and Donnelly, 1987; Xiong et al., 2010; Fang et al., 2016). This assumption has led to very little regional climatic information using silicate-based proxies specifically from mountain fronts being collected, although, as a rule, such silicate-based proxies derived from modern weathered crustal profiles have frequently been employed in paleoclimate reconstructions (Nesbitt and Young, 1982; Cullers et al., 1988; Fedo et al., 1995; Chen et al., 1999; Jin et al., 2001; Price and Velbel, 2003; Yang et al., 2006; Clift et al., 2008, 2014; Wan et al., 2010). The climatic interpretation of these widely used proxies is greatly dependent on the extent to which changes in mineral assemblages and differentiation can be recognized (McLennan et al., 1993); especially as the latter are affected by provenance and sedimentary sorting. Provenance and sedimentary sorting are amplified in tectonically active regions where physical erosion is significant; coarse clastic sediments become the principal component of any related strata.

The effect of sedimentary sorting on silicate-derived climatic proxies in coarse, clastic sediments is pronounced. Such sorting may not be as significant in the carbonate-derived Sr proxies found in bulk samples. It has been suggested that this may be because Sr has previously been released from Sr-bearing silicates and carbonate minerals into solutions within the source area, and has subsequently been principally sequestrated into carbonates in the sedimentary area, meaning that sedimentary carbonate-derived Sr can act as a potential proxy of climate and weathering (Zeng et al., 2012, 2013; Jin et al., 2006, 2015). Sr concentrations in carbonate fractions in bulk samples are most probably less affected by proportional changes in quartz/K-feldspar/plagioclase/clays due to sedimentary sorting, although this kind of change would of course greatly influence any Sr concentrations in the silicate fraction. Any provenance effect on carbonate-derived Sr concentrations can therefore be taken to have resulted principally from proportional changes in the quartz/K-feldspar/plagioclase/clays and carbonate contents in the source area. However, as carbonate minerals are usually widespread in upper continental crust (UCC) source areas (Taylor and McLennan, 1985), any impact caused by the provenance effect on the proportional changes in silicate mineral assemblages and/or in silicate/carbonate ratios on carbonate-derived Sr concentrations is likely to be largely offset, due to a much faster Sr release rate from calcite weathering than from silicate weathering (Meybeck, 1987; Lerman and Wu, 2008). Conversely, a change in provenance reflective of proportional changes in quartz/K-feldspar/plagioclase/clays may produce a pronounced change in silicate-derived Sr concentrations. Additionally, any detrital carbonate contributions to Sr concentrations from the source area found within the sedimentary area's total carbonate content are likely to be negligible if detrital carbonate content as a proportion of total carbonate content is minimal as a result of the much lower Sr/Ca ratios found in calcite and dolomite (Yang et al., 2015a).

A carbonate-derived Sr proxy is potentially quite useful, particularly in tectonically active regions where the usefulness of silicate-derived Sr proxies is limited. Up to the present, however, the paleoclimatic significance, over a geological timescale, of carbonate-derived Sr concentrations in fluvial sediments found in the northern sector of the TP has rarely been explored. The Linxia Basin (Fig. 1a) is a Cenozoic foreland basin that developed as a result of flexural loading during the thickening of the northeastern margin of the TP between 29 and 6 Ma (Fang et al., 2003). Previous studies of the Linxia Basin which have focused on the mostly fine grained lacustrine sediments found in the center of the basin have shown that the sediments of the basin can represent a complete archive of late Cenozoic climate on the northeastern TP (Ma et al., 1998; Dettman et al., 2003; Fan et al., 2006, 2007). In this study, we: (1) analyzed the distribution of Sr in a fluvial sedimentary sequence imbeded multi-layer paleosols near the mountain front in the Linxia Basin; (2) further evaluated Sr mobility during paleosol formation; and (3) finally reconstructed late Miocene regional climate and weathering history using silicate and carbonate-derive Sr records.

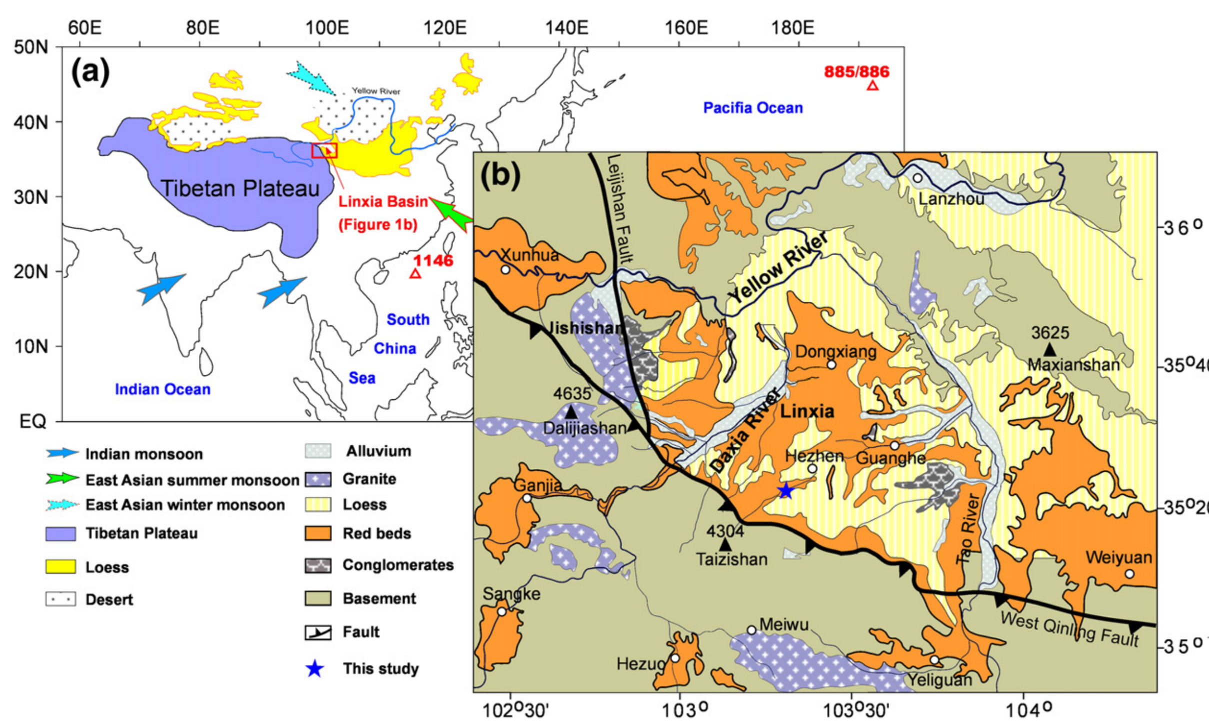

Fig. 1. (a) The location of the Linxia Basin (rectangle) relative to northeastern margins of the Tibetan Plateau (after Yan et al., 2014), with major climatic systems (Indian Summer Monsoon, East Asian summer and winter monsoons); (b) a simplified surface geological map of the Linxia Basin and adjacent regions showing the surrounding mountains, major structures, and the location of the studied section (redrawn from Fan et al., 2006). "Basement" shows the Paleozoic, Trassic and Cretaceous strata in the basin according to Fang et al. (2003) and Garzione et al. (2005).