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Late Miocene–Quaternary rapid stepwise uplift of the NE Tibetan Plateau and its effects on climatic and environmental changes

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ABSTRACT

The way in which the NE Tibetan Plateau uplifted and its impact on climatic change are crucial to understanding the evolution of the Tibetan Plateau and the development of the present geomorphology and climate of Central and East Asia. This paper is not a comprehensive review of current thinking but instead synthesises our past decades of work together with a number of new findings. The dating of Late Cenozoic basin sediments and the tectonic geomorphology of the NE Tibetan Plateau demonstrates that the rapid persistent rise of this plateau began ~8 ± 1 Ma followed by stepwise accelerated rise at ~3.6 Ma, 2.6 Ma, 1.8–1.7 Ma, 1.2–0.6 Ma and 0.15 Ma. The Yellow River basin developed at ~1.7 Ma and evolved to its present pattern through stepwise backward-expansion toward its source area in response to the stepwise uplift of the plateau. High-resolution multi-climatic proxy records from the basins and terrace sediments indicate a persistent stepwise accelerated enhancement of the East Asian winter monsoon and drying of the Asian interior coupled with the episodic tectonic uplift since ~8 Ma and later also with the global cooling since ~3.2 Ma, suggesting a major role for tectonic forcing of the cooling.

Introduction

The northeastern section of the Qinghai–Xizang (Tibetan) Plateau is the part of the plateau that is most remote from the India–Asia collision zone. In terms of not only the lithosphere and topography but also in climate, this part of the plateau is a transitional zone. In terms of topography, the Tibetan Plateau changes from its highest elevations of 4000–5000 m to lower ones of 2000–1500 m and finally to ca. 1000 m adjacent to the central Loess Plateau and the Gobi deserts. In terms of climate, it lies in the so-called monsoonal triangle zone, which is a transition zone from the Asian monsoon warm-humid climate to inland dry-cold climates (Li et al., 1988). A giant river, the Huang He (Yellow River), arises in this region. The headward incision of the Yellow River has caused not only the formation of a series of terraces but also the complete exposure of Cenozoic basin sediments. Most of these river terraces are covered by thick loess, whereas basin sediments are extremely thick, mostly continuous and bear mammal fossils. These two characteristics allow us to precisely date the river terraces and basin sediments and thereby gain insights into the tectonic uplift of the NE Tibetan Plateau and associated climatic change.

The two endmember dynamic models (thin viscous sheet and extrusion models) predict that the northern plateau was the last to form during simple unidirectional propagation (e.g., Molnar and Tapponnier, 1975; England and Houseman, 1989; Tapponnier et al., 1990, 2001; Meyer et al., 1998; Royden et al., 2008). The stepwise-growth model implies that (1) the present-day northern margin of the plateau formed only in the past few million years and (2) with the northeastward movement of the Altyn Tagh strike-slip fault, the upper crust of the entire NE Tibetan Plateau detached from the lower crust (Burchfiel et al., 1989; Tapponnier et al., 2001), resulting in the progressive northeastern growth of the South, Central and North Qilian Shan (Mts.) (Tapponnier et al., 1990, 2001; Meyer et al., 1998) (Fig. 1).

Fission-track analysis indicates that the Qilian Shan rapidly cooled during the Miocene (Metiver et al., 1998; Jolivet et al., 2001), and preliminary paleomagnetic studies indicate that the Danghe Nan Shan (South Qilian Shan) and western North Qilian Shan may have been uplifted in the Eocene or Oligocene (Yin et al., 2002; Dai et al., 2005). Recent U–Th/He dating of rocks in the central East Kunlun Shan (Mts.) and West Qinling (Mts.) and sedimentological analysis of basins indicate an Eocene–Oligocene deformation and uplift of the NE Tibetan Plateau (Fang et al., 2003; Clark et al., 2010; Lease et al., 2012). Other more recent thermochronologic studies and studies of sedimentary

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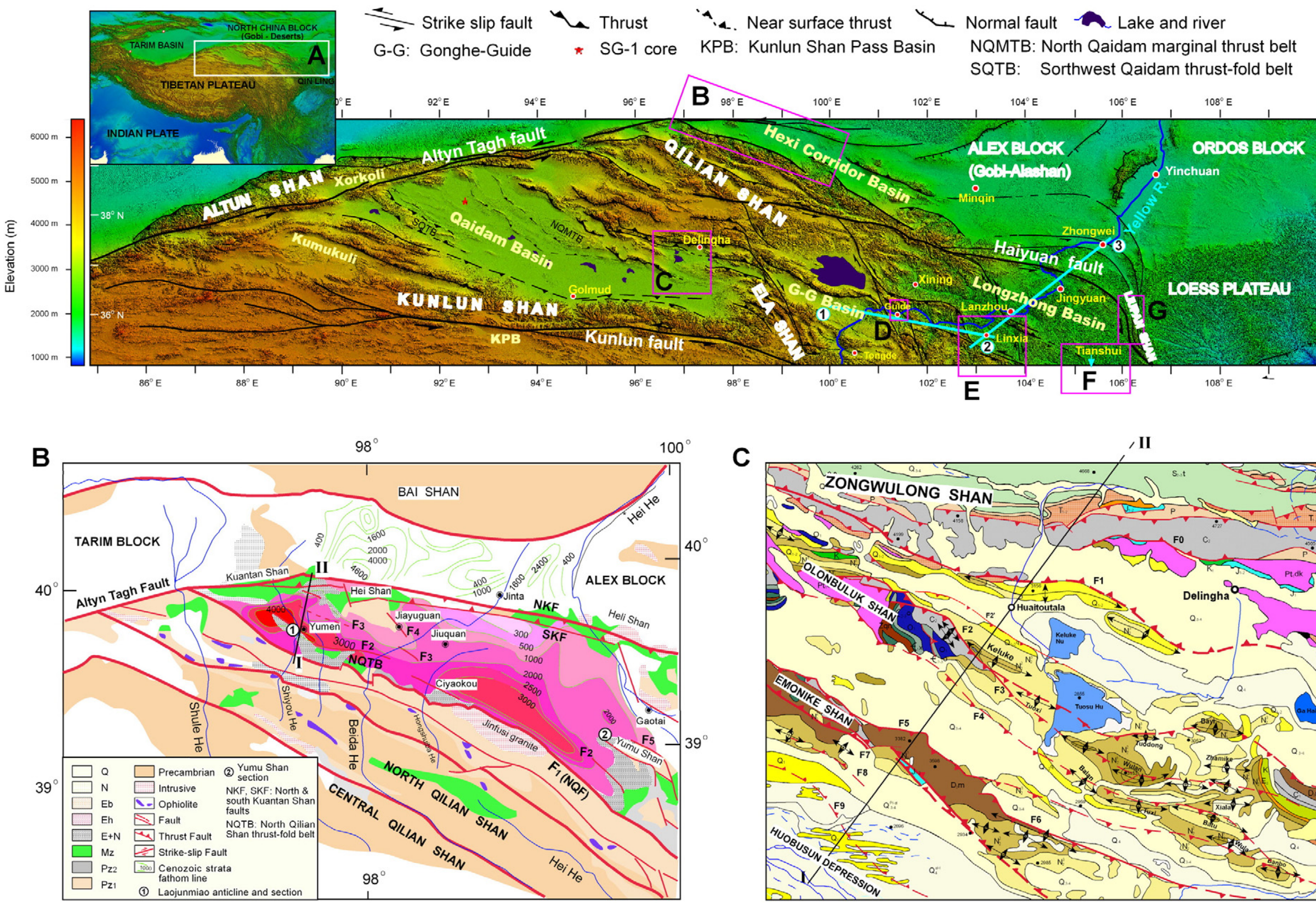

Figure 1. DEM presentation of the geomorphology and major tectonics of the NE Tibetan Plateau, showing the distribution of the mountains and intermontane basins. Insets indicate representative basins for presentation of geologic maps and synthesis in the paper. 1–3: Location of cross-sections along the Huang He (Yellow River) in Fig. 15. b–g: Geologic maps of the Jiuquan Basin, eastern Qaidam Basin, northern Guide Basin, Linxia Basin, Tianshui Basin and Liupan Shan region. Solid red line: surface fault; broken red line: sub-surface fault given by satellite images and seismostratigraphy.