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Sedimentary characteristics of Cenozoic strata in central-southern Ningxia, NW China: Implications for the evolution of the NE Qinghai–Tibetan Plateau

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ABSTRACT

Cenozoic sedimentary deposits in central-southern Ningxia province, NW China are an important record of Tertiary tectonic events along the evolving Qinghai–Tibetan Plateau's northeast margin. Shortly after the onset of the Indo-Eurasia collision to the south, a thrust belt and adjoining foreland basin began to form during 40–30 Ma. The Eocene Sikouzi Formation developed in a distal setting to this basin, in normal fault-bound basins that may have formed in a forebulge setting. Subsequent deposition of the Oligocene Qingshuiying Formation occurred during a phase of apparently less intense tectonism and the previous underfilled foreland basin became overfilled. During the Early Miocene, contractional deformation was mainly distributed to the west of the Liupan Shan. This resulted in deformation of the Qingshuiying Formation as indicated by an unconformity with the overlying Miocene Hongliugou Formation. The unconformity occurs proximal to the Haiyuan Fault suggesting that the Haiyuan Fault may have begun movement in the Early Miocene. In the Late Miocene, thrusting occurred west of the southern Helan Shan and an unconformity developed between the Hongliugou and Qingshuiying Formations proximal to the the Cha-Gu Fault. Relationships between the Miocene stratigraphy and major faults in the region imply that during the Late Miocene the deformation front of the Qinghai–Tibetan Plateau had migrated to the Cha-Gu Fault along the western Ordos Margin, and the Xiang Shan was uplifted. Central-southern Ningxia was then incorporated into the northeast propagating thrust wedge. The driving force for NE propagation of the thrust wedge was most likely pronounced uplift of the northeastern plateau at the same time. Analysis of the sedimentary record coupled with consideration of the topographic evolution of the region suggests that the evolving fold-and-thrust belt experienced both forward-breaking fold-and-thrust belt development, and out-of-sequence fault displacements as the thrust wedge evolved and the foreland basin became compartmentalised. The documented sedimentary facies and structural relationship also place constraints on the Miocene-Recent evolution of the Yellow River and its tributaries.

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1. Introduction

The Cenozoic development of the Qinghai–Tibetan Plateau has played a major role in the geological evolution of Asia and its modern climate systems. (Molnar and Tapponnier, 1975; Tapponnier et al., 2001; An et al., 2001; Yin and Harrison, 2000; DeCelles et al., 2007; Wang et al., 2003, and references therein.) Ongoing seismicity and modern geodetic data indicate that the plateau continues to evolve both structurally and topographically within the larger Indo-Eurasian deformation field (Lin et al., 2002; Zhang et al., 2004). Various spatial–temporal models of Tibetan plateau evolution have been proposed and include models advocating progressive NE growth of the plateau during the Eocene-Recent (Tapponnier et al., 2001; Metivier et al., 1998), synchronous growth from the central plateau area towards the south and north (Wang et al., 2008), and near-synchronous northward growth shortly after the onset of the Indo-Eurasian collision (Yin and Harrison, 2000; Yin et al., 2002; Jolivet et al., 2001; Dupont-Nivet et al., 2004; Wang et al., 2006; Fang et al., 2007).

For many workers the northern boundary of the Tibetan Plateau is well defined by the sinistral Altyn Tagh Fault and kinematically linked thrust ridges (Fig. 1; Yin et al., 2002; Yue et al., 2003). However, the NNE margin of the plateau is less well defined where the Qilian Shan fold-and-thrust belt and lesser ranges of the Hexi Corridor create a complex topographic transition from the plateau highlands in the SW to the relatively low Alxa Block to the NE (Fig. 1). In the eastern part of this transitional region, which includes the central-southern Ningxia region, thick volumes of plateau-derived Cenozoic strata are widely deposited (de Chardin

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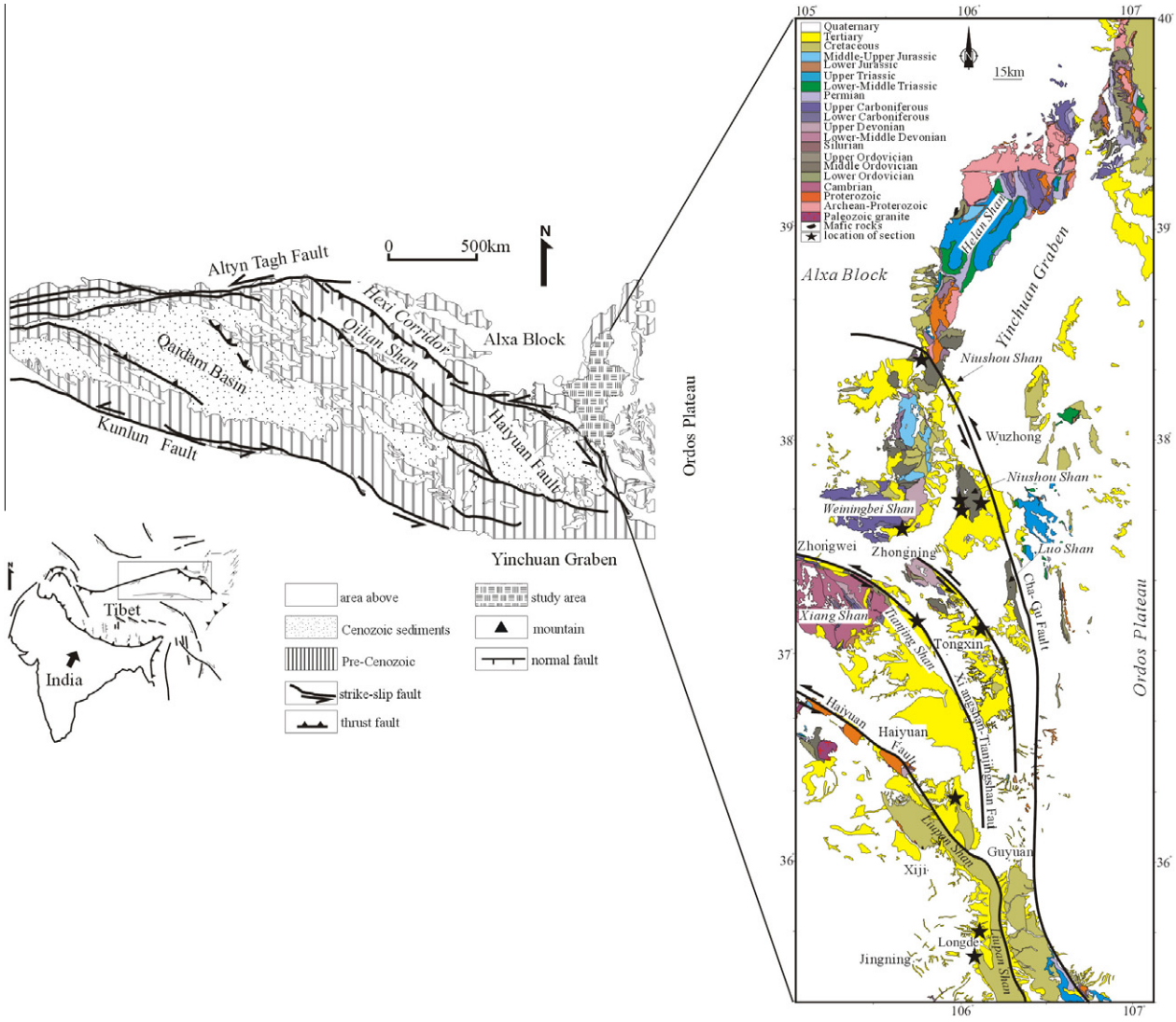

Fig. 1. Simplified geological map of NE Qinghai–Tibetan Plateau region showing study areas in Ningxia province and locations of Cenozoic stratigraphy.

and Licent, 1924; NARBGMR, 1996; Zhang et al., 2006). The Cenozoic sequences are thus tectonically important because they record the uplift and erosional denudation of the NE Tibetan Plateau and are potential archives of the Cenozoic climate history in the region. The deposits are also variably deformed by contractional structures related to outward growth of the plateau. Despite previous investigations into the neotectonic activity in this region (Zhang et al., 1990, 1991; Burchfiel et al., 1991), there are few studies documenting the Cenozoic stratigraphy and its tectonic implications.

Therefore, this study aims to address this shortfall by presenting new detailed stratigraphic data from around the central-southern Ningxia region coupled with documentation of Late Cenozoic fault activity which was responsible for deforming the stratigraphy. By combining new facies analysis with existing age data, we present a new evolutionary model for the tectono-sedimentary development of the NE Tibetan foreland region.

2. Geological setting and Cenozoic stratigraphy

Central-southern Ningxia is located at the deformation front of the northeastern Qinghai–Tibetan Plateau (Fig. 1). To the northwest of the region is the Alxa Block, to the north is the Cenozoic Yinchuan Graben and Mesozoic Helan Shan fold-and-thrust belt, and to the east is the Ordos Plateau (Fig. 1). To the southwest, the Haiyuan Fault is the boundary between the study region and the Qinghai–Tibetan Plateau (Fig. 1). Within the central-southern Ningxia itself, several large arcuate faults that have regional map traces convex to the northeast cut the Cenozoic stratigraphy (Fig. 1; RGAFSOMSSB, 1988). The Cenozoic strata are regionally divided into four formations based mainly on fossil and palynological data. From bottom to top they are the Sikouzi, Qingshuiying, Hongliugou and Ganhegou Formations (Fig. 2; Wang et al., 1994; NARBGMR, 1996). A brief summary of these four formations is presented below.

Generally, the Sikouzi Formation is massive brick-red medium-fine grained quartzo-feldspathic sandstone with basal conglomerate layers of different thicknesses and lateral extents that are interpreted as the alluvial fan deposits (NARBGMR, 1996). Across the study region, the thickness of the Sikouzi Formation ranges from 1853 m in the south to 70 m in the northeast. The Qingshuiying Formation is mainly purple thickly-bedded mudstone, muddy siltstones and grayish-green mudstone interbeded with thick gypsum beds interpreted as lacustrine deposits (NARBGMR, 1996). In the study region, the thickness of this formation varies between 300 m and 970 m. The Hongliugou Formation is mainly composed

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