Journal of Asian Earth Sciences 42 (2011) 1066–1073

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

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

Late Cenozoic tectonic deformation across the northern foreland of the Chinese Tian Shan

ChuanXin Li [a,b], ZhaoJie Guo [a,*], Guillaume Dupont-Nivet [a,c]

[a] Key Laboratory of Orogenic Belts and Crustal Evolution, Ministry of Education, School of Earth and Space Sciences, Peking University, Beijing 100871, China
[b] Research Institute of Petroleum Exploration & Development-Langfang, PetroChina, Langfang 065007, China
[c] Paleomagnetic Laboratory, Faculty of Geosciences, Utrecht University, Budapestlaan 17, 3584 CD Utrecht, The Netherlands

ARTICLE INFO

Article history:
Available online 17 September 2010

Keywords:
Late Cenozoic
North Tian Shan
Foreland basin
Growth strata
Shortening rates

ABSTRACT

To understand the reactivation and intensified uplift of the Tian Shan range in the Cenozoic, the age of development of the associated series of anticlinal belts formed in the southern and northern foreland basins must be constrained. To estimate the shortening magnitude and rates in the northern foreland basin, we provide here regional structural analysis based on identified growth strata dated with existing magnetostratigraphy, together with balanced cross sections from interpreted seismic data. These results indicate that three paralleled rows of anticlinal belts have developed sequentially from south to north accommodating a total shortening of ∼15 km at the location of the structurally restored seismic section provided here. These three belts present different structural deformational styles with the southern (Qingshuihe) anticline as a basement-involved fold, the middle (Huoerguosi) anticline as a fault-bend fold and the northern (Anjihai) anticline as a fault-propagation fold. Growth strata inferred from seismic profiles start stratigraphically far below growth strata observed on the outcrop. The latter coincide with accelerated folding of the anticlinal belts at ∼6 Ma for the southern, ∼2 Ma for the middle ∼1 Ma for the northern. Our results imply that the northern Tian Shan foreland rates of deformation were lower until late Miocene and increased in more recent times to values in line with GPS-derived rates.

1. Introduction

The Tian Shan orogenic belts (Fig. 1) provide an ideal setting to understand uplift, erosion and sedimentation processes and their relation to lithospheric deformation in response to the Indo-Asia collision (Molnar et al., 1993; Tapponnier and Molnar, 1979). As one of the best examples of active intracontinental orogenic systems, the Tian Shan has been the focus of a large number of geologic studies aiming in particular at constraining the age of the onset of deformation, the timing of the uplift and the rate of deformation and total associated convergence (Abdrakhmatov et al., 1996; Avouac et al., 1993). The continuous exposures of stratigraphic sequences found along the southern and northern forelands of the Tian Shan and the availability of sub-surface data from oil exploration seismic and well data, provide an ideal setting for constraining accurately in time the development of foreland structures associated to the range formation (Yin et al., 1998; Chen et al., 2007). To constrain the age of the stratigraphy, a large set of magnetostratigraphic studies have been conducted both on the northern and southern foreland basin sediments of the Tian Shan (Sun et al., 2004, 2007, 2008; Sun and Zhang, 2009; Charreau et al., 2005, 2006, 2008; Huang et al., 2006; Heermance et al., 2007; Lu et al., 2010). While most of the structural studies have concentrated on the southern foreland of the Chinese Tian Shan (Yin et al., 1998; Bullen et al., 2001; Heermance et al., 2007), few integrated studies are focused on the northern foreland structural such that the regional context of the evolution and propagation of deformation remains poorly constrained quantitatively (Avouac et al., 1993; Avouac and Tapponnier, 1993). In this study, we provide regional structural analysis based on identified growth strata dated with published magnetostratigraphy, together with balanced cross sections from interpreted seismic data. These enable to estimate the shortening magnitude and rates of late Cenozoic structural deformations across the northern foreland of the Chinese Tian Shan.

2. Geological setting and stratigraphy

The ancestral Tian Shan is thought to have undergone two Paleozoic accretion events within paleo-Asia (Windley et al., 1990; Gao and Klemd, 2003; Shu et al., 2004; Li, 2006; Sobel et al., 2006; Xiao et al., 2009; Han et al., 2010). The first one, occurring in the Late Devonian–Early Carboniferous, along the southern margin of the range, resulted in the accretion of the central Tian Shan onto the Tarim block. The second one, occurring in the Late

* Corresponding author. Tel.: +86 10 62753545; fax: +86 10 62758610.
E-mail address: zjguo@pku.edu.cn (Z. Guo).

1367-9120/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jseaes.2010.08.009

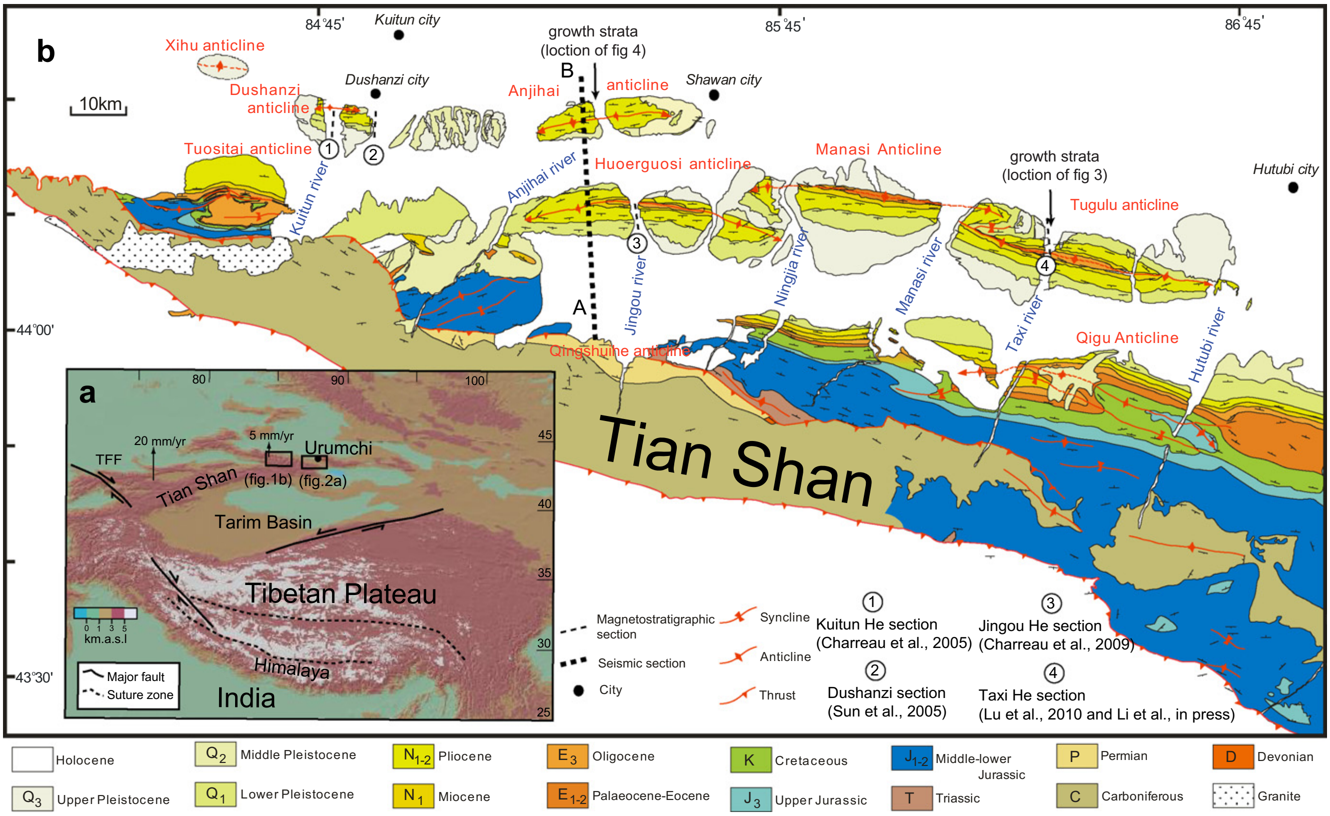

Fig. 1. Location and geologic setting of north Tian Shan. (a) Digital elevation model (GTOPO90) of the Indo-Asia collision zone. Arrows indicate GPS-derived shortening estimates (Abdrakhmatov et al., 1996; Wang et al., 2001). TFF: Talas Fergana Fault. (b) Schematic geologic map (modified from Deng et al., 2000) of the northern flank of the Tian Shan range including the location of sections sampled for chronostratigraphy from previous studies.

Carboniferous along the northern margin, led to the amalgamation of the Junggar block with the combined Tarim-central Tian Shan continental block. The present Tian Shan foreland is characterized by >10 km of Cenozoic strata deformed by Pleistocene detachment folds accommodating much of the recent shortening predicted by extrapolation of modern geodetic and Quaternary slip rates (Abdrakhmatov et al., 1996; Avouac et al., 1993; Scharer et al., 2006). The northern Tian Shan foreland is deformed by three recognized sets of east–west striking anticlinal belts (Deng et al., 2000) that are referred here (Fig. 1) as the southern belt (Tuositai-Qigu-Kalaza), the middle belt (Huoerguosi-Manasi-Tugulu) and the northern belt (Dushanzi–Anjihai). The orientation of these structures provides evidence for dominant north–south compression while the recurrence of these structures and the presence of faults on the north side of the anticlines suggest they are fault-propagation folds and/or fault-bend folds branching from a décollement layer at depth (Avouac et al., 1993).

Our study is focused on the north flank of the Chinese Tian Shan where the outcrop strata are mainly thick Cenozoic deposits that shed into the Junggar foreland basin from the south. Deformation on the middle belt exposes Paleogene lacustrine successions in the core of the anticlines to Plio-Pleistocene dipping fluvial and alluvial conglomeratic strata in the limbs (for detailed lithologic description and formation nomenclature, see Table 1). The Paleogene strata are mainly Lacustrine including the Ziniquanzi formation ($E_{1-2}z$), the Anjihai formation ($E_{2-3}a$) and the lower Shawan formation (E_3-N_1s). The Neogene strata are mainly composed of the fluvial Taxihe formation (N_1t) and Dushanzi formation ($N_{1-2}d$). The Quaternary strata are mainly alluvial massive gray poorly cemented conglomerate successions including the Xiyu formation (Q_1x) and the Wusu formation (Q_2w). These sediments have been dated at various sections along the strike of the northern Tian Shan foreland structures yielding ages that are especially diachronous for the onset of the alluvial Xiyu formation (Charreau et al., 2008; Li et al., in press; Lu et al., 2010). Our structural analysis is based on a long N–S seismic profile (along the Jingou River) that includes the complete stratigraphy and cuts through the three structural belts (Fig. 1). To assess the timing of the structural deformation observed on this profile, we first review a regional investigation of growth strata across those three belts.

3. Syntectonic growth strata observations

Syntectonic growth strata are an effective marker of tectonic deformation in foreland basin (Suppe et al., 1992; Hardy and Poblet, 1994; Burbank et al., 1996). Because they are not apparent in outcrops along the Jingou river seismic profile for all of the three structural belts, we conducted detailed investigations of the geometry of syntectonic sediments along strike of the three parallel rows of anticline belts. Syntectonic growth strata were thus recognized at each row of the three belts. Together with the published age control from magnetostratigraphy, growth strata provide a record of the timing of tectonic deformation. It should be noted that the preserved growth strata provide a minimum age for the initiation of folding. Indeed, older growth strata, if ever present, could have occurred closer to the core of the fold but not have been preserved or not be visible on the outcrop. This will be discussed below in light of seismic profile analysis.

3.1. Growth strata in the southernmost belt

Detailed field investigations indicate that growth strata are present in the southernmost of the three belts at the Kalaza anti-