Tectonophysics 659 (2015) 109–121

Contents lists available at ScienceDirect

Tectonophysics

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

Deep structures and surface boundaries among Proto-Tethyan micro-blocks: Constraints from seismic tomography and aeromagnetic anomalies in the Central China Orogen

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A R T I C L E I N F O

Article history:
Received 5 March 2015
Received in revised form 21 June 2015
Accepted 25 July 2015
Available online 15 August 2015

Keywords:
Proto-Tethys
Micro-block
Tomography
Aeromagnetic anomaly
Tectonics

A B S T R A C T

The Qinling–Qilian orogen preserves the records of Early Paleozoic convergence among the Proto-Tethyan micro-blocks. In this study, we analyze the seismic velocity structure and the aeromagnetic anomalies in the Qinling–Qilian orogen and its adjacent areas, showing that the northernmost boundaries of these Proto-Tethyan micro-blocks are defined by the Guyuan–Longshoushan Fault in the Qilian orogen and by the Luonan–Luanchuan Fault in the Qinling orogen, respectively. The lithosphere north of the Qinling–Qilian orogen subducted southward under the Qinling–Qilian orogen. The boundaries of the micro-blocks in the Qinling–Qilian orogen of the Proto-Tethys domain are mostly EW- or NE-trending. Combined with Early Paleozoic geological records, our results indicate that the south-dipping low-velocity anomaly under the Alxa block and the south-dipping high-velocity ones under the North Qilian orogen and the North China block might indicate that the Alxa block, the North Qilian Oceanic slab and the North China block subducted southward. The south-dipping high-velocity anomaly under the North Qilian orogen is interpreted as the remnant of the Proto-Tethys Ocean in that area. However, the north-dipping low-velocity anomaly under the South Qinling and the North Qinling orogens, the Qaidam block and the north-dipping high-velocity one under the Yangtze and the Bikou blocks suggest that the South Qinling and the North Qinling orogens, the Qaidam, the Yangtze and the Bikou blocks subducted northward. The present spatial framework of the Qinling–Qilian orogen is related to Early Paleozoic convergence among the Proto-Tethyan micro-blocks.

1. Introduction

The Qinling–Qilian orogen is located in the central segment of the Central China orogen, and is an important segment of the orogenic collage of the most northern part of the Tethyan tectonic domain. The Qinling–Qilian orogen is a typical continent–continent collisional orogen, which is separated into the Qilian orogen to the west from the Qinling orogen to the east by the Helan Rift in the middle part. The Qilian orogen is generally subdivided into three parts, called the North Qilian orogen, the Central Qilian block and the South Qilian orogen from north to south. The ophiolites in the North and South Qilian orogens are typical, standing for ancient oceanic crust and recording their tectonic evolution (Wang and Liu, 1976; Xiao et al., 1978). The ophiolites in the North Qilian orogen (Zuo and Liu, 1987; Zhang and Xu, 1995; Feng and He, 1995; Feng, 1997;), including the Dachadaban Ophiolites (Meng et al., 2010; Zhang et al., 1998b), the Jiugequan–Laohushan Ophiolites (Qian et al., 2001a, 2001b), the Tadungou Ophiolites (Song et al., 2009) and the Yushigou Ophiolites (Hou et al., 2006). In addition, the marine volcanic rocks in the North Qilian orogen confirmed the existence of a trench-arc-basin system and archipelago at the east side of the Proto-Tethys Ocean (Du et al., 2002, 2007; Xia et al., 1995, 1998, 2003). Xiao et al. (2009) proposed first one new Early Paleozoic tectonic model of the Qilian orogen with southward subduction polarity constrained by petrological, stratigraphic, geochemical, geochronological (Xu et al., 2010; Yang et al., 2009) and geophysical data (Wu et al., 1995). To the east of the Qilian orogen is the Helan Rift. Huang et al. (2010) determined that the eastern boundary of the Helan Rift between the North Qilian orogen and the North China block is located in the Qingtongxia–Guyuan Fault. Further to the east is the Qinling orogen, of which tectonic outline developed during the Paleozoic times (Li et al., 2007, 2009, 2010, 2011; Teng et al., 2014; Zhang et al., 1986, 1995, 1996b, 2001). The Qilian–Qinling orogen preserves the records of multiple collisional evolutionary history with

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http://dx.doi.org/10.1016/j.tecto.2015.07.033
0040-1951/

intense deformation and metamorphism, and has been the focus of many investigations. A series of Early Paleozoic ophiolite belts and high- to ultrahigh-pressure metamorphic belts provide important windows for studying the evolution of the Proto-Tethys Ocean (Gehrels et al., 2003a, 2003b; Pei et al., 1999; Xu et al., 1994, 2011; Yin and Harrison, 2000; Yin et al., 2007a, 2007b; Zuo and Liu, 1987; Zuo and Wu, 1997), as well as the history of the assembly of micro-blocks (Pan, 1994; Gao et al., 2005). However, previous studies (Gehrels et al., 2003a, 2003b; Pei et al., 1999; Xu et al., 1994, 2011; Yin and Harrison, 2000; Yin et al., 2007a; Zuo and Liu, 1987; Zuo and Wu, 1997) mostly focused on surface structural analysis and the observation of geological outcrops in various blocks within the Qinling–Qilian orogen to discuss their affinities and evolutionary processes.

Due to long-term multiple stages of tectonic activities and assembly among many blocks, the Qinling–Qilian orogen displays diverse geologic features with various ages and structural styles, ranging from regionally extensive ductile shear zones, high-pressure metamorphic belts, micro-blocks or blocks to scattered arc-related volcanic sequences and post-orogenic plutons (Gehrels et al., 2003a, 2003b; Xu et al., 1994). These complex tectonic belts separate the Qinling–Qilian orogen into several small blocks. However, there is no unified tectonic division of the small blocks in the Qinling–Qilian orogen. In recent years, based on new scientific research in the Qinling–Qilian orogen, especially with combined geophysical and geological data (Cheng et al., 2014; Xiao et al., 2009), many researchers have proposed new views and tectonic models on the lithospheric architecture and tectonic evolution for the Qinling–Qilian orogen and its adjacent areas. However, due to lack of information on deep geophysical data and their connection to surface geology, the temporal and spatial framework of the Qinling–Qilian orogen, subduction polarity, younging direction of arcs and crustal growth and collisional thrust polarity, among other features, remain equivocal (Feng, 1997; Gehrels et al., 2003a, 2003b; Song, 1997; Wang et al., 2005; Zhang and Xu, 1995). In particular, the location and nature of the sutures among the Proto-Tethyan micro-blocks, and their continuity to the east and the west remain disputed (Sobel and Arnaud, 1999; Yang, 1997; Yuan et al., 2002, 2003; Yue et al., 2004; Zhou and Graham, 1996).

In this study, we analyze three-dimensional (3-D) P- and S-wave velocity images of the crust and the upper mantle beneath the Qinling–Qilian orogen and its adjacent areas, using a large number of high-quality arrival-time data of local earthquakes. We also evaluate the shallow surface boundaries of these small blocks or micro-blocks to explore continental convergence using aeromagnetic anomalies and geological data. The aim of this paper is to review the spatial framework of the Qinling–Qilian orogen constrained by geophysical data in order to better understand its overall geodynamic evolution. We use these data to evaluate the relationship among the Proto-Tethyan micro-blocks (Chen et al., 1999; Gao et al., 1999; Tapponnier et al., 2001; Yin and Harrison, 2000) and discuss its implications for the architecture and evolution of the Qinling–Qilian orogen.

2. Tectonic setting and regional geology

The Qinling–Qilian orogen is composed of several geological units including the North Qinling and the South Qinling orogens, the North Qilian orogen, the Central Qilian block, the South Qilian orogen, the Oulongbuluk and the Qaidam blocks in the study area (Fig. 1).

The Qinling–Qilian orogen underwent a long-term, complex and multistage continental collisional process (Wu and Zheng, 2013). Several important ophiolite belts and high- to ultrahigh-pressure metamorphic rocks have been reported in this region (Fig. 1). The Qinling orogen is a composite orogenic belt, resulting from long-term assembly and multi-stage orogeny between the North China and the Yangtze blocks (Mattauer et al., 1985; Kroner et al., 1993; Meng and Zhang, 1999; Zhang et al., 1986, 2001). Among these are the subduction-related orogeny in the Paleozoic and the collisional orogeny in the Early Mesozoic between the North China and the Yangtze blocks (Wang et al., 2009).

The tectonic evolution of the Qinling–Qilian orogen can be divided into the following major stages. (1) Precambrian basement formation and evolution between late Archean and Paleoproterozoic. (2) Neoproterozoic to Early Paleozoic plate subduction and collision between the North Qinling orogen and the North China block along the Luonan–Luanchuan Suture representing a closure of the Kuanping

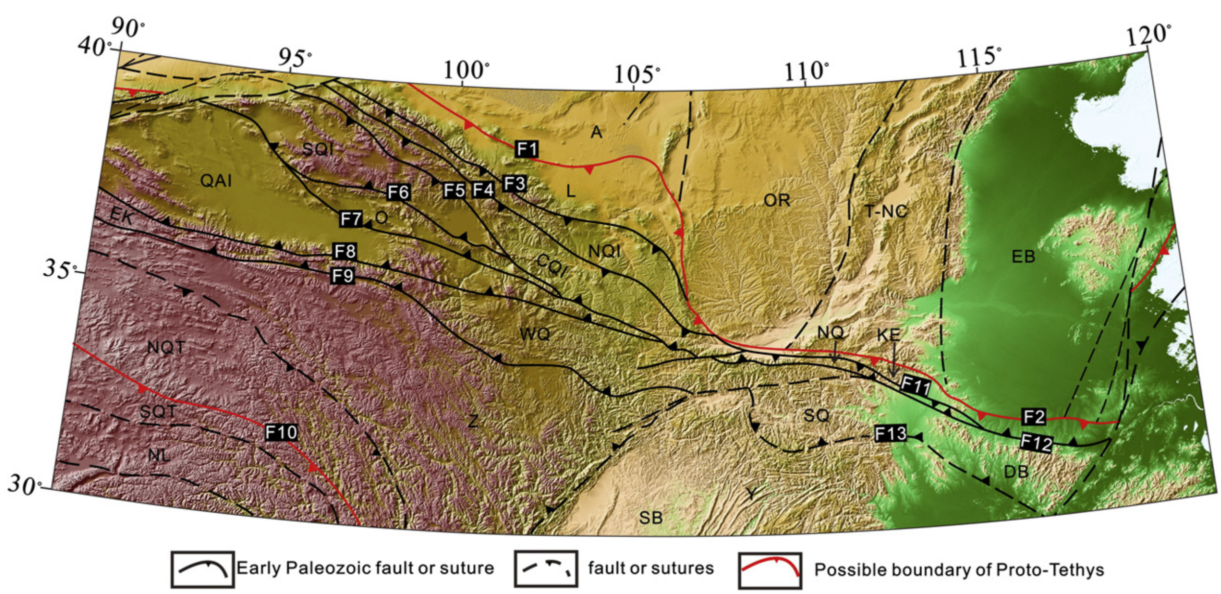

Fig. 1. Division of tectonic units in the Qinling and Qilian orogens. F1, Guyuan–Longshoushan Fault; F2, Luonan–Luanchuan Fault; F3, northern edge of the North Qilian Fault; F4, northern edge of the Central Qilian Fault; F5, Nan Shan Fault; F6, Tianjun Fault; F7, Wenquan–Wahongshan Fault; F8, Central Eastern Kunlun Suture; F9, A'nyemaqen Suture; F10, Longmu Co-Shuanghu Suture; F11, Huangtai–Waxuezi Fault; 12, Shandan Suture; F13, Mianlue Suture. A, Alxa block; L, Longshoushan accretionary wedge; NQI, North Qilian orogen; CQI, Central Qilian block; SQI, South Qilian orogen; O, Oulongbuluk block; QAI, Qaidam block; EK, East Kunlun block; WQ, West Qinling orogen; Z, Zoige block; NQT, North Qiangtang block; SQT, South Qiangtang block; NL, North Lhasa block; OR, Ordos Basin; T-NC, Trans-North China orogen; EB, Eastern block; KE, Kuanping-Erlangping; NQ, North Qinling orogen; SQ, South Qinling orogen; SB, Sichuan Basin; Y, Yangtze block.