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Tectonic evolution and continental crust growth of Northern Xinjiang in northwestern China: Remnant ocean model

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ABSTRACT

The Northern Xinjiang region is located in the southwestern part of the Central Asian Orogenic Belt (CAOB, also known as the Altaid Tectonic Collage). Despite extensive research aimed at understanding the crustal growth of the CAOB and the evolution of the Paleo-Asian Ocean, the tectonic evolution mechanism of continental crust growth in Northern Xinjiang remains controversial. The geology of Northern Xinjiang is characterized by widespread ophiolites, granitoids, intermediate–basic dikes. Most of the ophiolites were generated in the early Paleozoic. The ophiolites are widely spread around the Junggar Basin, but their distribution does not indicate a well-defined band. Their outcrops are generally related to various faults. The basic rocks widespread in Northern Xinjiang are grouped into two categories: (i) gabbros, diabases basalts of the ophiolites and (ii) basic dikes that intrude into the Paleozoic strata granite plutons. The basic rocks associated with the early Paleozoic ophiolites were reworked by later geothermal events with a peak $^{40}Ar/^{39}Ar$ age of 310–290 Ma. The basic dikes intruded into Paleozoic strata and granite plutons during the Carboniferous–Jurassic, displaying three peaks of emplacement at 260–250 Ma, 220 Ma, and 200–190 Ma. These two types of basic rocks and the documented Variscan magmatic rocks were derived from the same source. Their isotope geochemical characteristics and widespread distribution suggest that since the Paleozoic, a large geochemical province has existed in Northern Xinjiang with an affinity to mid-ocean ridge basalts (MORB) and ocean island basalts (OIB), which is related to a long-lived remnant ocean and the underlying early Paleozoic oceanic crust. The existence of remnant oceanic crust in Northern Xinjiang was confirmed by seismic, gravity and aeromagnetic data. Therefore, we propose the following remnant ocean model for the Paleozoic tectonic evolution of Northern Xinjiang. It consists of three stages: 1) oceanic crust formation and deposition of the overlying volcanic-sedimentary rocks during the early Paleozoic; 2) retaining of the remnant ocean with marine sediments deposited during the early stage of the late Paleozoic; and 3) widespread and pervasive emplacement of Variscan granites, intermediate–basic dikes, and their volcanic equivalents during the Late Carboniferous and Early Permian, and termination of marine sedimentation at the end of the Early Permian. The tectonic evolution of Northern Xinjiang has been in a state of intracontinental deformation since the Mesozoic. The Variscan granitoids and basic dikes of Northern Xinjiang originated from the partial melting of the remnant oceanic crust formed in the early Paleozoic. These Variscan intrusive rocks represent the production of continental crust transferred from the basic crust. The Phanerozoic continental growth of Northern Xinjiang was completed by mass transfer from the early Paleozoic remnant oceanic crust; this approach may considerably change our views of continental growth.

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1. Introduction

The growth and evolution of the continental crust has been an important subject of research and debate in the earth sciences (Jahn et al., 2000a, 2000b, 2002c; Hawkesworth and Kemp, 2006). It is widely agreed that the formation of the continental crust was essentially completed in the Precambrian and that the amount of new crust formed in the Phanerozoic is minor or insignificant (Reymer and Schubert, 1984; Armstrong, 1991; Stein and Hofmann, 1994; Taylor and McLennan, 1995; Albarède, 1998; Condie, 1998; Hawkesworth and Kemp, 2006). This hypothesis was supported in earlier Nd isotope studies of granitoids from several intensely studied classic orogenic belts, such as the Caledonides, the Hercynides, the Yangtze–Cathaysia of southeast China, and the Himalayas (Allègre and Othman, 1980; Liew and Hofmann, 1988; Patchett, 1992; Darbyshire and Shepherd, 1994; Chen and Jahn, 1998). However, the idea of negligible growth in the Phanerozoic was challenged by the presence of very large volumes of "juvenile" crust (unlike recycled Precambrian crust) in several orogenic belts, such as the western North American Cordilleras (DePaolo, 1981; Samson et al., 1989; Samson and Patchett, 1991; Samson et al., 1995; Whalen et al., 1996), the Lachlan and New England Fold belts of eastern Australia (McCulloch and Chappell, 1982; Hensel et al., 1985; Collins, 1996, 1998) and the Altaid Tectonic Collage (Sengör et al., 1993; Sengör and Natal'in, 1996).

The Central Asian Orogenic Belt (CAOB; Mossakovsky et al., 1994; Jahn et al., 2000b; Windley et al., 2007), also known as the Altaid Tectonic Collage (Sengör et al., 1993; Sengör and Natal'in, 1996), is situated between the European craton to the west, the Siberian craton to the east, and the Tarim and North China cratons to the south (Fig. 1A). It is the largest Paleozoic accretionary orogen in the world and is generally thought to be related to the closure of the Paleo-Asian Ocean (the Paleo-Ocean defined by units located between the European, Siberian, Tarim, and North China cratons during the Neoproterozoic–late Paleozoic; Coleman, 1989; Zonenshain et al., 1990; Şengör et al., 1993; Mossakovsky et al., 1994; Dobretsov et al., 1995; Şengör and Natal'in, 1996; Buslov et al., 2001; Dobretsov et al., 2003, and references herein; Kovalenko et al., 2004; Windley et al., 2007), representing one of the most important sites of Phanerozoic crustal growth in the world (Sengör et al., 1993; Dobretsov et al., 1995; Kovalenko et al., 1996a, 1996b; Hu et al., 2000; Jahn et al., 2000a, 2000b, 2000c, 2004; Hong et al., 2004; Jahn, 2004; Kovalenko et al., 2004; Wilde et al., 2010).

Northern Xinjiang, which occupies the northwest edge of China, is an important part of the CAOB (Fig. 1A). It has been the subject of extensive studies that examined the crustal growth of the CAOB and the evolution of the Paleo-Asian Ocean (Coleman, 1989; Feng et al., 1989; Xiao and Tang, 1991; Xiao et al., 1992; Sengör et al., 1993; He et al., 1994b; Sengör and Natal'in, 1996; Hu et al., 2000; Jahn et al., 2000b; Liu, 2002; Wang et al., 2003; Buckman and Aitchison, 2004; Xiao et al., 2008). However, the mechanism of continental crust growth and tectonic evolution in Northern Xinjiang remains controversial and is currently under debate, with models of a continuous single subduction–accretion processes (Sengör et al., 1993; Sengör and Natal'in, 1996; Wang et al., 2003), collision of various terranes with multiple subduction systems (Didenko et al., 1994; Mossakovsky et al., 1994; Buchan et al., 2001; Buslov et al., 2001; Badarch et al., 2002; Windley et al., 2002), an accretionary wedge (Xiao et al., 2008, 2009; Zhang, 2009), or mid-ocean ridge subduction (Liu et al., 2007, 2009; Geng et al., 2009; Yin et al., 2010). These models can be adapted to certain aspects of the tectonics of Northern Xinjiang. However, they are not supported by the following lines of geological facts: (1) the ophiolites are widespread around the Junggar Basin but their distribution does not indicate a band pattern (Fig. 1B); (2) the exposure of ophiolites is generally related to different faults and exhumation depths (Fig. 1B), and the strata in the fault zones are deformed by subvertical cleavages (Fig. 2A, B, and D); (3) outside the fault zones, the Paleozoic strata lie almost horizontally or tilt gently (Fig. 2B and C).

This study focuses primarily on basic rocks of different ages and occurrences in Northern Xinjiang. Based on geology, geochemistry, and geochronology observations, we present a new model for the tectonic evolution of Northern Xinjiang, which can better explain the continental crust growth of Northern Xinjiang.

2. Geological setting

Northern Xinjiang is located in the southwestern region of the CAOB (Fig. 1A) and includes (from north to south) the Altay, the Junggar Basin, and the Tian Shan tectonic domains (Fig. 3).

According to the geological data (Feng, 1985; Feng et al., 1989; BGMRXUAR, 1993), no Precambrian strata has been clearly identified north of Tian Shan (Fig. 3B), and the oldest units are the Ordovician formations intermediate to basic volcanic rocks and flysch-type deposits.

The Ordovician units are exposed mainly in the southwestern areas of the Junggar Basin and the Altay region. The main outcrops of Silurian rocks in the west are around the Tangbale and Mayile ophiolites, and in the east around the Kalamaili ophiolite (Figs. 1B and 3B). The Silurian strata are mainly Early-Silurian flysch-type deposits with ophiolitic

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