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Late Mesozoic tectonic evolution and kinematic mechanisms in the Daqing Shan at the northern margin of the North China Craton

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ABSTRACT

The Yinshan belt that lies along the northern edge of the North China Craton is an intraplate deformational belt that developed in the late Mesozoic. The Daqing Shan is located in the eastern part of this belt and has attracted increasing attention because of its large-scale thrust structures and the Hohhot metamorphic core complex. The structural dynamics and the tectonic relationships between compressional and extensional regimes in this region remain controversial. Our work indicates marked differences in the late Mesozoic deformation events that affected the western and eastern parts of the Daqing Shan. Compressional structures in the western part of the range are characterized by high-angle symmetrical thrusts consisted of S- and N-dipping thrust faults, whereas the eastern part is characterized by low-angle thrusting, most notificeably the thrusting of Meso–Neoproterozoic northwestwards across Late Jurassic–Early Cretaceous strata. Field mapping has revealed that the symmetric thrusting in the western part is overlain by the low-angle thrusting that is developed in the eastern part, and the latter is overprinted by the Hohhot metamorphic core complex. Therefore, the Daqing Shan area underwent complex tectonic processes during the late Mesozoic, which can be summarized as D1 late Middle Jurassic to pre-Cretaceous symmetrical thrusting, D2 Late Jurassic to Early Cretaceous low-angle thrusting, and D3 Early Cretaceous extensional development of a metamorphic core complex. Fault-slip data indicate spatial and temporal variations in the tectonic stress field. The symmetrical thrusting was the result of N–S compression, and the low-angle thrusting was the result of NW–SE compression. These structures may, respectively, be related to the far-field effects of the closure of the Mongolia–Okhotsk Ocean north of the Daqing Shan and the subduction of the Pacific Plate beneath eastern Asia. The formation of the Hohhot MCC could correlate with the extension of lithosphere in the east North China Craton. The characteristics of late Mesozoic deformation in the Daqing Shan indicate that tectonic processes in this intraplate deformation belt were controlled by the interaction of multiple adjacent plates, resulting in temporally distinct modes of deformation, kinematics, and dynamic mechanisms, and which cannot reasonably be interpreted in terms of a single tectonic mechanism or dynamic model.

1. Introduction

Intraplate deformation belts often record long and complex histories of deformation (Darby and Ritts, 2007). After the North China Craton (NCC) collided with Mongolian arc terranes along the Solon suture in the late Paleozoic (Zhang et al., 1984; Wang and Mo, 1995; Yin and Nie, 1996), the northern edge of the NCC evolved from a convergent plate margin to an intracontinental environment (Davis et al., 2001).

The E–W-trending Daqing Shan (Daqing Mountains), 200 km long (Zhang et al., 2009), is located in the eastern part of the Yinshan belt, which is located near the northern margin of the NCC (Fig. 1). As part of the Yinshan intraplate deformation belt, its tectonic evolution during the late Mesozoic has attracted much attention. Previous studies have confirmed the development of large-scale thrust structures and an extensional metamorphic core complex, but the structural relationships and the dynamic mechanisms involved are still debated (Davis et al., 1998, 2002; Zheng et al., 1998; Liu et al., 1999, 2003a; Darby et al., 2001; Du et al., 2005, 2009; Zhang et al., 2009; Davis and Darby, 2010; Guo et al., 2012a,b; Liu et al., 2014). The different ideas put forward by previous workers can be summarized as follows: (1) thrust structures formed before, and were overprinted by, the extensional

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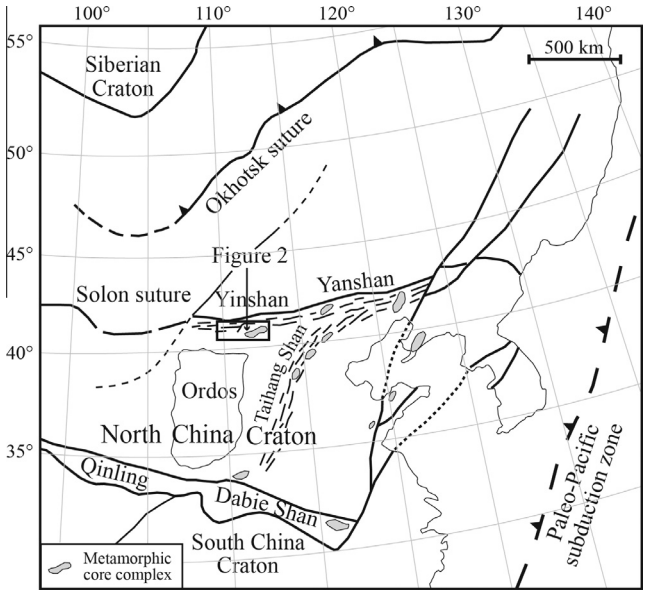

Fig. 1. Tectonic setting of the Yinshan belt (after Hu et al., 2010; Wang et al., 2011). Sutures include the Jurassic–Cretaceous Okhotsk, Permian–Triassic Solon, and Permian (?)–Triassic Qinling–Dabie zones (according to Darby et al., 2001).

Hohhot metamorphic core complex (MCC) (Davis et al., 2002; Davis and Darby, 2010); (2) thrust structures and the MCC formed simultaneously, and either the extension was accompanied by the intrusion of granite at depth that resulted in the development of the compressional structures nearer the surface (Guo et al., 2012a,b), or the northern China–Mongolia extensional tract formed simultaneously with the Yinshan–Yanshan outer thrust belt (Meng, 2003); (3) the Daqing Shan thrust is younger than the Early Cretaceous extensional structures (Liu et al., 2014). These quite different ideas might have arisen because of the following: (1) the previous conclusions were based on studies of either the western or eastern segments of the Daqing Shan alone, which separately cannot provide sufficient evidence for the tectonic features of the area as a whole; (2) interpretations of certain important pieces of evidence from the field are contradictory, and have depended on assumptions about the sequence of late Mesozoic structures in the Daqing Shan, this problem needs to be addressed.

In this paper, we use the results of new field mapping and structural analysis to describe the late Mesozoic structural architecture and sequence of deformation in the Daqing Shan area. Our results indicate that the late Mesozoic thrust structures in the western and eastern Daqing Shan are completely different from each other in their characteristics, and they have overprinted relationships. The low-angle thrusts of the eastern Daqing Shan were overprinted by the Hohhot MCC.

2. Regional geology

2.1. Structural architecture

The structural architectures of the western Daqing Shan (north Baotou to Tuzuoqi) and the eastern Daqing Shan (north Tuzuoqi to Hohhot) are very different from each other (Fig. 2). The western Daqing Shan contains a Late Triassic thrust (Darby et al., 2001; Liu et al., 2003b), an Early to Middle Jurassic half-rift basin (Ritts et al., 2001), and a late Mesozoic thrust (Darby et al., 2001; Liu et al., 1999). Movement on the Late Triassic thrust has resulted in strongly folded Paleozoic and Lower Triassic strata, which occur as a series of E–W trending synclines cut by large-scale thrust faults, and as early Paleozoic tectonic slices. The late Mesozoic structures of the western Daqing Shan are characterized by a network of E–W-striking, moderate- to high-angle thrust faults (Fig. 2). The minimum crustal shortening due to Late Jurassic N–S compression in the southwestern Daqing Shan is estimated to be 30% (Darby et al., 2001). In contrast, the eastern Daqing Shan contains a complex array of structural elements, including the Daqing Shan low-angle thrust, with 22–35 km of thrust movement (Zheng et al., 1998), and the Hohhot metamorphic core complex (Davis and Darby, 2010; Guo et al., 2012a,b) (Fig. 2).

2.2. Rock units and stratigraphy

Major rock units within the Daqing Shan include Archean and Proterozoic metamorphic basement rocks (Fig. 2), Paleozoic and Mesozoic sedimentary strata, and magmatic rocks of various ages. Rock units and stratigraphy differ between the western and eastern Daqing Shan (Fig. 3).

2.2.1. Western Daqing Shan

Metamorphic basement of the western Daqing Shan is mainly Archean gneiss, and Proterozoic strata are almost absent. Archean metamorphic rocks are thrust onto the Paleozoic and Mesozoic sediments in the Mesozoic south Shiguai Basin. Sedimentary cover rocks, distributed mainly in the Shiguai Basin and to the south of the basin, are of Paleozoic and Mesozoic age. Early Paleozoic rocks include Cambrian–Ordovician limestones and Carboniferous clastic rocks, they lie unconformably on Archean gneiss and have been deformed into E–W trending folds (Darby et al., 2001). Permian and Triassic coal-bearing clastic sediments strike nearly E–W. The most important sedimentary cover rocks are Jurassic in age, and consist of the Shiguai Group and the Daqing Shan Formation. Shiguai Group is Lower–Middle Jurassic in age, based on plant microfossils (NMBGMR, 1991) and palynological ages from the base of the section (Ritts et al., 2001). Strata are mainly found in the E–W trending Shiguai Basin. They rest unconformably on crystalline basement along the northern margin of the basin, but are in fault contact with older strata along its southern margin. Sediments of the Shiguai Group fine upwards. At the bottom of the group are pebble–boulder conglomerates, and above these, in turn, are sandstones and then shale and coal beds deposited in alluvial, fluvial, and lacustrine environments (Ritts et al., 2001). Locally distributed upper Daqing Shan Formation is dominated by conglomerate and lies unconformably on the Shiguai Group. In the western Daqing Shan, sediments of Cretaceous age are found only to north of the Daqing Shan. Widespread magmatic rocks in the western Daqing Shan include late Paleozoic–Triassic batholiths that yield zircon U–Pb ages ranging from 211 to 330 Ma (CESJU, 2003; Zhang et al., 2012).

2.2.2. Eastern Daqing Shan

Basement rock units within the eastern Daqing Shan include low-grade Proterozoic metasediments (mostly carbonates), Archean and early Proterozoic gneisses. Sedimentary cover rocks in the eastern Daqing Shan are of Jurassic and Cretaceous age, Paleozoic and early Mesozoic sediments are absent. Lower–Middle Jurassic strata in this area are similar to those in the western Daqing Shan, and rest unconformably on the Precambrian basement. The most extensively developed rocks in the area are of Early Cretaceous age, and they are dominated by purple conglomerates, sandstones, and volcanic rocks with $^{40}Ar/^{39}Ar$ ages of 119–135 Ma (Davis and Darby, 2010). Late Jurassic–Early Cretaceous rocks were deposited in a foreland basin, and the Early Cretaceous rocks are syn-extensional supradetachment strata (Ritts et al., 2009; Davis and Darby, 2010). Early Mesozoic granitic