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Cooling paths of the NE China crust during the Mesozoic extensional tectonics: Example from the south-Liaodong peninsula metamorphic core complex

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ABSTRACT

The south-Liaodong peninsula massif is the easternmost Mesozoic metamorphic core complex, recognized in Eastern China. It provides a good example of the combination of ductile shearing, syn-kinematic plutonism and polyphase exhumation. The Jurassic granodioritic plutons, located at the footwall of the detachment normal fault, and dated here at ca 160 Ma, recorded two different phases of cooling. A slow cooling regime of about 3–10 °C/my prevailing before 122 Ma, was followed by a significant increase in cooling rate of about 40–55 °C/my after that time. By contrast, a single fast cooling path was recorded by the Cretaceous monzogranite situated in the footwall of the detachment normal fault. This result indicates that the Jurassic and Cretaceous plutons recorded different exhumation processes: a Jurassic slow or negligible exhumation and a Cretaceous fast one assisted by normal faulting. These two cooling stages correspond to distinct geodynamic processes during the Jurassic and Cretaceous. Extensional tectonics seems not significant before Early Cretaceous. The second stage, dominated by an extensional regime which develops after ca 120 Ma, is tentatively correlated to the lithosphere removal of the North China Craton.

1. Introduction

The eastern part of north China represents an important tectonic element of the North China Craton (NCC). It is composed of several Archean blocks assembled during Early Paleoproterozoic times (Kusky and Li, 2003; Zhao et al., 2005; Faure et al., 2007; Trap et al., 2007) and covered by Meso and Neoproterozoic sediments (SBGMR, 1989; HBGMR, 1989). During the Late Paleozoic to Early Mesozoic, the tectonic evolution of the NCC was essentially located along its margins (Yin and Nie, 1993, 1996; Zhai et al., 2004). Along its southern border, the Qinling–Dabie–Sulu orogenic belt (Fig. 1A) corresponds to the collision zone between the NCC and the South China Block (SCB). As indicated by structural and metamorphic studies of UHP rocks, the lithosphere convergence accommodated more than 200 km of north-directed continental subduction (Mattauer et al., 1985; Hacker et al., 1998, 2006; Faure et al., 2003a,b; and references therein; Fig. 1A). To the north, the Central Asian Orogenic Belt (CAOB, Fig. 1A) corresponds to the successive accretions and collisions between the NCC and the intra-oceanic arcs and continental micro-blocks around the Siberian Craton during late Permian to Early Triassic times (Wang and Liu, 1986; Lamb and Badarch, 1997; Sengor and Natal'in, 1996; Xiao et al., 2003; Shang, 2004; Lin et al., 2008a).

Recently, the geology of the NCC has attracted great attention because of the coexistence of Ordovician diamondiferous kimberlites, Mesozoic lamprophyre-basalt and Cenozoic basalts in this craton, especially in the western part of Shandong province and in the South of Liaodong Peninsula. Silicate inclusions in diamonds, peridotites and disaggregated minerals in Ordovician kimberlites indicate the presence of a thick (~200 km), cold and refractory lithospheric keel beneath the NCC prior to the Paleozoic (Griffin et al., 1998; Xu, 2001). Based on geophysical data and petrological studies of mantle xenoliths from Late Mesozoic to Early Cenozoic basalts, it has been argued that the present lithosphere thickness lies between 120 km and 70 km (Fan and Menzies, 1992; Menzies et al., 1993; Menzies and Xu, 1998; Griffin et al., 1998; Zhang and Zheng, 2003; Deng et al., 2004; Zhang, 2005). This means that, during the Late Mesozoic (Griffin et al., 1998) or Cenozoic (Menzies et al., 1993), the lithosphere was thinned by more than 80 km.

At the crustal level, lithospheric thinning is accommodated by extensional tectonics represented by ductile and brittle normal

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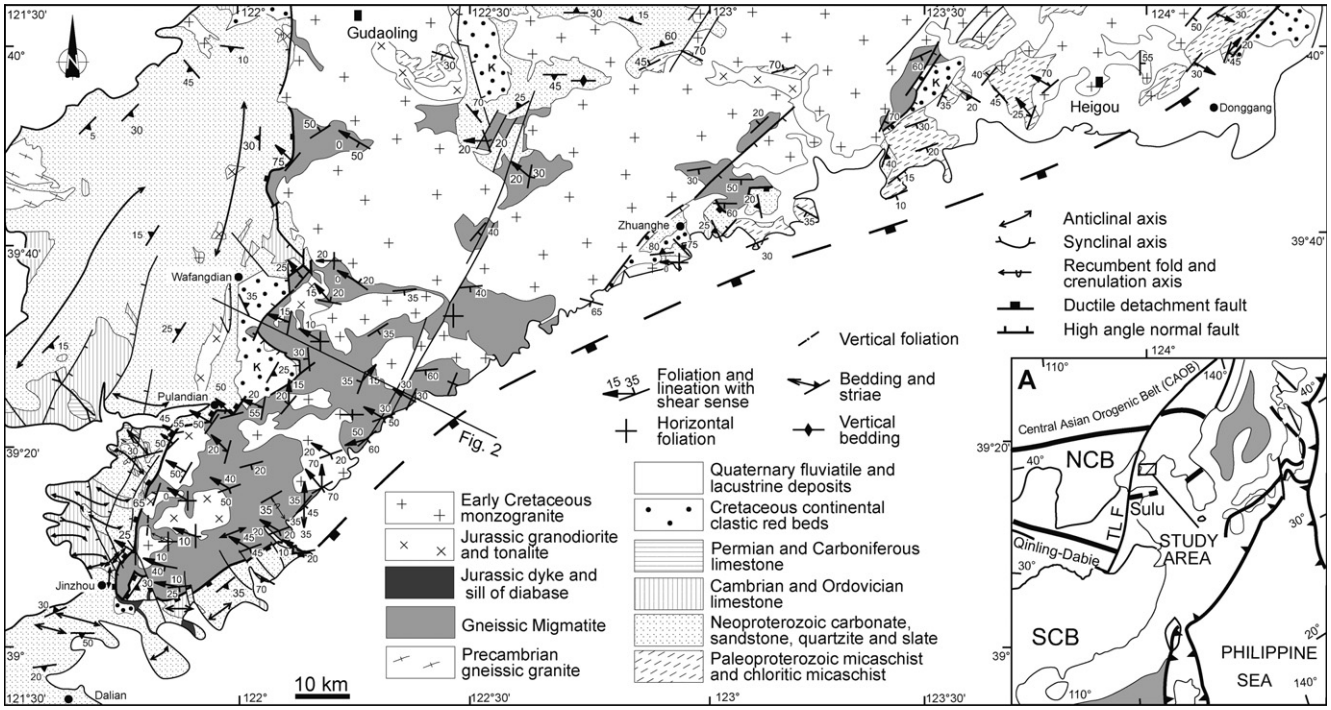

Fig. 1. Regional-scale structural map of the south-Liaodong peninsula massif. Inset shows the location of study area within the broader context of East Asia (modified from Lin et al., 2008b). NCB: North China Block; SCB: South China Block.

faulting active during the Cretaceous. This Late Mesozoic phase of extension occurred coevally with volumetrically important Cretaceous magmatism extending more than 4000 km, from the Okhotsk Sea in the North to Vietnam in the South (Zorin, 1999; Ren et al., 2002; Meng, 2003; Wu et al., 2005a). In East China, rift basins and related metamorphic complexes were recognized very early, even before the development of plate tectonics (Huang, 1945). Several models have been proposed to interpret the Mesozoic evolution of the NCC, involving processes such as rifting (Tian et al., 1992), mantle plume (Deng et al., 1998, 2004), thermal and chemical erosion of the lithospheric mantle (Xu, 1999, 2001), basaltic underplating (Zhang and Sun, 2002), mantle delamination (Gao et al., 1998, 2002) and subduction induced rollback (Ren et al., 2002). Both the exact timing and the processes of NCC thinning remain disputed. In NE China, the south-Liaodong peninsula massif has been recognized as a Cretaceous metamorphic core complex (MCC) with abundant plutonic rocks (e.g. Yin and Nie, 1993; Liu et al., 2005; Yang et al., 2007b; Lin et al., 2008b and references therein). Recently, a thermochronological study argued that the south-Liaodong peninsula massif experienced a fast cooling in Late Cretaceous between 120 and 107 Ma (i.e. Yang et al., 2007b). However, this study did not consider the Jurassic granodioritic plutons dated in the same area at 174–173 Ma on zircon by laser ablation ICP-MS method (Wu et al., 2005b). Therefore, a $^{40}Ar/^{39}Ar$ and U/Pb thermochronological study has been undertaken from undeformed, and deformed (foliated and mylonitized) granitoids, and their gneissic country rocks of the south-Liaodong peninsula massif, using a suite of minerals with different closure temperatures. The combination of the previous results with the new ones allows us to discuss the possible cooling path experienced by this MCC.

2. Geological framework of south-Liaodong peninsula massif

In the Liaoning Province of NE China, the south-Liaodong peninsula massif (Fig. 1) is composed of metamorphic and magmatic rocks, with Archean and Paleoproterozoic rocks occupying about half of the area (Yin and Nie, 1996; Lu et al., 2004; Faure et al., 2004; Li et al., 2005). Neoproterozoic and Paleozoic sediments overlie metamorphic rocks, which are intruded by Mesozoic granitoids (Wu et al., 2005a,b; Yang et al., 2007a,b,c). Mesozoic to Cenozoic terrigeneous rocks occur in fault-bounded troughs, suggesting basin formation related to extension (Allen et al., 1997; Okada, 1999; Ren et al., 2002). Structurally, the south-Liaodong peninsula massif is a Cretaceous asymmetric metamorphic core complex (MCC) called either the "Liaonan MCC" or "south-Liaodong peninsula" MCC with a NE–SW trending long axis (Fig. 1; Liu et al., 2005; Yang et al., 2007b; Lin et al., 2008b and references therein). It consists of three litho-tectonic units namely: (1) a gneissic migmatite unit, (2) a Paleo- to Mesoproterozoic micaschist and slate unit, and (3) a Neoproterozoic to Mesozoic sedimentary cover.

The south-Liaodong peninsula MCC shows NW-SE trending extension direction (Liu et al., 2005; Yang et al., 2007b; Lin et al., 2008b). The Paleoproterozoic gneisses and foliated migmatite that form the lower plate of the MCC are heterogeneously deformed with a relatively weakly foliated core and a mylonitic shear zone at the margin. The dome boundary is a low-angle ductile detachment normal fault locally reworked by a brittle high-angle fault (Fig. 2). Two types of granitic plutons intrude the metamorphic series. Jurassic granodiorites are pervasively foliated, whereas Early Cretaceous syntectonic monzogranitic plutons are weakly foliated except where they are involved in the detachment fault. In this latter structure, the granitic rocks were converted to mylonite or ultramylonite. Kinematic shear criteria show a top-to-the-NW sense of movement along the detachment fault. As observed in the metamorphic core complexes of North America (e.g. Lister and Davis, 1989), the detachment fault of the south-Liaodong peninsula MCC is arched, due to syn-extensional folding around a NE-SW axis (Fig. 1). As a result, the SE dome limb appears as a top-to-the-NW thrust, which is in reality a folded normal fault. In the hanging wall of the detachment fault, the Neoproterozoic and Paleozoic sedimentary rocks are deformed by northwestward verging folds (Fig. 1; Lin et al., 2008b).