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Footwall Tilting of Yunmengshan MCC, north of Beijing: Evidence and Implications for the Mechanism of Low-Angle Normal Fault

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Yunmengshan metamorphic core complex (mcc) is a cordilleran-type mcc firstly identified in the Yanshan fold-and-thrust belt, north of Beijing (Davis et al., 1996). Tectonically, Yunmengshan mcc was induced by the gravitationally-induced collapse of over-thickened crust in the middle epoch of early Cretaceous (125 Ma, Davis et al., 2001). The Hefangkou detachment fault exposed along the eastern and southeastern margin of the Yunmengshan batholith separates the hanging wall of the mid-crustal Miyun Reservoir ductile thrust system in the east and the footwall composed of the Sihetang recumbent anticlinal nappe and the Yunmengshan batholith in the west (Davis et al., 1996; Fig. 1). The Yunmengshan granodiorite batholith intruded at Late Jurassic-Early Cretaceous age (~143 Ma), and its intrusion has nothing to do with the formation of the metamorphic core complex (Davis et al., 2001). However, several early Cretaceous plutons exposed within the north and south of Yunmengshan batholith, and they are bound up with the detachment movement during the orogenic collapse. Among them, the typical one is Xuejiashiliang composite pluton, which is exposed in the southwest of Yunmengshan batholith (Fig. 1).

The oval shape Xuejiashiliang pluton is composed of Shangzhuang gabbro unit, Xuejiashiliang diorite unit, Heishanzhai quartz-monzonite unit, Heixiongshan granite unit, and Humen monzonite unit, which are successively exposed from NE to SW (Fig.1). The diorite, quartz-monzonite and monzonite units of the pluton are in transitional contact with each other, while the Heixiongshan granite unit and related acid dykes cut sharply the other units (Fig.1). The high precision zircon U-Pb geochronology indicates that the diorite unit intruded at 125 ± 2 Ma, the monzonite unit at 124 ± 2 Ma, and the Heixiongshan granite unit at 124 ± 1 Ma of (Davis et al., 2001; Su et al., 2007). Accordingly, both of the field

evidence and the isotope dating reveal that the different units in Xuejiashiliang pluton formed simultaneously during the detachment of Yunmengshan mcc.

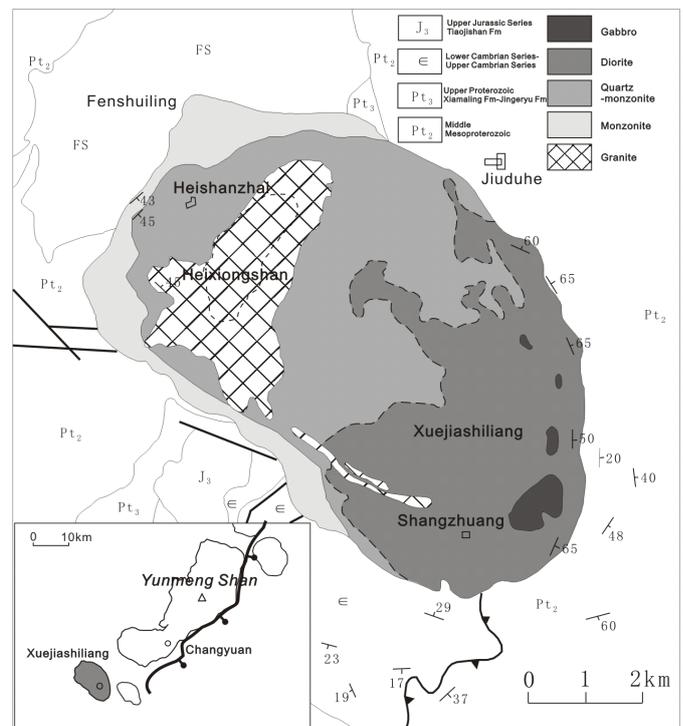


Fig. 1. Geological map of Xuejiashiliang pluton and its location in the Yunmengshan mcc.

From the field observation, petrographic and geochemical data, Xuejiashiliang pluton is interpreted as the consequence of dioritic magma through fractional crystallization. The original three-dimensional configuration of the pluton is a bottle-shape magma chamber with the upright longitudinal axis. The fractional crystallization of the dioritic parent magma dominates the spatial occurrence of units. The mafic gabbro cumulates in the bottom, and the Humen monzonite unit settles in the top of chamber due to the buoyancy of feldspars,

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meanwhile, the dioritic and quartz monzonite units are situated in between gabbro and monzonite successively. Interestingly, the planar view of Heixiongshan granite is like a half mushroom with a NW-SE directed “tail” behind. This phenomenon is understood as the mark of a hot magma batch penetrate through the semi-consolidate magmatic chamber. All of these evidences suggest that the Xuejiashiliang composite pluton was tilted after its settlement and consolidated.

The emplacement depths of the units of Xuejiashiliang pluton are estimated by Al-in-hornblende geobarometer calibrated by Schmidt (1992) and Anderson and Smith (1995). The results demonstrate that the emplacement depth for the diorite unit, which exposed in the southeast, is about 23 km, and that for the quartz-monzonite unit in the northwestern end is *ca.* 6 km. This confirms our interpretation on the SE to NW directed tilting of Xuejiashiliang pluton. Meanwhile, the Al-in-hornblende geobarometer gives a *ca.* 23 km emplacement depth for Changyuan dioritic pluton (~152 Ma) located in the northeast of Xuejiashiliang pluton but south of Yunmengshan batholith, and a *ca.* 12 km depth for Tieluzi granodioritic pluton (~133 Ma) in the west of Changyuan pluton. Accordingly, we argue that the footwall of Yunmengshan mcc had tilted significantly.

As a part of metamorphic core complex, the “low-angle normal fault (LANF)” is recognized as a important structural style for extension. However, under the tenets of classical fault mechanics, normal fault in the brittle upper crust should initiate at dips greater than 45°, and should be active at dips of no less than 30° (Anderson, 1951; Byerlee, 1978; Sibson, 1985). The mechanism of LANF is still a hotly debated topic. The controversy focuses primarily on whether the LANF observed in extensional environments formed and slipped at low angles or were rotated from an original high-angle orientation after large offsets (Lavier et al., 1999). Wernicke and Axen (1988) proposed that normal faults originate at high angle and, as fault offset increases, are rotated flexurally to an inactive low-angle configuration. Based on the numerical modeling, Buck and co-workers suggested that rotation could explain low-angle fault structures, and larger strength reduction leads to single faults that continue to slip no matter how large the fault offset (cf. Buck, 1991, 1993; Lavier et al., 1999).

Following these authors' opinion, we argue that the Hefangkou detachment fault of Yunmengshan mcc also developed from the rotation mechanism. It means that the Yunmengshan mcc originated from the high-angle normal faulting, and then the normal fault rotated to shallow angle, which is the Hefangkou detachment fault. Accompanying with the rotation of the normal fault, the

large angle (near 90°) tilting occurred in the footwall of Yunmengshan mcc. Xuejiashiliang dioritic-quartz monzonite pluton, which intruded simultaneously with the extensional movement of Yunmengshan mcc, initially emplaced at *ca.* 23 km depth as a bottle-like body, and experienced the differentiation and was also intruded by Heixiongshan granite with A-type granite affinity. It is suggested that the solidification of the Xuejiashiliang composite pluton accompanied with the uplift of Yunmengshan mcc's footwall, corresponding to the high angle normal faulting activity during the mcc development. Along with the large offset and rotation of the Hefangkou fault, Xuejiashiliang pluton tilted to NW gradually. The cartoon to illustrated our interpretation are shown in Figure 2.

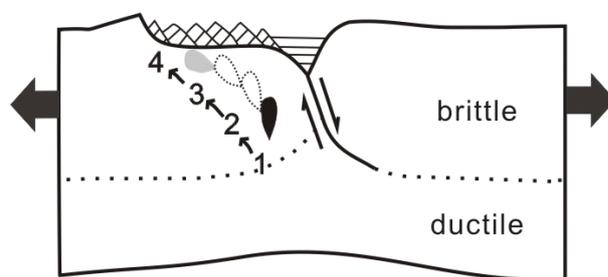


Fig. 2. The cartoon to interpret the rotation of low-angle normal fault and the successive tilting of the pluton bounded within the footwall of the metamorphic core complex

In summary, the field and petrological evidences preserved in the syn-extensional plutons occurred within the footwall of Yunmengshan mcc indicate a significant tilting along the hinge of detachment fault, and suggested that the Hefangkou low-angle detachment fault, which offsets the hanging wall and footwall in several tens kilometers, was resulted from the rotation of a former high-angle normal fault. Accordingly, the rotation model is preferred to explain the mechanism of the LANF which drives Yunmengshan mcc.

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