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Emplacement Depths and Exhumation of Mesozoic Granitoids Responding to Lithospheric Destruction in the Jiaodong Peninsula, North China Craton

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1 Introduction

The North China Craton (NCC) has experienced lithospheric destruction in Mesozoic accompanied with crustal exhumation. Fission track or (U-Th)/He dating of zircon and apatite for the Mesozoic granitoids in the western Jiaodong Peninsula has been done to reveal history of the crustal uplift (Yang et al., 2016; Sun et al., 2017; Zhang et al., 2017). However, the results solely record the low temperature stage and can reconstruct young thermal history. Widespread plutons exposed at the surface imply apparent exhumation has happened before, nevertheless, the specific timing, amount and rate of exhumation are unknown. Multiple-stage Mesozoic granitoids exposed in the Jiaodong Peninsula provide a compelling case to reveal the crustal exhumation process.

In this paper, we use the Al-in-amphibole barometers to estimate emplacement depths of Mesozoic granitoids and to build the exhumation history and mechanism in combination with previous reported mineral ^{40}Ar-^{39}Ar isotopic data.

2 Region Geological Setting

The Jiaodong Peninsula, located in the southeastern of the NCC, is divided into two units by the Kunyushan complex zone bounded by the Mouping and Mishan faults: Jiaobei terrane in the west (western Jiaodong Peninsula) and ultra-pressure metamorphic (UHPM) terrane in the east (eastern Jiaodong Peninsula). Mesozoic granitoids in the entire Jiaodong Peninsula are extensively outcropped with three stages of granitoids in the west and two stages of granitoids in the east. The Mesozoic granitoids are represented by the Linglong (LL, 158 Ma), Guojialing (GJL, 129 Ma) and Aishan (AS, 116 Ma) plutons in the western Jiaodong Peninsula, and the Duoguding (DGD, 161 Ma), Wendeng (WD, 160 Ma), Yuangezhuang (YGZ, 113 Ma), Haiyang (HY, 118 Ma), Sanfoshan (SFS, 118 Ma) and Weideshan (WDS, 108 Ma) plutons in the eastern Jiaodong Peninsula. In the field observation, the LL is intruded by the GJL and they both are invaded by the AS. The WDS crosscuts the WD and the SFS cuts through the DGD.

3 Application and Comparison of Two Al-in-amphibole Barometers

The estimated results show that the pressures derived from AS95 are lower in the range of <2 kbar and >6 kbar and higher between 2 to 6 kbar compared with the pressures derived from the Mutch16. The effect of temperature on pressure is up to 2 kbar per 100□ C and the elevated oxygen fugacity can decrease Mg/Fe ratio and Al substitution in amphibole. In the experimental calibration for the Mutch16, oxygen fugacity conditions are slight above the NNO, different from our estimated results between FMQ and NNO for the WD and GJL. The difference may overestimate the oxygen fugacity condition and lead to low pressure results in the range of 2-6 kbar. The experimental calibration of the AS95 is at 675□C and 760□C, higher than the temperature results derived from amphibole-plagioclase thermometer for these intrusions of <2 kbar, which likely cause excessive correction and deduct excessive Al amount in amphibole, leading to low pressure results in the range of <2 kbar. Considering the uncertainty, the pressure results based on the two Al-in-amphibole barometers are highly consistent at <2 kbar and indistinguishable at 2-6 kbar, imply the AS95 has a potential to apply into these intrusions of < 2 kbar.

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4 Emplacement Depths and Exhumation of Mesozoic granitoids

The calculated results show that the GJL and AS in the western Jiaodong Peninsula were emplaced at 3-4, 3.1 and 1.5 kbar, respectively. The DGD, WD, YGZ, SFS, WDS and HY in the eastern Jiaodong Peninsula were emplaced at 3-4, 3.3, 1.5, 2.1, 1 and 1.8 kbar, respectively. The emplacement depths of these granitoids gradually become shallow with the decreasing of their emplacement ages.

In western Jiaodong Peninsula, The AS (116 Ma) intruding the GJL (129 Ma) was emplaced at 3.7 km, which reflect that the exhumation amount of 6 km with exhumation rate of 0.46 mm/a has been achieved during 129-116 Ma. Previously, biotite from granites and mylonites of the GJL has identical cooling ages of 124 Ma (Li et al., 2003; Charles et al., 2013), which imply that the ductile shear took place before 124 Ma. Because the ductile shear generally occurred below 10 km, which imply rapid crust exhumation can be realized after 124 Ma ago. In eastern Jiaodong Peninsula, absence of intrusion of ~130 Ma makes it difficult to limit the precise timing of crustal exhumation. However, biotite ^{40}Ar-^{39}Ar dating indicates that the striking-up movement of major shear zones in eastern Jiaodong Peninsula took place at 126-123 Ma ago (Zhang et al., 2007), suggesting that the rapid crustal exhumation should occur after 126 Ma. As the WDS intruded into the WD, from 126 to 108 Ma, the crustal exhumation of 8.5 km with exhumation rate of 0.47mm/a has took place, being close to that in western Jiaodong Peninsula. As a result, crustal exhumation in terms of timing, amount and rate have no significant difference between western and eastern Jiaodong Peninsula.

This case is similar to that in the Taihang Mountains, central of the NCC. In the Taihang Mountains, data from apatite fission track revealed erosion thickness of >1.5 km with a rate of 0.1-0.13 km/Ma in the period of 165-135 Ma ago (Cao et al., 2015), followed by rapid exhumation with amount of ~5 km from 132 Ma to 126-120 Ma (Wang and Li, 2008). These exhumation rates are comparable to that of orogenic belts, but higher than that of cratonic intraplate settings (e.g., Zeilter, 1985; reference therein), which probably embody the intraplate orogeny (e.g., Luo et al., 2007) and responds to the destruction process of the NCC. The exhumation mechanism is ascribed to the lateral extrusion or ductile flow of lower crust due to eastward escaping of mantle and upwelling, triggered by far-field effect derived from the collision between the Lhasa-Qiangtang blocks and attendant magmatism in eastern China. The Paleo-Pacific Oceanic slab is of the second controlled factor.

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