Acta Geologica Sinica (English Edition), 2019, 93(supp.2): 238–239

Spatial Variation in Geochemistry of Mesozoic Qingshan Volcanic Suites in Shandong Province and its Implication for the Mechanism of Lithospheric Thinning

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Citation: Zhang et al.,2019. Spatial Variation in Geochemistry of Mesozoic Qingshan Volcanic Suites in Shandong Province and Its Implication for the Mechanism of Lithospheric Thinning. *Acta Geologica Sinica* (English Edition), 93(supp.2): 238–239.

Abstract:The North China Craton (NCC) is one of the major continental blocks in eastern China. Unlike most of the other cratons in the world, the NCC experienced large-scale igneous activities within its interior areas during the Mesozoic-Cenozic, which is indicative of a tectonic activation of stable craton. Many lines of evidences in geology, geophysics and geochemistry show that the continental lithosphere in NCC underwent an extensive thinning from a refractory lithospheric mantle of ~200 km in thickness with a heat flow < 40 mw/m^2 in the Paleozoic to a fertile lithospheric mantle of ~70 km with a heat flow ~ 80 mw/m^2 in the Cenozoic. However, it is still a hot debate over what caused this lithospheric thinning.

The Shandong province is located in the southeastern NCC where Mesozoic to Cenozoic igneous suites widely occurred. Tectonicly by the Tanlu Fault Belt, the province is divided into three unites, i.e. the western Shandong (WSU), Yishu fault belt (YFB) and the eastern Shandong (ESU) units. In this thesis, an integrated study of elemental-isotopic geochemistry and zircon U-Pb geochronology on the Mesozoic Qingshan volcanic successions is reported. It is shown that there are systemic spatial variations both in geochemical features and magmatic timing across the volcanic unites. Based on these observations, a modal for lithosphere thinning in the Shandong province is proposed. The major results of this study are summarized below:

(1) Geochronology of zircon U-Pb indicates a decreasing in timing for the Qingshan volcanic suites from WSU to ESU eastward. The Xidong suite in the WSU and Anqiu suite in the YFB were dated at 124±2 and 123±1 Ma, respectively, while the Wandi suite in the ESU gives ages of 116±4 to 118±1Ma;

(2) In lithology, the Qingshan volcanic succession varies from intermediate-basic volcanic rocks in the WSU to bimodal volcanic suites in YFB and ESU. These volcanic rocks are dominately featured by high-K calc-alkaline series. Among the Qingshan successions, the Xidong rocks comprise basaltic trachyandesite to trachyandesite, whereas the Anqiu bimodal suite consists of trachyandesite and dacite. The Wandi bimodal succession comprises basaltic trachyandesite and trachyte to dacite, showing a larger gap in SiO_2 between the mafic and acid rocks relative to the Anqiu suite.

(3) Chondrite-normalized REE diagrams for all Qingshan mafic volcanics display LREE-enriched OIB-like patterns. However, rocks from the Anqiu and Wandi volcanic suites show higher fractionation in REE relative to that of the Xidong volcanics. The two former suites are also discriminated by evident Eu anomaly from the Xidong volcanics. All Qingshan volcanic rocks are characterized by enrichment in LILE of Rb, Th, U, K and Ba, and depletion in HFSE of Nb, Ta and Ti. Spatial variations in geochemistry for the mafic rocks are displayed. From the WSU to ESU eastward, there is an increasing in Pb anomaly but decreasing in K anomaly. Negative anomaly in Th and U relative to Rb and Ba as well as variable degree of negative Zr and Hf anomalies characterizes the Xidong mafic suite. However, these anomalies are indistinct for the rocks from the YFB and ESU. Both mafic and silicic rocks from the Anqiu suite is featured by higher $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios relative to its neighbouring unites. Compared to the mafic rocks from the WSU, the Wandi rocks from the ESU show higher initial Sr isotopic ratio but lower $^{143}Nd/^{144}Nd$ ratio. On plot of $(^{87}Sr/^{86}Sr)_I$ versus e_{Nd}, the Xidong volcanics fall in a field close to EM I component, while the Anqiu and Wandi mafic volcanics close to a field between EM I and EM II.

(4) Positive correlations of Sr and Nd isotopic ratios with their elemental reciprocals, respectively, and negative correlation between Nb/Ta and La/Yb for the mafic rocks are absent. Along with a positive correlation between Nb and Th，it suggests that the role of crustal contamination was insignificant during magmatic ascending. In addition, variation trends on plots of SiO_2 vs.CaO/Al_2O_3 and La vs.La/Sm indicate that geochemical composition of the Wandi mafic volcanics dominately resulted from crystal fractionation, whereas that of the Xidong mafic volcanics from partial melting. However, it reveals that the elemental composition of the Anqiu mafic rocks resulted both from crystal fractionation and partial melting.

(5) Compared with rocks derived from partial melting of basaltic rocks, the Qingshan mafic rocks show unexpected high MgO content. Coupled with characters of a set of trace elemental ratios, it suggests that the parential magmas of the mafic volcanics experienced an interaction of rocks from lower crust with lithospheric mantle. This process accordingly is explained by a metasomatism of melts by partal melting of delaminated lower crustal rocks with surrounding mantle rocks of lithosphere during magma ascending. A simulation calculation shows that

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parental magmas of Xidong and Wandi mafic rocks can be interpreted by metamasisms of 75% and 80% mafic rocks from lower crust of the NCC and the Yangtza Craton, respectively, with lithosperic mantle rocks, while parental magmas of the YFB mafic volcanics were dominated by source rocks of depleted lithospheric mantle.

(6) Based on above observation and discussion, a model for regional lithosperic thinnig and its corelation with the Tanlu (Yishu) fault development is proposed:

1) The activation timing of the Tanlu Fault belt is synchronous with the Qingshan volcanic magmatisms, and the tectonic movements triggered delaminations of lithospheric mantle and its lower continent crust;

2) Lithospheric deleminations occurred at WSU and ESU are asynchronous. It was a few million years earlier in the WSU than that in the ESU. This is likely due to a western trend of the Tanlu fault and a westward concave angle between the fault belt and WSU, which pressed more dragging forces on the WSU;

3) Lithospheric delamination resulted asthenosphere upwelling and partial melting of mafic lower crust rocks foundering into mantle. These melts metasomatised with lithospheric mantle duirng magmatic ascending resulted EM I feature for the Xidong mafic suite of the WSU;

4) Coupled with strike slip of the Tanlu fault, increasing in geothermal grade weakened the resistance of delamination and induced the delamination of lithospheric mantle and lower continent crust in the ESU;

5) Though the EM I character of the mafic rocks in WSU is indicative of interaction or metasomatism between the melts from the delaminated lower crustal rocks and lithospheric mantle. However, enriched features of the mafic volcanics in the ESU necessitate a two-stage evolution, in which the EM II character were resulted by a previous subduction of Yangtza block beneath the NCC along the Dabie-Sulu orogen during the Triassic, whereas their EM I feature resulted from metasomatism of melts from delemenated continent crust with lithospheric mantle during Qingshan magmatism;

6) With a width of several kelometers, high temperature within the Tanlu fault resulted variable degree of partial melting of distinct lithologies at variable depth and hybridization among the melts. Evidently higher e_{Nd} values of the mafic volcanics within the YFB relative to those of its neighbour unites indicate melts from the asthenosperic mantle played an important role to the formation of magmas parental to the Anqiu mafic volcanics.

Key word: Qingshan volcanic suites, Geochemistry, Spatial variation, Tanlu fault, Model of lithospheric thinning

Acknowledgments: This work is granted by the national Science Foundation for Young Scientists of China (Grant No.41803047)

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