Geochronology and geochemistry of Early-Middle Triassic magmatism in the Argun Massif, NE China: Constraints on the tectonic evolution of Mongol–Okhotsk suture belt

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The Mongol–Okhotsk suture belt is located between the North Asian and the North China cratons and played an important role in the formation and tectonic evolution of eastern part of the Eurasian continent during Mesozoic. However, it remains debated whether the southward subduction of the Mongol-Okhotsk oceanic plate beneath the Argun Massif happened. In this paper, we undertook zircon U–Pb dating and geochemical data of the Early-Middle Triassic intrusive rocks in the Argun Massif which is bounded by the Mongol–Okhotsk suture belt to the northwest, with the aim of addressing the above-mentioned question.

Zircons from five representative intrusions in the Argun Massif are euhedral–subhedral, and display fine-scale oscillatory growth zoning in CL images, implying a magmatic origin. Zircon U-Pb dating demonstrates an Early-Middle Triassic magmatism in the Argun Massif, aged between 241 and 247 Ma. The Early-Middle Triassic rocks are composed of a suit of diorite, granodiorite, monzogranite, and syenogranite. They have SiO_2 = 57.71–72.86 wt.%, Mg# = 19–52, K_2O = 2.39–5.00 wt.%, and Na_2O = 3.28–4.28 wt.%. Chemically, they belong to the high-K calc-alkaline series. Moreover, they are characterized by enrichment in light rare earth elements (LREEs) and large ion lithophile elements (LILEs), and depletion in heavy rare earth elements (HREEs) and high field strength elements (HFSEs) such as Nb, Ta, and Ti. Their LREEs/HREEs ratios range from 9.68 to 21.56, and their δEu values vary from 0.61 to 1.31. Taken together, these Early-Middle Triassic intrusive rocks are similar to those from an active continental margin setting. Therefore, we conclude that the Early-Middle Triassic magmatism in the Argun Massif could be generated under an active continental margin setting related to the southward subduction of the Mongol-Okhotsk oceanic plate beneath the Argun Massif, which is also supported by the occurrence of the coeval porphyry Cu-Mo deposits such as the Erdenet Cu-Mo deposit in Mongolia and Taipingchuan Cu-Mo deposit in the Argun Massif, NE China.

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Theoretical calibration of Δ_{47} values of ^{13}C-^{18}O clumps for carbonates

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Equilibrium clumped isotope distribution has been suggested as a new thermometer for various low temperature systems. With the help of a newly developed cluster-model based method for solids, we re-check equilibrium Δ_i values of ^{13}C-^{18}O clumps of those important carbonate minerals: calcite, aragonite, dolomite, nahcolite and magnesite. Although our method is totally different from the method of Schauble *et al.* (2006), our results generally agree with what Schauble *et al.* (2006) predicted except for nahcolite ($NaHCO_3$). For example, Δ_i values of ^{13}C-^{18}O clumps for calcite and aragonite at 25 C degree predicted by Schauble *et al.* (2006) were 0.41 and 0.43 (in per mil), our results are 0.436 and 0.445, respectively. It confirms that the results of calcite and aragonite are close to each other and there is only marginal difference between them. However, the result for nahcolite from Schauble was 0.41, as same as their result for calcite. Our result for nahcolite is 0.454 which is different from the result of calcite.

Furthermore, there are kinetic effects of isotope fractionation during phosphoric acid digestion of carbonates. The calculated kinetic isotope effect on Δ_{3866} was found about 0.22 per mil for acid digestion processes and can be used to explain the offset between theoretical results and the experiments (i.e., Guo *et al*., 2009). However, the theoretical calibration lines provided by Guo *et al.* (2009) were still different from the experimental calibration line suggested by experiments (e.g., Ghosh *et al*. 2006) in terms of both position and slope. Recently, a new experimental calibration line was suggested (e.g., Dennis *et al*., 2011). Here, we used higher theoretical levels to re-check the theoretical calibration lines and found deviations from the previous ones. Our kinetic isotope effect results are obviously larger than what Guo *et al.* (2009) predicted. Combining our results of equilibrium Δ_i values of carbonates and the kinetic isotope effects by acid digestion, we can obtain theoretical calibration lines for Δ_{47} of carbonates. If put our calibration line into the absolute reference frame diagram suggested by Dennis *et al.* (2011), our calibration line is far above the previous theoretical line and falls between the two experimental lines suggested by Caltech and Harvard groups. The slope of our calibration line is smaller than that of Caltech group but very slightly larger than that of Harvard group.

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