Identification of modern-style plate subduction during the Archean: a perspective from metavolcanic rocks

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Abstract

The nature and evolution of Archean geodynamic regimes remain contentious (Nebel et al., 2024; Liu et al., 2022). Despite ongoing debates regarding the onset timing of Archean plate tectonics, some scholars focused on the style and evolution of Archean plate subduction processes (Wang et al., 2024; Zheng and Zhao, 2020; Moyen and Laurent, 2018). As revealed by the thermo-mechanical modeling data, the nature of mantle sources such as potential temperature, redox state and related crust-mantle interactions, are key parameters to constrain the geodynamic style of the lithosphere (Herzberg, 2022; Capitanio et al., 2020). Therefore, unraveling the magma sources and origin of (ultra-)mafic metavolcanic rock assemblages could offer valuable insights into the evolving Archean geodynamic regimes.

A suite of late Neoarchean metavolcanic rocks was reported in the Jiaobei terrane, eastern North China Craton. We conducted detailed petrogenetic analysis of the metavolcanic rocks, and then the nature of their mantle sources (i.e., thermal structure and oxygen fugacity) are quantitatively constrained by the geochemical and thermodynamic modeling methods (Gao et al., 2022; Herzberg et al., 2010; Lee et al., 2009). We found that the metavolcanic rocks show affinities to boninitic, tholeiitic and calc-alkaline rocks, and the three lithologies display a distribution pattern from the north to the south. Petrogenetic studies reveal that the ~2606 Ma boninitic rocks were generated by the partial melting of a shallow fluid-metasomatized and refractory mantle source, with the melting P-T-fO_2 conditions confined at ~1224-1239 °C, ~1.04-1.27 GPa, and -0.30 to -0.22 (ΔFMQ), respectively. The ~2549-2506 Ma tholeiitic rocks originated by the partial melting of a deeper fluid-metasomatized depleted mantle source at P-T-fO_2 conditions of 1327-1485 °C, 1.58-2.64 GPa, and -0.82 to +0.31. The ~2526-2503 Ma calc-alkaline andesitic rocks were derived from the partial melting of a fluid-metasomatized depleted mantle source, which further experienced clinopyroxene fractionation. Integrated with a comparison with the mantle sources of island arc basalts beneath the modern Mariana arc (P-T-fO_2 conditions of 1240-1379 °C, 0.89-1.85 GPa, and -0.21 to +1.44, respectively), a late Neoarchean modern-style plate subduction system can be reconstructed in the Jiaobei terrane.

We propose two diagnostic features that can be applied to the identification of modern-style plate subduction during the Archean: (1) the development of metavolcanic rock assemblage of boninitic rocks, island arc tholeiites and/or calc-alkaline andesites rocks; and (2) comparable P-T-fO_2 of the mantle sources as those beneath the modern Mariana island arc. A data compilation of global metavolcanic rocks shows that modern-style plate subduction could have been operated diachronously through the Archean. With sporadic records of the above

metavolcanic rock assemblage in the Greenland and Slave cratons, we proposed the initiation of modern-style plate subduction at ~3.7 Ga. In comparison, the above metavolcanic rock assemblage became widespread across major cratons globally during the late Archean (~3.0-2.5 Ga), which suggest the global operation of modern-style plate subduction processes.

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