Archean eclogite-facies oceanic crust indicates modern-style plate tectonics

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Establishing when modern-style plate tectonics with deep subduction began on Earth is one of the biggest questions in geosciences today. One of the key indicators of modern-style plate tectonics is the presence of eclogite in orogenic belts. A lack of Archean age orogenic eclogites or eclogite-facies crustal rocks has led to an assertion that modern-style plate tectonics did not operate in the Archean (*e.g.*, Stern, 2005). Recently, Ning *et al.* (2022) reported eclogite-facies garnet clinopyroxenite associated with metagabbro in 2.52–2.53 Ga old ophiolitic mélange in the northern Central Orogenic Belt (COB) within the North China Craton.

The garnet clinopyroxenite has a massive structure, and is enclosed in weakly-foliated isotropic metagabbro with distinct petrological contacts. It includes garnet (35–40 vol.%), clinopyroxene (50–55 vol.%), ilmenite (~5 vol.%) and magnetite (2–3 vol.%), with accessory plagioclase, quartz, rutile and titanite. Based on detailed petrographic observations and electron microprobe analysis, the garnet clinopyroxenite preserves mineral assemblages formed during four metamorphic stages, i.e., prograde granulite-facies, peak eclogite-facies, retrograde granulite-facies and later greenschist-amphibolite facies metamorphism. The peak eclogite-facies metamorphic assemblages (relatively-clean garnet compositional core + clinopyroxene compositional core) indicates P-T conditions of 792–890°C/19.8–24.5 kbar, calculated by various major and trace element geothermobarometers, which are also supported by abundant exsolution microstructures on garnet and clinopyroxene. The peak P-T conditions correspond to metamorphic T/P ratios of 323.3–449.5°C/GPa and geothermal gradients of 9.5–13.2°C/km, which is the lowest metamorphic geotherms reported from the Archean.

The garnet clinopyroxenites and metagabbros with normal mid-ocean ridge basalt (N-MORB) geochemical signatures are relicts of oceanic crust. The MgO, SiO_2, Al_2O_3, Ni and other major-trace element signatures of the garnet clinopyroxenites suggest it formed as oceanic gabbro. Zircon U-Pb dating of the metagabbros and a granitic dike crosscutting the metamorphic layering of the metagabbro constrains deformation and eclogite-facies metamorphism to > 2.47 Ga. We conclude that the garnet clinopyroxenite and metagabbros, as relicts of Archean oceanic crust, were subducted to at least 65–70 km, experienced eclogite-facies metamorphism at ~2.5 Ga, followed by the breakup, tectonic mixing, and differential exhumation in a subduction channel to form the ophiolite mélange.

Together with other asymmetric subduction records in the COB (*e.g.*, Kusky *et al.*, 2020), it is inferred that modern-style plate tectonics evidenced by deep and asymmetric subduction along the ca. 1,600 km long orogen was operating at least by the end of the Archean Era (~2.5 Ga). In a word, Ning *et al.* (2022) documented the oldest orogenic eclogite-facies oceanic crust, extending the known age of subduction-related eclogite-facies metamorphism back 400 million years, showing that modern-style plate tectonics operated by the close of the Archean (Fig. 1).

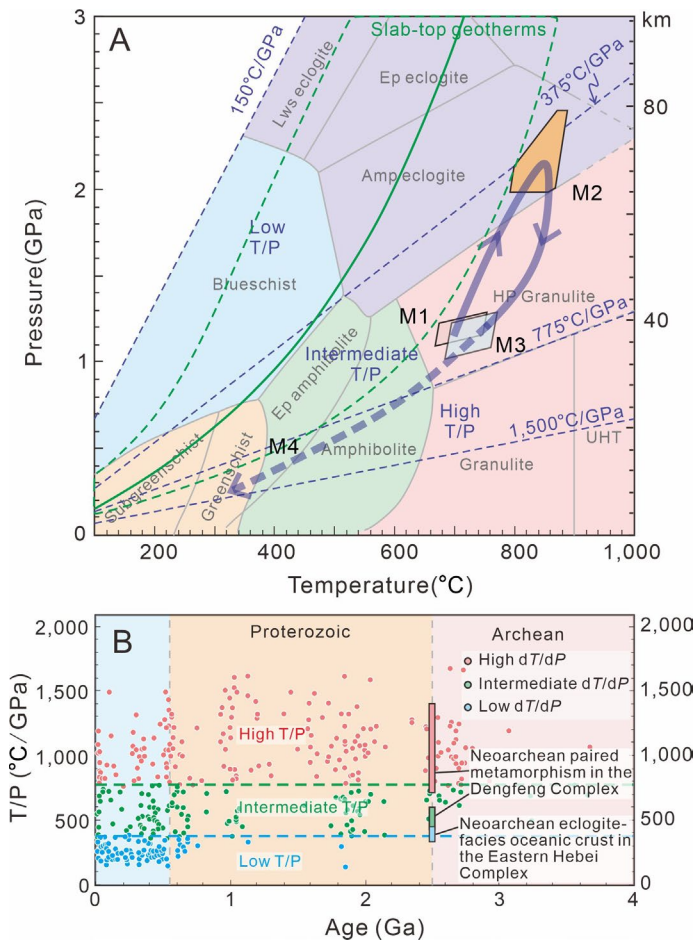

Figure 1- Retrieved P-T-t path and geothermal gradient (°C/GPa) of the Shangying garnet clinopyroxenite. The metamorphic facies and the slab-top geotherms of Neoproterozoic to Phanerozoic subduction zones (bounded by the light-green dashed lines) are shown. The high, intermediate and low dT/dP areas delineated by 1,500, 775, 375 and 150°C/GPa are defined based on the global metamorphic P-T dataset. The late Archean spatially- and temporally-linked paired metamorphism documented from the Dengfeng Complex (Kusky et al., 2020 and references therein), and the contemporaneous eclogite-facies oceanic crust in the Eastern Hebei Complex), both along the eastern margin of the COB, indicate that the modern plate tectonics, characterized by asymmetric and deep subduction, operated at the end of Archean.

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Stern, R. J., 2005. Evidence from ophiolites, blueschists, and ultrahigh–pressure metamorphic terranes that the modern episode of subduction tectonics began in Neoproterozoic time. *Geology* 33, 557–560.