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Evidence for deep subduction reveals modern-style plate tectonics operated in the late Archean

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Deep subduction is a hallmark of plate tectonics, and the leading mass exchange mechanism between the surface and deep mantle, thus is considered as the major control on the long-term habitability of Earth. However, establishing when modern-style plate tectonics with deep subduction began on Earth is uncertain due to limited index features documented from the Archean record (> 2.5 Ga) including eclogite-facies metamorphosed subducted slabs and ultrahigh-pressure (UHP) metamorphic minerals within them.

We report petrological and mineralogical evidence for deep oceanic subduction from the Zunhua 2.52–2.53 Ga Neoarchean ophiolitic tectonic complex (mélange) in the northern Central Orogenic Belt (COB) within the North China Craton, under a tectonic setting of oceanic subduction followed by arc-continent collision. The petrological evidence includes:

1 Eclogite-facies garnet clinopyroxenite associated with metagabbro blocks. The N-MORB garnet clinopyroxenites are relicts of oceanic crust, recording peak eclogite-facies metamorphic conditions of 792–890°C/1.98–2.45 GPa (geothermal gradients=11.2-12°C/km). Zircon U-Pb dating of the metagabbros and crosscutting relationships constrain deformation and eclogite-facies metamorphism to be > 2.47 Ga and younger than 2.52 Ga. This implies that Archean oceanic crust was subducted to at least 65–70 km at the end of the Archean.

2 Diopside exsolution lamellae in chromitite from the Zunhua complex. These lamellae require significant incorporation of SiO_2 and CaO in the host chromite, confirming a precursor of chromite with a UHP $CaFe_2O_4$-structure (chenmingite) stable at depths > 413 to 660 km, which decomposed during exhumation to form exsolution lamellae. Additionally, the chromite (formerly chenmingite) has multi-solid phase inclusions of UHP TiO_2(TiO_2(II)) + crustal minerals, inclusions of carbonate and graphite polymers. These mineralogical data record the operation of the deep element cycle in deep time, with plate-tectonic related subduction providing the mass circulation conveyor belt between the surface and deep mantle environments.

Together with other dual metamorphic belt, asymmetric subduction records in the COB, it is inferred that modern-style plate tectonics including deep and asymmetric subduction along the ca. 1,800 km long orogen was operating at least by the end of the Archean Eon, linking surface and deep environments, forging a habitable world.