

Quantification of Lengths, Depths, and Durations of Archean Paleo-Plate Boundaries Documents the Style of Plate Tectonics Throughout the Archean

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Plate tectonics describes the horizontal motion of plates away from mid-oceanic ridges and parallel to transforms, towards deep-sea trenches, where the oceanic lithosphere is subducted. This process is the surface expression of modern-day heat loss from the Earth, and can be quantified in terms of the size of the largest plates (related to the scale of the driving mantle convection cells), depths of subduction, time durations of specific tectonic cycles, and relative balances of different phenomena such as rates of magma supply and extension at divergent plate boundaries. We present and evaluate data that documents Archean plate boundaries from the rock record constrained by relevant geological, structural, geochemical-isotopic data, that shows 1) the formation of continental rifts and > 1,600 km long passive margins into the late Archean (>2740 Ma), 2) magma-rich and magma-poor type oceanic lithosphere was produced at oceanic ridges, travelled thousand of kilometers laterally along strike-slip faults, and was accreted along with the overlying ocean plate stratigraphy (OPS) in Archean accretionary orogens back to 4.0 Ga, 3) that oceanic lithosphere was subducted to at least the mantle transition zone (410 km) in the late Archean, 4) this subduction produced characteristic thrust-imbricated accretionary prisms paired with magmatic arcs with Phanerozoic-style geochemical signatures, at least as far back as the Eoarchean. Precambrian metamorphism generally reflects higher geotherms, but isolated eclogites occur as xenoliths in kimberlites, and have been suggested to occur in late Archean and Proterozoic collisional orogens, including along the north margin of the North China craton in the Northern Hebei orogen. Map patterns of gneiss domes penetrating and refolding intervening volcano-sedimentary sequences are shown to be not diagnostic of Archean times as many modelers suggest, but to reflect a specific tectonic environment in the roots of arc terranes, with examples shown from Archean, Proterozoic, Paleozoic, Mesozoic, and Cenozoic orogens. From the above geologically-constrained observations, we are able to place quantitative boundary conditions on Archean plate tectonics, including 1) plates were at least 1,600 km in diameter, oceanic lithosphere was subducted to at least 410 km at 2.5 Ga, 3) the duration of "Wilson cycle" type orogenic cycles was tens to hundreds of Ma, similar to the Phanerozoic time span, 4) the range of the rate of oceanic spreading/magma supply was similar to that in today's oceans, and 5) mantle temperatures and continental geotherms were slightly higher at 3.0 Ga (<200 C) than those on the modern Earth. These data can be used to place basic constraints on numerical models of Archean geodynamics. We conclude that the evidence shows indubitably that plate tectonics has been operating at least since the formation of the oldest rocks, albeit with some differences in processes, compositions, and products in earlier times of higher heat generation and mantle temperature, weaker oceanic lithosphere, and weaker subduction zones caused by more slab-melt generation, and under different biological and atmospheric conditions.