Newly-discovered Eoarchean TTG gneisses in the Tarim Craton imply plate tectonics at ~3.7 Ga

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Plate tectonics is the dominant process of continental evolution and deformation in the modern Earth. However, when did plate tectonics begin in the early Earth is a highly controversial question. This issue has been hampered by an increasingly scarce and fragmented geological record back into the early Archean.

Eoarchean (3.6 – 4.0 Ga) TTG (tonalite – trondhjemite – granodiorite) gneisses are the major component of Earth's oldest persevered continental crust, thereby holding the key to understanding how continental crust originated and when plate tectonics may have started in the early Earth. These rocks are extremely rare in the geological record and so far have been identified only in ~10 areas around the world. Using large-scale mapping and detailed zircon U-Pb dating, we identified a suite of Eoarchean (~3.7 Ga) tonalitic gneisses in the Aktash Tagh area, southeastern Tarim Craton (Ge et al., 2018). These are the oldest rocks in China except for the 3.8 Ga Anshan gneisses from the North China Craton, making Tarim one of the oldest continental blocks in the world. Filed observations indicate that these rocks occur as tectonic enclaves in ~2.0 Ga gneisses and were intruded by ~1.9 Ga carbonatites and ~1.8 Ga mafic and granitic dikes. SHRIMP zircon U-Pb dating indicates that the protolith of these tonalitic gneisses crystalized at ~3.71 Ga and were overprinted by two metamorphic events at ~3.56 Ga and ~2.0 Ga, respectively. Zircon Lu-Hf and O isotopic data suggest that these rocks were largely derived from juvenile material extracted from a near-chondritic undifferentiated mantle, thus representing initial continental growth in the early Earth.

Geochemical data show that the Eoarchean Aktash gneisses belong to sodic TTGs. More importantly, these samples have higher Sr and Sr/Y, but lower HREE and Nb-Ta-Ti than the Eoarchean TTGs from Greenland, Canada and North China. According to a recent classification proposed by Moyen (2011), the Aktash gneisses belong to high-pressure TTGs derived from partial melting of rutile-bearing eclogite, whereas the Greenland, Canada and North China mostly belong to medium to low pressure TTGs generated by partial melting of garnet amphibolite and/or mafic granulite. In addition, a few samples of the Aktash gneisses have relatively low SiO_2 and high MgO, Mg#, Cr, Ni, indicative of magma interaction with mantle peridotite (e.g., Martin and Moyen, 2002).

To further constrain whether these rocks were produced by subducted or delaminated mafic rocks, we carried out thermodynamic – trace element modeling using the latest solid solution models (Green et al., 2016) and a global geochemical database. Our results indicate that the parent magma of the Aktash tonalites could have been generated by water fluxed melting of moderately enriched arc-like basalt at relatively high pressure (1.8 – 1.9 GPa) and low temperature (800 – 830°C), suggesting a relatively low apparent geothermal gradient (~400 – 450 °C/GPa), which is typical for hot subduction zones (e.g., Drummond and Defant, 1990) but significantly lower than that for thickened and delaminated lower crust (> 900 – 1000 °C/GPa)(e.g., Johnson et al., 2017). Accordingly, we propose that these high-pressure TTGs were generated by partial melting of a subducted proto-arc during arc accretion. Our model implies that modern-style plate tectonics was operative, at least locally, at ~3.7 Ga and was responsible for generating some of the oldest continental nuclei.

References

Drummond, M.S., and Defant, M.J., 1990, A model for trondhjemite-tonalite-dacite genesis and crustal growth via slab melting -

Archean to modern comparisons: Journal of Geophysical Research-Solid Earth and Planets, v. 95, p. 21503-21521.
Ge, R.F., Zhu, W.B., Wilde, S.A., and Wu, H.L., 2018, Remnants of Eoarchean continental crust derived from a subducted proto-arc: Science Advances, v. 4, p. 1-11.
Green, E., White, R.W., Diener, J., Powell, R., Holland, T., and Palin, R.M., 2016, Activity□composition relations for the calculation of partial melting equilibria in metabasic rocks: Journal of Metamorphic Geology, v. 34, p. 845–869.
Johnson, T.E., Brown, M., Gardiner, N.J., Kirkland, C.L., and Smithies, R.H., 2017, Earth's first stable continents did not form by subduction: Nature, v. 543, p. 239–242.
Martin, H., and Moyen, J.F., 2002, Secular changes in tonalite-trondhjemite-granodiorite composition as markers of the progressive cooling of Earth: Geology, v. 30, p. 319-322.
Moyen, J., 2011, The composite Archaean grey gneisses: Petrological significance, and evidence for a non-unique tectonic setting for Archaean crustal growth: Lithos, v. 123, p. 21-36.