Archean Crust-Mantle Evolution: Constraints from Nb-Th-U Systematics, Arc Trace Element Ratios and Nd-Hf-Pb Isotopes

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Preservation of continental crust began between 3.8 and 4.0 Ga when the Nb/U and Nb/Th ratios of depleted mantle increased from sub-chondritic values. By 2.6 Ga, Nb/U and Nb/Th ratios reached values of ca. 45 and 12, respectively, reflecting extraction of ca. 40% of continental crust. After 2.0 Ga, Th/U ratio of depleted mantle decreased strongly because of recycling of continental U. This dates the establishment of a pandemic oxidizing atmosphere. Nb/Th systematics indicate that continental crust grew strongly between 2.6 and 2.0 Ga, slowly between 2.0 and 0.6 Ga, and more strongly again during the Phanerozoic. Net growth of the continents was reduced by increased post-2.0 Ga recycling, as well as by reduced addition of juvenile arc-derived material during times of supercontinent assembly, reflecting a decrease in total subduction zone length.

Fractionation of Nb, U, and Th is caused by supra-subduction zone processes. U and Th from the hydrated subducted oceanic lithosphere are preferentially transported (relative to Nb) into the over-lying mantle wedge via fluid transport. Other trace element ratios that are fingerprints of arc magmatism include: sub-chondritic Nb/Ta, Nd/Pb, and super-chondritic Li/Yb. We have verified that these characterize continental crust of all ages, including the oldest known TTG gneisses. Majority of Archean mafic magmas, including many komatiites, are derived from mantle sources depleted by supra-subduction zone melting.

The nature of pre-4.0 Ga crust is equivocal. Well-preserved 3.8 Ga Nulliak metakomatiites from Labrador have Nb/Th ratios (ca. 6.0) identical to 4.0 Ga Fra Mauro lunar highland basalts (Nb/Th = 5.3). These data, and Nd-Hf-Pb isotopic evidence for extreme fractionation in early Archean mantle reservoirs may reflect pre-hydrosphere differentiation, like that inferred for the moon. Secular changes in crust-mantle evolution were thus driven by the hydrosphere and atmosphere.