The creation and preservation of Archaean continental crust

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Thirty years ago Armstrong (1968) proposed that the crust of the Earth was formed by 4.0 Ga and since this time steady-state recycling has maintained it at a constant volume at the surface of the Earth. In his model, the small proportion of old rocks preserved at the surface today were simply remnants of crust that survived the recycling process. More recent models of crustal growth (i.e. Allègre and Rousseau, 1984; McCulloch and Bennett, 1994) invoke the gradual growth of continental crust, punctuated by a series of peaks in production. The latter models imply a relatively simple process of progressive depletion of the upper mantle and growth of crust, in which, by the end of the Archaean (2.5 Ga), only 50–60% of the crust had been formed. The input parameters to the models are the radiogenic isotopes of Sr, Nd and Pb, and, to a lesser extent constraints from U/Pb zircon distribution. The Pb and U balance of crust, OIB and MORB provide important constraints on the amount of sediment that is recycled into the mantle, and, based on current fluxes, most models cannot accommodate >10% of recycled sediment. In recent years improvements in analytical techniques have made it possible to obtain reliable estimates of key trace element ratios in Archaean basaltic and ultramafic material (i.e. Jochum *et al.*, 1991) and these authors argue that the sub-chondritic ratios of Nb/U and the depletion in epsilon-Nd in the early Earth are consistent with extraction of a proto-crust, since destroyed.

In recent years several authors have stressed the role of accreted large igneous provinces, rather than arc accretion in crustal growth (Kusky and Kidd, 1992, Abouchami *et al.*, 1990). These arguments were in large part based on the identification of the giant mafic-ultramafic basaltic provinces in the ocean basins (Coffin and Eldholm, 1994), and the detection of large tracts of geochemically juvenile material with oceanic plateau characteristics in ancient greenstone sequences.

I suggest here that many of the prejudices of the models of crustal growth mechanisms and crustal preservation are based on: (i) a vision of the crust of the Earth in plan view; (ii) biased geochemical sampling (rock, river and aeolian samples) involving only the upper crust of the Earth; (iii) a view of the current plate-tectonic cycle which does not take into account the destruction of juvenile crust that must occur in future tectonic cycles on Earth.

A basic concept of structural geology provides an important constraint on crustal growth models – tectonism in general involves the emplacement of younger rocks over older rocks. A three-dimensional study of the Canadian land mass, completed by LITHOPROBE, yields a remarkably different vision relative to a plan view. Extrapolation of Nd-model ages and reconstruction of the deep and shallow crust from seismic data indicates: (i) rapid growth of continental crust from 4.0 and 2.6 Ma in the Superior, Slave and Rae-Hearne and Wyoming provinces; (ii) large tracts of relatively undeformed Archaean crust preserved and hidden beneath younger orogens such as the Grenville, the Trans Hudsonian and the Penokean; (iii) imbricated sequences of gneisses of Proterozoic formation (U/Pb) age and Archaean Nd-model age; (iv) relatively minor assemblages of juvenile crust with model ages equivalent to their formation ages; (v) as shown recently by Henry *et al.*, (1998), most of the Superior province shows evidence for recycling of an enriched component, probably crust of at least 3.2 Ga.

In short, a compilation of the age/volume distribution of crust over from 4 Ga to 1 Ga indicates that at least 80% of the crust in this region of Earth has an Archaean model age.

An additional line of evidence that suggests that ‘things on the top are not the same as on the bottom’ comes from Os-isotope model ages. Data for mantle xenoliths from the Canadian Cordillera (Peslier *et al.*, this volume) indicate that the young juvenile terranes (<0.3 Ma) are underlain by continental mantle lithosphere of at least 1 Ga. Thus, as suggested from the seismic and Nd-model ages studies, on a global scale, a segment of post Archaean crust exposed at the surface may be significantly older, at its middle and lower crust and at its mantle roots.

The North American continent will continue to evolve and future origins will recycle its margins. It is reasonable to assume that ‘tectonic abrasion’ and erosion of the continental will remove much of the juvenile material accreted in the Phanerozoic.

Although oceanic plateau-type assemblages are preserved throughout geologic time, I suggest that these thickened pieces of oceanic crust act as catalysts in the subduction process, by blocking subduction zones, resulting in plate roll-back and plate reorientation. As such, they are not the principal component in crust formation. Both the tectonic and geochemical data from the North American continent indicate that subduction-related processes were the dominant means of crustal accretion, and the land mass is dominated by assemblages with a model age of 2.7 Ga or older.

In conclusion, extrapolating the inferences from the North American continent on a global scale, suggests that: (i) a much larger proportion of the preserved crust on Earth than previously estimated is Archaean; (ii) juvenile crust added to the continental land mass since the Archaean has in large part been removed by tectonic abrasion and erosion of the continents; (iii) oceanic plateaux play an important role as catalysts in crustal preservation, but are largely removed by later tectonic abrasion at the continental margins; (iv) recycling of older crust through subduction-related processes can be identified as an important process even in pre-3 Ga sequences.

These results support a model of crustal growth in the Archaean followed by a steady state evolution of the continents.

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