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Crustal evolution and the temporality of anorthosites

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Several types of anorthosite can be recognized, some of which show distinct age restrictions in Earth and planetary history [1]. Primordial, Archean and Proterozoic anorthosites are distinctly different and are restricted in time and space. Those of layered mafic intrusions and ophiolites show no apparent time restrictions. Primordial anorthosites (4.54 - 4.29 Ga) form the bulk of the lunar crust, and consist of very calcic plagioclase (An_{94-99}); these probably formed from magma oceans generated in response to planetary accretion. No surviving crust of this nature has yet been found on Earth.

Calcic (>An_{80}) megacrystic anorthosites are restricted to the Archean (3.73 – 2.73 Ga), are associated with mafic volcanics of greenstone belts, and may have formed by accumulation of An-rich plagioclase from mafic to ultramafic magmas; high H_2O content of parental melts may explain the calcic compositions, and the temporality might be linked to that of komatiitic magmatism, for which many tectonic settings, including subduction, have been proposed. Possible modern analogues are scarce, and include the mid-Paleozoic Black Giants anorthosite of New Zealand, proposed to have formed in a magmatic arc [2]. We also call attention to the calcic (An_{88-96}) megacrysts present in andesitic lavas such as in the Izu-Bonin arc of Japan [3].

Massif-type anorthosite is the most abundant of terrestrial types, and occurs as small plutons to huge composite batholiths that are entirely restricted to the Proterozoic (0.50 – 2.64 Ga). Compositions ($An_{50\pm10}$ vs. >An_{80}), textures (lathy vs. equant plagioclase) and size (massifs to ~15,000 km^2 vs. Archean bodies to ~560 km^2) effectively distinguish Proterozoic from Archean anorthosites. An arc environment for massifs is suggested by the long, linear belts of coalescent anorthositic plutons, some of which have been emplaced into continental crust over extensive time periods (>100 m.y.). Paleomagnetically-constrained continental reconstructions of massif anorthosite locations at the time of emplacement provide further support for this model. In these reconstructions most anorthosites are found to be marginal to the Rodinian supercontinent, implying a continental arc setting. Magma derivation was from depleted mantle (not mafic lower crust), although there is evidence for substantial crustal contamination. Plagioclase-rich mushes formed by flotation in deep crustal chambers, and may have ascended diapirically to the mid-crust. Massif anorthosites have not yet been found in Phanerozoic continental arcs, although anorthositic layers are present as parts of layered gabbros in some deep crustal sections (e.g. Argentina). It is not clear if different subduction styles alone can explain the differences between Archean, Proterozoic and Phanerozoic anorthosites. Their temporality might be caused by any combination of secular cooling of the Earth, secular variation in H_2O content of arc magmas and insufficient depths of erosion of young continental arc terranes.

Although the anomalous, monomineralic composition of anorthosites, of all ages and types, is explained by the simple accumulation of plagioclase from basaltic magmas, aspects of their temporal restriction and tectonic setting remain elusive. Conversely, however, the very presence of different types of anorthosites at different times in Earth's history indicates at least some degree of non-uniformitarianism. Testing the underlying processes causing this non-uniformitarianism is difficult, but the abrupt transition from calcic, Archaean anorthosites, to intermediate-composition Proterozoic anorthosites at ~2.5 Ga may indicate that stabilization of thick continental crust and changes in subduction geometry occurred at this time [4]. Whatever the ultimate cause of this non-uniformitarianism, a greater understanding of the temporal restriction of anorthosites of all types promises to shed light on Earth evolution through time.

References:

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