CONTINENTAL GROWTH IN THE PROTEROZOIC: A GLOBAL PERSPECTIVE

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Throughout the Proterozoic upper mantle-driven plate tectonics and deep mantle-generated plume tectonics led to major juvenile additions and volumetric growth of continents. Important contributions were: 1. subduction-generated island arcs and Andean-type magmatic arcs in active continental margins, 2. plume-generated oceanic plateaus within oceans, and mantle products associated with the opening of oceans and the abortive fragmentation of supercontinents,

The two end-member types of orogenic belts played different roles in Proterozoic crustal evolution (Windley, 1992). The formation of continent-continent collisional orogens, that contain relatively minor juvenile components, mostly involved major reworking of older crustal rocks. However, they commonly led to overthickening of the lithosphere and consequent introduction of new components from the mantle during extensional collapse, and their formation led to the creation of supercontinents. In contrast, the formation of accretionary orogens, which contain abundant mantle-generated juvenile components, gave rise to major continental growth as well as to eventual supercontinent construction.

Most continental crust formed or was amalgamated during the following tectonic regimes related to plate tectonic cycles:

1. Formation of accretionary orogens by the amalgamation of island arcs, active continental margins (Andean-type arcs), accretionary wedges, oceanic plateaus, obducted ophiolites, shelf sequences from passive continental margins, and older continental microcontinents. Some or all of these components are in: the Birimian of W. Africa, 2.1 Ga (Abouchami *et al.*, 1990), the Yavapai (1.8-1.7 Ga) and Mazatzal (1.71-1.62 Ga) belts in southwestern U.S.A (Karlstrom and Bowring, 1988), the Arabian-Nubian Shield, 1.0-0.5 Ga (Berhe, 1997), the Avalonian terrane in Newfoundland and the Armorican-Cadomian belts of NW Europe, 0.6-0.5 Ga (Mallard and Rogers, 1997), and early stages of the Central Asian Orogenic Belt (Altaids), 1.0-0.54 Ga (Sengör *et al.*, 1993).
2. Continental collisional orogens, which incorporated juvenile greenstone belt terranes. For example the 1.92-1.83 Ga Trans-Hudson in North America contains a central accretionary collage of oceanic arcs, MORB- and OIB-like basalts, back-arc basin basalts, and oceanic plateaus (Lucas e al., 1996).
3. Formation of supercontinents at 2.5 Ga (Kenorland, Roscoe and Card, 1993); 2.2-2.0 Ga (S. America-Africa, Ledru *et al.*, 1994; Feybesse and Milési, 1994); 2.2 Ga (Vaalbara, Zegers *et al.*, 1998; Nelson *et al.*, 1999); 1.5 Ga, (Laurentia, Hoffman, 1989); 1.1-1.0 Ga (Rodinia) and at ca. 0.7 Ga (Pannotia) (Dalziel, 1992). The formation of the earlier supercontinents at 2.5-2.0 Ga by the collision of continental blocks enabled the incorporation into the Proterozoic continental crust of Archaean greenstone belt material in the form of MORB-basalts, island arcs, oceanic plateaus and ocean islands.
4. Break-up of supercontinents as a result of plume tectonics, giving rise either to abortive intra-continental magmatism or to plume products adjacent to new oceans. Such intra-plate magmatism contributed significant mass to the Proterozoic continental crust. Main events were at 2.5-2.1 Ga, 1.5-1.3 Ga and 1.0-0.6 Ga. Important magmatic products were: (a) continental flood basalts (large igneous provinces): Hamersley, W. Australia, 2.5 Ga, Barley *et al.*, 1997; Onega, central Karelia, 2.0 Ga, Puchtel *et al.*, 1998; northern Quebec, Canada, 1.96 Ga, Legault et al., 1994; Coppermine River, N. Canada 1.27 Ga associated with the Mackenzie plume event, LeCheminant and Heaman, 1989; in the Mid-Continent Rift, USA, 1.1 Ga, Ernst and Buchan, 1997; (b) layered mafic-ultramafic and alkaline intrusions, some in continental rifts: at 2.49-2.441 Ga, Karelia, eastern Baltic Shield, Amelin *et al.*, 1995; at 1.108 Ga Coldwell Complex in the Mid-Continent rift, Canada, Heaman and Machado, 1992; at 1.3-1.0 Ga Gardar, S. Greenland Upton and Emeleus, 1987; (c) giant mafic dykes, often in radiating swarms: many worldwide at 2.4-2.0 Ga; Gardar, S. Greenland 1.2 Ga; Sudbury-Mackenzie dykes 1.2 Ga; Umkondo dolerites, Zimbabwe, 1.1 Ga; 800-780 Ma dykes in Laurentia and Australia focussed on a plume centre and breakup of Gondwana; Grenville dykes 590 Ma related to the opening of Iapetus (Ernst and Buchan, 1997). (d) anorogenic magmatism, USA on the margin of the Grenvillian ocean at 1.5-1.4 Ga (Windley, 1993). Mid-oceanic ridge hydrothermal plumes were responsible for the world peak in deposition of banded iron formations between 2.4 and 2.3 Ga within a major period of continental breakup and formation of new oceans and passive continental margins (Isley, 1994).

Proterozoic ophiolites were minor crustal additions, but diagnostic indicators of plate accretion: Portuniq, Canada, 2.0 Ga (Scott *et al.*, 1992); Jormua, Finland, 1.95 Ga (Peltonen *et al.*, 1996); Birch Lake, Trans-Hudson orogen, Canada, ca. 1.9 Ga (Wyman, 1999); Paysan, Arizona, 1.73 Ga (Dann, 1991); N. Zimbabwe; 1.4 Ga (Oliver *et al.*, 1998). Common ophiolite obduction in the Neoproterozoic was related to the formation of extensive accretionary orogens: e.g. Southeastern China, 1.0-0.93 Ma (Li *et al.*, 1997); Arabian-Nubian Shield, 870-730 Ma (Berhe, 1997); Bayanhongur and Tuva, Central Asia, 569 Ma (Kepezhinskas *et al.*, 1991; Pfánder, *et al.*, 1999). These ophiolites are relicts of ocean floor, the bulk of which was subducted, giving rise to subduction-generated crustal growth.

Eclogitic ultrahigh-pressure rocks were introduced from the mantle to the crust during thrust-wedge uplift in collisional orogens (Grenville of Canada), and during extensional collapse of orogens (Glenelg, NW Scotland). In the Glenelg inlier 1.05 Ga eclogites originally made up ca. 25% of the crust at the present exposure level.

Continental growth during the Proterozoic was episodic, punctuated by periods of supercontinent formation and breakup *versus* arc accretion and continental–collision. Current evidence suggests that at 2.5 Ga and 1.0 Ga continents may have been largely assembled into one or several supercontinents and that the formation of orogenic belts was at a minimum. In contrast, the period 2.1-1.9 Ga saw the formation of large continental blocks (Neva), of collisional orogens (Wopmay and early Trans-Hudson), and of accretionary orogens (Birimian). The relevance of the 1.5-1.4 Ga anorogenic magmatism in North America and the Baltic Shield to continental assembly is still poorly understood. The status of Pannotia at ca. 0.7 Ga as a supercontinent or as a collection of large continental blocks is still under dispute. Throughout Proterozoic time the alternating contributions of plume tectonics and plate tectonics were variable. Reymer and Schubert (1984) estimated that during the Cenozoic crustal growth at plate margins was three times greater than growth in intraplate environments. Such a ratio has not been calculated for the Proterozoic. Future models and tests should be devoted to a better understanding of the relative roles and importance of plate tectonic *versus* plume tectonic processes in the growth of Proterozoic continents.

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