Asteroid impact-induced magmatism and tectonics on the Hadean-Archean Earth

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In the previous talk by Graham et al., we suggested that: (1) The numerous fragments of Ti-Fe-rich meteorites, discovered in the ~3.45 Ga Apex Basalt near Marble Bar, Western Australia, most likely represent parts of a large (~10-20 km diameter?) asteroid body that created a large (~150 km diameter?) impact-crater on a deep (2,000 m) ocean floor; and (2) The Apex Basalt (~3-4 km thick) represents the crater-fill basalt magmas that were generated by the impact-induced, rapid decompression-melting of the deep-mantle peridotite. The close similarities in the abundance ratios of the high-field-strength elements (e.g., REEs, Nb, Y, Zr) between the Apex Basalt and the 120-90 Ma Ontong Java Oceanic Plateau Basalt, which has been suggested by some researchers to be the product of an ~20-30 km-diameter bolide impact, support the above model for the magmatism in the East Pilbara district ~3.5 Ga ago.

We have extended the examinations of the geological, petrological, and geochemical characteristics of the pre-3.0 Ga geologic formations in the Pilbara- and Kaapvaal Cratons, and suggest the following models for the magmatism, tectonics, and evolution of the oceanic and continental crusts of the early Earth: (1) The Last Heavy Bombardment of asteroids lasted until at least ~3.2 Ga ago, possibly until ~2.5 Ga ago. (2) Prior to ~3.2 Ga (or ~2.5 Ga), magmatism and tectonics on the Earth were mostly dictated by the impacts of asteroids (mostly in the oceans), rather than by the plate (horizontal) tectonics or the plume (vertical) tectonics that are caused by the large-scale convections in the mantle. Punctuations of the thick oceanic (and continental) crusts, as well as the large-scale melt-generation in the upper mantle by large bolide-impacts provided the effective mechanism to release the interior heat of the early hot Earth. (3) Rapidly declining meteorite impact events after ~3.2 Ga (or ~2.5 Ga) was the probable cause for the initiation of the plate- and plume tectonics, because the Earth had to find alternative ways to release its interior heat. (4) All major igneous-rock formations in the Archean greenstone belts, including komatiite, basalt, and granitoids, were formed from the magmas generated by impact-induced, rapid decompression-melting of mantle peridotite, and by the interactions between these magmas and the oceanic crust. (5) Until ~3.2 Ga (or ~2.5 Ga) ago, no significant difference in composition and thickness existed between the continental and oceanic crusts, i.e., the true continental crust did not exist. The oceanic (and continental) crusts were comprised of large circular/oval-shaped “blocks” (~10^6–10^7 km^2 in area) which were created by different asteroid impacts. Each “block” was chemically heterogeneous, and vertically zoned (generally by composition) from ultramafic in the lower zones to felsic in the upper zones. (6) The plate tectonics, which began ~3.2 Ga (or ~2.5 Ga) ago, caused preferential melting of the felsic to intermediate rocks (compared to the mafic and ultramafic rocks) of the Archean oceanic crust during its subduction, because of their lower temperatures of melting. The andesitic/felsic melts generated from the subduction zones ascended to create the continental crust. Because silicic continental crust is buoyant compared to the mafic oceanic crust, the continental crust has remained at a higher level than the oceanic crust since ~3.2 Ga (or ~2.5 Ga) ago. (7) Slower melting of the upper mantle peridotite by the hotter materials from the lower mantle in the post-Archean eras, compared to the rapid melting of the mantle peridotite due to sudden decompression caused by meteorite impacts during the Archean era, have created chemically homogeneous basalt magmas that have erupted at mid ocean ridges to create chemically homogeneous oceanic crust since ~3.0 Ga ago.

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