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Billion year cyclicity through Earth history: causes and consequences

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A billion year-scale (gigacycle) periodicity in global radiogenic Hf and Sr isotopic trends is investigated by integrating data from tectonics, geodynamics, and palaeomagnetism, in order to build a holistic geodynamic model linking modes of mantle convection to plate tectonic motions over the last 2,500 Myr. The gigacycle reflects an alternating dominance between degree-2 and degree-1 mantle convective flow, manifest as the presence or absence of a hemispheric subduction girdle, respectively. Degree-1 convection involves a single upwelling and opposed downwelling zone, whereas degree-2 has two upwelling zones located antipodally. Present-day convection is degree-2, with the two modern upwelling zones as the Pacific and African superplumes, located on either side of the circum-Pacific subduction girdle. The girdle is geologically recorded by circum-Pacific accretionary orogens, and has existed since ~550 Myr, indicating that degree-2 convection characterises the Phanerozoic eon.

Degree-1 convection resulted in the amalgamation of Columbia ca. 2,000 Myr ago and Gondwana ca. 550 Myr ago accompanied by peaks in crustal reworking (-εHf), whereas degree-2 convection produced Nuna ca. 1,600 Myr ago and Pangaea 200 Myr ago accompanied by peaks in mantle input (+εHf). The change from degree-2 to degree-1 at ~1.2 Ga coincided with Rodinia amalgamation at ~1,200 Myr, when the circum-Nuna subduction girdle collapsed upon itself. Subsequent, Early Neoproterozoic peri-Rodinian subduction systems followed, concentrated largely in the Pan-African domain and focussed on a single downwelling that localised the location of the Gondwanan supercraton. This plate motion arrangement characterises degree-1 convection. Another Early Neoproterozoic subduction system developed around northern Laurentia and Siberia, extending to the Tarim craton. However, it seems to have progressively retreated away from the Rodinian core (Laurentia) during the Late Neoproterozoic and collided onto northern Gondwana and Baltica. Remnants of this peri-Rodinian arc system include the Timanides, Taimyr, Baikalides, and probably Avalonia. The switch from degree-1 to degree-2 occurred diachronously between 650-500 Myr and is largely reflected by formation of the peri-Gondwana orogens, including Terra Australis orogen in the south and the Cadomian orogen in the north.

Another Early Paleozoic (540-460 Myr) subduction system began along the eastern (present-day) margin of Siberia, represented by the Ikh-Mongol arc. It may have extended to the Late Neoproterozoic Taymyr terrane of polar Russia, forming a peri-Siberian arc that ultimately linked with Terra Australis orogen to become the circum-Pacific subduction system. At this Early Paleozoic stage, global-scale degree-2 mantle convection was becoming established. In this context, the Central Asian Orogenic Belt (CAOB) began as part of the external circum-Pacific system, but it incorporated the eastern Variscides and Uralides, all of which were complexly infolded as a Late Paleozoic triple junction between Siberia, Pangea and Gondwanan fragments, forming the core of the future supercontinent, Amasia. Amasia will be complete as a Rodinian-type supercontinent following collapse of the circum-Pacific subduction system upon itself, as happened during Rodinia amalgamation during the Mesoproterozoic. Accordingly, the gigacycles are rhymthic oscillations of mantle circulation patterns that control plate motion trajectories and contrasting styles of supercontinent amalgamation.