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Extreme metamorphism, geodynamic regimes and supercontinent cycles

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This work is part of a larger project to use the geological record of magmatism and metamorphism to develop hypotheses about geodynamics that may be tested using numerical models. Apparent thermal gradients of metamorphism, as recorded by close-to-peak mineral assemblages, retrieved from rocks equilibrated at high P, P–T or T, for which the timing is obtained from various chronometers, may be used be interrogate the rock record to assess secular change in the apparent thermal gradients of metamorphism. One-sided subduction creates asymmetry in the thermal structure of convergent plate margins, with lower dT/dP in the subduction zone and higher dT/dP in the orogenic hinterland. During collisional orogenesis these distinct thermal environments are imprinted in the rock record as contrasting types of metamorphism. Proterozoic orogens record eclogite–HP granulite (E-HPG) metamorphism, with gradients of 350–750C/GPa, and granulite–UHT metamorphism, with gradients of 750–1500C/GPa. By contrast, Phanerozoic orogens register UHP metamorphism with strikingly lower gradients of 150–350C/GPa, and UHP metamorphism is the defining feature of Phanerozoic collisional orogenesis in Eurasia. What is the change in geodynamics recorded by these data?

For contemporary conditions, geodynamic modeling of collisional orogenesis shows that slab breakoff occurs at depths >300 km; strong lower crust results in coupled collision with UHP metamorphism, whereas weak lower crust results in decoupled collision with only E-HPG metamorphism. Increasing the ambient mantle temperature by 80–100C leads to shallow slab breakoff (<200 km) and unconventional modes of collision, viz a truncated hot collision regime (strong lower crust) and a two-sided hot collision regime (weak lower crust). Inverting these data, as ambient mantle temperature declined to <100C warmer than the present day the change to deeper slab breakoff generated a colder environment and enabled stronger crust?mantle coupling that allowed subduction of continental rocks to mantle depths. Thus, the appearance of UHP metamorphism is inferred to be a consequence of secular decrease in ambient mantle temperature. By contrast, granulite facies and UHT metamorphism in central East Gondwana likely represents deep crust metamorphosed under a large, moderately thick orogenic plateau that formed as a result of Ediacaran collision and hinterland thickening, with radiogenic heating generating peak metamorphic temperatures in the Cambrian. It may be no coincidence that Gondwana could have been located over the African LLSVP at the dawn of the Phanerozoic or that the first UHP belts had a subduction polarity broadly towards the core of East Gondwana.

The Ediacaran–Cambrian witnessed a change in the style of continental breakup and aggregation. In a Hoffman breakup, continental lithosphere fragments, disperses and reassembles by elimination of the complementary superocean (e.g. the process by which the Gondwanan elements of Rodinia were transformed into Gondwana). By contrast, in a Wilson cycle sensu stricto, continental lithosphere simply fragments and reassembles along the same (internal) contacts, closing an internally generated ocean basin (e.g. the transformation from Pannotia to Pangea). Internally generated ocean basins were opened and closed asymmetrically by rifting of ribbon terranes from the northern margin of Gondwana and their accretion to Laurentia, Baltica and Siberia forming the Caledonides, Variscides and Altaides, as reflected in the Cambrian to Triassic record of metamorphism. The change was also registered by multiple geochemical indices, such as epsilon Hf(t) and 87Sr/86Sr, with complex temporal records characterized by short wavelength variations that reflect the overlapping opening and closure of several major oceans (Iapetus, Rheic, Paleotethys and Neotethys). This pattern is superimposed on a simpler long wavelength variation that is temporally related to the supercontinent cycle.

Keywords: ultrahigh-temperature metamorphism, eclogite–high-pressure granulite metamorphism, ultrahigh-pressure metamorphism, geodynamic regimes, supercontinent cycles, Hoffman breakups and Wilson cycles