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One-sided subduction, extreme crustal metamorphism and tectonothermal regimes on Earth

M. Brown

Laboratory for Crustal Petrology, Department of Geology, University of Maryland, College Park, Maryland 20742-4211, USA (mbrown@umd.edu)

Where plates converge, one-sided subduction generates contrasting thermal environments in the subduction zone (low $\mathrm{d}T/\mathrm{d}P$) and in the arc–backarc/orogenic hinterland (high $\mathrm{d}T/\mathrm{d}P$). This hallmark is imprinted in the rock record as penecontemporaneous contrasting types of metamorphism, one characterized by higher-pressure–lower-temperature metamorphism and the other characterized by higher-temperature–lower-pressure metamorphism. Orogenesis and extreme crustal metamorphism are not recorded continuously throughout Earth history but are closely related to the supercontinent cycle, reflecting the consequences of mobile lid convection. Granulite facies ultrahigh-temperature metamorphism (G-UHTM; T >900˚C) occurs from the Mesoarchean–Neoarchean to the Cambrian, and is inferred at depth in Phanerozoic orogens; G-UHTM records apparent thermal gradients generally in the range 800–1,300˚C/GPa. Medium-temperature eclogite–high-pressure granulite metamorphism (E-HPGM; P greater than sillimanite stability and less than coesite stability) occurs in the Neoarchean, although well-characterized examples are rare in the Neoarchean-to-Paleoproterozoic transition, and at intervals through the Proterozoic–Paleozoic; E-HPGM records apparent thermal gradients generally in the range 350–700˚C/GPa. The appearance of E-HPGM registers a change in geodynamics that generated sites of lower heat flow than previously recorded, inferred to be associated with subduction-to-collision orogenesis. In contrast, G-UHTM registers penecontemporaneous sites of high heat flow, inferred to be similar to modern arcs–backarcs/orogenic hinterlands, where more extreme temperatures were imposed on crustal rocks than previously recorded. The appearance in the late Archean of two contrasting types of metamorphic

belt may be the first widespread imprint of one-sided subduction in the rock record. Blueschists first become evident in the Neoproterozoic rock record. High-pressure metamorphism (HPM)—characterized by lawsonite blueschists and low-temperature eclogites—and ultrahigh-pressure metamorphism (UHPM)—characterized by coesite or diamond—are predominantly Phanerozoic phenomena. HPM–UHPM registers the low apparent thermal gradients—generally in the range 150–350˚C/GPa—typically associated with modern subduction zones and the eduction of deeply subducted lithosphere, including the eduction of continental crust subducted during the early stage of the collision process in subduction-to-collision orogenesis. During the Phanerozoic, most UHPM belts have developed by closure of relatively short-lived ocean basins that opened due to rearrangement of the continental lithosphere within a continent-dominated hemisphere (for example, during formation of Laurasia from Rodinian supercontinent orphans and then due to successive closure of the Paleo-Tethys and Neo-Tethys Oceans as the East Gondwanan sector of Pangea began to fragment and disperse). In contrast, the Eoarchean-to-Mesoarchean period generally records P–T conditions characteristic of low-P–moderate-to-high-T metamorphism. Both high-grade terranes and greenstone belts may record high apparent thermal gradients in the range 800–1,000˚C/GPa, but Mesoarchean greenstones in Barberton, South Africa record lower apparent thermal gradients in the range 450–700˚C/GPa. Granulites are common, but neither extreme crustal temperature (UHTM) nor widespread high pressure metamorphism (E-HPGM) is documented before the Mesoarchean–Neoarchean. Blueschists are not found, and there is no identified imprint of subduction of continental crust to mantle conditions, although perhaps the continental crust, if subducted, was not returned but retained in the mantle. Neoarchean and Paleoproterozoic diamonds are enigmatic regarding crustal recycling and Precambrian UHPM. The occurrence of both G-UHTM and E-HPGM belts since the Neoarchean registers a change to one-sided subduction and manifests the onset of a 'Proterozoic plate tectonics regime', which evolved during a Neoproterozoic transition to the 'modern plate tectonics regime' characterized by colder subduction and HPM–UHPM. The change to one-sided subduction may have begun locally in the Mesoarchean–Neoarchean and become global in the Neoarchean-to-Paleoproterozoic transition. The age distribution of metamorphic belts that record extreme conditions of metamorphism is not uniform. Extreme metamorphism occurs at times of amalgamation of continental lithosphere into supercratons (Mesoarchean to Neoarchean) and supercontinents (Paleoproterozoic to Phanerozoic), and along sutures due to the internal rearrangement of continental lithosphere within a continent-dominated hemisphere during the formation and evolution of a supercontinent.