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Metamorphism and the evolution of subduction on Earth

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Abstract

Subduction is a component of plate tectonics, which is widely accepted as having operated in a manner similar to the present-day back through the Phanerozoic Eon. However, whether Earth always had plate tectonics or, if not, when and how a globally linked network of narrow plate boundaries emerged are matters of ongoing debate. Earth's mantle may have been as much as 200–300 °C warmer in the Mesoarchean compared to the present day, which potentially required an alternative tectonic regime during part or all of the Archean Eon. Here we use a data set of the pressure (P), temperature (T), and age of metamorphic rocks from 564 localities that vary in age from the Paleoarchean to the Cenozoic to evaluate the petrogenesis and secular change of metamorphic rocks associated with subduction and collisional orogenesis at convergent plate boundaries. Based on the thermobaric ratio (T/P), metamorphic rocks are classified into three natural groups: high T/P type (T/P > 775 °C/GPa, mean T/P ~1105 °C/GPa), intermediate T/P type (T/P between 775 and 375 °C/GPa, mean T/P ~575 °C/GPa), and low T/P type (T/P < 375 °C/GPa, mean T/P ~255 °C/GPa). With reference to published thermal models of active subduction, we show that low T/P oceanic metamorphic rocks preserving peak pressures >2.5 GPa equilibrated at P–T conditions similar to those modeled for the uppermost oceanic crust in a wide range of active subduction environments. By contrast, those that have peak pressures <2.2 GPa may require exhumation under relatively warm conditions, which may indicate subduction of young oceanic lithosphere or exhumation during the initial stages of subduction. However, low T/P oceanic metamorphic rocks with peak pressures of 2.5–2.2 GPa were exhumed from depths where, in models of active subduction, the slab and overriding plate change from being decoupled (at lower P) to coupled (at higher P), possibly suggesting a causal relationship. In relation to secular change, the widespread appearance of low T/P metamorphism in the Neoproterozoic represents a "modern" style of cold collision and deep slab breakoff, whereas rare occurrences of low T/P metamorphism in the Paleoproterozoic may reveal atypical localized regions of cold collision. Low T/P metamorphism is not known from the Archean geological record, but the absence of blueschists in particular is unlikely to reflect secular change in the composition of the oceanic crust. In addition, the premise that the formation of lawsonite requires abnormally low thermal gradients and the postulate that oceanic subduction-related rocks register significantly lower maximum pressures than do continental subduction-related rocks, and imply different mechanisms of exhumation, are not supported. The widespread appearance of intermediate T/P and high T/P metamorphism at the beginning of the Neoarchean, and the subsequent development of a clear bimodality in tectono-thermal environments are interpreted to be evidence of the stabilization of subduction during a transition to a globally linked network of narrow plate boundaries and the emergence of plate tectonics.

Keywords: Subduction, metamorphism, blueschist, eclogite, secular change