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Plate tectonics: what, where, why, and when?

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The theory of plate tectonics is widely accepted by scientists and provides a robust framework with which to describe and predict the behavior of Earth's rigid outer shell – the lithosphere – in space and time. Expressions of plate tectonic interactions at the Earth's surface also provide critical insight into the machinations of our planet's inaccessible interior, and allow postulation about the geological characteristics of other rocky bodies in our solar system and beyond. Formalization of this paradigm occurred at a landmark Penrose conference in 1969, representing the culmination of centuries of study, and our understanding of the "what", "where", "why", and "when" of plate tectonics on Earth has continued to improve since. Here, we summarize the major discoveries that have been made in these fields and present a modern-day holistic model for the geodynamic evolution of the Earth that best accommodates key lines of evidence for its changes over time. Plate tectonics probably began at a global scale during the Mesoarchean (c. 2.9–3.0 Ga), with firm evidence for subduction in older geological terranes accounted for by isolated plate tectonic 'microcells' that initiated at the heads of mantle plumes. Such early subduction likely operated at shallow angles and was short-lived, owing to the buoyancy and low rigidity of hotter oceanic lithosphere. A transitional period during the Neoarchean and Paleoproterozoic/Mesoproterozoic was characterized by continued secular cooling of the Earth's mantle, which reduced the buoyancy of oceanic lithosphere and increased its strength, allowing the angle of subduction at convergent plate margins to gradually steepen. The appearance of rocks during the Neoproterozoic (c. 0.8–0.9 Ga) diagnostic of subduction do not mark the onset of plate tectonics, but simply record the beginning of modern-style cold, deep, and steep subduction that is an end-member state of an earlier, hotter, mobile lid regime