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The evolution of subduction throughout the Earth's history

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Subduction drives plate tectonics and builds continental crust, and as such is one of the most important processes for shaping the present-day Earth. In this presentation, theory and observations for the viability and style of subduction since the Archaean are reviewed.
Earth's accretion and differentiation processes easily released enough energy to melt the entire planet, so Earth cooled from initially very hot conditions to the present-day ∼1350°C potential temperature. Liquidus temperatures from primitive melts suggest 100-300 K hotter Archaean ambient mantle[1], with a significant uncertainty due to unknown volatile content. Today, subduction is primarily driven by slab pull, and resisted primarily by mantle drag. A hot Archaean mantle might have changed this situation. It lowered viscosity, and promoted melting, resulting in a thicker oceanic crust, unless the Archaean mantle was very depleted[2]. Plates were more buoyant near the surface, perhaps inhibiting subduction initiation, but eclogitisation of crust resulted in dense deep slabs even when crust was thick. Plate strength was affected by hotter conditions in several contrasting ways: directly through temperature-dependent rheology, through dehydration strengthening, and through changing crust-mantle ratios. Although the net effect is somewhat unclear, Archaean plates were probably weaker than today. Combined plate strength and buoyancy differences resulted in different subduction dynamics (Fig.1). Plate tectonics could have been slower[3] or faster and/or intermittent[4]. Linking plate tectonic vigour to Earth secular cooling reveals that plate-tectonic rates were not very different from today. Several of the proposed Archaean subduction rates and styles fit available cooling data reasonably well.
Different types of geological observations are interpreted as subduction-related. Geochemically, a distinct 'arc' signature primarily arises from the fluid-mobility of some elements, which has an effect in a 'wet' environment such as a subduction zone, and gives decoupling of (fluid-mobile) LILE and (non-fluid-mobile) HFSE elements, resulting in the typical spiky 'spidergrams' with, e.g., pronounced low Nb/Ta ratios. Many Archaean igneous rocks ((ultra-)mafic greenstone rocks and felsic TTGs and sanukitoids) carry such arc signature, although arcs are not necessarily the only place or mechanism to form such arc signature. Several rocks (e.g. sanukitoids, certain TTGs) carry another arc signature that suggest formation (under wet conditions) at depths > 50 km (ref.5). Structural evidence for the existence and style of Archaean subduction includes accreted terranes, thrust belts, and dipping seismic reflectors. Deformation is more interpreted as gravity-driven tectonics, and perhaps indicates weaker lithosphere with less localized deformation, lower orogens, and more lateral flow near subduction zones. The co-existence of LT-HP and HT-LP paired metamorphic belts is a clear indicator of modern subduction zones, and recent discoveries of such paired belts in the Archaean (although at higher average geotherms) is interpreted as a subduction signature. Blueschists and ultra-high pressure metamorphism (typical for modern collision zones, where continental crust is temporarily subducted to high pressures) is absent for the Archaean, which could be caused by the inability of weaken Archaean plates to pull continental material to significant depths[4].
Combining geodynamical models and geochemical evidence suggest that 1) shallow flat subduction (as often proposed as the dominant style of subduction) is geodynamically not viable and geochemically not necessary. Instead, subduction was perhaps more episodic in nature, as suggested

by Archaean subduction models (Fig.1c) and geochemically evidenced by brief (few Myrs) arc signatures embedded in non-arc signatures.

References

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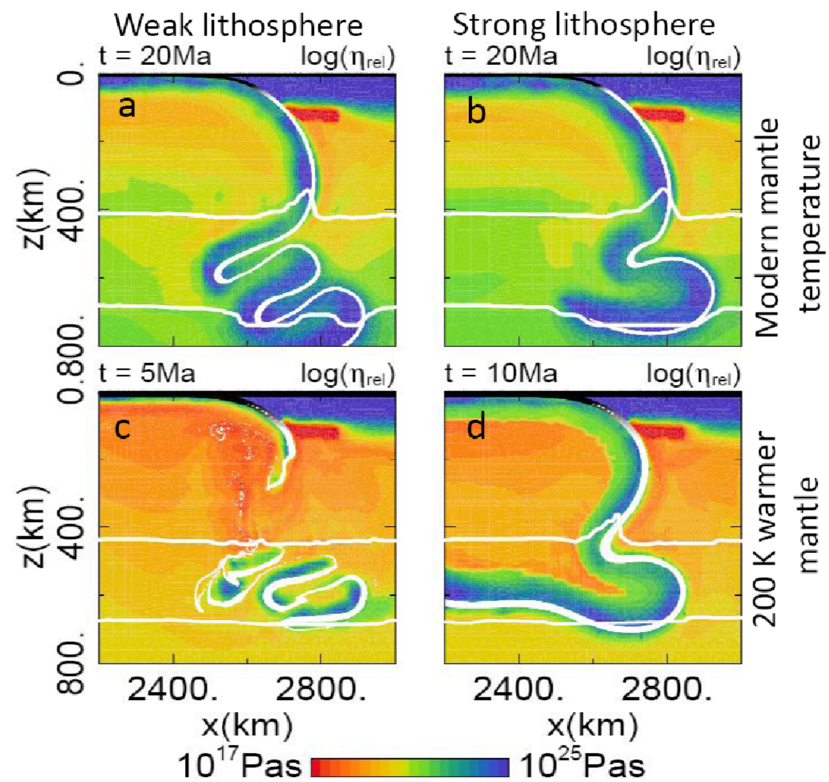

Figure 1: Archaean subduction modelling results. a) Modern potential temperature $\Delta T_{pot} = 0K$, oceanic crustal thickness $d_{cr} = 7km$, no dehydration strengthening; b) As a), but with increased effective plate thikness due to a 100x stronger depleted mantle lithosphere; c) $\Delta T_{pot} = 200K$, $d_{cr} = 7km$, no dehydration strengthening. Plate weakness results in frequent slab break-off and intermittent subduction with a typical Myr subduction time interval. d) As c), but for a 100x stronger depleted mantle lithosphere: no slab break-off occurs (after ref.4)