Earth has continents, subduction and mobile lid plate tectonics, but the details of the evolution are poorly understood. Geodynamic regimes proposed include: uniformitarian/non-uniformitarian mobile-lid plate tectonics; stagnant-lid plate tectonics, without subduction or with episodic short-lived subduction events; and, variation in regime in space and time.

The Hadean–Archean record. The oldest preserved crustal materials are Hadean: detrital zircons from the Jack Hills (Narryer terrane, Australia), which demonstrate the existence of crust as old as 4.374 Ga; the Nuvvuagittuq supracrustal belt (Superior craton, Canada), which may be as old as 4.4 Ga; and, components of the Acasta gneisses (Slave craton, Canada), which yield an age of 4.03 Ga. The Archean preserves a more extensive record. Despite differences in the tectonic structures of granite–greenstone and high-grade gneiss terrains, the overall composition of the crust is similar, but it is different from post-Archean crust. Tonalite–trondjhemite–granodiorite suite rocks (TTGs) dominate with subordinate high-Mg non-arc basalts, komatites and sediments. The characteristic dome-and-keel pattern of granite–greenstone terrains reflects sinking of volcanic-dominated sequences into the underlying gneisses, which responded by diapirc rise (e.g. Dharwar, India; Pilbara, Australia), whereas the high-grade gneiss terrains (e.g. West Greenland) record lateral accretion and extensional tectonics. Undisturbed Archean crust is generally thinner than post-Archean crust, with a lower proportion of internal boundaries, lower seismic velocities, an absence of high velocities in the lowermost levels, and a sharp flat Moho. These differences are consistent with delamination of dense residues of crystal fractionation or partial melting from the base. Paired metamorphism, a characteristic feature of post-Archean suites, is absent from the Archean record [1], although medium-temperature eclogites and high-pressure granulites are associated with the Mesoarchean–Neoarchean formation of cratons and stabilization of the SCLM. Thus, the dominant geodynamic regime for much of the Hadean–Archean may have been different to contemporary Earth, and models for the formation of TTG crust based on uniformitarian principles may be misleading.

A hotter Earth. Differences in geology and tectonic style between Archean and post-Archean crust, as well as the nature of the associated SCLM, may indicate a change in geodynamics related to Earth’s thermal evolution and mechanism of heat loss. Petrological data and thermal history models indicate that mantle temperatures were significantly hotter in the Archean, although petrological data suggest variation similar to the present day. A hotter mantle would have generated higher melt fractions and thicker primary crust, with MgO >18wt%, underlain by highly residual mantle. Mass balance considerations suggest that most of this crust is missing. Since TTGs were sourced from hydrated, garnet- (quartz-) bearing protoliths with MgO <18wt%, they cannot have been generated directly from primary crust. Thus, the preponderance of TTGs in the Archean were likely generated by reworking of secondary crust generated by fractional crystallization of sub-volcanic primary melts and internal differentiation of the primary crust, which is consistent with inversion of heat flow/production data that indicate suprasolidus temperatures in the deep Archean crust.

Geodynamic models. The stability of primary crust has been investigated by coupling calculated phase equilibria for hydrated or anhydrous compositions and their mantle residues with a 2-d geodynamic model [2]. In a stagnant-lid plate tectonics regime, magmatically overthickened crust delaminates by Rayleigh–Taylor instabilities at T >1500–1550°C generating a return flow of asthenospheric mantle and melting in both dripping crust and decompressing mantle. More recent experiments have revealed multiple tectonic settings where intermediate to felsic melts may be generated from hydrated basaltic crust [3]. Two distinct types of continental crust are generated in these experiments: a pristine granite–greenstone crust with dome-and-keel geometry formed over delaminating crust–upwelling mantle; and a reworked (accreted) crust comprising strongly deformed granite–greenstone and subduction-related sequences formed during short-lived subduction events. In previous experiments [4], there is a first-order transition from a regime with Rayleigh–Taylor instabilities but no subduction to a regime with subduction as ambient mantle temperatures declined from >200 to <175°C warmer than present-day. The transition to mobile-lid plate tectonics corresponds to the Neoarchean–Paleoproterozoic. This interpretation is consistent with the scarcity of eclogites in the orogenic rock record before 1.9 Ga, whereas eclogites recording P up to 2.0 GPa become increasingly common through the remainder of the Proterozoic [1].