[Plate tectonics] ***[Our N&V also have a broad subject area, for easy categorization.]***

Recycling style evolved

Crustal recycling evolving style

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Valentina Magni

The processes that form and recycle continental crust have changed through time. Numerical models reveal an evolution from extensive recycling on the early Earth as the lower crust peeled away, to limited recycling via slab break-off today.

Continental crust has been created and destroyed throughout Earth's history. Estimates of the balance between this loss and gain are vigorously debated, but there is a mounting consensus that a large portion of continental crust formed early in Earth's history and has since been partly recycled into the mantle[1,2]. Determining which processes were responsible for crustal recycling in the past is a difficult task because we have very little information on the dynamics and style of plate tectonics on the early Earth. Writing in *Nature Geoscience* Chowdhury *et al.*[3] use numerical simulations to show that on a hotter Earth, during the late Archaean and early Proterozoic, crustal recycling was likely much more extensive and rapid compared with today, and characterized by the peeling away of dense lower continental crust into the mantle.

Today, subduction zones are sites of continental crust formation and destruction[2,4]. Continental crust is mainly created in volcanic arcs when basaltic magmas generates and subsequently differentiate to more felsic compositions. It is recycled back into the mantle as the tectonic plates collide, through subduction and erosion of continental material. Subduction is also a driver for plate tectonics. It is therefore natural that in past decades significant focus has been put on understanding how subduction dynamics and, more generally, how plate tectonic style has evolved. Observations of the geochemical signature of volcanic arc magmas found in the felsic parts of Archaean continents has led to the idea that continental crust formed via subduction during the Archaean, too[5,6]. Yet some suggest that modern-style plate tectonics did not begin on Earth until later[7] and that early continental crust might have formed by different mechanisms, such as foundering of the thick, dense mafic crust into the mantle followed by mantle melting and consequent fractionation of mafic magmas[8]. Although there is no agreement on the processes leading to its formation, we know that early continental crust was on average more mafic compared to the present-day continents that are more silica-rich[9].

Recent continental growth models suggest that 60 to 70% of the present volume of continental crust was already present about 3 billion years ago[1]. However, only less than 10% of crust of that age is preserved today, implying that a large portion of the early continental crust has been lost back into the mantle.

Chowdhury and colleagues[2] propose a mechanism that can explain both the extensive crustal recycling and the formation of a more felsic continental crust during the late Archaean and early Proterozoic. They use numerical modelling to simulate continental collision at different mantle temperatures, thus at different times of Earth's history. Their simulations show that, under the much hotter mantle conditions that characterized the younger Earth, delamination would be would be more viable and easier to achieve than today. The delamination process is characterized by the peeling-off and sinking into the mantle of the dense lower crust and sub-lithospheric mantle from the less dense upper crust that remains at the surface (Figure 1a). If widespread, this process has the potential to recycle large amounts of lower continental crust rapidly. Moreover, the delaminated mafic crust and the upwelled mantle could melt and produce extensive felsic magmatism, leading to the formation of silicic continents.

As Earth's mantle temperature gradually decreased, the subduction dynamics, thus also the recycling style, likely changed. Today, delamination still occurs in some collision zones, but it is much less common than continental subduction followed by slab break-off. Interestingly, the recycling potential of slab break-off is considerably smaller than for delamination because only a fragment of the continental crust detaches with the oceanic plate (Figure 1b). Therefore, the model results show that it is much easier to preserve continental crust today than it was on the early Earth.

The changing style of collision dynamics and crustal recycling through time has some crucial consequences. For instance, it is thought that early continents, being more mafic and supported by a weaker mantle, would not have been above sea level. The removal of the sub-lithospheric mantle and the denser, mafic part of the crust due to delamination, in addition to the production of more felsic material, would create lighter continents that could rise above sea level. The subaerial emergence of the continents would lead to changes in weathering, erosion and microbial habitation that would drastically change the cycles of some key volatile elements, such oxygen. Indeed, the model results from Chowdhury and colleagues suggest that recycling via delamination would have been widespread and the silicification of the continents would have reached a peak at a time roughly coincident with the Great Oxidation Event about 2.4 to 2.1 billion years ago[10].

An interesting difference between a predominantly peeling-off style of recycling compared to a slab break-off style of recycling is the type of material that goes into the mantle, and thus the influence on mantle chemical composition. During delamination, the felsic upper crust remains at the surface, whereas with slab break-off a portion of the upper crust is recycled. In a convecting mantle, this means that fragments of upper crust could be entrained into upwelling mantle plumes and melt together with the mantle to produce new oceanic crust at mid-ocean ridges with an enriched component.

Chowdhury *et al.*[2] use estimates of the changes in crustal recycling flux to suggest that the transition to modern-style plate tectonics happened about one billion years ago. However, these estimates are affected by the intrinsic assumptions in numerical models and uncertainties relating to the evolution of mantle temperature, so it is difficult to pin point when plate tectonics started in the form we know it today. More importantly, we have to keep in mind that the rate of crustal growth not only varies through time but also varies considerably in space, among individual collision zones. Using one average estimate of recycling flux as characteristic of a particular time might not fully represent the complexity and variability of collision zones. Nevertheless, these new estimates are an important starting point to investigate the fate of recycled crust at a global scale.

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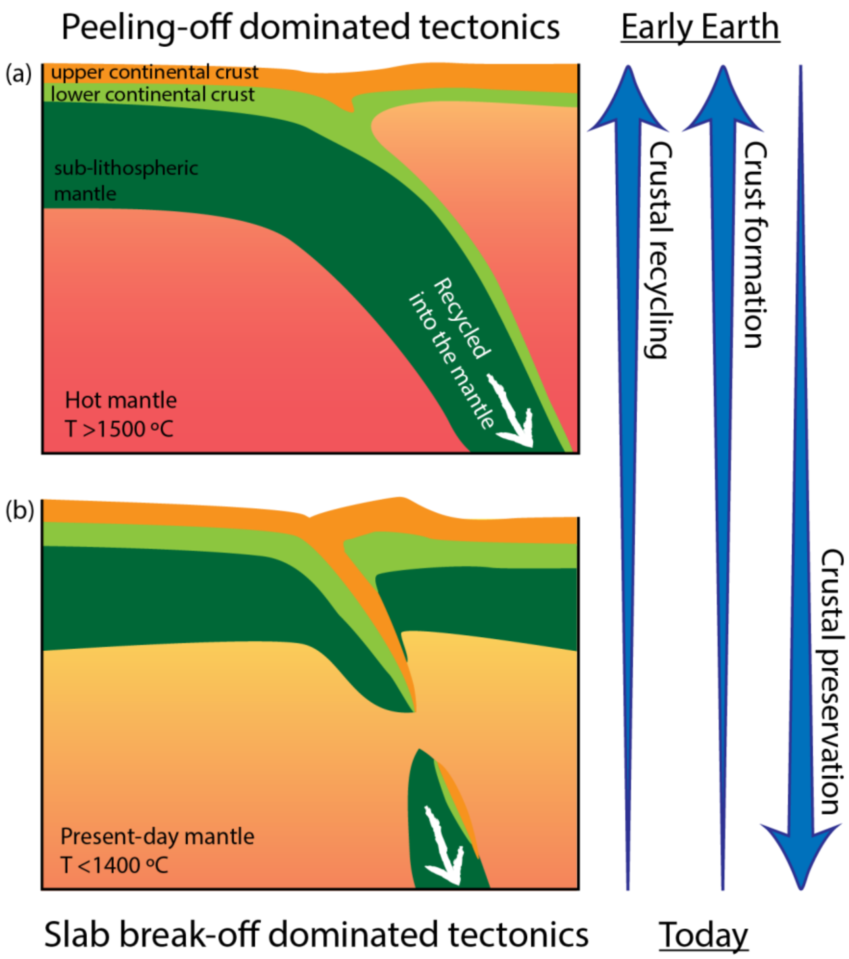

Figure 1. The evolving style of plate tectonics and continental crustal recycling in collision zones. Chowdhury and colleagues[3] use numerical simulations to show that the hotter, younger Earth could have been characterized by a delamination style of plate tectonics (a). The lower continental crust and sub-lithospheric mantle could have peeled away, recycling large volumes of lower continental crust into the mantle. In contrast, under present-day conditions, slab break-off is common, but this process only recycles small fragments of upper and lower continental crust (b).

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