



A silicon memory of subduction

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Early Earth:

A silicon memory of subduction

Subduction processes may have operated very early in Earth history according to the heavy silicon isotope compositions of Archean igneous rocks. The silicon that precipitated out of the Archean oceans as chert was subducted and melted to yield seawater-like heavy isotope signatures in early granitic rocks.

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The geodynamics of early Earth are challenging to decipher, because rock outcrops are limited and their metamorphic histories are complex. In this endeavor, the scientific community is constantly seeking reliable witnesses to the events of early Earth, such as the formation of continental crust from granitoid rocks. In this case, the witnesses are petrological and geochemical tracers that record the early geodynamic setting despite the multiple geological cycles the rocks have subsequently been subjected to. Writing in *Nature Geoscience*, André et al.¹ and Deng et al.² report independent analyses of silicon isotope compositions in igneous rocks from the Archean. They attribute their exceptionally heavy signatures to the recycling of ocean derived silicon, which indicates that silicified crust was subducted in the Archean.

Archean igneous rocks have lost most of their original texture and mineralogy in subsequent metamorphic and melting events through Earth's geological evolution. As a result, studies that attempt to reconstruct the geodynamical setting under which these rocks originally formed rely heavily on tracers, often their chemical and isotopic compositions^{3,4}. However, geodynamic reconstructions based on rock chemistries can be misleading, on occasion, even for younger Proterozoic rocks, despite their simpler geological history⁵. As a result, the geodynamic context under which Archean granitoids, and therefore Archean continental crust, originated remains debated^{3,6}. Stable isotope compositions of the major element silicon could be good candidates for robust tracers of this context, because they have been shown to be resistant to metamorphic and metasomatic processes⁷. This resistance sets silicon apart from a

number of trace elements, and even from the isotope signature of the main rock-forming element, oxygen.

André et al.¹ and Deng et al.² build on the silicon isotope composition database of more recent, Phanerozoic magmatic felsic rocks^{8,9} with bulk rock, silicon isotope analyses of 4.0 to 2.6 billion year old granitoid samples from South Africa¹, Greenland, Canada, Siberia and Scandinavia². Both studies find that Archean granitic igneous rocks have heavier silicon isotope compositions than any terrestrial magmatic rocks analyzed so far. Hence, a particularly heavy silicon isotope composition seems typical for granitoid rocks from that time. Such heavy silicon isotope compositions have not been recorded in modern igneous rocks; they are, however, found in present-day seawater and in cherts that represent aqueous silica precipitated from ancient seawater⁷. Therefore, both studies interpreted the heavy silicon isotope compositions of ancient granitoids as an indicator of a source that involved cherts precipitated from seawater, interspersed in the basaltic seafloor (Fig. 1).

An imprint of seawater-derived silica was previously hinted at by a small deviation towards heavy silicon isotope compositions in modern-style, subduction-derived Phanerozoic volcanic rocks⁸. For the early Earth, a previous study looked for heavy silicon enrichment through the study of zircons extracted from sedimentary rocks¹⁰ which supported a seawater origin for silicon. However, the analytically less challenging, but more precise bulk-rock analyses of André et al.¹ and Deng et al.² required fewer interpretative steps. Furthermore, they revealed much larger isotopic deviations in Archean igneous rocks compared with the Phanerozoic samples⁸.

The large silicon deviation in the Archean probably reflects that the Earth differed in at least two important ways in the Archean when compared to more recent Phanerozoic times (Fig. 1). First, the Archean oceans were less affected by life. Biological activity decreased the dissolved silica content in the Phanerozoic oceans by at least one order of magnitude relative to the Archean ocean¹¹. In the more ancient seawater, silica was therefore closer to its saturation, which led to more abundant silica precipitation and the formation of cherts on the seafloor. Secondly, Archean Earth was much hotter, with a stronger mantle geothermal gradient. As a result, if subduction was already in operation in Archean times, subduction-related magmatic rocks could have been generated from the direct melting of the subducting oceanic lithosphere rather than from the partial melting of the mantle wedge thanks to fluids

exsolved from the subducting slab as is the case in modern, cooler subduction⁴. Indeed, Deng et al.² specifically argued that the heavy silicon isotope composition of Archean granitoids is a direct tracer of hot subduction acting as early as 4 Gy ago on Earth. Taken together, due to limited biological activity, the Archean oceanic crust was richer in seawater-derived cherts that carried the heavy, seawater-derived silicon into a hotter geotherm where it was directly melted to produce subduction-related magmas with isotopically heavier silicon isotope signatures than igneous rocks formed in modern-style subduction. By contrast, in modern-style, subduction-related andesites, the small amount of seawater-derived silicon comes from fluids from the dehydrating subducted seafloor that contains less chert due to the biological removal of silicon from the oceans.

André et al.¹ and Deng et al.² find that Archean seawater played an important role in the formation of granitoids on early Earth. Deng et al. specifically suggest that subduction of silicified crust generated the heavy silicon isotope imprint of seawater left in these samples. Silicon isotopes therefore provide a key argument in favor of the controversial geodynamic hypothesis that horizontal plate tectonics occurred as early in the Earth's history as the Archean.

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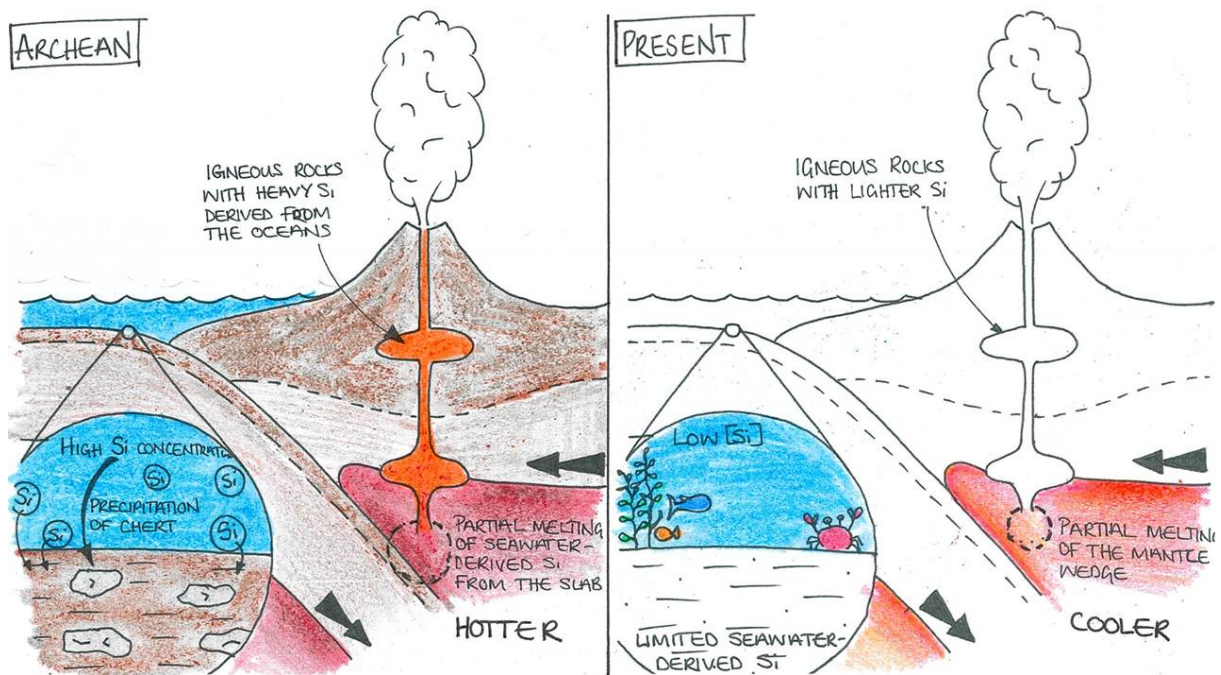


Figure 1: Comparison of the silicon geodynamic cycling between the Archean and present day. In the Archean (left), limited biological activity meant the dissolved silicon content of the oceans was higher than today. As a result, a larger proportion of isotopically heavy marine silicon precipitated as cherts in the aging oceanic crust. Furthermore, hot subduction at that time would have facilitated partial melting of the oceanic slab that contained the cherts, instead of just the mantle wedge above the subducting plate as in current times (Right). Together, chert precipitation and hot subduction can explain the heavy silicon isotope composition of Archean igneous rocks measured by Andre et al.¹ and Deng et al.² who conclude that seawater was strongly involved in the formation of granitoids on early Earth. The relative proportion of components and slopes are not to scale.