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What can alkaline rocks and carbonatites tell us about changes in Earth's mantle with time?

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Alkaline rocks and carbonatites typically occur in intraplate settings, as a result of incipient melting of the mantle. They span a range of magma types from rapidly erupted xenolith-bearing primitive volcanics to highly evolved compositions that have experienced extensive modification within the crust. The number of occurrences of both alkaline rocks and carbonatites increase from the Precambrian until the present day, and an increase is also observed in the kimberlite record [1]. In contrast, the occurrence of komatiites (thought to represent the hottest magmas generated on Earth [2]) decrease and are largely confined to the Archean. Previous work on continental basaltic magmas has demonstrated that the mantle has cooled throughout Earth's history and that the average melt fraction has decreased with time [e.g. 3]. Thus, mantle-derived magmas can be used to track the physio-chemical properties of the mantle over geological time.

We have compiled and updated the known examples of carbonatites (n=609) and alkaline rocks (n=2513) revealing an increase with time from the Precambrian, with a marked increase from 800 Ma. The effect of preservation on the abundance of the alkaline rock and carbonatite record is ambiguous. Our analysis reveals that for carbonatites, there is an association with older lithosphere (Precambrian) but that the alkaline rock distribution is closer to the age of the exposed continental crust. Thus, the effects of preservation cannot entirely influence the change in the abundance of carbonatites through time.

We propose a combination of a cooling mantle, reducing the average partial melt fraction, combined with the dynamic (but likely cumulative) effect of metasomatism of the lithosphere-asthenosphere boundary in incompatible elements which has resulted in increasingly favourable conditions for small-fraction partial melting. Such fusible regions then only require a minor lithospheric stress changes or accumulation of a critical volume of melt or metasomatised material to generate incompatible-element enriched magmatism responsible for carbonatites and alkaline rocks.

[1] Tappe, et al., (2018) Earth and Planetary Science Letters, doi:10.1016/j.epsl.2017.12.013

[2]Sossi, & O'Neill, (2016) Contrib Mineral Petrol doi:10.1007/s00410-016-1260-x

[3] Keller & Schone (2012) Nature, doi:10.1038/nature11024