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Early Archean onset of plate tectonics suggested by oldest confirmed diamonds – evidence from the Witwatersrand

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Diamonds derived from the ca. 3 Ga Witwatersrand Supergroup provide unparalleled insight into not only the physicochemical conditions of Meso- to Paleoarchean proto-cratonic mantle lithosphere, but also constraints on the cycling of volatiles on early Earth [1]. Age constraints produced from radiogenic isotope investigations of mantle xenoliths and diamond inclusions seldom exceed 3.3 Ga compared to the older and more extensive crustal record. One of the most critical questions in early Earth studies is when recycled surficial components (e.g. sediments, oceanic crust) became available within Earth's mantle. The appearance of eclogitic material (with assumed crustal protoliths) after ca. 3 Ga has been interpreted as evidence for the onset of plate tectonics at 3 Ga [2], but estimates derived from the crustal record have indicated an earlier onset [3].

In order to study diamonds with confirmed Archean ages, we have investigated three diamonds derived from the Witwatersrand Supergroup, South Africa. The moderate aggregation of nitrogen (6 – 64 %B) indicates that the Wits diamonds resided in the mantle for a few 100 Myr. Combined with the stratigraphic position of the placer diamonds within the Witwatersrand succession, it can be inferred that the diamonds formed as early as 3.5 Ga. Hence, any conclusion based on the geochemistry of the Wits diamonds has direct implications for deep volatile cycles during the Paleoarchean at, or prior to, 3.5 Ga.

We conducted detailed SIMS core to rim analyses of nitrogen contents and carbon and nitrogen isotope compositions of the Wits diamonds. The elevated nitrogen contents (up to 1231 at. ppm) and $\delta^{15}N$ values (between -0.5 and 2.7 ‰) indicate that recycled crustal nitrogen was involved in diamond genesis at mantle depths around 3.5 Ga ago. This conclusion is based on the fact that ancient sediments generally have high nitrogen contents and positive $\delta^{15}N$ values, compared to the low nitrogen contents (< 1 ppm) and negative $\delta^{15}N$ values of Earth's mantle [4]. This suggests that prior to Wits diamond formation at ca. 3.5 Ga, recycled crustal components were present within deep Earth reservoirs, which is best explained by widespread operation of plate tectonic processes during, or possibly before, the Paleoarchean.

Although the carbon isotope compositions ($\delta^{13}C$ values between -5.7 and -3.0 ‰) of the Wits diamonds do not further constrain the volatile sources, diamond core-to-rim increases in $\delta^{13}C$ values provide evidence for diamond crystallization from oxidized (CO_2 or carbonate-bearing) fluids/melts within the early Archean mantle. Thus, it follows that oxidized components were present in the proto-cratonic mantle by ca. 3.5 Ga. The first identification of oxidized components in the Paleoarchean mantle is significant given our sparse knowledge of the redox state of the Archean mantle, the uncertainties that surround secular mantle redox evolution, and finally, the marked absence of oxidized CO_2-rich magmatism near Earth's surface prior to 3 Ga [5].

References:

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