Diamonds - time capsules of ancient mantle volatiles and the key to dynamic earth evolution

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Diamonds are robust containers of volatiles trapped during their crystallisation in the Earth’s deep mantle (>180 km). As diamonds are known to have formed up to 3.5 Ga ago, they have the unique potential to reveal mantle volatile compositions through time. Of these volatiles, the noble gases (He, Ne, Ar, Kr, Xe) are the most important tracers of mantle processes. Consequently, analysis of noble gases in diamonds of known age is absolutely vital for addressing fundamental questions on the structure, evolution and geodynamics of the Earth’s mantle through time (e.g. testing the hypothesis of whole mantle versus two-layer convection).

As part of a broader investigation into the evolution of the noble gases through time, I studied the noble gas compositions of black borts (framesites) and polycrystalline diamonds of known peridotite/eclogite paragenesis from the Jwaneng Kimberlite pipe, Botswana. The most striking observation found in the framesites is the presence of crustal nucleogenic neon, released on graphitisation of the framesites. Neon of this composition can only have been produced in the crust and subsequently incorporated during formation of the framesites in the mantle. This may indicate that noble gases produced in the crust, such as nucleogenic neon, were introduced into the sub-continental mantle source during ancient subduction-related processes, and that some parts of the mantle contain significant quantities of crustal noble gases. Recent Re-Os analyses of eclogite xenoliths and eclogitic inclusions in diamonds from southern African Kimberlites suggest that subduction-related crustal recycling may have been a viable process during continent formation in the Archean (~2.9 Ga) and resulted in widespread formation of eclogitic diamonds at that time. If this is true, then crustal noble gases could have been introduced into the mantle at a very early stage in Earth history.

In contrast, the Jwaneng polycrystalline diamonds appear to have similar noble gas, particularly neon, isotope compositions as observed in present-day MORBs,
regardless of their parageneses. This implies that the Jwaneng polycrystalline diamonds may have formed in recent time, possibly as young as the kimberlite emplacement age of 235Ma. Furthermore, neon isotope compositions in the mantle where Jwaneng diamonds formed appear to have temporally changed from crustal Ne (as observed in the framesites) to the MORB-like Ne (as observed in the polycrystalline diamonds).

Seismic tomography studies of the Kaapvaal-Zimbabwe craton in southern Africa reveal distinct seismic velocity profiles at 150 km depth, within the diamond stability field, which appear to correlate with differences in diamond paragenesis. Diamond mines with predominantly eclogitic diamonds (e.g. Jwaneng, Orapa, Premier) overlie lithospheric mantle with relatively slow P-wave velocities, whereas localities with predominantly peridotitic diamonds (e.g. Kimberley, Finsch) are associated with faster P-wave velocities. This distinction in P-wave velocities can be interpreted in terms of different chemical compositions in the lithospheric mantle; the region with slower P-wave velocities could correlate with an oceanic lithospheric component and/or metasomatising fluids introduced by ancient subduction-related processes, whereas the faster P-wave velocity region may reflect mid-Archean mantle depletion events initiated by craton keel formation. As the mantle beneath the Jwaneng mine is characterized by slower P-wave velocities at 150 km depth, our finding of present-day MORB-like noble gases in Jwaneng polycrystalline diamonds appears to be consistent with the tomographic observations. On this basis, it is postulated that diamonds from eclogitic mines could clarify whether or not material subducted into the deep mantle retained crustal ± atmospheric noble gases, thus permitting quantification of subducted noble gases through time – currently a critical unknown in all mantle evolution and outgassing models. In contrast, diamonds from the peridotitic mines could contain ancient mantle noble gas compositions and would be more suitable for investigating the evolution of the noble gases through time.