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Re-Os Isotope Characterisation and Nitrogen Aggregation of the Off-Craton Ellendale diamonds, Kimberley Province, Australia.

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A suite of sulphide-bearing diamonds recovered from the Ellendale 4 and 9 pipes in the Ellendale diamond province of lamproite intrusions in north-western Australia have been investigated for their nitrogen aggregation state and the Re-Os isotope geochemistry of the sulphide inclusions.

The Ellendale lamproites, dated at ca. 20 Ma (Allsopp et al., 1985) intrude the King Leopold Mobile Zone just south of the Kimberley craton and are thus an atypical, off-craton diamondiferous locality. The diamonds contain equal proportions of both peridotitic and eclogitic inclusions (Hall and Smith, 1984; Griffin et al., 1988; Jaques et al., 1989) and provide a chance to explore the continental mantle.

Diamond Descriptions

The diamonds in this study range in size from 0.26 to 0.92 carats and are dominated, with the exception of one octahedron, by highly resorbed tetrahexahedra that have been smoothed by extensive resorption in the host lamproite. The diamonds are mainly yellow, with variable degrees of colour intensity including twelve colourless specimens. Cathodoluminescence images of the diamond plates were taken in order to reveal internal growth zoning. The diamonds exhibit an octahedral growth habit thought some diamonds show complex growth zones indicating several micro growth centres. Two diamonds (EL52 and EL53) have cubo-octahedral growth centres.

Nitrogen Content and Aggregation Characteristics

The diamonds in this study are dominated by nitrogen-rich Type Ia diamonds. While Taylor et al. (1990) showed limited IaB aggregation (<5%) for the Ellendale diamonds, the diamonds in this study all show much higher degrees of IaB aggregation (>35%). Time-averaged mantle temperatures (1118 – 1176 °C) for a mantle residency time of 1500 Ma were calculated after Taylor et al. (1990). Nitrogen studies on diamonds from the Argyle lamproite in the Halls Creek Mobile Belt, also adjacent to the Kimberley Craton, indicate that these diamonds resided in a slightly hotter lithosphere (1223 – 1303 °C, Taylor et al., 1990).
Jaques et al. (1989) calculated temperatures for garnet-olivine and pyroxene inclusions in Ellendale peridotitic diamonds. These temperatures (1175 and 1235 °C) are in agreement with mantle storage temperatures calculated in this study and by Taylor et al. (1990) if the diamonds formed during the late-Archaean to mid-Proterozoic.

Sulphide Inclusions and Re-Os Isotope Results

Twelve sulphide inclusions have been recovered from ten diamonds. The majority of the sulphides are very small (1-2 μg) and are dominated by high Ni (P-type) pentlandite compositions. Three pyrrhotite inclusions and one chalcopyrite inclusion were analysed. The sulphide compositions and Re-Os isotopic data are provided in Table 1.

A regression was plotted through 7 P-type sulphide inclusions, classified on the basis of their high Ni content and Os concentrations (Pearson et al., 1998 and references therein; Pearson and Shirey, 1999). This gives an age of 1428 ± 390 Ma with a low $^{187}Os/^{188}Os$ initial ratio of 0.101 ± 0.014.

Although the age regression has a large uncertainty due to limited spread in $^{187}Re/^{188}Os$, it indicates that the Ellendale P-type diamonds are of similar age to E-type diamonds from Argyle, which were dated at 1580 Ma from Sm-Nd on their silicate inclusions (Richardson et al., 1986).

The $^{187}Os/^{188}Os$ initial ratio is low for the convecting mantle at ~1.5 Ga, the indicated time of diamond formation, but has a large uncertainty that results at least in part from geological scatter and uncertainties on the Re blank correction to such tiny samples. While this may be considered indicative of an older depleted mantle source for these diamonds, the scatter on these data is large enough to conclude that this is not the case. The upper limit on the initial ratio (0.115) is close to that of a convecting mantle at the time of diamond

Sample	Sulphide (µg)	Composition	Ni wt %	Parageneses	Re (ppb)	Os (ppb)	$^{187}Re/^{188}Os$	±	$^{187}Os/^{188}Os$	±
EL10	33	pyrrhotite	0-1 %	E-Type	9.11	4.44	164	9	4.71	0.07
EL23	1	pentlandite	19-22 %	P-Type	73.07	89.35	4.12	0.52	0.208	0.006
EL26	2	pyrrhotite	<2 %	E-Type	493	6.19	587	74	4.35	0.34
EL50	2	pyrrhotite	21%	P-Type	981	1,274	3.755	0.113	0.195	0.002
EL51	1	pentlandite	7-20%	P-Type	2411	-	-		-	
EL54_1	1	pentlandite	10-22 %	P-Type	1076	9,967	0.520	0.002	0.1186	0.0005
EL54_3	1-2	pentlandite	17-32 %	P-Type	3780	17,626	1.033	0.031	0.1260	0.0004
EL55_1	1	pentlandite	15-18%	P-Type	723	11460	0.303	0.009	0.1109	0.0010
EL55_2	2	pentlandite	17-21%	P-Type	513	1279	1.94	0.07	0.127	0.007
EL57	6	chalcopyrite	0-4 %	E-Type	764	262	18.4	0.9	2.506	0.019
EL61	1	pyrrhotite with pentlandite exsolution	0-13%	E-Type	255	12.0	168	28	2.51	0.11
EL65	<1	pyrrhotite	20-30 %	P-Type	> 664	> 12,369	0.2603	0.0078	0.112	0.006

Table 1. Sulphide inclusion compositions and Re-Os isotopic data

formation (Shirey and Walker, 1998). It also overlaps the initial isotopic composition of Argyle lherzolites (0.113 to 0.116; Graham et al., 1999) when corrected to a 1.5 Ga age.

The presence of the P-Type Ellendale diamonds beneath the King Leopold Mobile Belt indicates that the lithospheric mantle keel has been preserved since at least the Mesoproterozoic and during any subsequent continent-margin accretion around the Kimberley Craton. This is in agreement with seismic studies which indicate that the high velocity zone representing dense cold lithosphere (underlying the Kimberley Block to depths of ~225 – 250 km) extends much further south than is suggested by the surface cratonic edge (Van der Hilst et al., 1998; Kennet, 2003; Fishwick et al., 2005). While the isotopic data presented here are not precise enough to require depleted Archaean mantle in this region as proposed by Graham et al. (1999), they do not exclude some depleted Archaean mantle either. In any case, the data clearly show sulphide –including peridotitic diamond formation in the Proterozoic.

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