Iron-in-perovskite oxygen barometry and diamond resorption in kimberlites and lamproites from southern Africa, Russia and Australia

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INTRODUCTION

- Diamond resorption in kimberlites and lamproites is well documented
- Has a significant impact on diamond content, size-distribution and, in some cases, diamond value
- Discrepancies in the extent of resorption displayed by diamonds enclosed in mantle xenoliths relative to those extracted directly from the host kimberlite indicates that a significant amount resorption takes place in the magma itself
- The extent of resorption is highly variable between different kimberlites and lamproites and may be related to the oxidation state of the host magma
- Currently, estimates of diamond resorption potential are mostly based on the composition of megacryst ilmenite
- However, ilmenite is not always present and, as a xenocryst mineral, its relationship to magma oxidation state is equivocal

Fe-in-perovskite barometry

- Bellis and Canil (2007) recently calibrated an oxygen barometer based on the ferric iron content of $CaTiO_3$ perovskite
- Provides a direct estimate of the oxygen fugacity of magma
- Recent application to Lac de Gras kimberlites in Canada (Canil and Bellis, 2007) indicates a correlation between perovskite-based fO_2 estimates and diamond resorption

Methods

- Perovskite was analysed using a JEOL JXA-8100 (wavelength dispersive EMP) at the University of Cape Town, South Africa
- Acc. voltage - 25kV, beam - 20nA; 1-2 micron beam
- Oxides determined: SiO_2, TiO_2, total iron as Fe_2O_3, MnO, MgO, CaO, Na_2O, SrO, La_2O_3, Ce_2O_3, Nb_2O_5, ThO2, Pr_2O_3, and Ta_2O_5
- Counting times were 10 seconds on peak and 10 seconds on background, exceptions:
  REE, Th, Ta and Nb – 20 s peak and 20 s background
  Fe – 40 s peak, 40 s background

- **Oxygen fugacity** (relative to the NNO buffer) was determined using the iron-in-perovskite oxygen barometer of Canil and Bellis (2007):

$$\Delta NNO = [(-0.5 \times Nb) + (Fe - 0.03)]/0.004$$

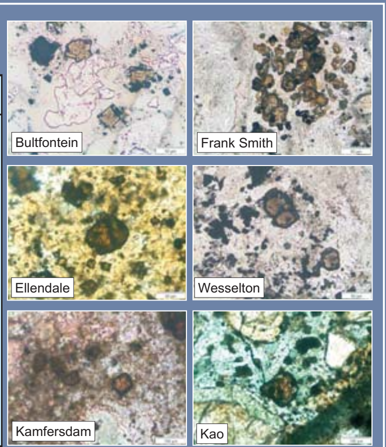
- Estimates of **diamond resorption** were based largely on the relative proportion of octahedral vs resorbed dodecahedral diamond shapes
- Diamond preservation index: **PI** = #octa / (#octa + #dodec)
- Each locality was ranked and grouped into preservation categories based on PI, augmented by other descriptive information

LOCALITY AND KEY SAMPLE INFORMATION

Localities ordered by diamond preservation rating. Localities are mostly kimberlites. Ellendale is an olivine lamproite. Number of analyses per sample shown in parentheses.

Locality	Country	No. of samples	Mean ΔNNO	Min ΔNNO	Max ΔNNO	PI	Preserv. Rating	Preserv. Rank
Zarnitsa	Russia	1(9)	-2.9	-3.3	-2.5	0.73	1	1
Aikhal	Russia	1(8)	-3.3	-3.7	-2.9	0.60	1	2
Jubilee	Russia	2(4)	-3.1	-3.8	-2.0	0.60	1	3
Udachnaya	Russia	2(8)	-3.0	-3.6	-2.2	0.50	1	4
Wesselton	South Africa	2(8)	-2.3	-3.3	-1.3	0.50	2	5
Monastery	South Africa	2(8)	-2.4	-2.9	-1.6	0.36	2	6
Frank Smith	South Africa	1(9)	-3.9	-4.1	-3.6	0.38	2	7
Premier	South Africa	2(9)	-4.0	-4.3	-3.6	0.37	2	8
Samada	South Africa	2(9)	-3.1	-3.6	-2.4	0.30	3	9
Bultfontein	South Africa	2(5)	-2.1	-2.4	-1.5	0.22	2	10
Orapa	Botswana	2(9)	-3.7	-4.1	-3.1	0.11	3	11
Kao	Lesotho	2(7)	-2.2	-3.0	-1.3	0.20	3	12
Kamfersdam	South Africa	1(8)	-3.4	-4.2	-2.7	0.11	3	13
De Beers	South Africa	2(6)	-3.5	-4.1	-3.2	0.10	3	14
DuToits Pan	South Africa	2(8)	-3.4	-4.2	-2.7	0.10	3	15
Letseng	Lesotho	2(9)	-1.8	-3.3	-0.2	0.01	4	16
Ellendale	Australia	2(10)	-1.2	-2.3	-0.5	0.00	4	17

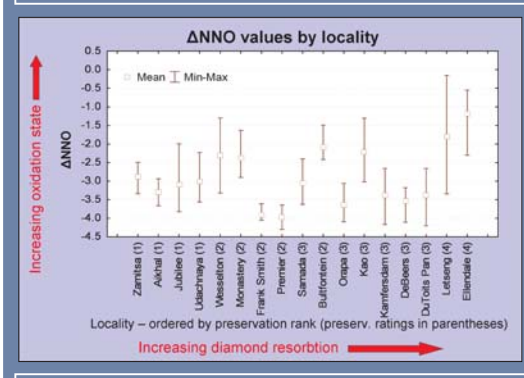
*ΔNNO = deviation of fO_2 from NNO buffer; PI = preservation index (see methods); Diamond preservation ratings: **1** – well preserved (PI > 0.50); **2** – moderately well-preserved (PI ~ 0.5 to 0.3); **3** – poorly preserved (PI ~ 0.3 to 0.1); **4** – marginally preserved (PI < 10)*

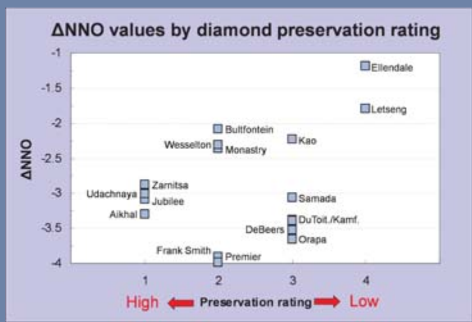


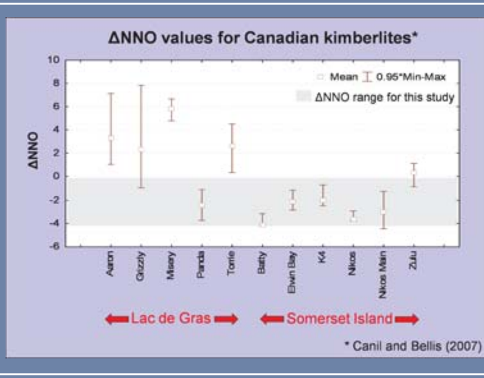
Photomicrographs showing examples of perovskites analysed. Scale bar = 50 microns

AVERAGE PEROVSKITE COMPOSITIONS (ordered by ΔNNO)

Locality	n	ΔNNO	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	SrO	La_2O_3	Ce_2O_3	Nb_2O_5	Nd_2O_3	ThO_2	Pr_2O_3	Ta_2O_5	Total
Premier	9	-3.98	0.04	56.14	0.22	0.92	0.04	0.04	39.93	0.39	0.00	0.29	0.93	0.36	0.36	0.23	0.05	0.07	100.03
Frank Smith	9	-3.90	0.02	54.77	0.10	0.97	0.00	0.05	37.36	0.68	0.00	0.96	2.87	0.51	1.02	0.46	0.33	0.09	100.20
Orapa	9	-3.65	0.01	55.00	0.03	1.06	0.03	0.06	39.13	0.52	0.15	0.57	1.51	0.61	0.53	0.00	0.00	0.00	99.22
DeBeers	6	-3.53	0.04	54.55	0.24	1.11	0.01	0.03	37.37	0.66	0.00	0.73	2.65	0.68	1.17	0.64	0.31	0.12	100.31
Kamfersdam	8	-3.39	0.08	52.66	0.22	1.18	0.01	0.12	37.37	0.73	0.00	0.80	2.73	0.88	1.15	0.48	0.33	0.10	98.85
DuToits Pan	7	-3.38	0.01	54.63	0.07	1.12	0.01	0.05	37.75	0.63	0.00	0.73	2.50	0.61	1.10	0.49	0.29	0.09	100.07
Aikhal	8	-3.29	0.02	54.59	0.20	1.15	0.02	0.06	39.12	0.39	0.00	0.71	1.92	0.63	0.61	0.29	0.18	0.10	99.99
Jubilee	4	-3.09	0.33	53.55	0.14	1.28	0.02	0.18	36.58	0.72	0.00	0.91	2.70	0.96	0.90	0.63	0.30	0.19	99.38
Samada	8	-3.06	0.01	55.46	0.08	1.17	0.03	0.05	38.96	0.61	0.16	0.57	1.81	0.51	0.70	0.00	0.00	0.00	100.12
Udachnaya	7	-3.01	0.01	53.57	0.15	1.33	0.00	0.15	36.84	0.74	0.00	1.11	3.22	1.04	1.08	0.70	0.40	0.22	100.56
Zarnitsa	9	-2.88	0.02	55.40	0.23	1.25	0.04	0.08	39.31	0.41	0.00	0.58	1.60	0.60	0.54	0.15	0.13	0.07	100.42
Monastery	8	-2.36	0.02	54.76	0.19	1.39	0.03	0.03	37.96	0.66	0.00	0.68	2.07	0.73	0.81	0.28	0.22	0.08	99.91
Wesselton	7	-2.31	0.01	53.51	0.11	1.41	0.00	0.05	36.18	0.94	0.00	1.03	3.45	0.84	1.43	0.76	0.44	0.14	100.29
Kao	7	-2.23	0.03	55.23	0.24	1.33	0.02	0.09	39.65	0.38	0.04	0.50	1.43	0.38	0.57	0.13	0.07	0.04	100.15
Bultfontein	7	-2.08	0.04	52.18	0.20	1.47	0.00	0.08	35.74	0.90	0.03	1.24	4.16	0.90	1.71	0.69	0.48	0.13	99.96
Letseng	9	-1.80	0.02	55.58	0.24	1.40	0.03	0.04	40.05	0.33	0.00	0.40	1.20	0.28	0.45	0.14	0.07	0.04	100.27
Ellendale	9	-1.19	0.62	52.04	0.27	1.60	0.00	0.12	34.92	0.80	0.00	1.69	4.14	0.68	1.11	0.50	0.55	0.10	99.15







RESULTS – Range in fO_2

- Results indicate limited range in ΔNNO with most localities yielding values between -3 and -2
- Variation in ΔNNO within localities is mostly within the uncertainty of the method; no evidence for multiple populations of perovskite
- Letseng, Ellendale and Wesselton show wider ranges in ΔNNO but the data do not define sub-populations indicative of multiple perovskite generations
- The range of average fO_2 values is equivalent to the margin of uncertainty of the oxygen barometer calibration (± 1 fO_2 log unit) and corresponds with the mode for kimberlitic perovskite worldwide (Canil and Bellis, 2007)
- None of the kimberlites yield high fO_2 values as reported by Canil and Bellis (2007) for certain kimberlites from Canada

RESULTS – fO_2 and diamond preservation

- The two localities with the highest average fO_2 values determined in this study (Ellendale and Letseng) have the lowest estimated degree of diamond preservation
- This suggests that in these bodies, the observed extreme resorption of diamonds is at least partly related to relatively oxidising host magmas
- However, ΔNNO values for other kimberlites do not show any relationship to diamonds preservation estimates
- The four Russian kimberlites which contain the best preserved diamonds have ΔNNO values close to the average for the dataset
- DeBeers and DuToits Pan kimberlites, both with high proportion of resorbed diamond forms, yield ΔNNO values within error of the Russian kimberlites

CONCLUSIONS

- fO_2 values are similar to those estimated for kimberlites worldwide and do not show evidence for highly oxidising conditions
- Results suggest that in most cases, the oxidation state of the magma is not the main factor determining diamond preservation
- This may indicate that a significant amount of resorption takes place prior to entrainment of the diamond in its host magma
- Alternatively, other factors such as rate of magma ascent and / or the quantity and nature of volatiles may be important

REFERENCES

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