

Variations in Stable Isotope Compositions for Carbon and Oxygen in some
South African and Lesothan Kimberlites

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The 142 samples studied are of kimberlite matrix from some diamond-bearing pipes and other kimberlite bodies visited on the field trips associated with the First International Kimberlite Conference in 1973. These rocks were grouped into three types in a compound classification scheme based on, (a) descriptions in the literature, (b) textural, mineralogical and petrographic descriptions on the hand specimens and thin sections, and (c) field relationships within each kimberlite body. They are:

Type 1 kimberlite or massive kimberlite lacks fragments and has a dense, dark matrix composed of olivine, serpentine, ilmenite, small fibrous aggregates of phlogopite, and carbonates. The carbonates in the 42 samples analysed occur in one or more of the following habits:

- (a) segregations or ocelli,
- (b) irregular bladed carbonate crystals that look like a quench product,
- (c) disseminated anhedral grains,
- (d) replacement products in sub- and anhedral olivine grains.

Type 2 group, represented by 23 samples, occurs generally in tabular bodies composed predominantly (>60%) of anhedral carbonate, with minor magnetite or ilmenite and serpentine, and accessory phlogopite in a medium to fine-grained hypautomorphic granular textured rock. These "dikes" differ in color (grey) and texture (granular and locally poikilitic) from the adjacent kimberlite, and they are considered to be "late stage" carbonatite-kimberlites. Carbonate metasomatism of the host rock has produced the "piebald kimberlite" at Premier Mine.

Type 3 group (77 samples) is termed fragmental kimberlite due to their brecciated appearance. Phenocrysts of "rounded" olivine, serpentinized olivine, pyroxene, pyrope garnet, and angular fragments of country rocks occur in a dense matrix of serpentine, phlogopite, and carbonates. Lapilli of earlier generated kimberlite are an important but rare autolithitic component. The carbonate minerals occur in the following habits:

- (a) large "rounded" nodules of crystalline limestone,
- (b) angular limestone fragments (sedimentary),
- (c) small aggregates of carbonates in the matrix,
- (d) finely dispersed grains in the matrix.

The only carbonate minerals detected by XRD analysis were calcite and dolomite. Figure 1 is $\delta^{13}\text{C}$ versus $\delta^{18}\text{O}$ plot of the isotopic data obtained with geographic locality. The carbon values are more variable than has been determined previously by other workers. The average carbon and oxygen isotopic compositions of the kimberlites by location are summarized in Table 1, under title of matrix, inclusions or segregations, and the total. In Figure 2 the mean $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values have been plotted for each locality, together with "error" bars to represent standard deviations from the mean. Each location is numbered except for the solid square, which represents the mean isotopic composition of the Premier Mine carbonatite-kimberlite dikes (type 2), and the solid circle which indicates the fragmental kimberlite (type 3) at this same location.

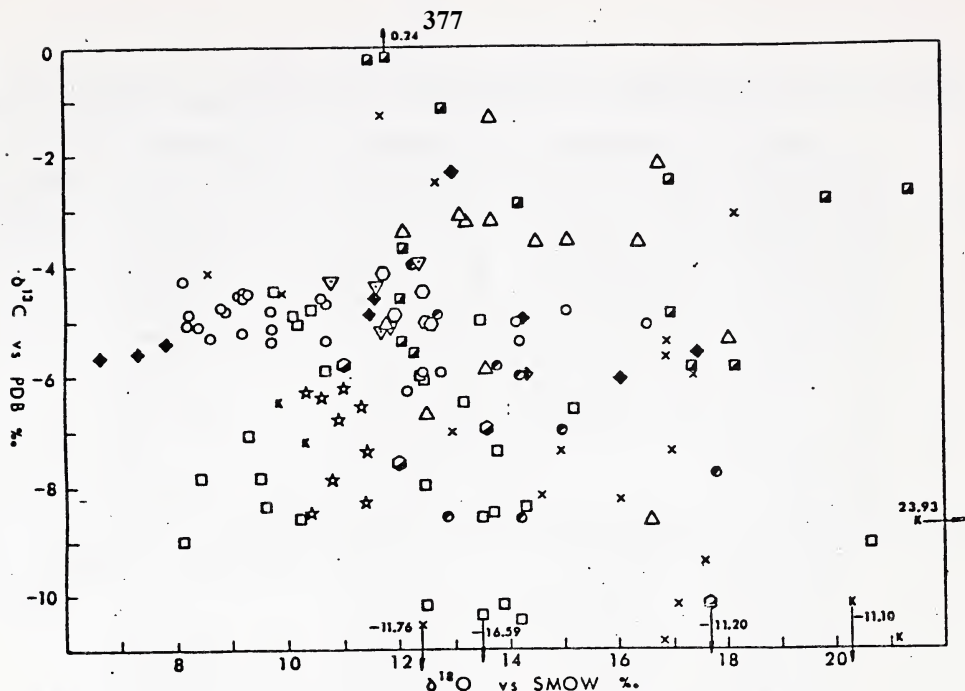


Figure 1 The isotopic composition of South African and Lesothan kimberlite carbonates of this investigation. Symbols are for localities and represent: ○ = Benfontein Sill, × = DeBeers Mine, ◆ = Wesselton, △ = Monastery Mine, □ = National, □ = Premier, ▽ = Ngopetsou, ☆ = Star Mine, ● = Pipe 200, K = Kao, ● = Marakabei, ● = Roberts Victor.

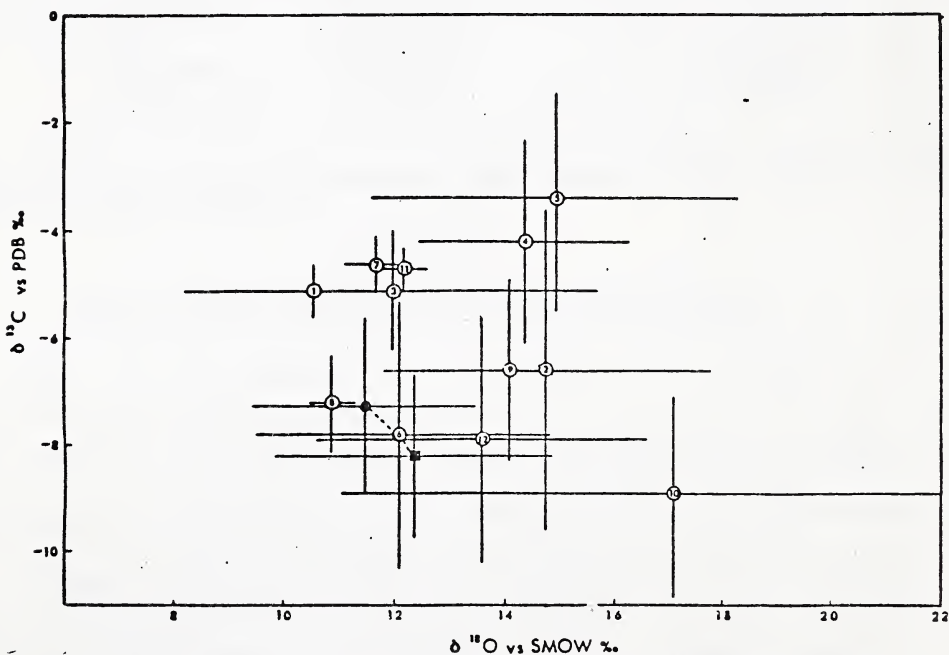


Figure 2 The mean isotopic composition for kimberlite carbonates this investigation by location. Numbers within circles represent: 1 = Benfontein Sill, 2 = DeBeers Mine, 3 = Wesselton, 4 = Monastery Mine, 5 = National, 6 = Premier Mine, 7 = Ngopetsou, 8 = Star Mine, 9 = Pipe 200, 10 = Kao, 11 = Marakabei, 12 = Roberts Victor.

TABLE 1

The Mean Carbon and Oxygen Isotopic Composition of Kimberlites of this Study

| | Location | Matrix | Inclusion | Total |
|--------------------------------------|-----------------|-----------------------|-----------------------|-----------------------|
| $\delta^{13}\text{C}$ vs PDB (‰) | Benfontein Sill | -5.21 \pm 0.54 (13) | -4.91 \pm 0.38 (12) | -5.07 \pm 0.48 (25) |
| | DeBeers | -5.99 \pm 2.29 (7) | -7.11 \pm 3.45 (10) | -6.65 \pm 3.00 (17) |
| | Wesselton | -4.88 \pm 1.32 (6) | -5.44 \pm 0.65 (4) | -5.12 \pm 1.10 (10) |
| | Monastery | -4.50 \pm 2.30 (6) | -4.03 \pm 1.73 (8) | -4.23 \pm 1.92 (14) |
| | National | -4.41 \pm 1.17 (5) | -2.90 \pm 2.29 (9) | -3.44 \pm 2.05 (14) |
| | Premier | -7.18 \pm 1.86 (18) | -9.10 \pm 3.37 (8) | -7.77 \pm 2.52 (26) |
| | Ngopetsou | -4.60 \pm 0.41 (3) | -4.59 \pm 0.86 (2) | -4.59 \pm 0.52 (5) |
| | Star | -7.61 \pm 0.80 (6) | -6.33 \pm 0.04 (3) | -7.18 \pm 0.90 (9) |
| | Pipe 200 | -6.84 \pm 1.51 (5) | -6.22 \pm 2.29 (3) | -6.61 \pm 1.71 (8) |
| | Kao | -8.89 \pm 2.09 (5) | | -8.89 \pm 2.09 (5) |
| | Marakabei | -4.74 \pm 0.41 (5) | | -4.74 \pm 0.41 (5) |
| | Roberts Victor | -6.81 \pm 0.89 (3) | -11.20 (1) | -7.91 \pm 2.31 (4) |
| | ***** | | | |
| $\delta^{18}\text{O}$ vs SMOW (‰) | Benfontein Sill | 11.62 \pm 2.86 | 9.42 \pm 0.92 | 10.56 \pm 2.39 |
| | DeBeers | 12.82 \pm 2.72 | 16.22 \pm 2.23 | 14.82 \pm 2.93 |
| | Wesselton | 10.62 \pm 4.21 | 13.98 \pm 1.85 | 11.97 \pm 3.74 |
| | Monastery | 16.26 \pm 1.29 | 12.96 \pm 0.72 | 14.37 \pm 1.94 |
| | National | 13.70 \pm 3.47 | 15.70 \pm 3.31 | 14.98 \pm 3.38 |
| | Premier | 11.38 \pm 2.11 | 13.87 \pm 3.14 | 12.14 \pm 2.68 |
| | Ngopetsou | 11.40 \pm 0.51 | 12.09 \pm 0.46 | 11.68 \pm 0.57 |
| | Star | 11.04 \pm 0.38 | 10.66 \pm 0.32 | 10.91 \pm 0.39 |
| | Pipe 200 | 14.71 \pm 1.95 | 13.14 \pm 1.02 | 14.12 \pm 1.77 |
| | Kao | 17.10 \pm 6.56 | | 17.10 \pm 6.56 |
| | Marakabei | 12.23 \pm 0.39 | | 12.23 \pm 0.39 |
| | Roberts Victor | 12.23 \pm 1.31 | 17.74 | 13.61 \pm 2.95 |

The mean carbon and oxygen isotopic compositions for the different kimberlite types are given in Table 2.

TABLE 2

Mean Isotopic Composition of Kimberlites by Type

| Item | | Matrix | Inclusion | Total |
|------------------------------|--------|----------------------|----------------------|----------------------|
| $\delta^{13}\text{C}$ (‰) | Type 1 | $-5.67 \pm 1.46(29)$ | $-4.84 \pm 0.44(13)$ | $-5.41 \pm 1.29(42)$ |
| | Type 2 | $-7.09 \pm 2.19(15)$ | $-7.58 \pm 1.17(7)$ | $-7.24 \pm 3.64(22)$ |
| | Type 3 | $-6.01 \pm 2.08(38)$ | $-5.38 \pm 3.00(39)$ | $-5.67 \pm 2.59(77)$ |
| $\delta^{18}\text{O}$ (‰) | Type 1 | 11.98 ± 2.11 | 9.64 ± 1.18 | 11.26 ± 2.16 |
| | Type 2 | 11.73 ± 2.30 | 14.33 ± 3.59 | 12.56 ± 2.96 |
| | Type 3 | 13.40 ± 4.04 | 14.39 ± 2.68 | 13.90 ± 3.43 |

Angular carbonate xenoliths have similar $\delta^{13}\text{C}$ values as the matrix carbonate. Xenocrystic carbonates tend to be enriched in $\delta^{13}\text{C}$ (heavier) with respect to the matrix. Unzoned and "rounded" carbonate nodules yield similar isotopic values to the matrix carbonates, and are interpreted as cognate xenoliths. Ocelli in the Benfontein sill have a similar $\delta^{13}\text{C}$ value to the matrix carbonates, but are heavier by about 1‰ than early "quench" carbonate needles. Pisolithic kimberlite lapilli and the carbonate matrix, that occur in pipe-like habit in the Star Mine, have similar $\delta^{13}\text{C}$ values, suggesting they originated from the same source. Both the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values of "replacement" carbonates are highly variable and distinctive from those of the matrix carbonates.

Statistical treatments of the data were utilized to construct frequency distributions and to test the various categories for normality. Each of the several groups of kimberlites were analysed with regard to their mean carbon isotopic composition by an Analysis of Variance procedure (ANOVES/ANOVUM). The mean $\delta^{13}\text{C}$ of type 2 (carbonatite-kimberlite) was found to test significantly different from either type 1 (massive) or type 3 (fragmental) kimberlites, and the type 1 and type 3 kimberlites were found to be isotopically similar. The mean $\delta^{13}\text{C}$ of the three general groups of kimberlites are:

Type 1 = -5.41 ‰, \pm 1.29;

Type 2 = -7.24 ‰, \pm 3.64;

Type 3 = -5.67 ‰, \pm 2.59.

Another test (ANOVUM) showed that the mean $\delta^{13}\text{C}$ of isotopically similar kimberlite types (e.g., 1 and 3) may be significantly different with locality. A similar analysis of the $\delta^{18}\text{O}$ data yielded inconclusive results. However, a comparison of the mean $\delta^{18}\text{O}$ values of kimberlites by their geographic location reveals a possible significant difference.

Dolomite samples from the Benfontein kimberlite sills were found to be significantly heavier in $\delta^{13}\text{C}$ (+0.65 ‰) than coexisting calcites. It was noted that the enrichment in $\delta^{13}\text{C}$ in dolomites is characteristic of primary carbonatites.

A comparison between subsamples with different habits of carbonate indicates there is a high "in-sample" variability, and that steep isotopic gradients can occur between different phases. This comparison, the statistical tests of the $\delta^{13}\text{C}$ and the $\delta^{18}\text{O}$ data, and a search of the recent literature suggests that the observed isotopic variation may be a number of factors, the most likely being:

- (1) Carbon isotopic fractionation process between an initial "heavy" silicate + CO_2 kimberlite phase, and a later "light" carbonatite phase;
- (2) meteoric-hydrothermal fluid interaction with the kimberlite after emplacement, evidenced by isotopically distinctive replacement carbonates within the kimberlite;
- (3) a degassing process of the isotopically heavy CO_2 - H_2O phase during emplacement;
- (4) isotopic inhomogeneities due to geography and elevation, which may be a function of, (a) a "combined isotopic effect" of all the above factors, (b) isotopic inhomogeneity of the kimberlite magmas, and (c) isotopic inhomogeneity of carbon in the mantle.

Summary and Conclusions

1. The mean isotopic composition of carbonates in 142 kimberlite samples from 12 kimberlite localities in Southern Africa were determined as $\delta^{13}\text{C} = -5.92\text{‰}$ vs PDB ($\sigma \pm 2.42$), and $\delta^{18}\text{O} = 12.91\text{‰}$ vs SMOW ($\sigma \pm 3.23$).
2. Although the mean isotopic (carbon) composition is comparable to the values established for diamonds and carbonatites (see Figure 3), the mean oxygen isotopic composition of these kimberlites is enriched in $\delta^{18}\text{O}$ by several permil with respect to carbonatites.
3. The $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values range from 0.24‰ to -11.76‰ , and 6‰ to 24‰ respectively.
4. Three main types of kimberlite (massive, fragmental, and carbonatite-kimberlite) were distinguished on textural, petrographic and isotopic criteria.
5. There is a significant difference in the mean $\delta^{13}\text{C}$ of some kimberlites from different localities. For those kimberlite locations where the differences between their mean $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values are too great to be explained by a "combined isotopic effect process", then an inhomogeneous source reservoir of carbon isotopes is inferred.
6. Many samples and analyses are needed for a meaningful isotopic characterization of a kimberlite body.

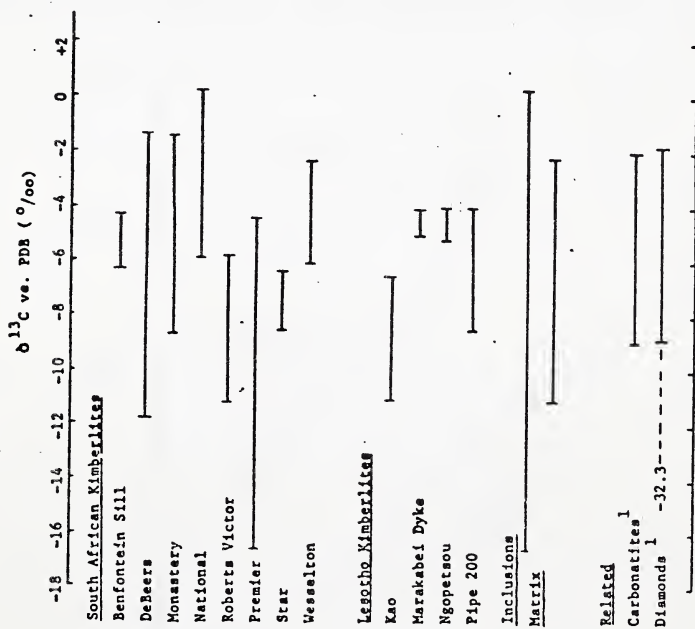


Figure 3 The overlap of the carbon isotopic composition for kimberlite carbonates from the kimberlite localities of this study. Data for carbonatites and diamonds are from : 1. compiled by Deines and Gold (1973) from various works.