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A review of the use and application of mantle mineral geochemistry in diamond exploration

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Abstract

The formation of diamonds and their carrier modes are discussed. Different models with respect to kimberlite and lamproite carriers are considered and the minerals present in these rocks are discussed. Their Formation takes place in peridotite and ecologite in the mantle lithosphere associated with thick cool roots of archaen continent nuclei. The presence of the root may be detected by geochemical studies of the macrocyst mantle minerals in diamondiferous kimberlite and to a lesser extent lamproites. The interpretation of indicator mineral compositions is being upgraded continually by the use of modern analytical techniques and data bases with a view to diamond prospecting. Today this is an extremely successful aid to the discovery of diamonds.

INTRODUCTION

Although it is common knowledge that diamond-bearing kimberlites and lamproites occur primarily on Precambrian cratons, particularly on those underlain by rocks of Archaean age (e.g., Clifford, 1966; Janse, 1991), hypotheses explaining this phenomenon have not provided a rigorous theoretical base for area selection in diamond exploration.

Only after it was recognized that most diamonds in kimberlites and lamproites probably do not belong to the igneous mineral assemblage of their host rocks, but represent xenocrysts, has it become obvious that the understanding of the geotectonic environment of diamond formation is an entirely separate, but equally important problem. The geotectonic foundations of a diamond exploration model include the following three components:

1. Prediction of regions under which diamonds may have formed.
2. Selection of those areas where diamonds may have survived to be sampled by younger kimberlites or lamproites.
3. Establishment of regional tectonic and local structural controls for the emplacement of kimberlites, lamproites, or related rocks in the appropriate areas.

MANTLE ROOTS

Petrological signature

The correlation between diamondiferous kimberlites and Archaean cratons as well as Archaean isotopic dates from southern African diamonds (e.g. Kramers, 1979; Richardson et al., 1984) show that diamonds formed since early lithosphere development and were able to survive beneath Precambrain shield to be picked up by kimberlites and lamproites ranging in age from probable late Archaean to Cenozoic.

Studies of mineral inclusions in diamonds and of mineral assemblages in diamond-bearing xenoliths revealed that diamond formation in the subcratonic lithosphere worldwide was associated with two rock types, garnet peridotites in which harzburgites predominate over lherzolites (yielding P-type diamonds with peridotitic inclusions) and eclogites (with E-type diamonds containing eclogitic highly depleted, peridotitic mantle source with lenses of eclogitized mafic rocks.

Chemical compositions of coexisting minerals in the peridotitic assemblages suggest that the diamonds were stable at pressures corresponding to depths of 150 to 200 km and temperatures generally not exceeding 1200°C (Boyd et al., 1985). Archaean vertical geothermal gradients were thus locally comparable to the lowest values calculated for the present Earth and considering a generally hotter Archaean Earth (e.g., Bickle, 1978), lateral temperature gradients almost certainly exceeded those in the upper mantle today. Diamonds, therefore, were formed and survived in relatively cool lithospheric roots with convex downward-deflected isotherms and a corresponding convex upward expansion of the diamond stability field (Fig. 1).

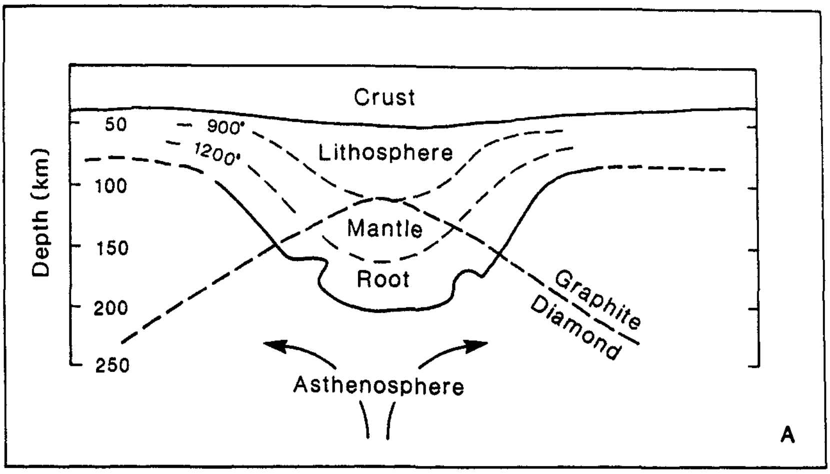

FIGURE 1A. Simplified model of a diamondiferous mantle root (*after Haggerty, 1986*)

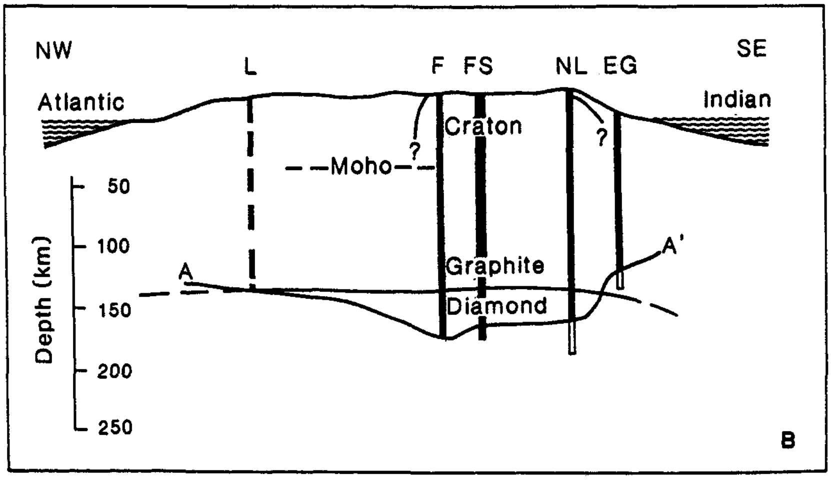

FIGURE 1B. Model for lithosphere below southern Africa based on geothermobarometry on xenolith suites (after Boyd and Gurney, 1986). Ratio of depth to horizontal scale is 4:1 below sea level. Line A–1′ represents points of inflection in xenolith geotherms interpreted as lower boundary of the lithosphere.
L – Louwrencia; F – Finsch; FS – Frank Smith;
NL – northern Lesotho; E – East Griqualand

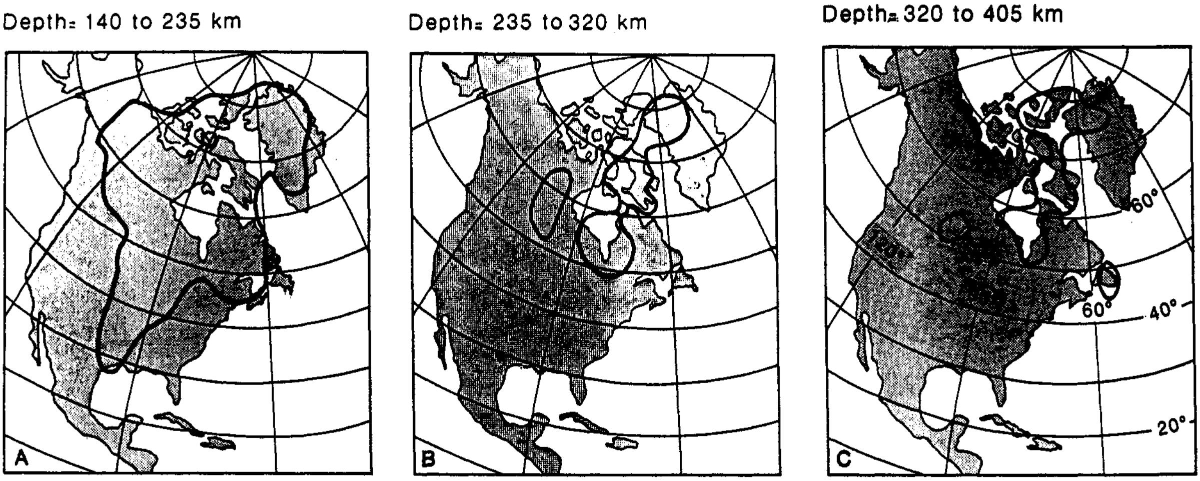

FIGURE 2. Shear wave velocity perturbations under North America (after Grand, 1987). For clarity, only the +3% contour is indicated for depths of 140–325 km (2A) and 235–320 km (2B). Contour for 320–405 km (2C_ is +1.5%

As diamond-bearing kimberlites and lamproites nearly always contain garnet and chromite xenocrysts that resemble the mineral inclusions of P-type diamonds, the presence of diamonds and the indicator minerals (subcalcic, chromium-rich garnets and high-chromium chromites) can be used as a mantle-root signature, suggesting that their host rocks have penetrated a mantle root on their way to the surface. Such a mantle-root signature is particularly strong in southern Africa, where the distribution of P-type diamond indicator minerals in primary diamond sources closely parallels the inferred outline of the Archaean parts of the Kalahari craton (Gurney, 1984). A mantle root consisting of ancient diamond source rocks has thus survived only under the combined Kaapvaal and Zimbabwe craton, where it was sampled by kimberlites of many different ages. In contrast, off-craton kimberlites have a low diamond potential, because mantle roots either never existed in their intrusive paths, or such roots were eroded prior to kimberlite emplacement.

Geophysical signature

Of potential importance for diamond exploration is that petrological evidence from the lamproite- and kimberlite-borne mantle sample is supported by seismological and geothermal data also suggesting that continental cratons have up to 400 km deep lithospheric roots. This exceeds the depth range required by thermobarometric studies for P-type diamonds but would include that of the deepest reported E-Type diamonds (Moore and Gurney, 1985). Based on lower temperatures and higher seismic velocities in the subcratonic upper mantle, Jordan (1975, 1978, 1988) proposed that plates in older continental regions are of greater than average thickness and are underlain by an extensive layer of anomalous mantle material (the tectosphere) which translates with the continents during the plat motions. On the basis of seismic tomography, Grand (1987) found that the shield and stable platform of North America coincide with a region of relatively fast shear waves and that deep, high-velocity mantle roots are situated beneath the Archaean Superior and Slave provinces of the Canadian Shield (Fig 2). As the roots are gravitationally stable, and thus must be composed of less dense material, the higher shear wave velocities within the roots require cooler temperatures relative to adjacent hotter asthenosphere. The seismic properties of mantle roots are thus consistent with the model of relatively cool and chemically depleted, highly refractive lithospheric roots proposed on the basis of petrological studies (Fig 1).

The petrologic model of mantle roots is also consistent with heat flow models attempting to explain the differences in surface heat flow between Archaean cratons and surrounding younger terrains. According to Ballard and Pollack (1987), a cratonic root of relatively cool, non-convecting and poorly conducting, depleted material, extending to depths of 200 - 400 km, can divert enough heat away from the craton to account for 50 - 100% of the observed contrast in surface heatflow between the Archaean Kaapvaal-Limpopo-Zimbabwe craton (about 40 mW/m^2) and the surrounding mobile belts (about 65 mW/m^2).

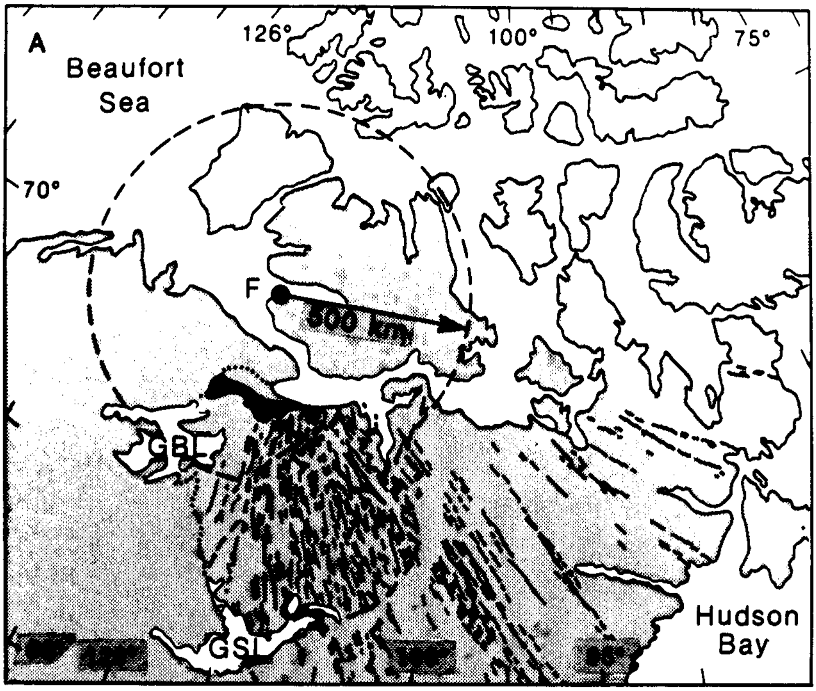

FIGURE 3A. Map showing distribution of Proterozoic MacKenzie dyke swarm with respect to Copper Mine River flood basalts (after LeCheminant and Heaman, 1989). F is assumed focal point of dyke swarm, and dashed circle encloses area of inferred plume. Archaean Slave craton is outlined by dashed line.

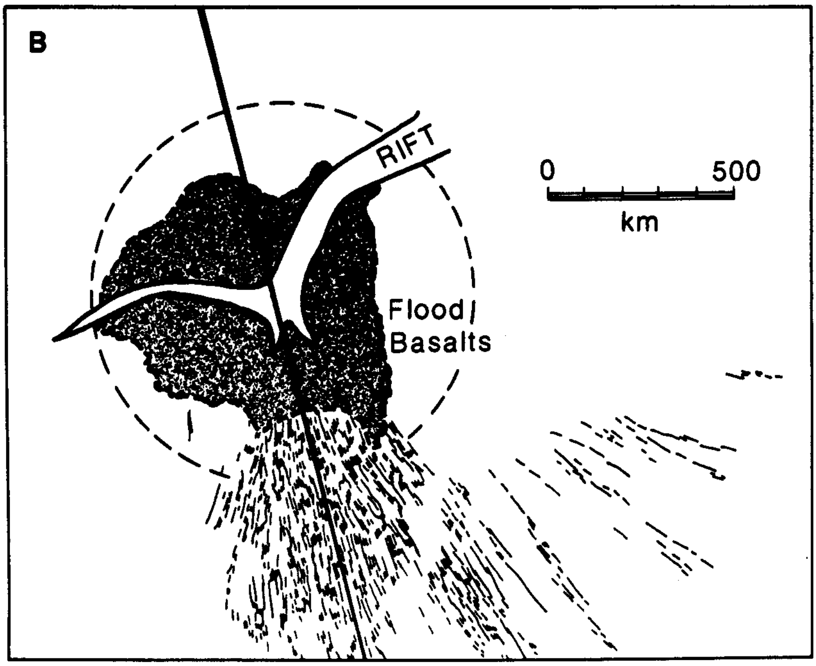

FIGURE 3B. Schematic diagram showing relationship between dyke swarm, flood basalts above centre of plume, and rift (also after Le Cheminant and Haeman, 1989(. North-west striking line (A–B) is line of cross-section on Figure 4.

PRESERVATION AND DESTRUCTION OF MANTLE ROOTS

Although relatively ancient mantle roots appear to have been a requirement for diamond formation, the distribution of the generally much younger kimberlites and lamproites may have no direct correlation with such roots. Preservation of the diamonds requires that the refractive, relatively cool and low-density peridotitic roots stayed insulated against reheating and excessive tectonic reworking and remained attached to the cratons during subsequent plate motions. Large-scale area selection for kimberlite search should therefore concentrate on regions in which Archaean mantle roots have survived either into the Recent, or existed long enough to have been sampled by at least one kimberlite event.

In traditional diamond exploration, the diamond potential of a region would be assessed from the mantle-root signature of alluvial or kimberlite-borne diamond indicator minerals. However, if enough seismological data are available, it should be possible to establish this potential also on the basis of geophysically recognizable mantle roots, as all kimberlites postdating the formation of these roots could be expected to have a strong mantle-root signature and to have tapped the mantle from within the diamond stability field. On the other hand, kimberlites on cratons without geophysical evidence of mantle roots would have diamond potential only if they were emplaced prior to the destruction of an earlier mantle root.

In such cases, a careful assessment of the orogenic and magmatec processes that may have destroyed or preserved the roots is necessary.

Since there is currently a diamond exploration boom in Northern Canada, North America is a suitable area to use as an example.

On the North American craton, which is underlain by a general zone of high shear-wave velocity (Fig. 2A), high-velocity mantle roots extending to depth of approximately 400 km can be recognized under much of the Archaean Superior Province and the southern half of the Slave Province (Grand, 1987) (Figs 2B, C). Both provinces are underlain by Archaean rocks that have not seen major basement reactivations since about 2.4 Ga. The small velocity-high under the Slave Province and adjacent Churchill Province to the south, approaches the present horizontal resolving power of the tomographic inversion (approximately 400 km). Assuming that these mantle roots are of Archaean age (see also Hoffman, 1990), post Archaean kimberlites in these regions should have a better diamond potential than those in the surrounding areas.

The geological constraints on the formation and preservation of these mantle roots were discussed by Hoffman (1990), who pointed out that roots under Archaean crust survived the emplacement of extensive mafic dyke swarms, but were eroded near the sites of mantle plumes. We use the relationship between the middle Proterozoic Coppermine plume in the northern Slave Province to the contemporaneous Mackenzie dyke swarm for an illustration of the resolving power of the present data and to discuss the interaction between these "mantle-root-friendly" and "mantle-root-destructive" structures.

The Mackenzie igneous event comprises a widespread episode of mafic magmatism in the northwestern Canadian Shield that occurred within a time-span of only a few million years at 1270 Ma (LeCheminant and Heaman, 1989) and produced the Copper Mine River flood basalts, the Muskox layered intrusion, and the extensive, fan-shaped Mackenzie dyke swarm (Fig. 3A). The short time-span, large volume and specific focus of the event are attributed to magmatism above a large, plume-generated hotspot that led to rifting and ocean opening (Fig. 3B) (see also Fahrig, 1987). Flow patterns in the dykes of the Mackenzie swarm, determined by measurements of the low-field anistropy of the magnetic susceptibility show a tightly constrained transition from vertical to horizontal flow between 500 and 600 km away from the apex that is believed to map the outer boundary of the plume (Ernst and Baragar, 1991) (Fig. 4).

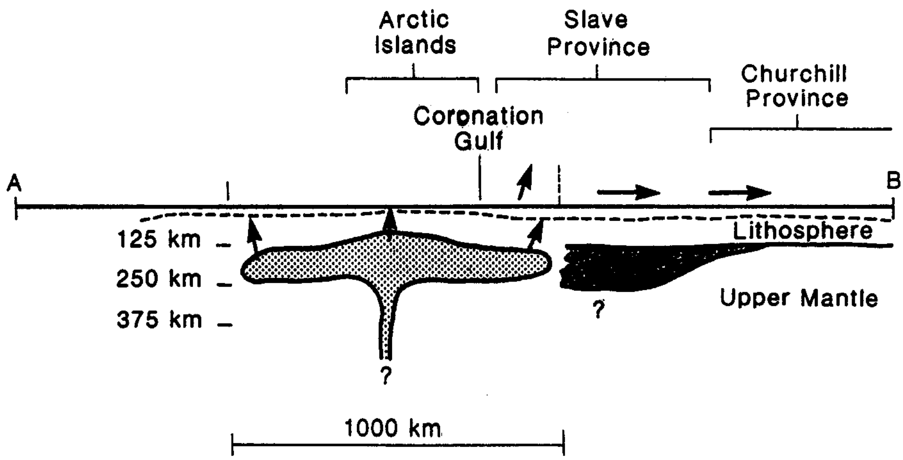

FIGURE 4. Hypothetical cross-section through MacKenzie plume and dyke swarm (Figure 3B). Shaded area under central and southern part of Slave Province represents remnant of mantle root. Arrows above line of section represents change in flow directions in dykes from vertical, above plume, to horizontal, south plume margin indicated by vertical dashed line (after Ernst & Baragar, 1991)

It is interesting to note that the southern margin of the "mantle-root-destructive" plume in the northern Slave Province is located near the northern margin of the observed high-velocity mantle root in this area (Fig. 2B). South of the plume margin (approximately 200 km south of the Copper Mine River flood basalts), the Mackenzie dykes change into "mantle-root-friendly" structures, as they were intruded laterally, probably entirely within the brittle upper part of the lithosphere, leaving the lithospheric root beneath this part of the swarm intact (Figs. 3 and 4). This region of the Slave Province should thus be diamond prospective. Recent discoveries demonstrate this is so.

INDICATOR MINERALS AS A TOOL FOR DIAMOND EXPLORATION

The more resistant mineral macrocrysts in kimberlite; garnet, chromite and ilmenite; are sought in streams and soils on a worldwide basis as evidence for the proximity of a source rock. This has been the practice for more than one hundred years virtually since kimberlite was first recognised as a host for diamond in South Africa. In the past two decades the use of heavy minerals in diamond exploration has been refined to permit as assessment of the diamond potential of that source. This is routinely applied in various major diamond exploration programmes and relies on the interpretation of the composition of the so called "indicator minerals" mentioned above. The criteria used vary widely and can be regionally dependent. Most of the screening mechanisms used to interpret the mineral compositions have been developed within exploration groups along independent lines, are considered to be classified information, and have not been published.

In this paper the indicator minerals distribution and compositions are presented within the framework of a set of rules devised by J J Gurney and recently improved by R O Moore.

The method was designed specifically for kimberlite occurrences in southern Africa, where it has been very profitably applied in many instances. It has also been applied on other continents as well, including North America (e.g. Dummett et al., 1986; Carlson and Marsh, 1989).

It should be noted right at the outset that the scheme was empirically derived and the localities constituting the orientation survey did not include lamproites, It has been apparent for some time that it may not be directly applicable to olivine lamproites in Australia. Although lamproitic diamonds have similar origins to those in kimberlite, the key indicator mineral contents of the host rocks seem lower and less informative with respect to diamond content.

The model on which the method is based considers that macro-diamonds are xenocrysts in the volcanic diatremes from which they are discovered, and that they derived from disaggregated mantle equilibrated diamond-bearing peridotites and eclogites that pre-date the age of emplacement of the volcanic intrusion. This is consistent with evidence reviewed earlier.

The validity for this approach rests on the fact that some diamonds contain mineral inclusions that can clearly be assigned to an eclogitic or peridotitic source, a few are found in xenoliths of eclogite, or more rarely peridotite. The unequivocal assignation of the paragenesis of most diamonds is, however, not possible because they are recovered as single crystals and are often without any definitive inclusions. It is assumed that these diamonds have the same original as the minority that can be defined. On the basis of carbon isotope measurements in inclusion-free diamonds compared to those of known paragenesis this seems reasonable (Jaques et al., 1989; Gurney, 1990). The volcanic host rock is therefore seen only as a transporting agent for macro-diamonds from the upper mantle to the earth's surface. The amount of diamond it contains will depend on at least six variables:-

1. How much diamond peridotite did it sample?
2. What was the average grade of the diamond peridotite?
3. How much diamond eclogite did it sample?
4. What was the grade of the diamond eclogite?
5. How well were the diamonds preserved during the transportation?
6. How efficiently were the diamonds transported to the earth's surface?

The amount of diamond peridotite or diamond eclogite that has been sampled (a & c) should be reflected in the amount of disaggregated mineral grains and/or xenoliths in the diatreme. If these can be identified, it should be possible to forecast whether diamond could be present or not. Identification of garnets and chromites that have specific compositions has indeed turned out to be a useful diamond indicator (e.g. Gurney, 1989). Forecasting accurately the diamond content of a rock that is in the mantle and cannot be directly sampled is unfortunately impossible, so that variations in (b) and (d) cannot be quantified in any rigorous way. Fortunately, the diamond indicator minerals can be identified by certain compositional parameters and the higher the abundance of these minerals that are present in kimberlites, the better the diamond content of the body usually is. However, there are exceptions as must be expected from considerations (a-e) above.

INDICATOR MINERAL GEOCHEMISTRY

It has already been stated that diamond is derived from peridotite and eclogite source rocks. When prospecting for diamonds, fragments of these diamond-bearing rocks need to be discriminated from other rocks including non-diamond bearing peridotites and eclogites, of which there are a large variety. This can be done in various ways. Cluster and multiple component discriminant analysis are widely used on databases of indicator mineral analyses. For instance Dawson and Stephens (1975) classified kimberlite garnets into 12 groups by cluster analysis in an attempt to clarify source rocks for garnet macrocrysts. Danchin and Wyatt (1979) identified 52 group within a much larger database and Jago and Mitchell (1986) advocate a classification technique that combines cluster and discriminant analysis. In the scheme presented here, a simple graphical approach has been applied, since the essential discriminating criteria come down to a few simple facts. Statistical approaches yield similar results (e.g. Fipke et al., in prep).

In the peridotitic diamond paragenesis three sub-groupings are apparent: garnet harzburgite, chromite harzburgite and garnet lherzolite. The harzburgites are depleted in calcium relative to the lherzolites in three ways: the absence of a calcium saturated phase (diopside), a low bulk rock calcium content and low mineral content of calcium. As with most classification schemes there is a little overlap between categories. For instance chromite and garnet can occur in the same harzburgite and chromite can be present in a lherzolite. Other features are incompatible: for instance a sub-calcic garnet can not be in equilibrium with diopside and is therefore never found in a lherzolite. It has been established that the relative importance with respect to diamonds is: garnet harzburgite > chromite harzburgite > garnet lherzolite. In addition garnet lherzolite is not a major component of a diamond inclusion suite at any locality yet described. This is fortunate since garnet lherzolite is the most common mantle xenolith found in kimberlite and it is difficult to differentiate between a diamond-bearing and a barren lherzolite (see Gurney, 1984 for a more detailed discussion). Therefore, garnets of lherzolitic composition have to be discriminated against in an exploration programme. The method described by Gurney (1985) has repeatedly proved to be useful in exploration programmes on several continents.

The minerals closely associated with diamonds have well defined ranges in composition (e.g. Meyer, 1987). In the case of harzburgite diamonds, the garnets are high in MgO and Cr_2O_3 and low in CaO (Gurney & Switzer, 1973; Gurney, 1984; Sobolev, 1974). The component of diamonds derived from garnet harzburgite is assessed by considering both the number of sub-calcic garnets found in a diatreme and their degree of calcium depletion. Whilst not strictly correct in terms of the Dawson & Stephens (1975) classification, these garnets are referred to as "G10" garnets in this text and associated figures whilst lherzolitic garnets are referred to as "G9". The fields are defined in Fig 5.

The so called "G10" field is actually better described as a "diamond in" field. It will contain lherzolitic garnets but these will be from high pressure (> 45kb) garnet lherzolites which could be diamond bearing. Garnets in the "G9" field may be harzburgitic particularly if they plot close to the G9/G10 boundary line but they will not be high pressure enough to be diamondiferous. The problem with a "lherzolite field" as frequently discussed in the literature is that the boundary is pressure dependent. The G9/G10 boundary drawn in Figs. 5 & 6 approximates the position of calcium saturation in garnets in chrome pyrope peridotites at ~45kb only. Nevertheless it has proved to be an excellent diamond indicator line on a world wide basis. Specific examples of its use are displayed in Fig. 6A - D, for Finsch, Premier, Newlands and G025, all of which are diamondiferous.

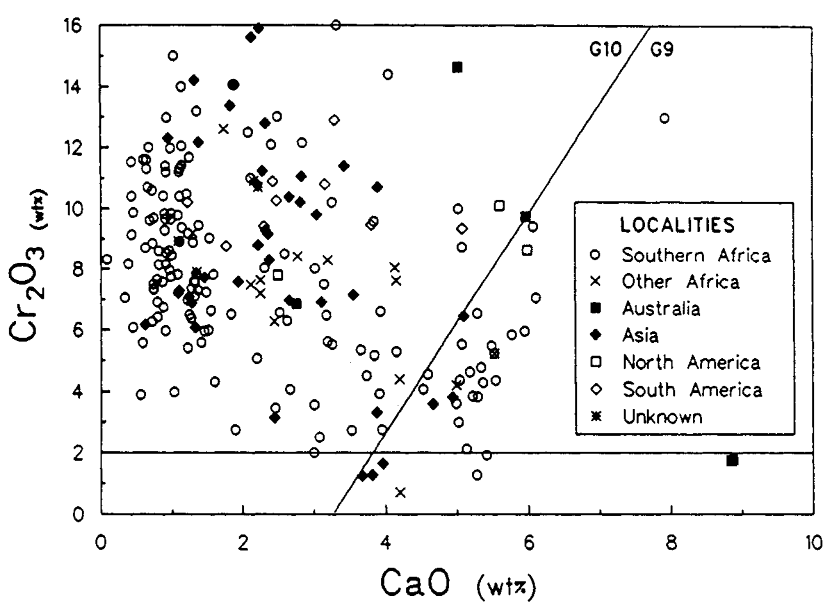

FIGURE 5. A plot of Cr_2O_3 against CaO for peridotitic diamond inclusion garnets from worldwide locaties. The diagonal line distinguishing sub-calcic 'G10' garnets from calcium-saturated 'G9' garnets was defined by Gurney (1984) on the basis that 85% of peridotitic garnets associated with diamond plot in the G10 diamond field. The line may be regarded as a 'diamond in' (G10 side)/ 'diamond out' (G9 side) boundary. The horizontal line drawn at 2 wt% Cr_2O_3 is used as an arbitrary division between eclogitic garnets (<2 wt% Cr_2O_3) and peridotitic (>2 wt% Cr_2O_3).

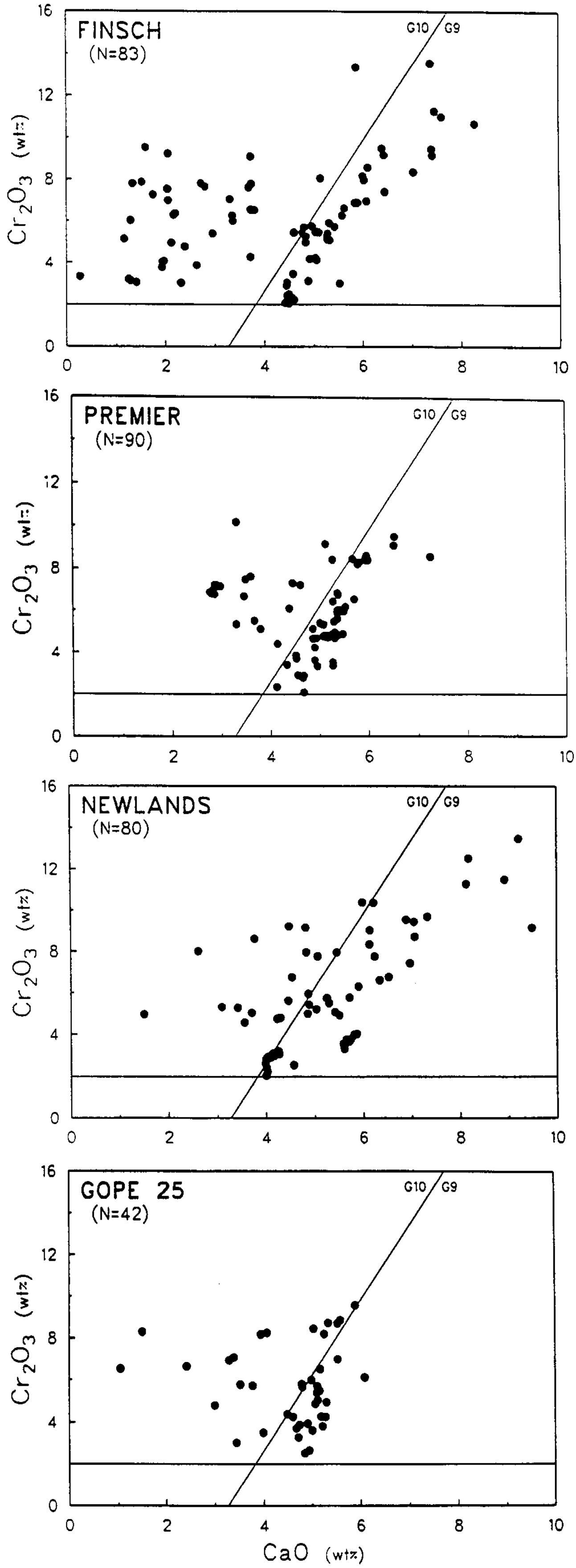

FIGURE 6.
The usefulness of the chrome/calcium plot for peridotitic garnets from Kimberlite pipes is graphically demonstrated by four examples from diamond bearing occurrences

A. Finch Mine, RSA

B. Premier Mine, RSA

C. Newlands Mine, RSA

D. Gope Prospect, Botswana

Chromites associated with diamond show a high average Cr_2O_3 content and some xenocrysts have Cr_2O_3 > 62.5 wt% (Lawless, 1974; Sobolev, 1974; Dong & Zhou, 1980). Chromite is used in a similar manner to garnet to provide an indication of the amount of diamond in the diatreme derived from disaggregated chromite harzburgite. The useful chromite compositions are defined in Fig. 7.

In respect of eclogitic sources for diamonds the most distinctive features of the eclogite garnets associated with diamonds are the trace amounts of Na_2O in garnet ($Na_2O \geq 0.07$ wt%) (first noted by Sobolev & Lavrent'yev, 1971) and the elevated levels of TiO_2 (Danchin & Wyatt, 1979). The composition of eclogitic garnets associated with diamonds worldwide with respect to these two key oxides is

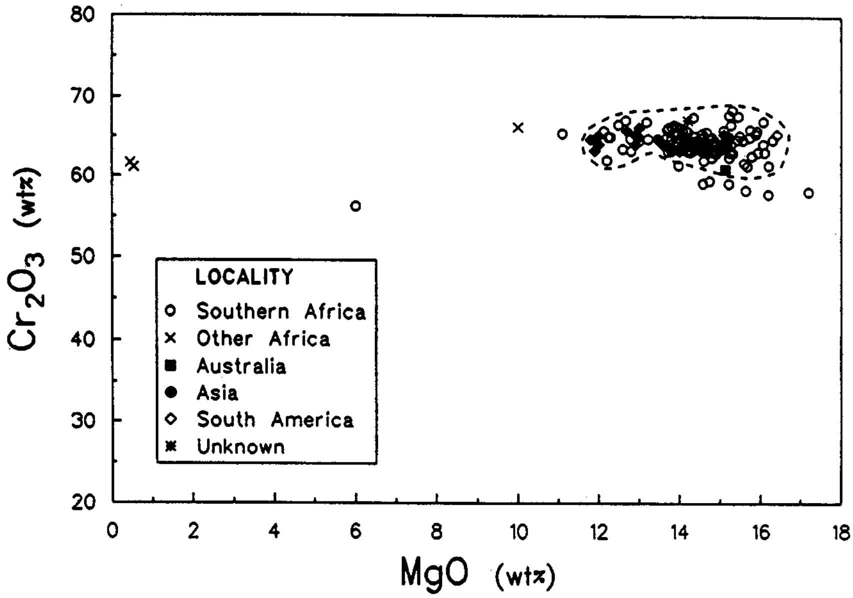

FIGURE 7. A plot of MgO versus Cr_2O_3 for chromite diamond inclusions from worldwide localities. Note the highly restricted chrome-rich character of the inclusions. The preferred compositional field for exploration applications which includes >90% of the data points is indicated.

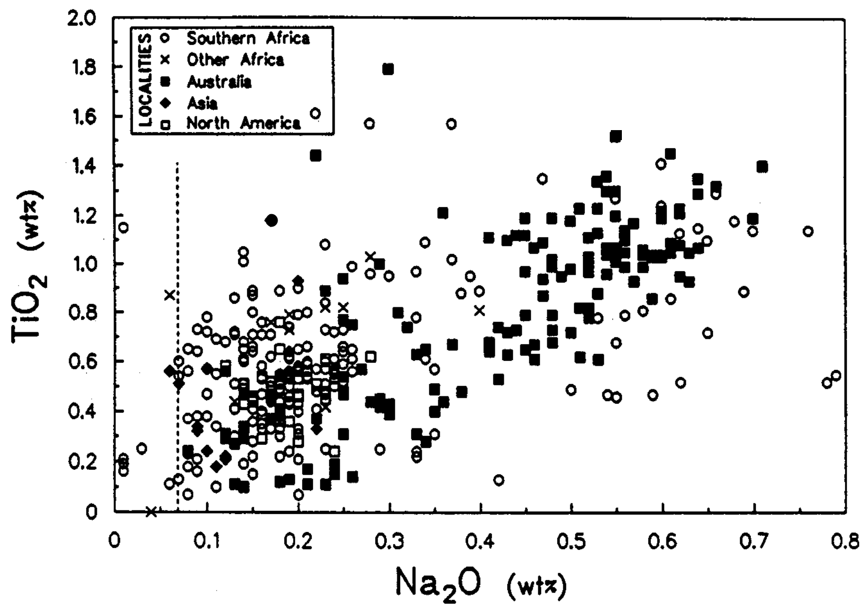

FIGURE 8. A plot of TiO_2 versus Na_2O for eclogitic diamond inclusion garnets from worldwide localities. Note that the elevated levels of both these two elements is characteristic of eclogitic garnets associated with diamonds. In exploration applications, garnets with $Na_2O \geq 0.07$ wt% are considered significant.

presented in Fig. 8. Megacryst garnets contain trace levels of Na_2O that overlap with potentially diamondiferous (Group 1) eclogite. However, since megacryst are not related to diamond in any way, they must be discriminated against. This can be done by using geochemical parameters such as TiO_2, CaO, MgO and FeO contents.

At each locality the contribution to the overall diamond population from each of the garnet harzburgite, chromite harzburgite and eclogite parageneses is assessed by establishing the abundance of the garnets and chromites derived from disaggregation of the mantle host rock. It should be clearly realised that these three diamond sources are additive and that a really good contribution from any one of them could be sufficient to provide an economic grade in diatreme. It should also be apparent from this discussion that it is necessary to establish both the compositions of the indicator minerals and their relative abundances. In the case of G10 garnets it has been noticed empirically that richer kimberlites with abundant harzburgite diamonds tend to have more sub-calcic and chromiferous G10 garnets.

DIAMOND PRESERVATION

Having sampled a diamondiferous rock or rocks in the mantle, an igneous intrusion must carry the mantle sample to the surface. Whilst so doing it is quite clear that conditions within the magma en-route upwards must eventually be outside the diamond stability field and providing the kinetics of the reaction are sufficiently rapid, diamond may be converted to graphite or more frequently to CO_2. The latter will happen more rapidly as a result of higher oxygen activity in the magma. The effect of this resorption on the diamond content of an intrusion can be large. In the model developed for southern Africa, it appears that ilmenite compositions give some measure of these redox conditions. Ilmenite with low Fe^{3+}/Fe^{2+} ratios are associated with higher diamond contents than those with more Fe^{3+}, whilst diamonds are not associated with ilmenites with high Fe^{3+} contents at all. In kimberlitic ilmenites, high Fe^{3+} is associated with low MgO. High Cr^{3+} can be found in either association but is only a positive factor when it occurs with high Mg. Favourable and unfavourable trends can be readily seen on simple MgO/Cr_2O_3 plots or on ternary diagrams such as that presented by Haggerty & Tomkins (1983), and shown here as Fig. 9. The best trend yet described for ilmenites is shown for Tshibua in Zaire in Fig. 10.

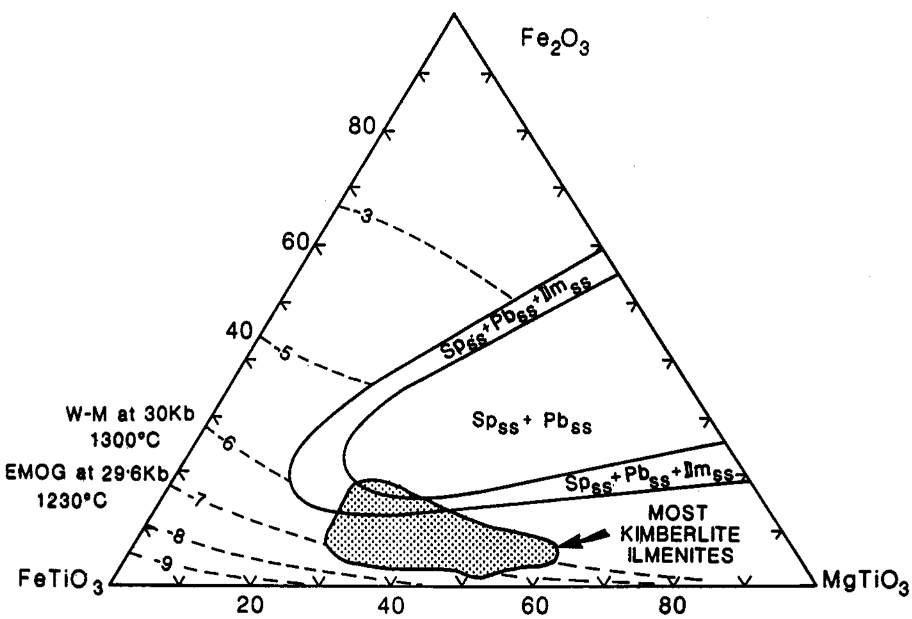

FIGURE 9. Ternary plot from Haggerty and Tompkins (1983) showing the field for Kimberlitic ilmenites and the relationship of composition to redox conditions related to ilmenite, gekielite and hematite end members.

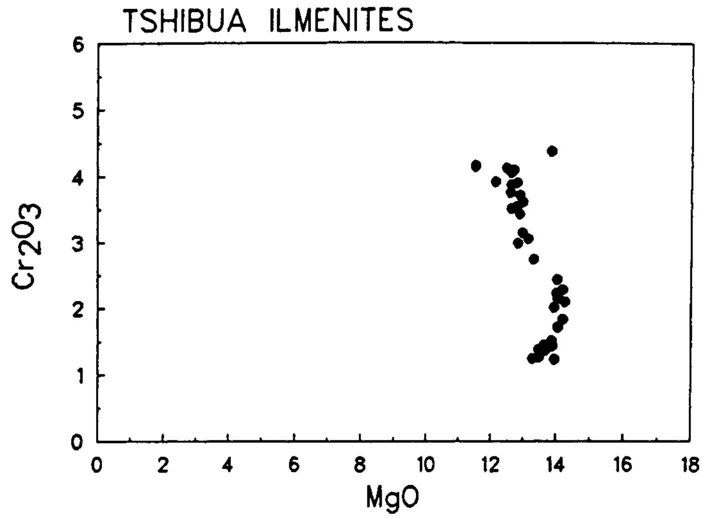

FIGURE 10. Cr_2O_3 vs MgO plot for Tshibua ilmenites. High MgO correspondence to high gekielite. Stoichiometry indicates these ilmenites have very low ferric iron indeed. The high chrome contents of the Tshibua ilmenites are unusual.

It is interesting to point out that Tshibua diamonds are notable for frequently being fibrous and for gem quality macro-diamonds to sometimes have fibrous coats. There is some evidence from carbon isotope measurements and nitrogen studies to support a young origin for fibrous diamond. Perhaps redox conditions favoured late stage diamond growth at Tshibua whereas at other localities in southern Africa the diamonds underwent resorption at this stage? (See Gurney 1989).

Any assessment of the economic potential of a kimberlite based on indicator mineral compositions must view the evidence as an integrated package. The peridotitic and eclogitic diamond potentials are additive and a preservation index is only valid if diamonds were present in the first place.

Different diamond provinces appear to obey different sets of rules particularly with respect to preservation. For instance at most kimberlite localities on the Kalahari craton resorption of diamonds is a very significant process. In the Malo-Botuoba and Daldyn-Alakhit regions of the Siberian Platform which include the Mir, Udachnaya and Jubilee kimberlites, resorption is of much lower significance. In Zaire and Sierra Leone, late stage fibrous coats on numerous diamonds suggest that the last event in the diamond history in those regions was a period of diamond growth. Variations in the eclogitic to peridotitic ratio of the diamonds may also be regional. The three kimberlite mines in Botswana for instance show higher than average proportions of eclogitic diamonds, which is also the case for the described primary diamond sources in Australia (Hall & Smith, 1984; Jaques et al., 1989). As with most geochemical approaches to mineral exploration, an orientation survey within a prospective area is a strongly advisable prerequisite and in detail the interpretations must be continuously adapted to the database compiled.

A final question is how much reliance to place on diamond potential forecasts based on the geochemistry of indicator minerals. The method is not infallible as detractors do not hesitate to point out whenever a locality is discovered that does not fit the model. The kimberlites in the Kuruman area, South Africa, are examples to add to the lamproite localities mentioned earlier. Overall, however, the system is a major aid to exploration programmes. In Botswana, where it was applied by Falconbridge Explorations to several tens of kimberlites discovered under Kalahari cover in the early 1980's, the heavy mineral analyses correctly identified all the barren kimberlites, all the diamond-bearing kimberlites and had flagged the best diamond bearing body found (G025) immediately the first batch of heavy minerals from that source passed in front of the microprobe. In this environment of hidden ore bodies, it was an unqualified success.

In a Venezuelan stream sampling programme in 1975, the presence of G10 garnets from a nearby diamond source was picked up in the Guaniamo region where the primary source of some of the alluvial diamonds has now been found (Nixon et al., 1989). Earlier than that, the system demonstrated the proximity of a then unknown primary source (Dokolwayo) to the Hlane alluvial diamonds in Swaziland.

Accurate forecasts about the presence or absence of diamonds has also been made for Brazilian kimberlites and for numerous localities in southern Africa both barren and diamond-bearing which now constitute the data base mentioned earlier. The method has been successfully applied in the Banankoro region in Guinea, West Africa. In North America, it was used to prioritise the sampling of the Georges Creek dyke in the Colorado/Wyoming State Line District, it provided acceptable forecasts for the nearby Schaffer and Sloan 2/5 diatremes, and predicts the absence of diamonds at Iron Mountain. The heavy mineral assessment of the kimberlites in the Upper Peninsula, Michigan is again in good accord with the known facts in that area (McGee, 1988). Even the Twin Knobs lamproite in Arkansas conforms to the general kimberlite pattern (Waldman et al., 1987). The fact that the diamonds are being traced by association with fragments of the mantle rocks from which they have been originally released by disaggregation is such a fundamental association that whatever geological vehicle has been used to convey them to surface there is a chance semi-quantitative relationships may hold.

Where they do not, further geochemical detective work may reveal relevant clues. The diamonds may not have been preserved en-route to surface, the lithosphere may not have been thick enough or the geothermal gradient sufficiently low to permit diamond formation and/or storage to have occurred. The apparently necessary metasomatic activity that may have a particularly important role in the formation of peridotitic diamonds may never have occurred and a suitable carbon source may therefore not be available. There may be clues available to these facts, some of them in the major and trace element contents of other mantle minerals that occur in the diatreme under investigation. Given the wide range of uncertainties, a balanced view has to be permissive of exceptions to the rules since these are obviously certain to occur.

G10 garnets can be produced in environments other than the deep cool keels of continents (e.g. Boyd and Nixon, 1989). They can also occur in continental keels that are too hot and thin to contain diamonds (Shee et al., 1989). Clues to these exceptions can be obtained from the calcium and aluminium contents of orthopyroxenes, the Ca/Ca+Mg ratios of clinopyroxenes, or the nickel geothermometer of Griffin et al., (1989). It is even possible that the metasomatism in G10 garnets documented by Shimizu & Richardson (1987) is a prerequisite for peridotitic diamond formation, in which case the absence of unusual trace element patterns in the G10 garnets would be a negative indicator. Such trace element determinations and even the nickel in garnet measurements are too difficult to obtain at present to make them routine determinations during prospection. On the other hand, as long as mineral compositions are determined only by electron microprobe therefore, some errors of assessment will continue to occur. The essential point from a forecasting point of view remains that analysis of indicator minerals by electron microprobe can give a relatively cheap, rapid and useful indicator of diamond potential in the source.

The current discovery of diamond bearing Kimberlite north east of Yellowknife in the North West territories is a classic example of the usefulness of the diamond indicator mineral composition analyses. The original heavy mineral trail was picked up by geologist, Chuck Fipke working in association with Steve Blusson and Hugo Dummett, then of Superior Oil. The mineral compositions indicated derivation from an outstanding diamondiferous source if that could be traced.

Not only did the early identification of the outstanding potential of the yet to be discovered source area sustain interest over a nine year search period, but the mineral compositions were also used to delineate the area staked by the current Diamet/BHP joint venture from other less prospective ground. At the present time diamond indicator mineral compositions and abundances are considered when prioritising drill targets.

This discovery is precisely in the region of the Slave Province described earlier as being diamond prospective on structural, tectonic and geophysical grounds. It is another example of the convergence of different approaches to establishing the fundamentally important presence of a thick, cold, ancient lithospheric root to store diamonds in the earth's upper mantle.

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