GEOTECTONIC CONTROLS OF DIAMONDS AND KIMBERLITES AND THEIR APPLICATION TO DIAMOND EXPLORATION.

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Although it is common knowledge that diamond-bearing kimberlites occur primarily on Precambrian cratons, particularly on those underlain by rocks of Archean age, hypotheses explaining this phenomenon have not provided a rig orous theoretical base for area selection in diamond exploration. One of the major problems was the general assumption that exploration for kimberlite diamonds consists of searching for diamondiferous kimberlites and that efforts to establish exploration models need focus only on understanding the larger-scale geotectonic and regional structural controls of kimberlite distribution. Only after it was recognized that most diamonds in kimberlites may represent xenocrysts, has it become clear that understanding the geotectonic environment of diamond formation is an entirely separate, but equally important problem. Realistic diamond exploration models must thus 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 picked up by kimberlites or lamproites.
3. Establishment of regional tectonic and local structural controls of kimberlites, lamproites, or related rocks in the appropriate areas.

The correlation between diamondiferous kimberlites and Archean cratons as well as Archean isotopic dates from southern African diamonds (Kramers, 1979; Richardson et al., 1984) clearly indicate that diamonds formed since early lithosphere development and were able to survive in mantle roots beneath Precambrian shields to be picked up by kimberlites and lamproites ranging in age from the Proterozoic to Late Mesozoic. Judging from mineral inclusions in diamonds and the mineral assemblages of diamond-bearing xenoliths (eclogites and garnet harzburgites), these mantle roots consisted mainly of highly depleted peridotites with lenses of eclogitized mafic rocks. This composition as well as the fact that, in a generally hotter Archean lithosphere, the relatively high P - low T gradient required for diamond formation could only be achieved by tectonic burial of relatively cool material, suggest that the mantle roots were formed by subduction of oceanic lithosphere (e.g., Schulze, 1986; Helmstaedt and Schulze, 1989). Survival of the diamonds is possible only if the refractive, relatively cool and low-density roots stay attached to the craton during subsequent plate motions and remain insulated against later re-heating and excessive tectonic reworking.

Of importance for diamond exploration is the fact that the presence of relatively low-density and low-temperature mantle roots can be detected by their high shear-wave velocities relative to adjacent hotter asthenosphere (e.g., Grand, 1987). Available data indicate that such roots are more common under Archean cratons (as compared to Proterozoic shields and Phanerozoic orogenic belts), though they are not equally developed or present under all Archean crust (e.g., Hoffman, 1990). The key to understanding this secular control on the formation of mantle roots is the Archean tectonic environment, in which a buoyant, shallow mode of subduction was predominant allowing continental nuclei to become tectonically underplated by depleted oceanic lithosphere. Subduction zones became generally steeper in post- Archean times, when the shallow subduction mode was restricted to regions of exceptionally fast plate convergence and/or subduction of young ocean floor (Helmstaedt and Schulze, 1989). Although relatively ancient mantle roots appear to have been a requirement for diamond formation, the distribution of the generally much younger kimberlites may have no correlation with such roots. Large-scale area selection should thus concentrate on regions in which mantle roots have survived at least until kimberlite emplacement. On cratons with geophysically recognizable mantle roots, all kimberlites postdating the establishment of the mantle root should have a relatively high diamond potential. 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 magmatic processes that may have destroyed or eroded the roots is necessary.

In North America, mantle roots underlie the Archean southern Slave Province and much of the Superior Province (Hoffman, 1990), suggesting that post-Archean kimberlites in these regions should have diamond potential. On the other hand, if an ancient mantle root had survived the Proterozoic orogenic activity along the margins of the Archean North Atlantic craton (Nain and Greenland), it was destroyed by the Iceland plume that initiated the opening of the Atlantic (Hoffman, 1990). Mesozoic kimberlites on this craton thus have a low diamond potential. Although the Archean Wyoming province has no mantle root at present, the diamond potential of the State Line kimberlites is probably the result of kimberlite emplacement in the Devonian (Naeser and McCallum, 1977), predating the erosion of remnants of an old mantle root by Tertiary shallow subduction (Helmstaedt and Doig, 1975; Bird, 1988) related to the Laramide orogeny.

In southern Africa, on-craton kimberlites of many different ages are diamondiferous, because parts of an ancient mantle root survived under the Kaapvaal craton at least until the end of the Cretaceous. Off-craton kimberlites have a low diamond potential, because mantle roots either never existed in their intrusive paths, or such root were eroded prior to kimberlite emplacement. During area selection on diamondiferous cratons, post-mantle root and pre-kimberlite tectonic and magmatic processes must be considered when evaluating regional or local structural controls that have provided pathways for the kimberlites. Thus mantle-root-friendly features, such as mafic dyke swarms (e.g., Karroo) must be distinguished from mantle-root-destructive structures, such as larger-scale crustal fractures, hotspots, and plumes, that may control the location of kimberlites, but have a negative effect on the diamond potential of the root. Examples of the latter are crustal-scale fractures in the Brazilian shield, that have controlled the ascent of magmas during the Late Proterozoic Brazilian event and have later served as pathways for Mesozoic kimberlites. An early mantle root under the Brazilian shield, indicated by the occurrence of detrital diamonds in Proterozoic sedimentary rocks, must have been destroyed during Proterozoic orogenic events, for the Mesozoic kimberlites following the Brazilian structures do not contain significant amounts of diamonds.

As shown by the diamond potential of the Kimberley region of Western Australia, post-Archean mantle roots may also be prospective exploration targets, and kimberlites are not the only magmas to tap the roots. The Kimberley region provides an excellent opportunity to test the effects of tectonic and magmatic events on the gradual erosion or destruction of mantle roots, for similar lamproites have sampled the mantle root in the Late Proterozoic (1180 Ma) and the Mid-Tertiary (20-22 Ma) with vastly different economic results (e.g., Jaques, 1989). Here, as in regions of multiple kimberlite events, studies of xenoliths, xenocrysts, diamonds, and diamond inclusions should be more closely integrated with structural and tectonic studies to monitor the status and diamond potential of mantle roots through time, and to establish improved theoretical models for future exploration.

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