TRACE ELEMENTS IN INDICATOR MINERALS: AREA SELECTION AND TARGET EVALUATION IN DIAMOND EXPLORATION

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Early recognition and rejection of uneconomic prospects is essential to an economically rational diamond exploration program. Some powerful new techniques for prospect evaluation have been developed by the CSIRO, based on the trace-element capabilities of the proton microprobe (Griffin and Ryan, 1995). On the larger scale, these techniques also can contribute to the process of area selection.

The nickel content of chrome-pyrope garnet equilibrated with mantle olivine increases with temperature; because the Ni content of mantle olivine is large and relatively constant (2900±360 ppm), the Ni content of the garnet gives a temperature estimate without prior knowledge of the coexisting olivine's composition. This "Ni thermometer" can be used to measure the distribution of equilibration temperatures (T_{Ni}) in garnet concentrates from exploration targets such as kimberlites and lamproites. A "Cr barometer", based on the partitioning of Cr between garnet and orthopyroxene in equilibrium with chromite, gives a minimum estimate of pressure (P_{Cr}) for each grain.

By combining T_{Ni} and P_{Cr}, the position of the local paleogeotherm (the "Garnet Geotherm") can be derived from garnet ± chromite concentrates (see Ryan et al., 1995, and this volume), and the depth of origin of each garnet grain can be determined by referral of its T_{Ni} to the derived geotherm. For our purposes, the lithosphere is defined as the depth to which depleted (Y≤ 10 ppm) garnets are found. The depth to the base of this chemically-defined lithosphere can be derived from plots of Y content vs. T_{Ni}, and where xenolith data are available, this depth is seen to correspond to the "kink" or "step" in xenolith P-T estimates. This depth therefore is regarded as the point where conduction is no longer the dominant mechanism of heat transfer, and suggests that the chemical and thermal definitions of the lithosphere are roughly coindident beneath many cratonic areas.

Assuming that most macrodiamonds are derived from the lithosphere, the "Diamond Window" is defined as the range of T_{Ni} between the intersection of the geotherm with the diamond-graphite equilibrium curve and the base of the lithosphere. Diamond-rich pipes contain a large proportion of garnets with T_{Ni} in the diamond window, while diamond-poor pipes typically contain a high proportion of garnets with lower T_{Ni}, reflecting greater sampling of mantle within the graphite field. Many weakly diamondiferous and barren pipes also contain abundant garnets with high Zr, Ti and Y contents, reflecting metasomatic processes in the mantle. These relations show that the diamond content of a kimberlite is determined firstly by the extent to which it has sampled mantle within the diamond window, and secondarily by the previous depletion/metasomatism history of that volume of the mantle.

The observed correlation (within some Archons) between subcalcic "G10" garnets and diamond grade reflects a stratification of the lithosphere in these regions, in which most harzburgitic rocks lie at depths within the diamond stability field. However, in some regions these rocks occur at shallow depths, while in others magmatic processes have raised the geotherm and brought the harzburgites into the graphite stability field (cf. Sablukov et al., this volume). "G10" garnets therefore are only useful as a guide to diamond prospectivity where they can be shown by Ni thermometry to be derived from within the diamond stability field.

An empirical Zn thermometer (Griffin et al., 1994; Ryan et al., 1995 and this volume) allows temperature estimates for single chromite grains. The relation between Cr/Cr+Al and T_{Zn} allows a rough estimate of the local paleogeotherm, which can be used to verify the Garnet Geotherm. T_{Zn}, used in concert with statistical discriminants based on major- and trace elements, also helps to identify high-Cr chromites ("diamond-inclusion-like" chromites) that are derived from crustal source rocks.

A combined measure (Γ) of T_{Ni} distribution, rock type proportions and metasomatism in garnet concentrates shows a strong correlation with diamond grade, and can be used to predict the maximum probable grade of an exploration target. Significant deviations from this correlation are shown by some pipes, such as Sloan and Jwaneng, that contain a high proportion of eclogitic diamonds; in these cases the predicted grades are lower than the actual ones. Pipes with unusually high proportions of small diamonds, such as Roberts Victor, deviate in the opposite direction; the Γ estimator predicts a higher ("geological") grade than the relevant ("commercial") one. Despite these problems, the technique is a useful tool in prioritising exploration targets, including drainage samples, for further work.

Areas with elevated geotherms are inherently less prospective for diamonds, since the geotherm enters the diamond stability field only within the deepest part of the lithosphere, or not at all. Determination of the Garnet Geotherm therefore is immediately useful in the area selection process for diamond exploration, and this can be done on the basis of early heavy-mineral sampling, before any primary source rocks have been found. With more data, stratigraphic sections showing the thickness and thermal and compositional structure of the lithosphere can be constructed from garnet and chromite concentrates. These sections can be compared with those from well-known areas of different age and diamond prospectivity, to evaluate the probability that economic diamond deposits will be found within a region.

References

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