# Presence of Diamonds in British Columbia: Inconsistencies with the South African Model

Richard T. Walker
Dynamic Exploration Ltd
2601 - 42nd Avenue South
Cranbrook, BC V1C 7H3

**Notice to Readers:** This report was originally published by the author on the East Kootenay Chamber of Mines (EKCM) website in 1999. Archival reference to the original paper is available through on The WayBack Machine website under the URL address:
http://web.archive.org/web/19991004013647/www.cyberlink.bc.ca/~ekcm/book.htm.

## INTRODUCTION

The Cordillera has been considered non-prospective for diamonds for a number of factors, including: (1) location in a Paleozoic - Cenozoic mobile belt, on thin, attenuated (non-cratonic) basement; (2) lack of abundant indicator minerals, including pyrope garnet, chrome diopside, picro-ilmenite and/or chrome spinel (chromite); (3) lack of abundant kimberlite and/or lamproite pipes; and (4) lack of a thick lithospheric keel underlying the Cordilleran portion of western Canada. In support of the above factors, a study undertaken by the G.S.C. (1989; Fipke et al., 1995), apparently confirmed these conclusions. However, the best diamond indicator of all, diamond itself, has been recovered from at least four separate diatreme occurrences, namely: the Jack and Mark occurrences north of Golden and the Ram 5 and 6.5 pipes northwest of Elkford. Furthermore, diamonds were reportedly recovered near Christina Lake, far removed from any thick cratonic areas or kimberlite and/or lamproite intrusions.

To rationalize these diamondiferous localities, the author proposes one or both of the following exploration models, the Lamproitic diamond (LD) and/or the Eclogitic Subduction (ES) model. These models differ from the South African Diamond (SAD) model in that they: (1) do not require a thick, long lived lithospheric keel (ES model); (2) can account for diamonds in a wide variety of ultramafic to mafic, potassic to ultrapotassic lithologies (ES model); (3) accommodate, or even require, thinner, hotter, and possibly younger crust than the SAD model; (4) account for a range of delta $^{13}$C values in E-diamond, compatible with diamonds derived from high pressure - temperature metamorphism of subducted sediments and oceanic crust; (5) may or may not include abundant indicator minerals and/or (6) provide a source for diamonds at relatively shallow mantle levels in comparison to mantle depths interpreted for kimberlite (ES and, to a lesser degree, LD models).
Furthermore, consideration of the geological environment into which the diatremes were intruded is the critical factor to evaluate rather than the present day location above attenuated lithospheric crust. Basement domains identified in the Alberta Basin can arguably be documented extending at least as far west as: (1) the Rocky Mountain Trench area on the basis of geophysics, (2) the Revelstoke area on the basis of geochronological analysis of gneissic exposures, and (3) the Fraser River on the basis of isotopic geochemistry.

In addition, the geological (and tectonic) environment into which the diatremes were intruded is interpreted to be that of a miogeocline on a stable passive margin. The diatremes were intruded into this miogeocline during one of three periods; the Ordovician-Silurian, pre-basal Devonian and the

Permo-Triassic. To the authors knowledge, there have been no studies regarding the lithosphere - asthenosphere relationship nor the thickness/presence of a possible lithospheric keel during the Paleozoic to Mesozoic. Postulated eastward directed subduction during the East Kootenay Orogeny may have emplaced a subducted slab at suitable depths for E- type diamonds to form and subsequently be entrained during later alkaline igneous episodes.

The author therefore presents empirical arguments regarding application of the LD and/or ES diamond models to explain documented diamond recovery in unconventional settings inconsistent with the SAD diamond model. Further work is required to test the validity of the models with respect to alkaline diatremes of the Cordillera.

**Lamproite Diamond (LD) Model**

"The geological setting and diamond paragenesis at Argyle do not fit the SAD model. In fact, use of this model actually delayed discovery of Argyle because there were no key diamond indicator minerals ... near the deposits. The diamonds occur in a lamproite (rather than a kimberlite) diatreme within the Proterozoic Halls Creek Mobile Zone, well away from the Archaean craton. Further, most of the Argyle diamonds are E-diamonds. These diamonds have not formed below an Archaean craton ..." (Barron et al., 1994).

The LD model can be generally summarized as follows: "Lamproites occur along the margins of cratons or in cratonized accreted mobile belts in regions of thick crust (>40-55 km) and thick lithosphere (>150-250 km). This lithosphere typically records multiple episodes of resurgent tectonic events, both extensional and compressional ... Many lamproites occur along continent-scale lineaments which parallel ... or cross-cut Proterozoic mobile belts ... Lamproites are not related to active subduction zones. However, trace element and isotopic studies suggest that the subducted materials found in paleo-Benioff zones are excellent candidates for the lithospheric sources of lamproite" (Mitchell, 1991).

"Thus the Argyle diamonds formed below the (Halls Creek) Mobile Zone, but only after prolonged conductive cooling had allowed lithospheric thickening to 200 km, more than 50 km into the diamond stability field. This thick lithosphere and related aesthenosphere were slightly hotter and not quite refractory enough to produce kimberlite magma and partial melting, so lamproite magma was produced and carried the diamonds to the surface" (Barron et al., 1994).

**Eclogitic Subduction (ES) Model** (taken from Barron et al., 1994)

In New South Wales, eastern Australia, secondary (alluvial) production of diamonds may exceed 500,000 carats. Despite this, there are no indications of lithospheric crust thick enough for formation of diamonds and no primary kimberlite or lamproite has been identified. Furthermore, the underlying lithosphere is interpreted to be too young and hot and does not extend into the diamond stability field, precluding application of either the SAD or LD models. Finally, small diamonds have been reportedly recovered from nephelinites and/or alkali basalts. These facts, together with the diversity of alkaline lithologies interpreted to have originated in the mantle at shallower levels than kimberlite and/or lamproite, led to the Eclogitic Subduction (ES) model. The ES-model may also explain occurrence of diamonds in geologically comparable diamond provinces in Kalimantan, Parana (eastern Brazil) and China and may account for the presence of diamonds in Kamchatka, India and the Klamath Mountains of California.

According to this model "... diamonds form during active subduction, within a subducting slab which is up to a thousand degrees cooler than the surrounding mantle. The slab transforms according to the prograde facies trend of lawsonite blueschist - eclogite- coesite eclogite - diamond eclogite. As a result, the age of crystallization, isotopic composition and affinity of the diamonds are characteristic of the subducted slab, and are independent of the cratonic lithosphere ... (Subsequently), the slab must remain static below the lithosphere, to be sampled much later by nephelinite magmas which pass through on the way to the surface ... Partial tectonic excavation may precede and aid this sampling process by increasing the spectrum of magmas able to participate" (Barron et al., 1994).

## DIAMOND POTENTIAL OF SOUTHEAST BRITISH COLUMBIA

The Rocky and Purcell Mountains are characterized by thin-skinned tectonics, in which the miogeocline has been thrust onto North American crust, with little or no basement involvement. Lithoprobe studies document continental crust as "... a regionally extensive, west-facing transition from thick craton on the east to thin transitional, basinal or oceanic crust on the west ..." (Cook et al., 1991). Furthermore, based on geochemistry, highly attenuated North American continental crust has been interpreted as far as the Fraser River (Varsek, pers. comm., 1994). Additional support for the presence of North American basement has been identification of basement gneiss documented in the Thor-Odin, Frenchman Cap and Malton Gneiss complexes.

Villeneuve et al. (1993) and Ross et al. (1991) have correlated exposures of the Canadian Shield into the sub-surface of the Alberta Basin using aeromagnetic data, confirmed using geochronological dating of core from 90 basement penetrating drill-holes in the Alberta Basin. The resulting domains can be traced to the eastern Purcell Mountains. Furthermore, the southernmost portion of the Alberta Basin is underlain by Archean basement correlated to the Hearn Province. This predominantly Archean domain underlies the Rocky Mountain Alkaline Belt (RMAB), from the International Boundary to the approximate area of Radium, BC.

There are a range of mafic to ultramafic, alkaline occurrences in the eastern Cordillera, ranging from kimberlite to lamprophyre, including olivine melilitites, lamproites, kimberlites, alkaline to basaltic lamprophyres, alnöites and aillikites. There is only one widely acknowledged kimberlite in the RMAB, the Cross Kimberlite. The Joff occurrence has been described as an alkaline lamprophyre (olivine melilitite) (Pell, 1994) or a hypabyssal facies phlogopite-bearing kimberlite (Fipke et al., 1989). A second kimberlite was reported west of Invermere (Pope and Thirlwall, 1991), having an identical emplacement age and similar mineralogy to the Cross Kimberlite.

Many of the diatremes in the Quinn Creek area have been interpreted to preserve the crater facies in strata of the Beaverfoot Formation, suggesting intrusion during Ordovician-Silurian time (Pell, 1994). Helmstaedt et al. (1988) interpreted other diatremes in the RMAB to be pre-Devonian in age as several diatremes are in sharp contact with, and underlie, the basal Devonian unconformity, suggesting intrusion prior to the unconformity. Finally, the only two kimberlites in southeast BC, the Cross Creek and the Toby Creek occurrences have both been dated at approximately 245 Ma, having a Permo-Triassic emplacement age. Therefore, the critical factor for evaluating diamond potential in southeast British Columbia is not the current location within a mobile belt but the geological environment during emplacement.

To date, the diamond potential of southeast British Columbia has been considered negligible to poor.

This interpretation appears to be supported by lack of sufficient quantities of key indicator minerals, comprised of pyrope garnet, chrome diopside, picro-ilmenite, chrome spinel and/or diamond itself. In addition, a study coordinated by G.S.C. (Open File 2124), concluded that: (1) none of the occurrences studied in the RMAB had any diamond potential, and (2) only the Jack occurrence had any preservation potential. Furthermore, diamonds were recovered from only the Jack and Mark occurrences. However, the same study concluded that the Argyle Mine in Australia (a lamproite), while having very good diamond preservation potential, had negligible to low potential to host diamonds using the criteria of the study. A subsequent study (Fipke et al., 1995) similarly predicted negligible to low diamond content for the Argyle (similar to occurrences in the RMAB) with very good potential for diamond preservation. Yet the Argyle Mine is the most prolific producer of natural diamonds in the world. This suggests that application of the SAD model, possibly even the LD model, may be misleading in a comprehensive diamond exploration program evaluating cratonic margins.

**LD-diamond model**

The LD model predicts the diamond potential of lamproites in ancient mobile belts which have been inactive for geologically long periods of time and in which the mobile belt itself has been cratonized. As such, the regions characterized by such a model would have thinner and possibly hotter crust (with a higher geothermal gradient) and therefore be incompatible with the SAD model. Alternatively, a thich craton which undergoes rifting coincident with crustal thinning may result in a geological environment for which diamond potential might be predicted using the LD model and have features similar to tectonic excavation.

Tectonic excavation is "... a complex process of readjustment that occurs after collision of two continental plates. There is an initial doubling of crustal thickness in the zone of collision (the mobile belt), followed by rotational down-faulting of the uplifted material and upward thrust migration of the depressed material. This process can unroof material from down to 150 km depth, bringing blueschist/eclogite and ultramafic/eclogite belts to the surface ... Incomplete excavation may simply be responsible for bringing the diamond bearing portion of a slab to a high-level position in the crust so that sampling by basalts can take place. This would explain the reports of diamonds found in alkali basalt in Kamchatka" (Barron et al., 1994).

In the geological period between the Late Proterozoic - Early Cambrian rifting event and initial accretion of allochthonous terranes along the west coast, the region was a stable passive margin with associated development of a miogeocline. Although the present lithosphere - aesthenosphere thickness underlying the Cordillera is not interpreted to be deep enough for genesis/storage of diamonds (SAD model), the configuration between the Cambrian and the Jurassic may have been consistent with a SAD and/or LD-model, prior to thermal erosion following eastward-directed subduction.

Therefore, in a manner analogous to tectonic excavation, rifting may have "unroofed" the lithosphere sufficiently to bring the diamond stability field upward into the region of the mantle in which alkaline magmas, characteristic of the shallow mantle, could entrain diamonds. Lithologies which might be expected are the more alkaline (± ultrapotassic) lithologies, and include such rock types as alkali basalts, transitional alkaline to tholeiitic basalts, nephelinites, phonolites, trachytes and carbonatites. Therefore, any alkaline, potassic to ultrapotassic intrusive body having upper mantle xenoliths may have potential to host diamonds.

**ES-diamond model**

An alternative approach to diamond exploration would be identification of any igneous lithologies which may have originated in the mantle and subsequent evaluation of these lithologies for diamond potential. In support of this approach, the author suggests critical evaluation of the documented alluvial diamond production of the New South Wales area of eastern Australia (Barron et al., 1994, Jacques et al., 1984). The following synopsis has been modified from these references.

The model considers the possibility of dynamic formation of diamonds arising from progressive, prograde metamorphism of subducted oceanic crust of basaltic composition with a veneer of unconsolidated forearc sediments. The sediments are interpreted to consist largely of anoxic marine sediments, explanating for the wide range of delta$^{13}$C values associated with E-diamonds. As the subducted slab is driven to progressively deeper levels, it undergoes prograde metamorphism along the following interpreted path:

**blueschist facies - eclogite blueschist - coesite eclogite - diamond eclogite**

Development of diamond eclogite facies is interpreted to arise as a direct result of depressed isotherms associated with the presence of the cooler subducted slab in the mantle. An obvious requirement of the model is that the cooler, subducted slab must achieve pressures and temperatures compatible with the diamond stability field. It is interpreted that the diamond stability field associated with subduction may be reached when the slab reaches depths of approximately 80-90 km, corresponding to pressures of about 22-25 kb.

Furthermore, tectonic "... underplating is normally associated with temperatures too high for diamond to remain stable at the base of thin lithosphere. The assumption must be made that tectonic underplating does not occur for the source rocks involved in the formation of ES-diamonds. Furthermore, continuing subduction would take the subducting slab to depths too great to be sampled by a rising magma. Collision of two continental cratons is one way of terminating subduction and trapping the diamond-bearing portion of the subduction slab within a depth range appropriate for the entrainment of diamonds in an ascending magma, adjacent to or below the mobile zone" (Barron et al., 1994). Alternatively, in the case of western North America, progressive shallowing of the subduction zone may allow development of diamonds in the subducted slab, allowing alkaline magmas, sourced at shallow mantle levels, to entrain eclogitic diamonds before the subducted slab is driven to depths too great to facilitate access by rising magmas.

At depths of approximately 80-90 km, diamond eclogite facies lithologies may be sampled by alkaline mafic to ultramafic magmas originating at depths considered too shallow for kimberlite and/or lamproite. Therefore, magmas having compositions ranging from alkali basalt to nephelinite to melilitite, originating from depths in the mantle as shallow as 90-100 km may entrain E-type diamonds according to this model.

**SUMMARY**

North American cratonic basement has been identified geophysically, geochronologically and isotopically at least as far as far west as the Monashee Mountains. The presence of diamond-bearing lamprophyric (lamproitic) diatremes west of the Columbia Icefields and diamond-bearing kimberlites west-northwest of Elkford suggest the possibility of magmas originating at relatively shallow levels in the mantle entraining diamonds from (a) diamoniferous horizon(s) and subsequently bringing them to surface. These occurrences are therefore, by definition, diamondiferous. The critical issue to be resolved is whether they are **economically** diamondiferous. The identification of diamonds and/or diamond-bearing "kimberlites" in the Buffalo Hills, Peace River Arch, Hinton and Lethbridge area suggests that the mantle underlying cratonic basement in portions of the Alberta Basin is similarly diamondiferous. These same basement blocks, and possibly one or more diamondiferous horizons, may extend under the eastern portion of the Cordillera, indicating the possibility that diatremes documented in this area may also have diamond potential, according to the lamproitic diamond (LD) model.

In addition, interpreted eastward directed subduction in the Proterozoic prior to rifting and subsequent development of the miogeocline suggests the possibility that the eclogitic subduction (ES) model may also be applicable. This would significantly enhance the interpreted diamond potential of southeast British Columbia, allowing the possibility of two compatible models for exploration purposes. Furthermore, the possibility for mafic lithologies to be considered as potential hosts for diamonds significantly increases the overall number of potential host lithologies. Many of the diatremes identified to date in southeast British Columbia are of similar composition to those identified in the New South Wales area, including olivine melilitite, nephelinite, alkali basalt and alnöite. It is the authors opinion that comparatively small samples taken to date do not eliminate any diatreme from further consideration as a potentially diamond-bearing occurrence. Furthermore, the occurrences were evaluated utilizing the SAD model, in which even the Argyle mine returned negligible to low diamond potential. Serious evaluation using the LD- and/or ES-diamond models needs to be undertaken before any conclusive statements can be made regarding diamond potential in southeast British Columbia. In support of this statement, recent work confirmed low abundances of chemically favourable indicator minerals from the Cross Kimberlite. However, additional occurrences were identified in the immediate vicinity having both extremely favourable indicator mineral chemistry and gem quality diamonds (**the most reliable indicator mineral**).

## REFERENCES


Armstrong, R.L., Parrish, R.R., van der Hayden, P., Scott, K., Runkle, D. and Brown, R.L. 1991. Early Proterozoic basement exposures in the southern Canadian Cordillera: core gneiss of Frenchman's Cap, Unit I of the Grand Forks Gneiss, and the Vaseaux Formation. Canadian Journal of Earth Sciences, vol. 28, pp. 1169-1201.

Barron, L.M., Lishmund, S.R., Oakes, G.M. and Barron, B.J. 1994. Subduction diamonds in New South Wales: implications for exploration in eastern Australia. Geological Survey of New South Wales, Quarterly Notes 94, pp. 1-23.

Cook, F.A., Varsek, J.L. and Clarke, E.A. 1991. Proterozoic craton to basin craton transition in western Canada and its influence on the evolution of the Cordillera. Canadian Journal of Earth Sciences, vol. 28, pp. 1148-1158.

Fipke, C.E., Gurney, J.J. and Moore, R.O. 1995. Diamond exploration techniques emphasizing indicator mineral geochemistry and Canadian examples. Geological Survey of Canada, Bulletin 423, 86p.

Gabrielse, H. and Yorath, C.J. 1991. Tectonic Synthesis, Chapter 18 in Geology of the Cordilleran Orogen in Canada, H. Gabrielse and C.J. Yorath (ed.), Geological Survey of Canada, Geology of Canada, No. 4, pp. 677-705.

Geological Survey of Canada. 1989. The development of advanced technology to distinguish between productive diamondiferous and barren diatremes. Geological Survey of Canada, Open File 2124, 1183 p.

Helmstaedt, H.H., Mott, J.A., Hall, D.C., Schulze, D.J. and Dixon, J.M. 1988. Stratigraphic and structural setting of intrusive breccia diatremes in the White River - Bull River area, southeastern British Columbia. in British Columbia Ministry of Energy, Mines and Petroleum Resources Geological Fieldwork 1987, Paper 1988-1, pp. 363-368.

Jacques, A.L., Ferguson, J. and Smith, C.B. 1984. Kimberlites in Australia. in J.E. Glover and P.G. Harris, eds. Kimberlite Occurrence and Origin: A Basis for Conceptual Models in Exploration. Department of Geology and University Extension, University of Western Australia, Publication No. 8, pp. 227-274.

Janse, A.J.A. 1984. Kimberlites - where and when. in J.E. Glover and P.G. Harris, eds. Kimberlite Occurrence and Origin: A Basis for Conceptual Models in Exploration. Department of Geology and University Extension, University of Western Australia, Publication No. 8, pp. 19-61.

Kirkley, M.B., Gurney, J.J. and Levinson, A.A. 1992. Age, origin and emplacement of diamonds: a review of scientific advances in the last decade. Canadian Institute of Mining Bulletin, vol. 84, pp. 48-57.

Levinson, A.A., Gurney, J.J. and Kirkley, M.B. 1992. Diamond sources and production: past, present and future. Gems and Gemology, vol. 28, pp. 234-254.

Mitchell, R.H. 1991. Kimberlites and Lamproites: primary source of diamonds. Geoscience Canada, vol. 18, pp. 1-16.

Pell, J. 1994. Carbonatites, nepheline syenites, kimberlites and related rocks in British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, Bulletin 88, 136p.

Pope, A.J. and Thirlwall, M.F. 1991. Tectonic setting, age, and regional correlation of ultrabasic-ultrapotassic dykes in the northern Purcell Mountains, southeast British Columbia. Canadian Journal of Earth Sciences, vol. 29, pp. 523-530.

Ross, G.M., Parrish, R.R., Villeneuve, M.E. and Bowring, S.A. 1991. Geophysics and geochronology of the crystalline basement of the Alberta Basin, western Canada. Canadian Journal of Earth Sciences, vol. 28, pp. 512-522.

Villeneuve, M.E., Ross, G.M., Theriault, R.J., Miles, W., Parrish, R.R. and Broome, J. 1993. Tectonic subdivisions and U-Pb geochronology of the crystalline basement of the Alberta Basin, western Canada. Geological Survey of Canada Bulletin 447, 86 p.

Walker, R.T. 1994. Diamond Potential in southeast British Columbia. Northwest Geology, Proceedings Volume From the Joint Meeting of the British Columbia Geological Survey Branch, Geological Survey of Canada, East Kootenay Chamber of Mines, Consolidated Ramrod and Tobacco Root Geological Society, vol. 23, pp. 77-79.