KIMBERLITES - WHY, WHEN, AND WHERE? A HIERARCHY OF GEOTECTONIC CONTROLS.

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In spite of many attempts in the literature to explain the temporal and spatial distribution of kimberlites, no consensus has emerged regarding their geotectonic controls. Among others, kimberlite magmatism has been correlated with lithospheric flexures, regional uplifts above upwelling convection currents (mantle diapirs, mantle hot spots), rifting of continents, flat-dipping subduction zones, non-laminar flow above subduction zones, transform faults, and magneto-hydrodynamic activity in the core, however, none of these models can explain all the aspects of the problem. Much of the uncertainty about the geotectonic controls derives from the fact that our knowledge of virtually every aspect of the complex process of kimberlite formation and ascent to the surface is still very speculative. In addition, there is the problem of correlation between the mainly sublithospheric processes involved in kimberlite formation and the geotectonic environment in the upper parts of the lithospheric plates through which the kimberlites erupt.

The problem of explaining timing and locations of kimberlites may be more tractable by considering the various aspects of kimberlite formation in an appropriate geotectonic hierarchy. Assuming that kimberlites result from partial melting of "fertilized" garnet peridotite in the lower lithosphere or sublithospheric mantle, we must identify for each kimberlite province:

1. What processes or events can fertilize the upper mantle so that it may yield a kimberlitic melt?
2. What processes may trigger melting and ascent?
3. What is the timing of the fertilization and trigger events? Are they related or totally unrelated upper mantle processes?
4. What controls the mode and extent of surface and near-surface kimberlite emplacement?

As many previous hypotheses attempting to explain kimberlite distribution are province-specific, consideration of this hierarchy of controls for many different kimberlite provinces may help to further constrain some of the problems involved.

Whereas diamond formation appears to occur mainly in, and adjacent to, the lithospheric roots or keels of ancient cratons, with economic quantities of diamonds confined to the Archean parts of these cratons, the similarity between "on-craton" and "off-craton" kimberlites suggests that the fertilization process affects much wider regions than those underlain by the highly depleted and dehydrated Archean mantle roots. Previous models for enrichment of the potential source areas have concentrated on processes of upper mantle metasomatism as a result of either plume- or subduction-related events. At present there is little tangible evidence to distinguish between the two, but the possibility must be considered that subducted material is carried upwards by convection. The question of mantle refertilization may also be approached by considering the secular pattern of kimberlite magmatism, especially the absence of kimberlites older than approximately 1.8 Ga. Although diamonds and indicator minerals in the Witwatersrand basin are indicative of Archean kimberlites in southern Africa, the lack of Archean kimberlites and indicator minerals in the Archean and earliest Proterozoic sedimentary record elsewhere cannot be simply a matter of preservation. It appears to be no coincidence that the first detrital kimberlitic diamonds occur in the Witwatersrand basin which is located near the oldest preserved collisional orogen (Limpopo belt), where thickening of the crust and lithosphere not only caused diamonds to form (ca. 3.3 - 3.2 Ga), but where also the first continental plate was accreted that was large and thick enough for genuine intraplate magmatism, including the first kimberlite event (>2.9 Ga). In a volatile-impoverished Hadean Earth (>4.0 Ga), that was covered by a convecting magma ocean (e.g., Kumazawa and Maruyama, 1994), plate-tectonic-like processes developed gradually, as early crust and mantle were re-hydrated through recycling of hydrated and carbonate-altered oceanic crust (e.g., de Wit and Hart, 1993). The introduction into the mantle of CO_2 and H_2O necessary for kimberlite formation must be seen in the context of this transition from plume to plate tectonics. The first Proterozoic kimberlite event (ca. 1.8 - 1.6 Ga) was wider-spread and occurred after the break-up of the first supercontinent (ca. 2.4 Ga) and the development of the first platformal carbonates in lower Proterozoic sequences. Subduction of some of these carbonates may have caused a major increase in the CO_2 budget of the upper mantle. Judging from the widespread presence of lithospheric "graveyards" under the present continents (e.g., Fukao et al., 1994), there appears to be no problem envisaging the contribution of subducted material and volatiles to the sub-continental lithosphere throughout the Paleozoic and Mesozoic, when kimberlites erupted on virtually every major craton.

As to the processes which trigger kimberlite melting, there is no easy way of distinguishing between decompression melting or a sudden release of volatiles by dehydration and decarbonation reactions at depth. However, it is clear that a tensile stress parallel to the surface is required for fractures to nucleate along which kimberlites can ascend into the upper crust. As tensile stresses at the base of the lithosphere are small compared to the hydrostatic pressure in this region of the upper mantle, such fractures can propagate only if an abundant supply of low-viscosity liquid can follow into the tip of the crack (e.g., Anderson, 1979). The surface tectonic settings in which these conditions are realized appear to vary greatly among different kimberlite provinces. Whereas Mesozoic kimberlite magmatism in southern Africa was contemporaneous with continental break-up, the late Cretaceous/early Tertiary kimberlites of the Slave Province in Canada were emplaced while thrusting and terrane accretion occurred along the western continental margin of North America.

Relative and absolute timing of fertilization and trigger events can only be established if the metasomatic enrichment of the source region can be dated separately and compared to the age of kimberlite emplacement. Integrated with the tectonic history of the province in question, such data are necessary to establish whether fertilization and melting are related, or whether a time lag exists between fertilization and the triggering of the kimberlite event. By considering these age relationships and comparing data from well known kimberlite provinces with observations from newly discovered kimberlite provinces in Canada, it may be possible to assess the importance of hot spot and plume activity which, according to a number of authors, play an important role in kimberlite magmatism. Although it is tempting to correlate the Mesozoic kimberlites of southern Africa with the plume activity preceding and accompanying continental break-up, such correlation cannot be made for the kimberlites of the Slave Province, where the latest plume activity recognizable from surface geology occurred in the late Proterozoic. If plumes exert a secondary control on kimberlite formation by causing metasomatic enrichment of adjacent mantle, the time gap between this type of fertilization and formation of the kimberlite may be large.

On the large scale, within cratons, the distribution of kimberlite provinces appears to be controlled by the extent of refertilized upper mantle source regions. On the regional and more local scale, examples abound where the location of kimberlites is influenced by a variety of structural features (fractures, faults, dikes, large-scale folds, monoclines, etc.), such that the location of actual kimberlite fields and clusters is a function not only of the complex interplay between fertilization and triggering processes, but also of the structural state and rock types in the upper crust. Whether the crustal structures are active during kimberlite emplacement or merely serve as passive pathways, they influence the mode of kimberlite emplacement but probably bear little or no relationships to the lower or sub-lithospheric processes causing kimberlite formation.

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