TIMING OF KIMBERLITE MAGMATISM AND DIFFERENT TYPES OF DIAMOND-BEARING COMPLEXES

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DATA SOURCE

The timing of kimberlite/lamproite magmatism was assessed based on available published radiometric data. Data are summarized in four tables; source of the data in the tables is listed in Erlich and Hausel (2002). These tables include radiometric data for specific astrobleme-like ring structures that are usually diamondiferous (after Malkov, 1998), diamond deposits located in high-pressure metamorphic complexes in China, Kazakstan, etc. (Abdulkabirova and Zayanchkovsky, 1996; Perchuk et al., 1995), flood basalt events (Rampino and Stothers, 1988), and the timing of different types of tectonic transformations [Stille (1924) data modified using radiometric data from Rubinstein, 1967]. For the youngest pulses of alkaline magmatism we summarized radiometric dates for Post Eocene time (last 40 mln. years).

PULSATIVE NATURE OF ULTRAMAFIC ALKALINE MAGMATISM

PULSES OF THE FIRST ORDER

Kimberlite bodies are essentially formed during the course of synchronous global pulses of magmatic activity. These pulses may be accompanied by lamproitic volcanism. A series of such pulses occurred during the Proterozoic (900 Ma, 1100 Ma, 1300 Ma, 1500 Ma, and 1700 Ma, and near 2600 Ma). In the Paleozoic, the more prominent pulses occurred around 500 Ma, 340-369 Ma, and 220-240 Ma. In the Mesozoic, pulses are well expressed in the Jurassic (near 100 Ma, at 110-120,140-150 Ma) and Cretaceous (90-70 Ma). The youngest pulses occurred in the Cenozoic - (near 35 Ma, 21-24 Ma, near 16 Ma, 4-12 Ma, 0-2 Ma).

The global synchroneity and short duration of magmatic pulses is well illustrated by a pulse coinciding with Savsky and Steirian epochs of tectonic transformation (about 21 Ma and 24 Ma, respectively). During these episodes within the Alpine-Himalayan global mobile belt (which stretches over several thousand miles) a series of simultaneous events are recognized. At the westernmost edge of the belt in Morocco the Beni-Bousera stratified ultramafic complex was emplaced (23 Ma). In addition, ultramafic volcanism in Schwabia intensified (22-24 Ma). Intensification of orogenic uplift in the Alps and Himalayas is reflected in the emplacement of granitic intrusives and the rejuvenation of radiometric ages of metamorphic rocks. Lamproitic volcanism is recognized in Pamir (Central Asia) at 24 Ma, and at the easternmost edge of the belt in Western Australia (17-24 Ma). During tectonism of the Alpine-Himalayan mobile belt, serpentinized breccia of kimberlitic affinity and minettes erupted on the Colorado Plateau (20-22 Ma), alkaline volcanics erupted on islands near the Brazilian coast in the Atlantic (22 Ma), and the post-caldera complex of the Kisingiri volcanic complex within East African rift zone erupted (22.5 Ma).

The timing of magma generation often coincides with the timing of cratonization resulting in the deep transformation of the crust and upper parts of the mantle. This can be accepted as a modification of Clifford's rule. The scale of cratonization correlates with increased kimberlitic activity.

The synchroniety of magmatic episodes reflects a pulsation of volatile/heat flow generated at the core/mantle boundary. Such synchronous pulses disregard the boundaries of plates and apparently have no association with subduction zones.

A high (0.8-0.95) correlation between the timing of ultramafic-alkaline magmatic pulses in tectonically different environments shows that these are independent of tectonic conditions in the upper lithosphere. For example, pulses of alkaline volcanism simultaneously occurred in backarc environments (e. g. rear volcanic zone of Ryukyu island arc), stable blocks - median massifs (volcanism around Tyrrhenian block and within Massif Central in France), and the forefront of orogenic belts (Murcia-Almeria province in front of Betic Cordillera, Spain, lamproites within Po river lowland in front of Alps).

Intensification of synchronous alkaline and ultramafic-alkaline magmatic activity is combined with global synchronous periods of lull or extreme scarcity of magmatic activity (16-20, 25-28, 36-60, 160-180 Ma). Lulls in magmatic activity can't be explained by simultaneous exhaustion of magma chambers. It is suggested that these reflect strain in the crust, preventing magma from ascending to the upper levels. Some lulls occurred within a single region (Barremian hiatus of magmatic activity in Brazil). The intensification of global pulses and lulls of magmatic activity is a reflection of the pulsative regimes of the Earth's dynamics. The development of potentially diamond-bearing astrobleme-like ring structures and stratified ultramafic intrusions coincides with some pulses. Formation of astrobleme-like ring structures is randomly distributed in time and shows no specific coincidence with boundaries of units of the International Stratigraphic Scale.

PULSES OF THE SECOND ORDER

Kimberlitic districts are characterized by polychronous eruptions. It is possible to consider kimberlitic fields to be an analogue of asthenoliths that potentially fed ultramafic-alkaline massifs. As a result of polychronous stages of emplacement along the northern edge of the Anabar anteclise, Siberian Platform, fresh grains of kimberlitic indicator minerals have been recognized in the basal horizons of Permian, Lower Jurassic, Upper Jurassic, Lower Valanzhinian and Late Cretaceous sediments. Within the Wyoming kimberlite Province, kimberlites yield Upper Proterozoic, Early Devonian and Tertiary ages. Continuous magmatic activity within the same field is direct indication that stress within this field was preserved during the entire time range of kimberlite emplacement.

TIMING OF MAGMATIC ACTIVITY AND TECTONIC TRANSFORMATIONS

Kimberlitic magmatism is synchronous with major epochs of tectonic reconstruction such as phases of the Caledonian, Pan-African, Herzinian, Laramide orogenies, some phases of accelerated uplift in the Alpine-Himalayan orogenic belt, and expansion along the strike of island arcs in the Western Circum-Pacific. Emplacement of granitic intrusives and rejuvenation of metamorphic rocks accompany epochs of orogenic uplifts. Accordingly they are reflected in peaks on histograms of radiometric ages of granites and rejuvenated metamorphic rocks. If strike-slip fault related horizontal movements prevails during tectonic episodes, magmatic pulses are expressed by lows on histograms of radiometric ages. During these pulses different types of diamond deposits were formed. Once generated by volatile/heat flow from the upper core boundary, tectonic transformations take place at the asthenospheric level and are closely related to transformation of the upper mantle and lower crust (restoration of isostatic equilibrium resulting in redistribution of structures within platforms and the growing of "mountain roots"). Examples include diamondiferous deposits associated with high-pressure metamorphic terranes in Kazakstan and China, stratified ultramafic complexes (e.g., Beni-Bousera), and formation of specific astrobleme-like ring structures. The duration of such pulses typically does not exceed several million years.

TIMING OF KIMBERLITE/LAMPROITE MAGMATISM AND FORMATION OF SPECIFIC ASTROBLEME-LIKE RING STRUCTURES

Summary of data on times of formation of specific astrobleme-like ring structures shows clear tendency to concentrate at specific times (Archean, near 1900 Ma, 502 Ma, 350-360 Ma, 145-150 Ma, near 100 Ma, 73-90 Ma, near 50 Ma, 35, 16 Ma). These periods are randomly distributed and have no relation to boundaries of units of the International Stratigraphic Scale, and they clearly coincide with pulses of ultramafic-alkaline magmatic activity. The idea that impact events occurred during time of development of astrobleme-like structures (Malkov, 1998) is not acceptable because astrobleme-like ring structures are usually located far away from nearest kimberlitic fields (districts) and so can not trigger kimberlitic eruptions.

DURATION OF MAGMA EVOLUTION

Indications are that once formed at depth kimberlitic magmas persist in magma zones for up to 1,000 mln. years and repetitive eruption of kimberlites occur due to the squeezing of fresh magma by tectonic processes.
Based on the range of radiometric ages, ultramafic-alkaline massifs are divided into two groups. One is characterized by short duration (range of radiometric dates 5-20 millions years). Examples include the Khibines, Lovozero massifs (Kola Peninsula) and Guly massif (Maimecha-Kotuy Province, Siberian Platform). Within this time interval these giant massifs evolved from carbonatite-ijolitic to nepheline syenites (Guly massif, Siberian Platform) and ultramafic-alkalic to peralkalic magmas (Khibines and Lovozero massifs, Kola Peninsula). A similar evolution is traced within massif in the Kruger Mountains of the Canadian Cordillera. Data for some regions in North America indicates that there were several overlapping periods of

ultramafic-alkalic and alkalic magma generation. The shorter formation time for alkalic complexes in Urals compared to cratons is probably the result of more stable tectonic conditions within the latter. A range of ages (200-400 mln. years) characterizes the radiometric data for the second type of massifs. These include the Kovdor massif (Kola Peninsula), Tomtor massif, (Siberian Platform), a syenitic massif in Alaska, Quincy granites and White Mountain rock series in the Appalachian Province. Range of radiometric ages characteristic for these plutons is constant for all provinces and reflects a constant time for heat exhaustion of the magma-feeding asthenoliths. Range of radiometric dates does not depend on the size of the massifs.

Comparison of radiometric ages of different kimberlites and ultramafic-alkaline rocks in general, establishes a general tendency and time rate for magma evolution. In S. Africa mica-bearing group II kimberlites show radiometric ages 200-110 Ma whereas basaltic kimberlites prevail at a range of 110 to 50 Ma (Smith et al., 1986). In Kola Peninsula, Caledonian ultramafic-alkaline massifs are replaced by massifs of agpaitic nepheline syenites in Hercynian time. Similar observations are possible in Udja Province, Siberian Platform, where Upper Proterozoic and Lower Paleozoic ultramafic-alkaline intrusions are followed by agpaitic nepheline syenites (about 250 Ma).

ULTRAMAFIC-ALKALINE MAGMATISM, FLOOD BASALTS AND CARBONATITES

Ultramafic-alkaline magmatism is characterized by small volumes of magma simultaneously emplaced in different regions of the world, reflecting a general dissipate character of energy distribution. By contrast, flood basalt episodes reflect a different type of global magmatic event characterized by massive volumes of basaltic magma erupted during comparatively short time episodes within few, or even a single, region. This type of global magmatic pulse probably reflects a formation of hot spots.

Based on volume of erupted material, flood basalts are global volcanic events, but each episode of flood basalt eruption occurred only within a single structure or within a small number of locations. This is true for Siberian flood basalts, Karroo basalts in South Africa, Parana basalts in Brazil, and the Columbia River basalts. In contrast, the timing of kimberlitic/lamproitic volcanic activity shows a strong tendency to synchroneity worldwide. Thus, this is another type of global volcanic event in comparison with flood basalt eruptions. While kimberlitic/lamproitic magmatism can be considered as a dissipate form of distribution of internal energy, flood basalt eruptions are concentrated within localized regions and represent hot-spot formation. Ultramafic-alkaline magmatic activity is synchronous with major stages of flood basalt eruptions. Radiometric dates of ultramafic-alkaline intrusives within Northeastern Siberian platform nearly match the timing of the main flood basalt event and formation of Tunguska syneclise (250±5 Ma).

Contemporary kimberlites belongs to Permo-Triassic epoch.

The timing of kimberlite/lamproite magmatism and the timing of carbonatitic magmatism are similar or identical.

SUGGESTED MODEL

Synchronous pulses of the first order disregard plate boundaries and apparently have no association with subduction zones. Some pulses coincide with the timing of the opening of the Atlantic Ocean, but this coincidence is not compulsive. Thus the type of magmatism under consideration is associated with a very deep-seated source - probably located beneath plates at the mantle/core boundary.

A high (0.8-0.95) correlation between the timing of alkaline magmatic pulses in tectonically different environments show that these pulses are independent of tectonic conditions in the upper lithosphere. For example, simultaneous pulses of alkaline volcanism occur in backarc environments (e. g. rear volcanic zone of Ryukyu island arc), stable blocks - median massifs (volcanism around Tyrrhenian block and within Massif Central in France), and within the forefront of orogenic belts (lamproites in front of Betic Cordillera, Spain, lamproites within Po river lowland in front of Alps).

The latter point establishes a primacy of volatile/heat flow generated at the deepest possible level - probably at the outer core boundary. This heat engine may have initiated tectonic processes at the lithospheric level. This in turn later resulted in different types of magmatic activity within different tectonic systems - granites in orogenic zones and ultramafic-alkaline volcanism within platforms and median massifs.

The model suggests the existence of two orders of pulses of magmatic activity. Pulses oft the first order are generated by a sharp increase of volatile/heat flow at the outer core level. This resulted in creation of ultramafic-alkaline asthenoliths, plutons and districts of kimberlite. The initial stage of kimberlite magma generation coincided with cratonization epochs. Such pulses are interrupted by lulls of magmatic activity, which is a result of increased simultaneous tension in the crust. Pulsation of the second order resulted in a squeezing of small portions of magma from asthenoliths created in

the course of first order pulses to to the upper crustal level.
The ultramafic-alkaline, and/or kimberlite magmas were retained at depth within the mantle or even within the lower crust for very long time up to hundreds of millions years.
At this stage, tectonics played a major role in the process of magma emplacement.

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