9th International Kimberlite Conference Extended Abstract No. 9IKC-A-00409, 2008

Formation types of lamproite complexes-systematization and chemism.

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For the last 25 years the lamproites from different provinces of the world have been thoroughly studied. Due to various chemical and mineral compositions lamproites fall out of the single group of rocks or the single formation. It is clear now that rocks with the lamproite composition can have a different origin and can be related to different rock formations.

The classification of lamproites is complicated by significant variations in the chemical composition of lamproites for example: MgO from 30-5 %, SiO2 from 40-65 %, K2O-3-12 % etc., that is connected with specific mineral composition of lamproites. Three lamproite varieties are distinguished: olivine, leucite and sanidine. Six rock-forming minerals are common to lamproites. A contrast chemical composition of minerals and their varying quantitative ratio in the rock result in significant changes in lamproite chemical composition. In addition the lamproites are marked by a unique sharp differentiation even during the crystallization of volcanics - from olivine to leucite varieties.

Element concentrations in minerals of lamproite (%).

mineral	SiO2	MgO	CaO	K2O	Al2O3
olivine	41	50	-	-	-
diopside	55	18	26	-	-
mica	35-40	24	-	10	8-10
K-richterite	50	18	10	5	-
leucite	58	-	-	20	22
feld spar	64	-	-	16	20

So, what rocks can be regarded as lamproites?

Lamproites are volcanic, subvolcanic and intrusive rocks containing different ratio of main six rock-forming minerals (which demonstrate relatively stable chemical composition): olivine, clinopyroxene, micas, leucite, K-richterite and K-feldspar (sanidine). The presence of at least 3 of these minerals is obligatory. Depending on mineral ratio in lamproites the chemical composition of the rocks considerably varies: SiO2-40-65 %, Al2O3 - 5-12 %, MgO-30-5 %, K2O - 3-12 %, at MgO> CaO, K2O>> Na2O.

The first diagnostic mineral feature of lamproites is **a complete lack of sodium leucophases: plagioclase, nepheline**. Melilite is frequently not found in lamproites. If the potash alkaline rocks demonstrate plagioclase it is an evidence that this rock does not belong to the lamproite series.

The second diagnostic feature is the composition of rock-forming minerals: olivine - 86-94 % forsterite minal, clinopyroxene of diopside – sahlite series, mica - Fe- phlogopite Ti- phlogopite - tetraferriphlogopite, amphibole – series of K- richterite - K- arfvedsonite, leucite as a rule contains 1-4 % FeO and surplus of SiO_2, K-feldspar (sanidine) is pure potassic and contains 0,5-4 % FeO. The charactristic asseccory minerals include: chromite, Cr-magnetite, perovskite; titanates (priderite, armocolite; Zr-Ti-silicates – wadeite, K-batisite, davainite. However, most of them are found in the differentiated agpaitic leucite lamproites while chromite, Cr-magnetite, perovskite, possibly sphene, apatite and seldom zircon are characteristic of diamondiferous olivine lamproites.

By mineral association early olivine lamproites are slightly different from massive (non-breccia) magmatic kimberlites. Their main difference from kimberlites is potential possibilities for differentiation of primary magma. Massive crystallized kimberlites are extreme differentiate of the kimberlite magma. Massive kimberlites terminate the magmatic process, while olivine lamproites start magma differentiation (it is the earliest product). Leucite and sanidine varieties of lamproites are crystallized later on.

High-baric minerals such as pyrope and picroilmenite are as a rule not typical of lamproites, this is a feature distinguishing lamproites from kimberlites**. Xenoliths of the mantle rocks are uncommon to lamproites.** As primary lamproitic magma is high-potassic and possesses high reactionary ability the deep xenoliths and megacrysts are most likely dissolved in it, that can be associated with high titanium concentrations in the late lamproite differentiates.

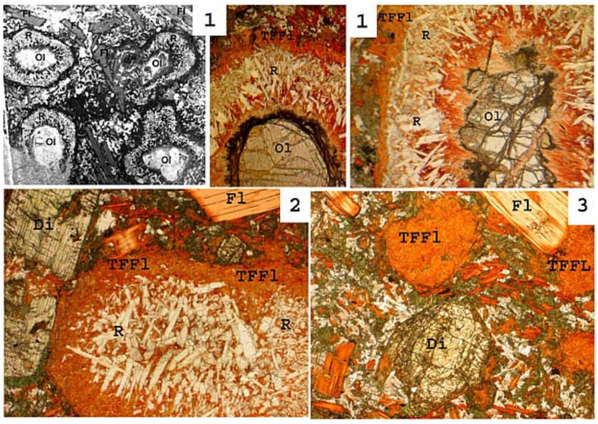

Fig. 1. Magmatic dissolution (peritectic reaction) of olivine in lamproites, (1,2,3 stage). Ol-olivine, R –K-richterite, TFFl-tetraferriphlogopite, Di-diopside**.**

It should be noted, that early olivine lamproites containing over 20 % of olivine, do not contain leucite. It is crystallized later from a more differentiated and silicate magma residue. Olivine becomes unstable; it reacts and is dissolved in more silicate leucite magma. (Fig.1). This process of olivine «corrosion» is visible in dykes of the Murun lamproites.

As regard to geochemistry the diagnostic features include high concentration of Cr - 500-3000 ppm, Ni - 300-2000 ppm (Cr> Ni), the increased contents of Zr, Nb, Ti and cerium TR. Depending on the degree of lamproite differentiation (early - olivine, late - leucite) rare element concentrations are also varying. Early lamproites show high Cr and Ni concentrations, which decrease in later differentiates, while Zr, Nb, Ti, TR contents sharply increase in late lamproites. At relatively high Ba and Sr concentrations early lamproites frequently contain more Ba than Sr, while in late lamproites Sr content significantly increases, as opposed to early ones.

The high titanium content is a feature of differentiation, and a sign that a rock is free of diamonds. Central parts of mica phenocrysts contain 2-3 % of TiO2 and 0,5% Cr, while the external margin, which crystallized together with matrix contains 5-8 % TiO2 and 0.001 Cr, correspondingly. Similar zoning is observed not only in lamproites, but also in alkaline basalts and alkaline rocks.

Formation types of lamproite complexes.

There are options of geologic relations of lamproites with other rocks.

1. Lamproites form separate volcanoes and diatremes, which are not genetically associated with other rocks. They include lamproites of Australia, Spain and the USA. They are of Tertiary and Quaternary age and it is it is not inconceivable that their differentiates are not outcropped by the erosion.
2. Lamproites form separate bodies (sills, dykes and diatremes) and are frequently genetically related to kimberlites and picrites. This type includes lamproites of Anabar area, Finland, China, India. Their age is similar to that of kimberlites.
3. Lamproites form separate bodies (sills and dykes) and even volcanic flows among other K-alkaline rocks. Lamproites are spatially and genetically related to these rocks, are of the same age and form a common petrochemical trend of compositions. This type involves lamproites of different massifs of alkaline rocks of the Aldan shield.
4. Lamproites form different bodies (dykes) among other dykes of rocks, demonstrating a higher Na content. Their age is similar. They include lamproites of Altai, Paraguay [6], Montana (USA). The lamproites of the Urals and Karelia can be regarded as belonging to this type.

These 4 genetic types of lamproites can be united into the following formation complexes: 1) “pure” (proper) lamproites, 2) picrite (kimberlite) - alnoite - lamproite, 3) massifs of K-alkaline rocks, 4) dyke belts. The above formations can comprise other important rocks of the association.

Inside the formation of "pure" (proper) lamproites we distinguish petrogenetic varieties (olivine-bearing) and olivine-free. The first variety includes lamproites of Australia and Spain. The second one comprises lamproites of Leucite Hills (USA). The Australian lamproites contain an early phase of olivine (absolutely without leucite) lamproites, while the leucite differentiates can contain scarce olivine. Lamproites of Spain do not show proper olivine varieties, and olivine is found almost in all varieties. Lamproites of Leucite-Hills most likely belong to another genetic group. They do not contain olivine. Their early varieties (madupites) consist of phenocrysts of pyroxene and mica and glassy (crystallized) matrix. By the chemical composition these rocks correspond to micaceous pyroxenites and are their volcanic analogs. By all parameters they are similar to biotite pyroxenites of K-alkaline-lamproite complexes of the Aldan shield. It is most likely that these two varieties of lamproites were formed at partial melting of different mantle rocks: magma of Leucite Hills from the pyroxenite mantle, and the rest ones - from olivine-containing ultrabasic rocks of the mantle.

Depending on dynamics of intrusion and crystallisation lamproites can be divided into volcanic (flows of lava and diatremes), subvolcanic (sills and dykes) and intrusive (separate bodies, dykes, stocks, and phases of intrusion in massifs).

TR spectra in lamproites of Siberia are of the same type (Fig.2).

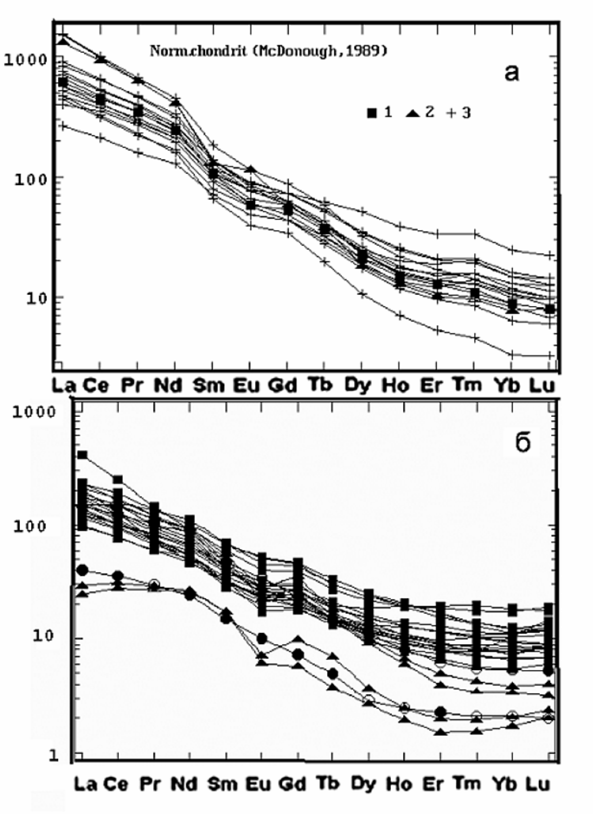

Fig. 2. TR spectra in lamproites of Aldan (b), Anabar Region (a) and Australia (a): 1-Argail, 2-Ellendale- 11-olivine lamproites, 3-crosses – Anabar

There are several lamproite magmatic occurrences of various genesis in Siberia. The most studied among them include: 1) lamproites of the Aldan shield associated with K-alkaline magmatism ; 2) lamproites of the Eastern Anabar Region and Tomtor massif, belonging to kimberlite-picrite-lamproite-carbonate association (formation); 3) veined and diatreme lamproites of Taimyr, lamproites of Sayan mountains and lamproites of Altai, related to dyke complex of alkaline rocks. In the Asian region of Russia there are lamproite occurrences in Kamchatka, which are derivatives of basaltic magmatism, Urals Mountains lamproites, some bodies in the Okhotsk Region in Sete-Davan area and diatreme in the Koksharovskyi massif, Primorsky Region . They are also found in Karelia, Ural and Ukraine.

Detailed prospecting works are being conducted at present to find lamproites among K-leucite volcanics in Belarus. In terms of petrochemical data the lamproites of Aldan and Anabar Region are different in titanium concentrations.

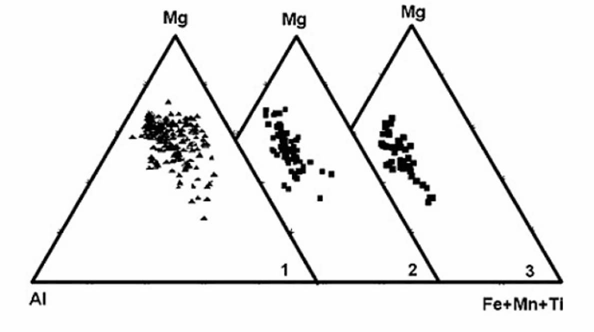

Fig. 3. Composition of mica from lamproites of the world (1), Aldan (2) and Anabar Region (3).

Trends of composition of mica from lamproites of Australia, Spain and the USA and lamproites of Aldan and Anabar Region are similar (Fig.3).

Geochemistry of isotopes, genesis, and diamond-bearing potential of lamproites

We studied the geochemistry of Sr, Nd, Pb isotopes in lamproites of Siberia.

The olivine lamproites of the Konder, Murun and Bilibin massifs demonstrate $Sr^{87}/Sr^{86}=0.7045$, while for other Aldan lamproites Sr87/Sr86 ratio ranges within the limits from 0.706 to 0.709. Considering data of Pb, Nd and Sr isotopes , lamproites from the Murun massif form a field between fields of Leucite-Hills and Smoky Butte, the USA. These lamproites are located between the schiled and platform.

On the Sr/Nd diagram lamproites from the Murun massif form the field close to the field of the North American lamproites. The source of their melting is the enriched EM-1 mantle. By geochemistry of rare elements the Aldan lamproites are similar to lamproites of the North America. Isotope characteristics indicate a deep-seated mantle origin of sources for lamproite and K-alkaline Aldan magmas . The age of the primary mantle substratum which was used for melting magma of the Murun massif, is estimated as 3200 Ma using Pb isotopes galenites. The lamproites of Khani massif and Aldan are considered to be the most ancient (2700 Ma). Lamproites of Australia and Spain (Fig.4) are located on the periphery of craton in zones of completed folding. The enriched mantle source EM-2 is characteristic of them. Using Pb isotope data it is possible to border between lamproites of the schileds and platforms with EM-1 mantle and lamproites of folded areas (EM-2).

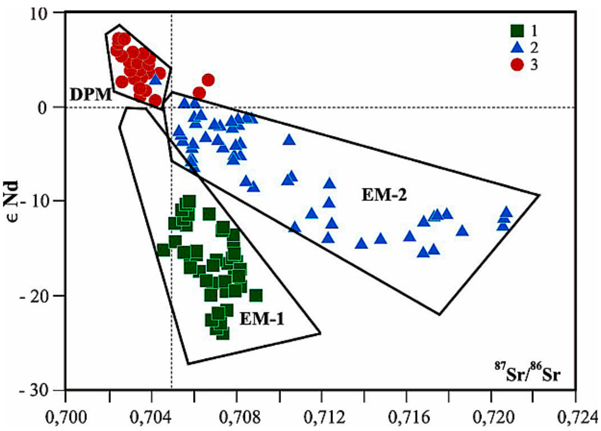

Fig. 4. Diagram of ratios of epsilon Nd and 87Sr/86Sr in lamproites and carbonatites.

(Circles- carbanatites of the framing of the Siberian Platform, Squares – lamproites of Aldan, Russia and USA, Triangles-carbonatites and lamproites of folded areas)

Diamond-bearing potential of lamproites is due to many factors. The majority of researchers suggest mostly xenogenic pattern for the most of diamonds, both in kimberlites, and in lamproites. There are two aspects of this problem.

The first aspect concerns the depth of magma origin that should be located in the area of diamond stability; and the second concerns the preservation of diamonds during the transportation and crystallization of magma. Taking into account isotope and geochemical characteristics of lamproites, they are regarded as deep mantle rocks, and the first condition is most likely observed. As to the second condition is concerned a fast magma transportation is required for preserving diamonds. Such fast magma transportation is the case in diatreme structures. A particular fast cooling is found in sandy tuff where quartz grains served as a good cooler, therefore similar lamproite tuffs are rich in diamonds (e.g. Argail lamproites). Diamond-bearing sandy tuffs, consisting of quartz sand (95 %) and lamproite substance (5 %) contain more diamonds (in one order of magnitude), than massive lamproites, consisting of 100 % of the lamproite substance. Diamonds in intrusive lamproites, most likely, burned down during a relatively slow magma crystallization.

The studies were supported by Russian Foundation for Basic Research, grants 06-05-64416, 08-05-90002