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DIAGRAM TA-SC - THE UNIVERSAL DISCRIMINATION DIAGRAM FOR GEOCHEMICAL CLASSIFICATION OF THE KIMBERLITIC ROCKS

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INTRODUCTION

The kimberlitic rocks occurring in different regions worldwide vary in composition very widely, and their variety appears to widen with routine discoveries of new kimberlite occurrences and as the known occurrences become better studied. The great diversity of kimberlitic rocks does not fit in with the commonly accepted strict classification scheme which includes just two kimberlite groups (Group 1 and Group 2) and a single lamproite group. There is a need to develop a regular classification system accounting for the totality of kimberlite varieties, since a good rock classification scheme is a useful research tool for genetic derivations.

The necessity of using such a diagram has arisen in the study of unusual and extremely diverse kimberlite magmatism of Arkhangelsk diamond-bearing province (North of the Russian Platform).

The Ta-Sc diagram is the most efficient and universal to subdivide more reasonably the kimberlite rocks by geochemical properties into series (types, groups) and to distinguish the kimberlite varieties within the series. This diagram takes into account both the geochemical type of kimberlite mantle source and the differentiation degree of kimberlite melts.

JUSTIFICATION OF THE CHOICE OF ELEMENTS

It is these two elements - Sc and Ta - that are preferred for use in the universal geochemical chart of kimberlite rocks for several reasons.

1) These two elements fully reflect the geochemistry of the rocks for coherent elements (Sc), and non-coherent elements (Ta), which is extremely important especially for kimberlite rocks.

2) These two elements reflect this primary, deepseated geochemical characteristics of the formation of kimberlite melts because they are concentrated primarily in the rock-forming minerals of a melting mantle substrate.

The major deep-seated Sc minerals-concentrators are clinopyroxene and garnet (Ilupin et al., 1978), therefore the Sc content in the kimberlite rock reflects the olivine/clinopyroxene+garnet ratio in the mantle source and differentiation degree of the kimberlite melts. The major deep-seated Ta mineral-concentrator is picroilmenite (product of asthenospherics melting), therefore the Ta content in the kimberlite rock reflects the degree of asthenosphere influence on the mantle source of the kimberlite melts.

3) These two elements are characterized by low but quite determinable concentrations, close intervals of content in kimberlite rocks (7-40 ppm for Sc and 0.4-45 ppm for Ta) and at the same time by a sharp difference in the contents of different rock types (for Sc 6 times at for Ta 100 times).

4) These two elements are little travelling, very stable and practically do not change their concentration with superimposed secondary alterations that are so characteristic of kimberlite rocks.

In kimberlite geochemistry studies, only autoliths and bulk of rock with xenogenic material content not higher than 5% are usually dealt with. The bulk rock composition is indicative of the abundance of depth-derived mantle material relicts (primarily, olivine macro crystals) in the examined rock, and the composition of autoliths has bearing on the character and extent of kimberlitic melt differentiation. It is precisely the pair “autolith-rock bulk free of xenoliths” that yields maximum geochemical information on a kimberlitic rock. As regards isotope chemistry studies, these are only worthwhile with autoliths or effusive-appearing rocks.

Figure 1 shows the general position of points of kimberlitic rocks in relation to the compositions of rock-forming mantle minerals: olivine, clinopyroxene, garnet and picroilmenite. The composition points of kimberlite rocks occupy a completely natural position with respect to these deepseated minerals and are grouped into separate fields that can be used for geochemical classification of kimberlite rocks. Points of model compositions of primitive mantle (Yagouts, 1979) and depleted mantle (Sablukov et al., 2002) are shown separately.

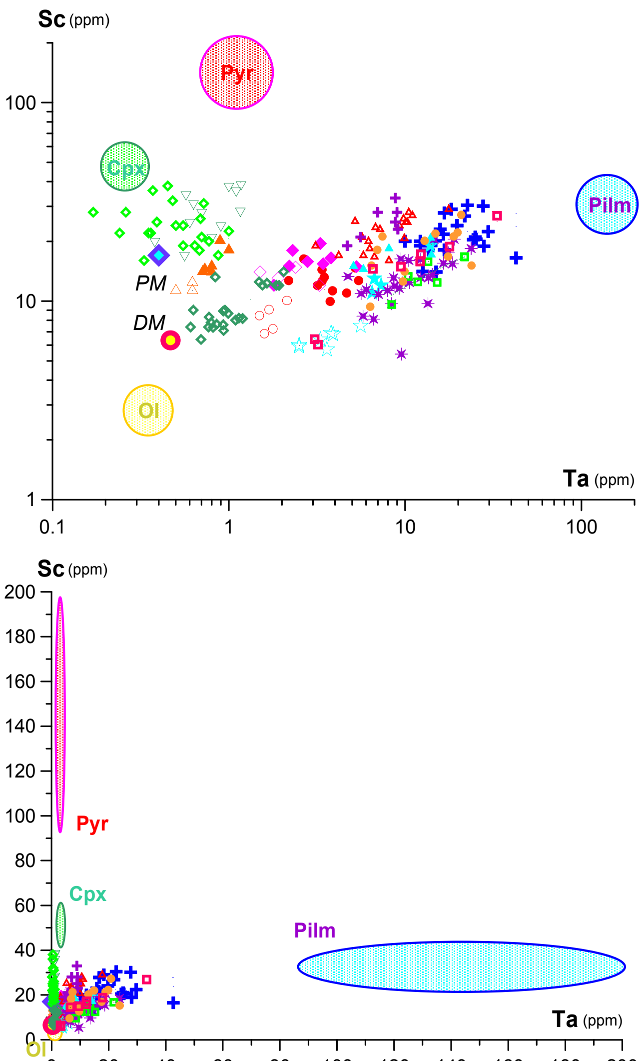

Fig. 1. Ta-Sc diagram for different kimberlitic rocks: top – logarithm scale; bottom – linear scale.

ARKHANGELSK PROVINCE

The kimberlite (and related) magmatism of the Arkhangelsk Province is developed on the Zimni Bereg, Terski Bereg of the Kola Peninsula, the Middle Timan (Umba) and Onega peninsula (Nenoksa) (Fig. 2, top). The magmatism of the Zimni Bereg has the greatest diversity.

Zimni Bereg

Comprehensive examination of Zimni Bereg volcanic rock occurrences revealed that among local kimberlites rock are representatives of two distinct groups (series), drastically different from each other in most of the compositional characteristics, including geochemistry, isotope chemistry and high-pressure mineralogy: Al-series and Fe-Ti-series (Sablukov, 1990:) (Fig. 2, bottom). Within each of these series, kimberlitic rocks also differ from each other, however, only “quantitatively”. The “qualitative” dissimilarity in rock composition is related to peculiarities of the initial mantle substrate, the “quantitative” distinctions are due to differentiation nuances of the products of initial mantle substrate transformation (extent of disintegration and partial melting).

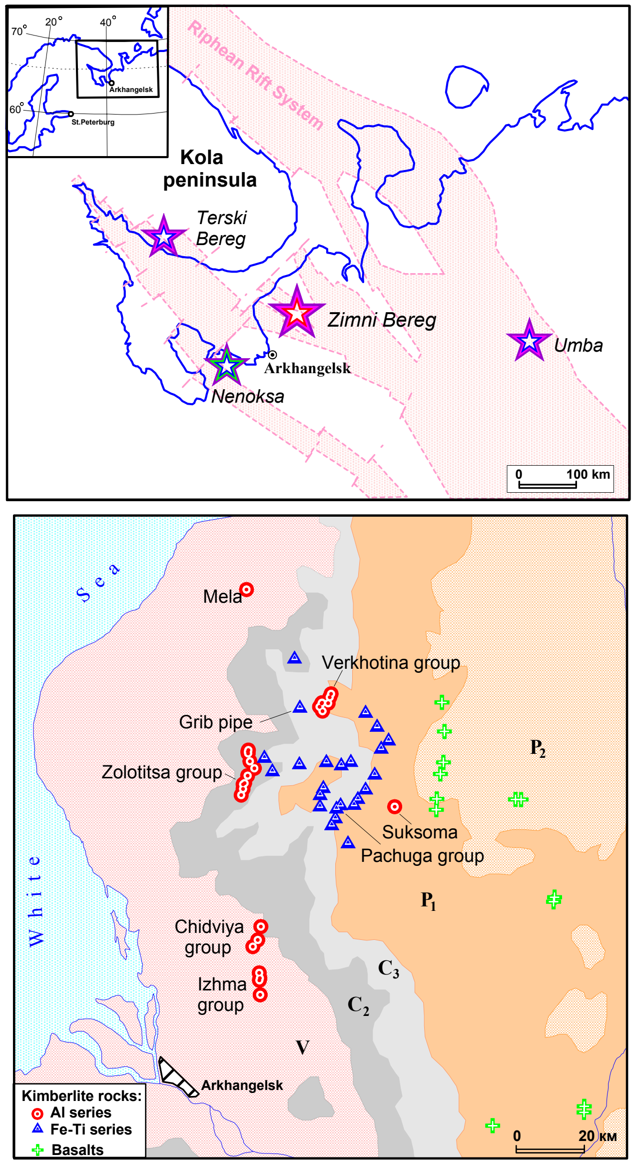

Fig. 2. Distribution of volcanic rocks on the Russian Platform North (top) and Zimni Bereg region (bottom).

The Al-series rocks form a sequence (row) from diamondiferous kimberlites of the Zolotitsky pipe cluster (the Lomonosov deposit) to kimmelilitites (the term taken from Milashev, 1974) and divine melilitites of Verhotina, Suksoma, Chidviya and Izhma. The Fe-Ti-series rocks form a row from diamondiferous kimberlites of the V. Grib deposit and poorly diamondiferous kimberlites of Pachuga to kimpicrites (Milashev, 1974) and melilite picrites of Shocha, Kepina, Soyana, Pachuga and Megra.

By a set of compositional characteristics, the Fe-Ti-series kimberlitic rocks of Zimni Bereg are similar to the petrological type reckoned as Group 1 South African kimberlites (Makhotkin et al., 1993). Al-series rocks are in some respect similar to the petrological type known as Group 2 South African kimberlites.

The Ta-Sc diagram was developed on the basis of detailed investigation of 70 kimberlite and related bodies in the Zimnii Bereg area.

The composition points of kimberlite rocks of the Zimni Bereg in the diagram "Ta-Sc" (Fig. 3) form separate fields and regular stable trends. Rocks of Fe-Ti series form a single trend of a hyperbolic type with similar Sc/Ta ratios in the isolation of only two rock groups: 1 - Grib pipe diamond-bearing kimberlites and 2 – poor diamond-bearing kimberlites and non-diamond-bearing kimpicrites and picrites of other pipes and sills.

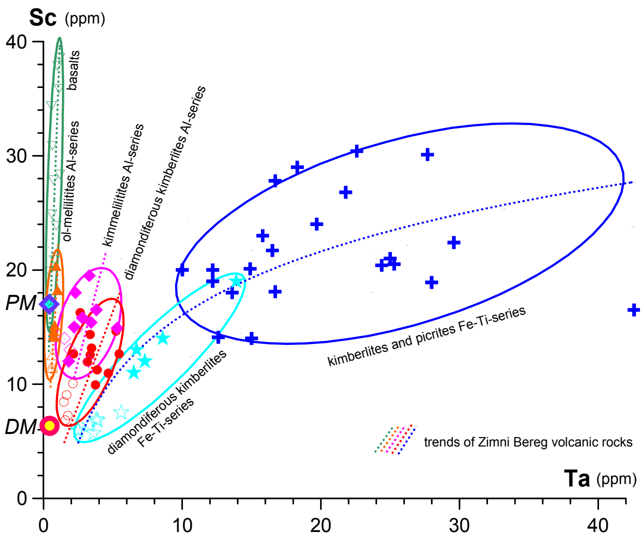

Fig. 3. Ta-Sc diagram for different kimberlitic rocks of the Zimni Bereg

The Al-series rocks form three linear trends with different Sc/Ta ratios in the isolation of three rock groups: 1 - Lomonosov deposit diamond-bearing kimberlites, 2 - kimmelilitites and 3 – pyroxene-free olivine melilitites. This sequence of rock types has a regularly increasing Sc/Ta ratio (reaching a maximum for basalts developed at the Zimni Bereg).

In this diagram, the composition field of and composition trends of different types of rocks are located quite natural and apart. Composition trends begin from the starting point of the composition of the depleted mantle and show a regular decrease in the degree of asthenospheric exposure to mantle sources of kimberlite rocks from kimberlite of Fe-Ti series to kimberlites, kimmelilitites and melilite of Al-series.

Composition fields of different kimberlites marked on the Ta-Sc diagrams are also distinctly isolated on the Sr-Nd isotopic diagram. Hence, the geochemical types of the kimberlite rocks were distinguished reasonably (Fig. 4).

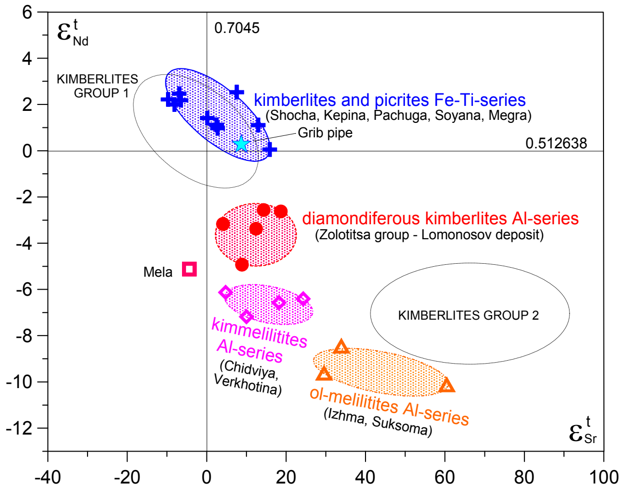

Fig. 4. Nd-Sr-isotope diagram for different kimberlitic rocks of the Zimni Bereg region.

Other regions of the Arkhangelsk Province

Terski Bereg of the Kola Peninsula has pipes of poor diamond-bearing kimberlites and pyroxene-free melilitites and olivine melilitites.

The Middle Timan (Umba area) has non-diamond-bearing kimberlites, kimmelilitites and olivine-phlogopite melilitites. Points of kimberlite rocks of these two areas in the diagram Ta-Sc (Fig. 5) occupy an intermediate position between the rocks of Fe-Ti series and Al series of the Zimni Bereg, generally "moving away" from composition of the depleted mantle.

The Onega Peninsula (Nenoksa area) has developed a number of rocks: kimmelilitites – pyroxene-free olivine melilitites - olivine melilitites. The diagram Ta-Sc (Fig. 5) shows how points of these rocks continue the trend of pyroxene-free melilitites of Al series of the Zimni Bereg "moving away" in the direction of basalt compositions.

According to the diagram, the location of composition points of the kimberlitic rocks of these three areas is fully consistent with their mineralogical, geochemical and isotopic characteristics.

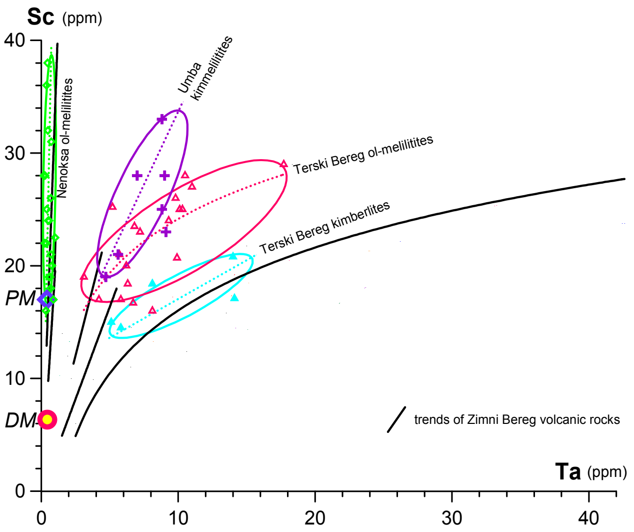

Fig. 5 Ta-Sc diagram for different kimberlitic rocks of the Russian Platform North.

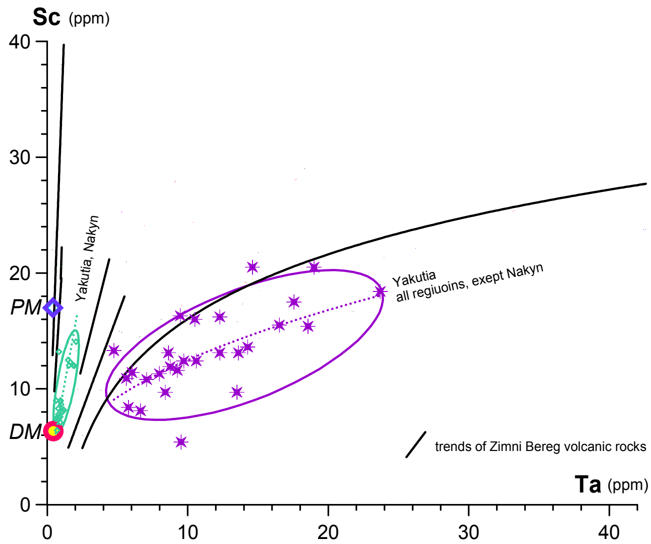

Fig. 6 Ta-Sc diagram for kimberlitic rocks of the Yakutian Province.

KIMBERLITE PROVINCE OF THE WORLD

Yakutia Province

The use of diagrams Ta-Sc for kimberlite regions in the world shows its high information content. This is evident in respect of the kimberlites of the Yakutian province (Fig. 6); we have only studied the magmatism of Nakyn field, other points after Bogatikov et al., 2004). The geochemical rock type of most of the fields of this province corresponds to kimberlite rocks of Fe-Ti series of the Zimni Bereg. Kimberlites of Nakyn field occupy an isolated position between kimmelilitites and melilitites of Al-series of the Zimni Bereg, which is quite consistent with their sharp geochemical depletion.

Some World Provinces

We have studied kimberlites of some provinces of the World; these kimberlites occupy their special places in the diagram Ta-Sc (Fig. 7).

Kimberlite rocks of the Piaua region, Brazil, form a composition trend that is exactly coincident with the composition trend of kimberlite rocks of Fe-Ti series of the Zimni Bereg, which is quite consistent with mineralogical, geochemical and isotopic characteristics.

At the same time, composition of kimberlites of Venezuela (Guaniamo area) also coincides with composition of kimberlite rocks of Fe-Ti series of the Zimni Bereg, which is in contradiction with the mineralogical, isotopic characteristics, some of the geochemical characteristics of rocks of Venezuela and should be explained in further studies.

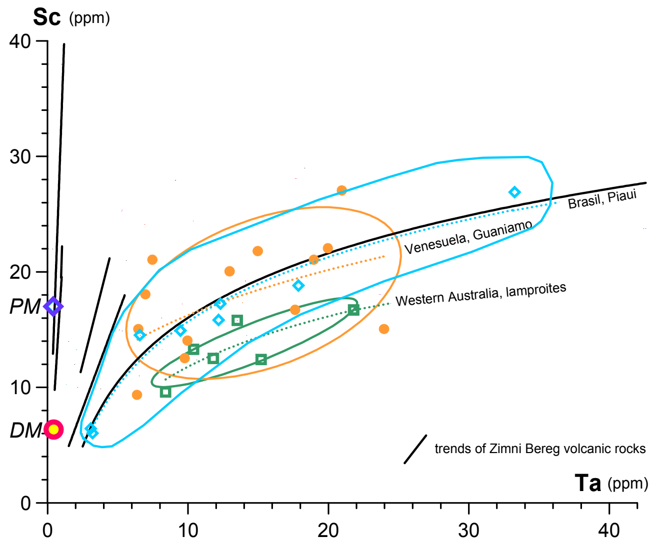

Fig. 7. Ta-Sc diagram for some kimberlitic rocks of the World.

The composition points of lamproites of Western Australia occupy an isolated area with a minimum Sc/Ta ratio, which is quite consistent with isotopic and geochemical characteristics.

Composition points of diamondiferous kimberlites of different geochemical types form a compact isolated area very close to the calculated composition of the depleted mantle (Fig. 8).

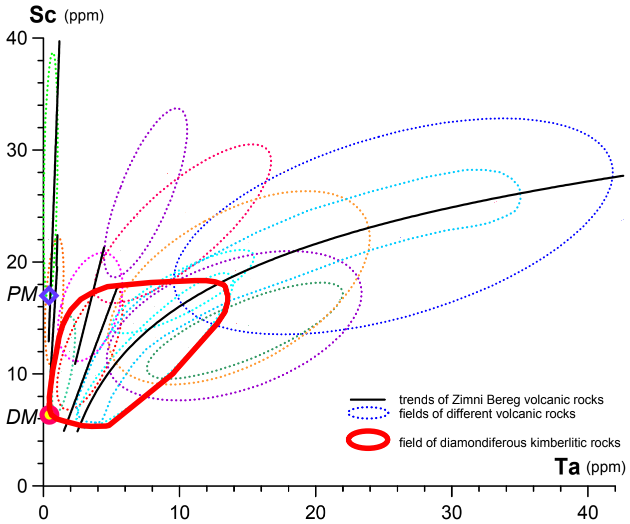

Fig. 8. Field of the diamondiferous kimberlitic rocks of the World on the Ta-Sc diagram.

CONCLUSIONS

Composition points of the kimberlite rocks on the Ta-Sc diagram form isolated fields and regular stable trends virtually similar for kimberlites from different parts of the world. This emphasizes the similarity of formation processes of the uniform kimberlite rocks in different parts of the world.

The composition variation trend lines of kimberlites begin virtually in one point, i.e., in the peridotite composition area of the "depleted" lithospheric mantle (not "primitive" mantle). Composition points of diamondiferous kimberlites of different geochemical types form a compact isolated area very close to the calculated composition of the depleted mantle.

Composition fields of different kimberlites marked on the Ta-Sc diagrams are also distinctly isolated on the Sr-Nd isotopic diagram. Hence, the geochemical types of the kimberlite rocks were distinguished reasonably.

The absolute Sc values yield differentiation degree and ultramaficity, and thus a potential diamond content of the rocks. The absolute Ta values yield the degree of asthenospheric influence on the initial mantle substratum, while the Sc/Ta ratio defines the kimberlite geochemical types.

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