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Distribution of trace elements in crystalline rocks of rift zones

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More than 1000 precise analyses of trace elements in basic and ultrabasic rocks of the Mid-Indian Ocean Ridge have been used for geochemical comparison with similar data for the continents, islands and chondrites.

We can draw a preliminary conclusion that the transport of trace elements in the oceanic segment of the Earth was controlled by two main processes: (*a*) degassing of the mantle, and (*b*) primary formation of the oceanic upper mantle and crust. Results of both processes may jointly occur.

Basic and ultrabasic rocks from rift zones of the Mid-Indian Ocean Ridge, sampled by the thirty-sixth expedition of R.V. *Vitiaz* four years ago and the second expedition of R.V. *Academician Kurchatov* two years ago were characterized by more than 1000 exact analyses of some trace elements. We used spectrographic, X-ray spectrographic, chemical and radioactivation methods of analyses for them.

Data of these analyses were compared with similar data for the main types of rocks and chondrites. We utilized most of the published data and the average geochemical compositions of the main rock types given by Vinogradov (1962), and Engel & Engel (1968). This comparison shows that basic rocks from rift zones, represented by basalts and gabbro, contain equal or almost equal amounts of trace elements on the average.

Table 1. Some trace elements of the ferrous group in ultrabasic rocks from rift zones of the Mid-Indian Ocean Ridge (average)

In brackets is the number of analyses

	Mn % by mass	V parts/10^6	Cr % by mass	Co parts/10^4	Ni % by mass
chondrites (Vinogradov 1962)	0.20	70	0.25	8	1.3
ultrabasic rocks from the Mid-Indian Ocean Ridge	0.12 (100)	45 (100)	0.26 (100)	1 (100)	0.2 (100)
ultrabasic rocks (Vinogradov 1962)	0.15	40	0.20	2	0.2
ultrabasic rocks from the Urals (Malakhov 1967)	0.08	0.8	0.27	1	0.2

The distribution of trace elements in ultrabasic rocks from rift zones gives us still more interesting results. We divided these data into three groups accordingly to three main geochemical groups of trace elements. The table, containing all the data, is very large. Therefore we show here only schematic tables, summarizing all data. Table 1 was constructed for the ferrous group of trace elements. It may be seen here that average ultrabasic rocks from rift zones are similar to average ultrabasic rocks from continents and almost similar to average chondrites.

Table 2 shows the concentration of the chalcophile group of trace elements in the same rocks as the first table. There it may be seen that our ultrabasic rocks contain equal or greater amounts of these elements in comparison with average ultrabasic rocks and chondrites.

Data on the concentration of the lithophilic group of trace elements in ultrabasic rocks from rift zones are shown in table 3. It is easily seen that our ultrabasic rocks (from rift zones) contain an average concentration of lithophilic trace elements almost similar to that in acid or basic rocks and much greater than that in ultrabasic rocks of the alpine type from continents or in chondrites.

TABLE 2. SOME TRACE ELEMENTS OF THE CHALCOPHILIC GROUP IN ULTRABASIC ROCKS FROM RIFT ZONES OF THE MID-INDIAN OCEAN RIDGE (AVERAGE)

In brackets is the number of analyses

	Cu % by mass	Hg parts/10^8	Cd parts/10^8
chondrites (Vinogradov 1962)	0.01	3.0	10
ultrabasic rocks from the Mid-Indian Ocean Ridge	0.005 (100)	2.2 (80)	2 (80)
ultrabasic rocks (Vinogradov 1962)	0.002	1.0	5

TABLE 3. SOME LITHOPHILIC TRACE ELEMENTS IN ULTRABASIC ROCKS FROM RIFT ZONES OF THE MID-INDIAN OCEAN RIDGE AND IN SOME OTHER ROCK TYPES

In brackets is number of analyses

	U parts/10^9	Th parts/10^9	Zr parts/10^5	Li parts/10^7	Be parts/10^7	K % by mass
chondrites (Vinogradov 1962)	50	40	3	30	35	0.08
ultrabasic rocks from the Mid-Indian Ocean Ridge	800 (20)	1500 (20)	10 (80)	20 (30)	8 (30)	0.07 (30)
ultrabasic rocks (Vinogradov 1962)	3	5	3	5	2	0.03
basalt (Vinogradov 1962)	500	3000	10	150	4	0.83
oceanic basalt (Engel *et al.* 1965)	—	—	95	—	10.x	1.3
granite (Vinogradov 1962)	3500	18000	20	400	55	3.34

We should like to say some words about the geochemical relations of basalts and ultrabasic rocks, before we explain these data.

It is known from general experimental data and from thermodynamic calculations of distribution coefficients of trace elements in solid and liquid phases, and from investigations of the melting systems, that trace elements are usually enriched in the liquid phase during crystallization. Therefore basalts are enriched and residual ultrabasic rocks are depleted in lithophilic trace elements relative to the primary pyrolite during the formation of basaltic crust by zone melting of the mantle. It is also possible that a similar process takes place during melting and separating of basalt during partial melting of the mantle. This is confirmed by data on the distribution of trace elements in continental rock types. In this case peridotites of the alpine type are represented by the residual matter after separation of the common basalts from pyrolites.

It is possible to think that the process of oceanic basalt formation is similar to that of continental basalts, because both have a similar concentration of trace elements. However, oceanic peridotites contain much more lithophilic trace elements than peridotites of the alpine type, more than chondrites, which may represent pyrolites, and as much and sometimes more than basalts. We can see this from table 3.

Table 4. Lanthanoids in different types of basalts and ultrabasic rocks from the Mid-Indian Ocean Ridge and in chondrites

	number of analyses	rare earth parts/10^6	$\Sigma Ce/\Sigma Y$
chondrites (Haskin *et al.* 1966; Frey *et al.* 1968)	29	5.1	0.71
ultrabasic rocks from the Mid-Indian Ocean Ridge	5	15.5	0.97
high alumina basalts and dolerites	10	76.4	0.84
tholeiites and gabbro	16	114.5	0.66
subalkaline basalts	2	94.0	1.44
alkaline basalts	3	219.0	3.37

Table 4 gives the results of analyses of the concentration of the rare-earth group of trace elements, which were carried out in the Vernadsky Institute of the U.S.S.R. Academy of Sciences for different kinds of basalts and peridotites from rift zones.

Data in this table indicate that all these basalts and peridotites could not form during a single comagmatic process, because in this process the Ce subgroup would become enriched in basalts relatively to peridotites. This conclusion was drawn by Balashov (1963), Haskin, Frey, Schmitt & Smith (1966), and others during the investigation of lanthanid distribution in different comagmatic series for most rock types.

Thus, on the whole, we have a complex picture of the distribution of trace elements on comparison of the oceanic and the continental parts of the Earth.

This complexity is illustrated by a schematic picture (see figure 1). The left part of it shows the section across the oceanic segment of the Earth, the right one across the continental segment. (A similar picture was shown by Engel & Engel at the International Oceanographic Congress in Moscow in 1966.) In this picture the density of shading shows the concentration of lithophilic trace elements. In the lower part is the primary concentration as in chondrites. In the upper part is the localized zone of enrichment. Between them lies the zone of depletion in lithophilic trace elements.

Previously, in 1967 at the Upper Mantle Congress in Zurich, Vinogradov & Yaroshevsky demonstrated that for the continental segment this distribution of trace elements may be connected with zone melting of the mantle which preceded the sialic crust formation. They also showed that the thickness of these zones must vary for each trace element, because its reaction is different in the process of zone melting of the mantle.

Now it is necessary to explain the new geochemical peculiarities of the oceanic mantle, if the ultrabasic rocks from rift zones actually represent the upper mantle and this schematic picture is to be close to reality.

We have earlier seen that there is no geochemical connexion between basalts and ultrabasic rocks from rift zones. It is likely that these basalts were melted from greater depths of the upper mantle, where their geochemical composition is similar to common ultrabasic rocks or ultrabasic nodules in basalts and where the conditions were more favourable to melting. According to petrological data this depth must be no less than 50–60 km.

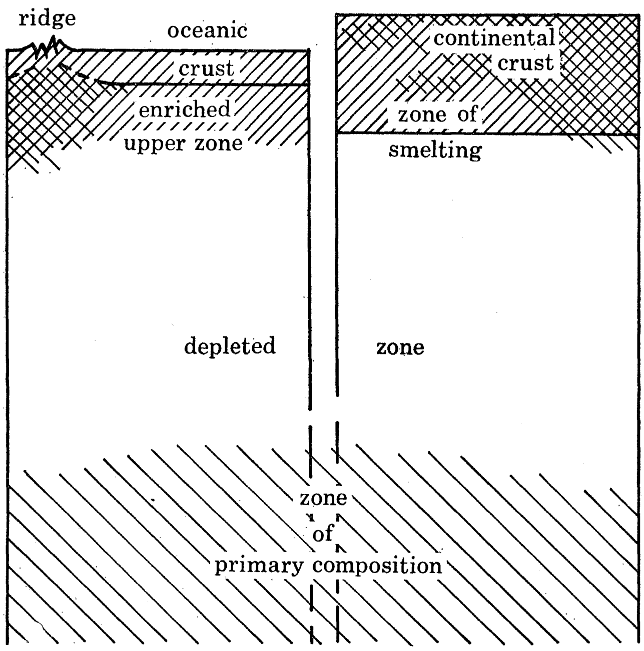

Figure 1. A hypothetical scheme of distribution of the lithophilic trace elements in the upper mantle and in the Earth's crust. The density of shading corresponds to the concentration of these elements.

In the upper zone of the mantle which is located under the oceanic crust, the melting process becomes more difficult and in the highest part it is quite impossible.

We think that this upper zone of the mantle may be represented by undifferentiated pyrolite. The high concentration of lithophilic trace elements in this zone of the mantle may be explained by two notions.

First, the process of transportation of trace elements was similar for both segments of the Earth, and preceded the formation of the Earth's crust. Later, after the formation of the continents, the lithophilic trace elements concentrated in the sialic layer and after the formation of the oceanic crust they were preserved in peridotite which represents the less differentiated upper mantle of oceanic type.

Secondly, the enrichment of the lithophilic group of trace elements in ultrabasic rocks under oceanic ridges is possible owing to the hydrothermal process which may be realized by the mantle degassing. This process may be supported by the high permeability of zones characterized by tectonic activity. These zones are commonly used by hydrothermal solutions.

The two ideas are not contradictory and both processes may occur jointly. These ideas are useful for hypotheses about the independent development of the oceanic and the continental parts of the Earth.

It is interesting to note that the last expedition of R.V. *Academician Kurchatov*, which was finished in November 1969, obtained samples from rift zones of the Mid-Atlantic Ridge, which show the hydrothermal activity of the upper mantle. These samples consist of calcite veins and contain high Cu, Sn, Pb, Zn and Hg concentrations. The surrounding rocks—peridotites—also contain high concentrations of the same elements. This supports the second notion, that mantle degassing is a cause of trace element enrichment of peridotites from rift zones.

As yet we are only beginning to study these processes and our ideas should therefore be regarded as only preliminary.

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