Trace Elements in Alkali Basalts and Their Inclusions in the Dariganga Area, Mongolia

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Abstract

Alkali basalts of Dariganga contain inclusions of dunite, harzburgite, peridotite, and eclogite-like rock. The dunites and peridotites contain few trace elements, but these are somewhat more abundant in the eclogite-like rock, and the alkali basalts are rather rich in them. The trace elements show a more or less continuous change in abundance that can be related by recognized crystal-chemical laws to the major elements of the minerals that are present in the various rock types.

Hypotheses for the origin of basaltic magma are discussed in relation to the trace-element distribution in the Dariganga rocks, but it is concluded that the available evidence does not permit any definite decision as to which is correct.

Basaltic lavas of Pleistocene age in the Dariganga area, Mongolia, contain inclusions of two types: dunite-peridotite, and eclogite-like rocks. Some are xenoliths, but others are segregations. The Dariganga volcanics are very similar petrographically to those of analogous continental areas elsewhere. The average chemical composition of six Dariganga lavas, and compositions of three inclusions, are given in Table 1.

Chemically, the lavas are alkali basalts. They contain phenocrysts of olivine, orthopyroxene, and clinopyroxene, and some of them contain anorthoclase. The groundmass consists of pyroxene, plagioclase (oligoclase to labradorite), and ore minerals. Some rocks contain analcime.

The inclusions consist of olivine, orthopyroxene, clinopyroxene, and spinel, and one contains also omphacite and garnet. Most of them

TABLE 1

	Basalt (Average from 6 analyses)	*Eclogite-like rock*	*Peridotite*	*Dunite*
SiO_2	43,80	48,10	43,68	40,47
TiO_2	2,90	0,25	0,25	0,02
Al_2O_3	11,30	3,46	2,09	1,10
Fe_2O_3	6,90	2,50	2,47	0,86
Cr_2O_3	n.d.	0,06	0,16	—
FeO	7,43	5,11	7,18	8,96
MnO	0,19	0,10	0,12	0,12
CoO	n.d.	0,04	0,03	—
NiO	n.d.	0,15	0,20	0,12
MgO	10,92	32,63	41,62	48,40
CaO	9,49	7,20	1,70	0,08
Na_2O	3,67	0,44	0,36	0,15
K_2O	1,60	0,10	0,13	0,14
H_2O^+	0,88	0,44	0,38	—
H_2O	0,35	0,04	0,07	—
P_2O_5	0,57	—	—	—
CO_2	—	0,10	0,26	—
	100,00	100,72	100,70	100,42
a	9,8	0,9	0,7	0,4
c	2,3	1,4	0,7	0,1
b	38,5	54,6	60,9	66,4
s	49,4	43,1	37,7	33,1
a′	—	—	—	0,9
f′	32	10,5	11,7	10,1
m′	45	79,6	88,2	89,0
c′	23	9,9	0,1	—
n	78	87	86	75
a:c	4,3	0,6	1	4
Q	−23,1	−17,0	−26,7	−34,7

may be classified as dunites, harzburgites, and peridotites. The inclusion containing omphacite and garnet is classed as a garnet peridotite, or better as an eclogite-like rock.

The trace elements in the rocks have been determined by A. S. Dudikina and A. A. Yaroshevsky by semiquantitative spectral analysis. The results are given in Table 2. The alkali basalts contain 0.1×10^{-12} to 0.5×10^{-12} Ra, and 0.3×10^{-6} to 1.5×10^{-6} U, and one sample contains 0.25×10^{-5} Th. These elements have not been determined in the inclusions.

Nearly all of the elemnets found in the Dariganga rocks and minerals form a closely contiguous group in the geochemical table of A. N. ZAVARITZKY (1950). They include all the elements of the rock group, all those of the iron group, half of those in the metal group, six from the conditional group of « rare elements », three from the group of radioactive elements, and five from the group of magmatic emanations.

Except in the anorthoclase, the most widely distributed trace elements in the Dariganga rocks and minerals are V, Cr, Co, Ni, Cu, and Ga. Zr and Ba are present in the eclogite-like rock and the alkali basalts. Co, Ni, and Cu have been found in all samples. Less widely distributed are Zn, Ag, Be, W, Sn, Sr, Nb, Mo, Sc, Pb, Li, Rb, and Cs, in decreasing order of abundance. Least common are Y and Th, each of which has been found in only one sample.

According to the principles of crystal chemistry, all of these elements may isomorphically replace the major elements in minerals, particularly those that have the same valence. Those of different valence may be replaced endocryptically, — that is, they enter into the structure only on the basis of similar ionic radii.

Comparison of the abundance of the trace elements in the rocks with their clarkes shows that the contents of Be, Sc, Co, Ni, Ga, Sr, Zr, Ba, and W are greater than the clarkes, and those of V, Cr, and Nb are the same as the clarkes. The abundance of other elements is less than the clarkes.

The number of trace elements found in the inclusions is very different from that in the basalts. The dunite contains 4 trace elements, the peridotite contains 8, and the eclogite-like rock contains 11, plus one qestionable one. In contrast, the alkali basalts contain 22 trace elements and 3 radioactive elements.

The abundance of most elements changes progressively from dunite to alkali basalt. Al, Fe^3, Ca, Na, K, Ti, Mn, Ba, Zr, and Ag

TABLE 2 - The abundances of the elements in the rocks and their clarkes.

Elements	*Xenoliths*			*Lava*	*Clarkes according to* VINOGRADOV *(1949)*
	Dunite	*Peridotite*	*Eclogite-like rock*	*Alkaline basalt*	
Si	18,88	20,38	22,44	20,40	27,6
Ti	0,01	0,15	0,15	1,74	0,5
Al	0,59	1,11	1,83	5,86	8,80
Fe^{3+}	0,61	1,73	1,75	4,83	5,10
Fe^{2+}	6,97	5,59	3,98	5,77	
Mn	0,09	0,09	0,08	0,15	0,09
Mg	29,20	26,11	19,68	6,54	2,10
Ca	0,06	1,22	5,15	6,76	3,6
Na	0,11	0,27	0,33	2,72	2,64
K	0,12	0,11	0,09	1,33	2,60
H^{+}	—	0,05	0,05	0,10	0,10
P	—	0,02	—	0,25	0,08
C	—	0,08	0,03	0,01	0,1
S	—	—	—	0,10	0,05
Cl	—	—	—	0,01	0,045
Li	—	—	—	0,0003	0,0065
Be	—	—	0,003	0,001	0,0006
Sc	—	0,0003	—	0,0001	0,0006
V	—	—	0,03	0,016	0,015
Cr	0,1	0,11	0,03	0,023	0,02
Co	0,04	0,02	0,03	0,005	0,003
Ni	0,09	0,16	0,12	0,019	0,008
Cu	0,0001	0,0003	0,01	0,004	0,01
Zn	—	0,005	—	0,0017	0,005
Ga	—	—	0,007	0,005	0,0015
Rb	—	—	—	0,0005	0,03
Sr	—	—	—	0,05	0,04
Y	—	—	—	0,0005	0,0028
Zr	—	—	0,005	0,028	0,02
Nb	—	0,01	?	0,001	0,001
Mo	—	—	—	0,00003	0,0003
Ag	—	—	0,0001	0,0003	0,00001
Sn	—	—	—	0,0003	0,004
Cs	—	—	—	0,00004	0,00009
Ba	—	0,0015	0,1	0,21	0,05
W	—	—	0,005	0,0008	0,001
Pb	—	—	—	0,0005	0,0016
Ra	—	—	—	$0,25 \cdot 10^{12}$	$1 \cdot 10^{10}$
Th	—	—	—	$0,25 \cdot 10^{5}$	$8 \cdot 10^{-4}$
U	—	—	—	$0,9 \cdot 10^{-6}$	$3 \cdot 10^{-4}$

In xenoliths Li, Rb, Cs, Ra, Th and U have not been determined.
In the samples studied no As, Sb, Te, Ta, Tl, Bi, La, Cd and Ce, have been found.

increase, while Mg, Ga, Zn, Be, and Sc decrease. Especially great is the change in Mg — from 29.2 percent in the dunite to 6.5 percent in the basalt. On the other hand, the contents of Si, Cr, Ni, and Cu first increase and then decrease, reaching a maximum in the eclogite-like rock, whereas that of Fe^2 first decreases and then increases. Co decreases in peridotite, regains its dunite value in the eclogite-like rock, and then decreases greatly in the alkali basalt. The changes are shown in Figure 1.

The xenoliths may be fragments of the rocks that formed the roof of the magma reservoir, or they may be (especially the dunite) residual material left from partial melting of the parental material of the upper mantle from which the alkali basalt magma was derived.

As is well known, there are several hypotheses for the origin of alkali basalt. KUNO (1958, 1959, 1963), and others, think that alkali basalt magma is derived from peridotite, at greater depth than tholeiitic basalt magma. MACDONALD (1958) believed that eclogite is a more probable source of basalt magmas. VINOGRADOV (1959, 1961) believes the substance of the upper mantle to be close to peridotite in composition, and that basaltic magma is derived from it by melting, in a process resembling zonal fusion, leaving a residue of dunite. YODER and TILLEY (1962) assumed that basaltic magma is derived from parental garnet peridotite of eclogitic facies, different proportions of garnet and omphacite being melted at different pressures. In this way they believe tholeiitic magma is formed under relatively low pressure, and alkali basalt magma under higher pressure and consequently at greater depth. WYLLIE (1963) believes that the upper mantle is variable in composition, and that basaltic magma can form either by partial melting of feldspar peridotite of by total melting of eclogite.

Since inclusions of dunite, peridotite, and eclogite-like rock all occur in the Dariganga lavas within the small area of about 10,000 km^2, it may be assumed that the roof of the magma chamber within the upper mantle, from which the magma was derived, consists of all of these rock types, and that the upper mantle is not homogeneous. Unfortunately, the data does not lead to a unique solution of the problem of the origin of the magma. If we accept Vinogradov's concepts, the basaltic magma was melted out of the upper mantle, leaving dunite and possibly peridotite as residuals. On the other hand, the presence of the eclogite-like rock tends to support the hydrothesis of Yoder and Tilley. And finally, the presence of xenoliths of varying composition tends to support Wyllie's hypothesis of variable composition of the upper mantle.

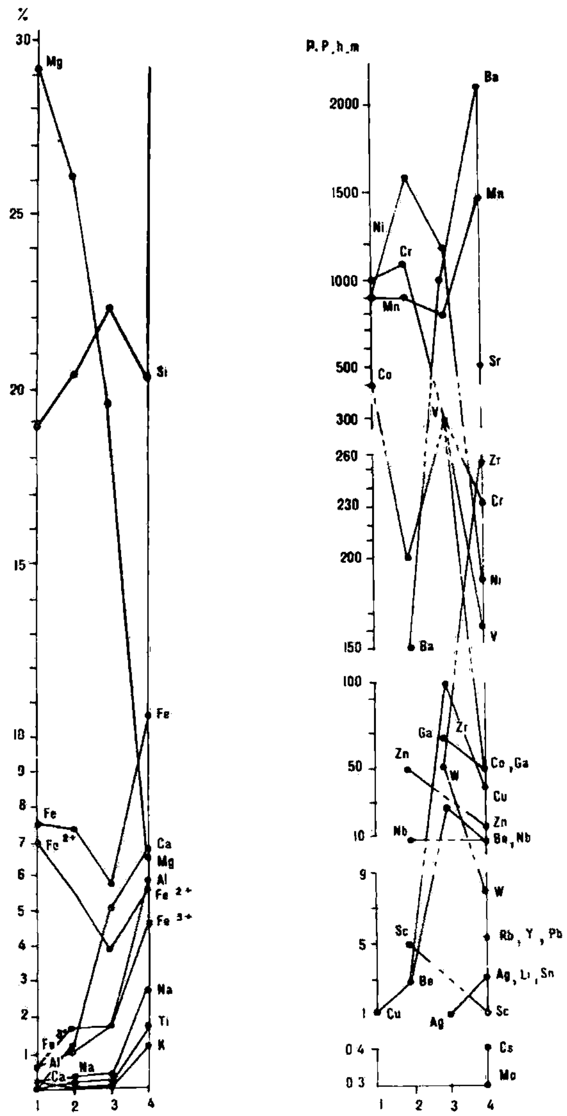

FIG. 1 - Abundances of elements in different rock types. 1 - dunite, 2 - peridotite, 3 - eclogite-like rock, 4 - alkali basalt.
The abundances of the trace elements in the right-hand graph are in part per hundred million.

If one assumes that the xenoliths represent parental rocks of the alkali basalt magma, the variation in the trace elements is the result of differentiation in the upper mantle during the crystallization of these rocks. The amounts of different trace elements in them are partly, or perhaps largely, dependent on the compositions and amounts of the different minerals in the rocks. Dunite is a nearly pure olivine rock — a rock of magnesium and divalent iron — with a predominance in it of elements that have nearly the same ionic radii: Ni, Cr, Co, and Cu. The mineral composition of subsequent rocks (peridotite, eclogite-like rock, and alkali basalt) becomes progressively more complex, with a gradual increase in the number of minerals with different lattices, and there is a corresponding increase in the number of trace elements in them. Since this is the case, one can hardly agree with the suggestion that the trace elements absent in the xenoliths, but present in the alkali basalt, have been assimilated by the basaltic magma from other rocks.

Thus, the presence in the rocks of varying amounts of trace elements is probably related to the abundance of various minerals, which resulted in turn from the differentiation and subsequent crystallization by which these rocks were formed.

Finally, the great differences in number and abundance of the trace elements in the xenoliths and the alkali basalts could lead to the conclusions that the rocks of the xenoliths are only roof rocks of a magma chamber in the upper mantle or lower crust, that they are not the parent rocks of the Dariganga alkali basalt magma, and consequently that the formation of the magma is related to some other material.

For the time being, it is difficult to say which of the suggested hypotheses for the origin of the alkali basalt magma of Dariganga is correct.

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