

**SPECULATIONS ON THE GENESIS OF ALKALINE
AND SUB-ALKALINE BASALTS FOLLOWING EXODUS
OF THE CONTINUAL CRUST**

JOHN A. PHILPOTTS
AND
C. C. SCHNETZLER

*Planetology Branch, Goddard Space Flight Center,
Greenbelt, Maryland*

ABSTRACT

K, Rb, Sr, Ba, and rare-earth data and partition coefficients indicate the plausibility of alkali basalts and subalkaline basalts being derived by limited and extensive fusion respectively of residual material created during continent formation.

Considerable evidence, as summarized recently by Gast (1968), indicates that subalkaline oceanic basalts are derived from material residual from previous partial melting events. The nature of the melts that were previously tapped from this material is open to speculation. They might have been alkali basalts. Another possibility is that these melts are now represented by the bulk material of the continental crust. The purpose of this note is to demonstrate the plausibility of the latter hypothesis insofar as K, Rb, Sr, Ba, and rare-earth concentrations are concerned and to suggest where alkali basalts might fit in such a petrogenetic scheme.

A number of estimates of the bulk chemical composition of the continental crust are available in the literature, and tend to show general agreement. We have chosen K, Rb, and Sr values based on those given

TABLE 1. TRACE ELEMENT CONCENTRATIONS, IN P.P.M., FOR THE CONTINENTAL CRUST, A SUBALKALINE BASALT, AN ALKALINE BASALT, AND FOR THE NORMALIZATION VALUES

	Continental crust	Subalkaline basalt	Alkaline basalt	Normalization values
Sr	462	145	825	11
Rb	60	1.05	35	0.38
K	14,000	1160	13,000	133
Ba	324	8.60	432	3.6
Ce	75	7.58	94.4	0.787
Gd	6.1	3.71	9.47	0.256
Yb	4.5	2.49	2.26	0.188

by Hurley (1968), the remarkably uniform rare-earth values for shales (Haskin *et al.* 1966), and a Ba value based upon our own analyses of igneous and sedimentary rocks. The concentration of these trace elements are given in the Table; rare-earths other than Ce, Gd, and Yb are not included in the interest of brevity. Normalized concentration values are plotted in Figure 1. The normalizing values are the concentrations suggested by Hurley (1968) for the bulk earth which are the same as those in chondritic meteorites except for K and Rb; the normalizing values are given in the Table.

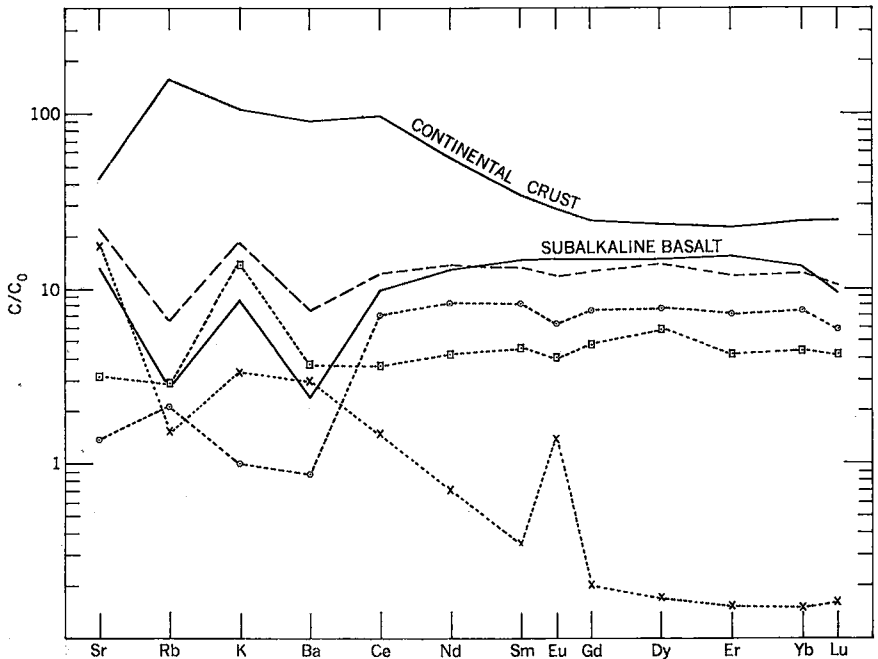


FIG. 1. Normalized trace element concentrations in the continental crust and a sub-alkaline basalt, in a hypothetical amphibolite (dashed line), and the proportional contributions from its constituent 40% amphibole (\square), 35% clinopyroxene (o), and 25% plagioclase (x).

Recent analyses of fresh sub-alkaline oceanic basalts (Hart 1969; Philpotts & Schnetzler 1969) have indicated a rather remarkable uniformity in trace element concentrations, particularly if crystallization and cumulation of olivine and plagioclase are taken into account. Normalized trace-element concentrations for a representative fresh sub-alkaline basalt from

the mid-Atlantic ridge are plotted in Figure 1; the concentrations are given in the Table.

Consideration of the plausibility of a liquid-solid relationship between the continental crust and the residual material from which sub-alkaline oceanic basalts are derived is simplified by assuming that most of the K, Rb, Sr, Ba and rare-earths in this residual material are taken up by the sub-alkaline basalt during the later fusion event. In other words, the abundance of these trace elements in the subalkaline basalt would be similar to their abundance in the source material. This is a fairly reasonable assumption inasmuch as subalkaline basalts most likely result from extensive partial fusion (Gast 1968) and the residual material created by their extraction would be very severely depleted in the trace elements of interest for likely values of the partition coefficients. With this assumption, the continental crust and the basalt, should, as a first approximation, bear a liquid-solid relationship to each other if the hypothesis is valid. The relationship can be checked in terms of measured phenocryst-matrix (liquid) partition coefficients for K, Rb, Sr, Ba, and the rare-earths (Schnetzler & Philpotts 1968; Philpotts & Schnetzler 1970; Schnetzler & Philpotts 1970), assuming these are appropriate.

The distribution of the rare-earth elements between sub-alkaline basalt and continental crust is virtually identical to some that we have measured between amphibole or Ca-clinopyroxene and their respective "liquids." This identity gives considerable support to the plausibility of the hypothesis. The relatively high K/Rb and K/Ba of the sub-alkaline basalt would seem to require amphibole, in agreement with Oxburgh (1964) and Hart & Aldrich (1967). Similarly, the relatively high Sr concentration would seem to require plagioclase. The uncertainties in the chemical composition of the bulk continental crust and the limited number and range of partition coefficient values, particularly the absolute values, make it difficult to specify with any great precision the modal proportions of minerals in the solid. Mica and garnet in any great quantities, however, would seem to be excluded because of the high Ba and Rb partition coefficients of the former and the high heavy rare-earth partition coefficients of the latter. Based upon actual measured partition coefficients, the trace element concentrations, similar to those for subalkaline basalt, of a hypothetical rock consisting of 25% plagioclase, 35% augite, and 40% amphibole, and presumed to be in equilibrium with a "continental-crust" liquid, are shown in Figure 1 by the dashed line; the contributions of the minerals to the whole-rock values are indicated by the dotted lines. The model is not very sensitive to the abundance of olivine or orthopyroxene in the solid because of the very low values of their partition

coefficients; an amphibole peridotite would seem to fit as well. In either case fusion at relatively shallow depths is indicated.

The partition coefficients indicate the plausibility of the hypothesis that subalkaline basalts may be produced by extensive fusion of the residue created by extraction of the continental crust. What about alkali basalts? As in the case for shales and for subalkaline basalts, our unpublished data on alkali basalts, both continental and oceanic, indicate a fair amount of uniformity in trace element concentrations, particularly the rare-earth elements. Concentrations for a fairly typical alkali are given in the Table and plotted in Figure 2. As we have noted elsewhere (Phil-

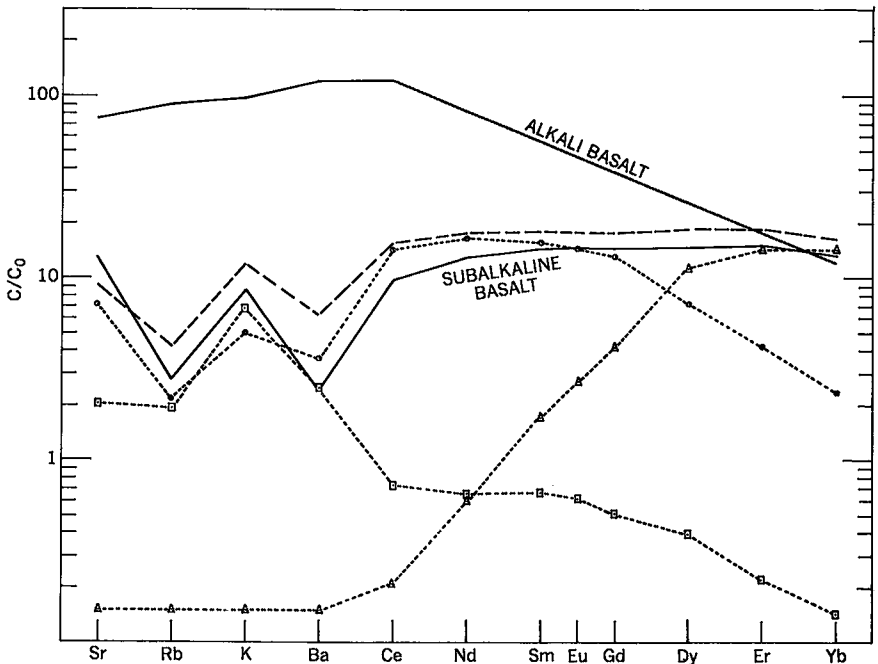


Fig. 2. Normalized trace element concentrations in an alkali basalt and a subalkaline basalt, in a hypothetical eclogite (dashed line), and the proportional contributions from its constituent 65% clinopyroxene (o), 30% garnet (Δ), and 5% amphibole (\square).

potts & Schnetzler 1970), trace element partition coefficients are consistent with a liquid-solid relationship between alkali basalt and the source material of subalkaline basalt in a garnet-bearing assemblage (eclogite or garnet peridotite). The presence of garnet in the solid phase effects a lowering of the concentrations of the heavy rare-earth elements

in the equilibrium liquid. The difference in the rare-earth patterns of the continental crust and alkali basalts could reflect this effect. The dashed line in Figure 2 indicates trace element concentrations, similar to those of subalkaline basalt, of a hypothetical rock in equilibrium with alkali basalt liquid; based upon the partition coefficient data, the proportional contributions of 65% clinopyroxene, 30% garnet and 5% amphibole to the total rock are shown by the dotted lines. As we have discussed elsewhere (Philpotts & Schnetzler 1970) amphibole may not be a necessary constituent; mica is a possible substitute, but it is not obvious that any potassic phase is required. In any case it appears quite plausible that alkali basalts might result from very limited partial fusion or zone refining of residual material created by continent formation while such material was in a garnet bearing assemblage.

REFERENCES

- GAST, P.W. (1968) : Trace element fractionation and origin of tholeiitic and alkali magma types. *Geochim. Cosmochim. Acta* **32**, 1057-1086.
- HART, S.R. (1969) : K, Rb, Cs contents and K/Rb, K/Cs ratios of fresh and altered submarine basalts. *Earth Plan. Sci. Lett.* **6**, 295-303.
- HART, S.R. & ALDRICH, L.T. (1967) : Fractionation of K/Rb by amphiboles: implications regarding mantle composition. *Science* **155**, 325-327.
- HASKIN, L.A., FREY, R.A., SCHMITT, R.A. & SMITH, R.H. (1966) : Meteoritic, solar and terrestrial rare-earth distributions. *Physics and Chemistry of the Earth* **7**, 167-211, Pergamon Press.
- HURLEY, P.M. (1968) : Absolute abundance and distribution of Rb, K and Sr in the Earth. *Geochim. Cosmochim. Acta* **32**, 273-283.
- OXBURGH, E.R. (1964) : Petrological evidence for the presence of amphibole in the upper mantle. *Geol. Mag.* **101**, 1-19.
- PHILPOTTS, J.A. & SCHNETZLER, C.C. (1969a) : Submarine basalts: some K, Rb, Sr, Ba and rare-earth data bearing on their alteration, modification by plagioclase, and possible source materials. *Earth Plan. Sci. Lett.* **7**, 293-299.
- (1970) : Phenocryst-matrix partition coefficients for K, Rb, Sr and Ba, with applications to anorthositic and basalt genesis. *Geochim. Cosmochim. Acta* **34**, 307-322.
- SCHNETZLER, C.C. & PHILPOTTS, J.A. (1968) : Partition coefficients of rare earth elements and barium between igneous matrix material and rock forming mineral phenocrysts. *Origin and Distribution of the Elements*, 929-938, Pergamon Press.
- (1970) : Partition coefficients of rare-earth elements igneous matrix material and rock-forming mineral phenocrysts-II. *Geochim. Cosmochim. Acta* **34**, 331-340.