Two Types of Alkaline Rocks-Two Types of Upper Mantle *

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Abstract

1) Petrochemical studies of volcanic rocks shows that alkaline rocks of continents and oceans are different genetically in spite of their mineralogical and chemical similarity.

2) Oceanic rocks develop according to the following type: tholeiitic basalt — olivine basalt — alkaline rocks.

3) Continental alkaline rocks are derivatives of initially alkaline basalts and are connected by gradual transitions with calc-alkaline rocks of island arcs.

4) The source of all volcanic rocks is the upper mantle. Therefore the existence of two main types of rocks — oceanic and continental — reflects basic heterogeneities in composition and structure of the upper mantle.

Introduction

In a number of his publications (GORSHKOV, 1960-1965) and in a summarizing review (GORSHKOV, 1967) the author paid attention to the existence of two classes of volcanic rocks — continental and oceanic. The preceding works were based mainly on the data obtained in the Pacific area and the adjacent regions. It seems interesting to analyze petrochemical peculiarities of oceanic and continental volcanism in the Atlantic area and its nearest surroundings as well. Especially as a great number of new chemical analyses of volcanic rocks has been carried out in the last years in this region.

It has been stated in the Pacific area that in the system of

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petrochemical recalculation by Zavaritsky [1] method variational lines on the plane ASB drawn according to the mean values of analyses form two families of lines. Variation lines for lavas of intraoceanic volcanoes form the angle with the vertical of 30-35°. (These rocks were called oceanic).

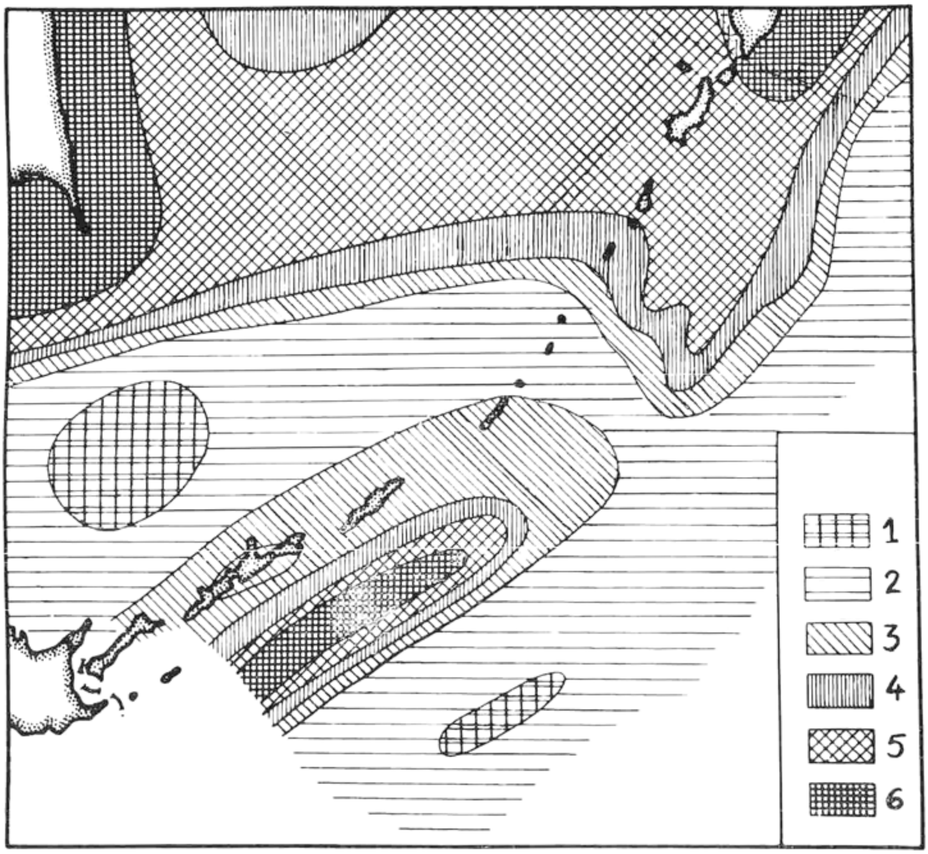

FIG. 1 - Thickness of consolidated Earth's crust in the area of the Kurile Islands. 1: 5 km, 2: 5-10 km, 3: 10-15 km, 4: 15-20 km, 5: 20-25 km, 6: 25-30 km.

Volcanic rocks of island arcs and intracontinental volcanoes belong to one and the same class (continental), they are genetically bound in space and time. The angle of inclination of variational lines towards the vertical comprises 15-20° and sometimes up to 22°.

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[1] The book by Zavaritsky was published in German and English now, therefore the explanation of this method is not given here.

The inclination angle depends on the rate of alkalinity increase in the process of differentiation. Thus the main difference between the rocks of oceanic and those of continental class is the different rate of alkalinity increase in the process of their evolution.

It is extremely essential that petrochemical peculiarities of volcanic rocks do not depend on variation of thickness or even of the type of the Earth's crust structure. Thus in the region of the Kurile island arc the type of the Earth's crust structure varies from typically continental to oceanic one in fact (Fig. 1). Peculiarities of petrochemistry however remain unchanged along the whole arc at the distance of more than 1000 km. At the same time alkalinity of rocks increases noticeably across the strike of the arc from the ocean to the continent at the distance of first tens of kilometers on one and the same type of the crust.

In some island arcs, located on the oceanic crust (*e.g.* Tonga, Idzu and others), not oceanic but extremely calc-alkaline magmas flow out. These circumstances together with the account of geophysical peculiarities have led the author to the conclusion that the upper mantle is the source of volcanism whereas the effect of the crust is little. In other words volcanism is a « transcrustal » process.

Circum-Atlantic Area

Let us start our analysis of the Circum-Atlantic area from continental volcanism. In continental part of both Americas all volcanism is clearly connected with the « Pacific ring of fire » to which the isalnd arc of Scottia belongs as well. The island arc of the Minor Antilles, though located geographically in the periphery of the Atlantic ocean, is evidently associated with the system of the Pacific island arcs in genetic respect. In petrochemical way lavas of the Antilles arc belong to extremely calcic representatives of calc-alkaline family and occupy an extremely left position on the plane ASB of the petrochemical diagram (Fig. 2).

On the eastern shore of the Atlantic ocean recent (post glacial) volcanism is known in the Central French Massif (Auvergne) and in Africa - Tibesti massif in the Sahara and in the Cameroons. Volcanoes of Italy and Greece belong to the Mediterranean region while volcanoes of East-African rift to that of the Indian ocean; they will be discussed in separate publications.

Volcanoes of Auvergne (France) have ceased their activity about 7,500 years ago. The composition of lavas varies in wide limits from trachybasalts (47 % SiO_2) to trachytes and leucotrachytes (up to 67 % SiO_2). Fig. 2 gives the variational line obtained by mean values for 29 new analyses (BENTOR, 1955; BROUSSE, 1954). According to Zavaritsky the position of the line corresponds approximately to the type of Etna.

Volcanic activity in Tibesti region has started already in the Tertiary time and was going on in the Quaternary period. At present only fumarolic activity is being observed. The range of rocks is rather wide - from basalts (42 - 43 % SiO_2) to liparites (73 - 75 % SiO_2). Ignimbrites are of considerable spreading. The variational line drawn in accordance with several recent analyses of lavas from the Tousside massif (VINCENT, 1960) is in the field of alkalescent rocks between variational curves of Yellowstone and Etna type by Zavaritsky. The mean inclination of the line versus the vertical comprises 17°.

The lavas of Mount Cameroon are represented by little differentiated nepheline trachybasalts (42 - 44 % SiO_2) belonging to the Maros-Highwood type by Zavaritsky.

The rocks of volcanoes of the East-African rift which are not analysed in detail here refer mainly to alkaline basalts. They get into the field of the Maros-Highwood type or to more alkaline types, alkalinity varies often not only in the adjacent massives but within the limits of one and the same volcanic massif. The line for highly alkaline lavas ($Na_2O + K_2O = 10\text{-}15$ % with $SiO_2 = 38\text{-}46$ %) of the Niragongo volcano (SAHAMA, 1962) on the diagram 2 is given as an example of extremely alkaline rocks. The angle of inclination versus the vertical comprises 22°.

All analysed intracontinental volcanoes are not connected with the alpine zones of folding. Their lavas belong to alkaline varieties. In contrast to continental margins of the Pacific shore with their calc-alkaline lavas, the rocks of Mount Cameroon which is at the very edge of the Atlantic shore of Africa, are also alkaline.

Islands of the Atlantic Ocean

Islands of the Atlantic ocean may be divided into two categories: 1) isolated oceanic islands and island groups and 2) islands connected with Mid-Oceanic ridge.

Isolated islands are represented on diagram 2 by the data on 20 new analyses for the Canary islands (mainly for the Tenerife

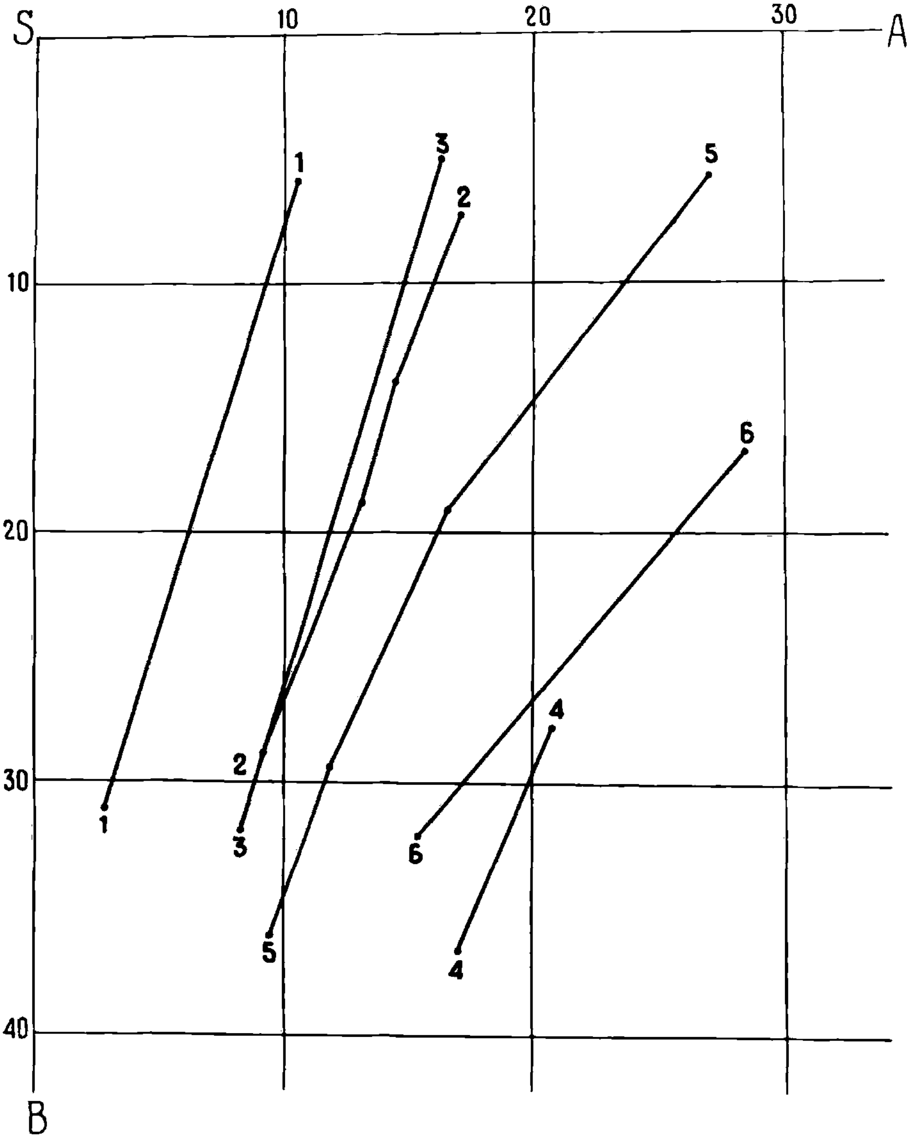

Fig. 2 - Variation lines for lavas of Circum-Atlantic region. 1 - the Antilles, 2 - Massif Central France, 3 - Tibesti (Africa), 4 - Nyiragongo, 5 - the Canaries, 6 - Mount Fogo (Cape Verde Islands).

island) [2] and on 15 new analyses for the Fogo volcano from Cape Verde islands (SAN MIGUEL, 1967; MACHADO, 1967).

The rocks of both groups of islands are alkaline, the angle of inclination versus the vertical varying for the Canary islands from 24° in the lower part of the diagram to 38° in the uper part of it. For the Fogo volcano (whose rocks are more alkaline) the respective angle is 40°. The diagrams for other isolated islands are of a similar type as well.

As we see variational lines for lavas of continental and oceanic volcanoes are of remarkably different inclination versus the vertical axis. For the area of the Atlantic ocean the diversity of values is somewhat greater than for that of the Pacific. The lines for continental volcanoes have here the inclination versus the axis SB from 15 to 22°, while for oceanic — from 24° to 40°. Being so the inclination of 30°-40° prevails for the latter, while the less values are observed only in the lower part of the diagram where the inclination of variational lines for continental volcanoes is also less.

The mid-oceanic ridge passes along all the Atlantic ocean from Jan-Mayen island through Iceland to the southern part of the Atlantic, where it turns eastwards and to the Indian ocean. The width of the ridge is 1-2 thousand kilometers. The system of grabens or rift valleys strikes along the axis of the ridge. A highly increased conductive heat flow, exceeding 6-7 times the mean value for the ocean is also confined to the central part of the ridge. The value of the heat flow falls down rapidly in direction to the wings of the ridge and at the distance of 100-200 km from the axis of the ridge the heat flow acquires a normal value. In contrast to aseismic areas of the ocean bed the epicenters of numerous earthquakes are confined to the axis of the ridge. Their depth does not exceed 60 km as a rule. The Earth's crust in the region of the ridge is somewhat thinner while seismic velocities in subcrustal parts of the mantle have reduced values (7.3-7.5 km instead of 8.0-8.2 under the ocean bed).

For many islands connected with the Mid-Atlantic ridge, some new data on chemism of lavas are obtained recently. These data can make more precise the assumptions put forward earlier.

Iceland is the greatest island located on the ridge axis itself. The rift valley strikes along the whole island; recent volcanoes and

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(2) Numerous new analyses were published at the Symposium for separate islands. These data will be used in the following publications.

hydrothermal fields are connected with this valley. Volcanoes in Iceland were active in the Tertiary time too.

Variational lines for the Tertiary volcano Thingmula (CARMICHAEL, 1964) and for recent eruptions of the volcano Hekla (THOARINSSON, 1954) are drawn on the diagram of Fig. 3. Both lines correspond to calc-alkaline family. The variational line for the Helka volcano coincides with the Lassen-Peak type, while the line of the Thingmula volcano is located between the lines of the Lassen-Peak type and Yellowstone type. The angle of inclination of lines towards the axis SB is 15-18°.

Not far from the ridge axis, at the distance of 90-100 km, volcanic islands are located: the Ascension island — in the central part of the ocean and the Bouvet island in the extreme southern part. Variational lines for the lavas of these islands (DALY 1925; BAKER, 1967) are of complicated character. For the Ascension island the variational line in the lower part has the inclination towards the axis SB of 30° which is typical for intraoceanic islands. The inclination of the upper part of the line comprises 19° which corresponds to that of continental variational lines. The variational line for lavas of the Bouvet island with respective inclinations of 32 and 17° is of the same character (lines 3 and 4 on Fig. 3).

Tristan-da-Cunha island is located at the distance of 480 km from the axis of the Mid-Atlantic ridge. The lavas vary in composition from alkaline basalt (43 % SiO_2) to trachytes (60 % SiO_2). According to the data of new analyses (BAKER *et al.*, 1964) the variational line is of somewhat more alkaline character than in the preceding groups. The line inclination towards the axis SB is 25-28°, (Line 5 Fig. 3).

The Azores in the northern part of the Atlantic ocean are located like a chain across the strike of the Mid-Atlantic ridge. The islands closest to the ridge (Faial, Pico, San Jorge) are at the distance of 100-150 km from the ridge axis, San Miguel island is 480 km far from it. The variational line for lavas of the Furnas volcano on San Miguel island drawn by the data of new analyses (MACHADO, 1967) is of typically oceanic character with inclination towards the axis SB equal to 30°; nearly along the whole length it coincides with the Hawaii line (line 7, Fig. 3).

The variational line for lavas of islands of Faial group (line 8, Fig. 3) was plotted less confidently because some old analyses were partially used. This line is inclined towards the axis SB more gently comprising the angle of 22° with it.

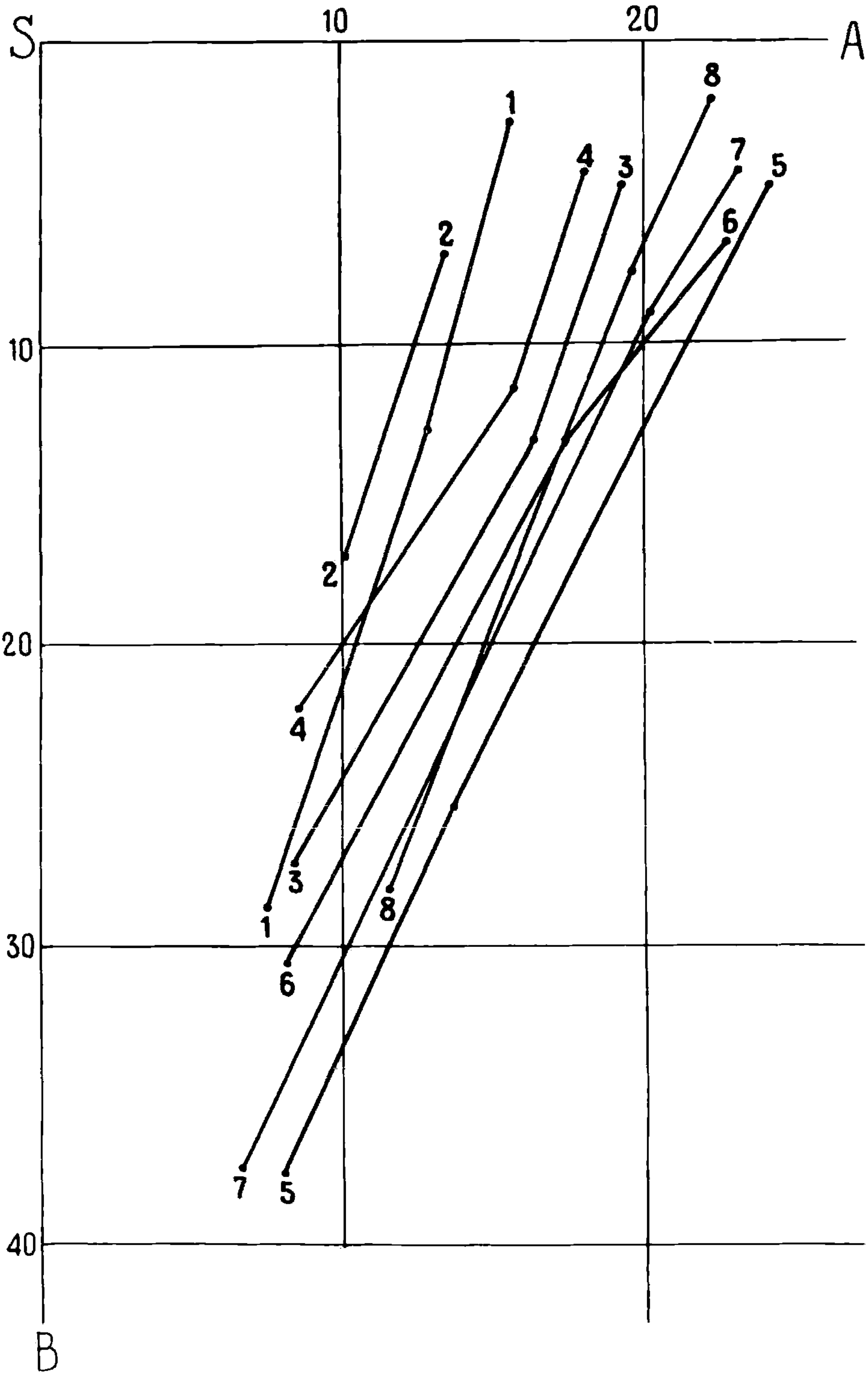

FIG. 3 - Variation lines for lavas of Mid-Atlantic Ridge. 1 - Thingmula volcano (Iceland), 2 - Hekla (Iceland), 3 - Ascension Island, 4 - Bouvetøya Island, 5 - Tristan da Cunha, 6 - Gough Island, 7 - Furnas Volcano (the Azores), 8 - Faial Island (the Azores).

Thus a certain regularity can be observed in petrochemistry of lavas of islands connected with the Mid-Atlantic ridge: volcanoes on the axis of the ridge (Iceland) are of clearly marked continental calc-alkaline character corresponding to the Lassen-Peak Yellowstone type. The islands not far from the ridge axis (about 100 km) — the Ascension and Bouvet islands have the transitional character of lavas: close to the oceanic with basic representatives and close to the continental or continental with more acid representatives. Finally, the islands which are still farther from the ridge axis are of purely oceanic or close to oceanic nature. The transition from the second to the third type of lava petrochemistry can be seen in a transveral chain of the Azores.

Conclusion

To the area of the Atlantic ocean and adjacent parts mainly alkaline lavas are issued. Here as well as in the area of the Pacific ocean two petrochemically different classes of volcanic rocks are distinguished: oceanic and continental. These two classes are observed on petrochemical diagrams of Zavaritsky by different inclination of variational lines on the ASB plane. The diversity of values of inclination angle versus the axis SB in the Atlantic area is greater than in the Pacific one; for continental rocks it varies within the limits of 15-22°, for oceanic — from 24° to 40° (the values of 30-40° are prevailing). There is a tendency to an increase of the inclination angle by means of an increase of general alkalinity.

The areas of rocks of continental and oceanic classes overlap each other to a great extent, being different only in the inclination angle of variational lines. Hence the following conclusion can be drawn, a very essential one for volcanic petrography: initial magmas of continental and oceanic classes similar in chemical composition give quite different series of differentiation. Thus alkaline rocks of intraoceanic and intracontinental volcanoes often of a close mineralogical and chemical composition, are the products of quite different series of differentiation and can not be considered as identical rocks. For instance, oceanic olivine basalt with relatively low alkalinity gives the differentiation series up to trachyte. A similar by chemical composition trachyte in continental conditions is the product of differentiation of essentially alkaline continental basalt.

In the area of the Mid-Atlantic ridge quite complicated and extremely important for volcanological theory picture has been revealed concerning distribution of petrochemical peculiarities of lavas across the strike of the ridge: calc-alkaline or alkalescent lavas of continental type flow-out in the central part of the ridge; purely oceanic lavas issue at the slopes of the ridge at the distance of 400-

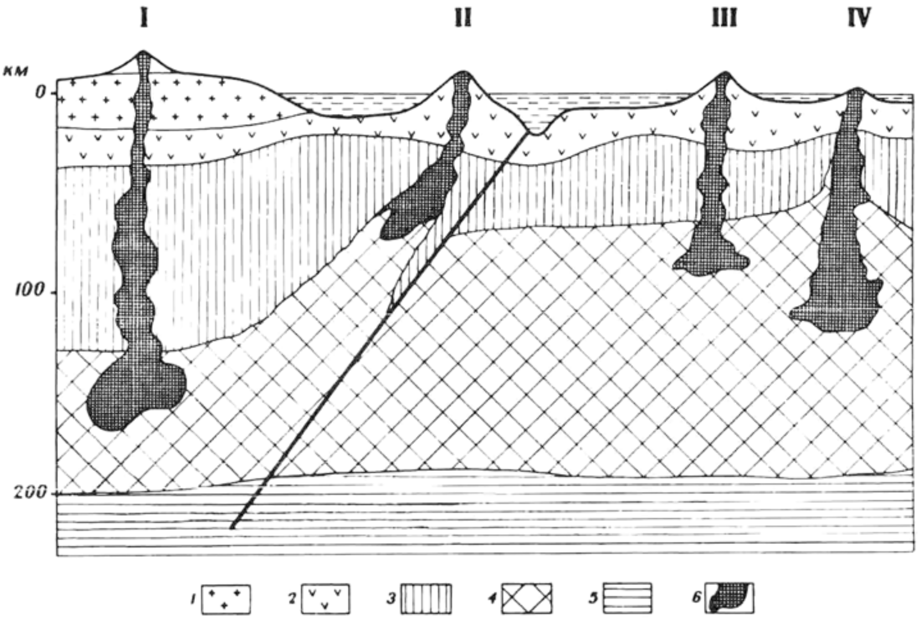

FIG. 4 - Hypothetical profile across different volcanic areas. I - continental volcanoes, II - island arcs, III - oceanic volcanoes, IV - mid-oceanic ridges. 1 - « granite » layer, 2 - « basalt » layer, 3 - subcrustal parts of mantle, 4 - asthenosphere layer (Gutenberg's zone), 5 - subasthenospere layer, 6 - zones of magma generation and volcanic chimneys.

500 km from its axis; the rocks of intermediate composition having both oceanic and continental features of petrochemistry are erupted at the distance of 90-100 km from the ridge axis. An impression is made that deep processes occurring in the central part of the oceanic ridge cause the replacement of oceanic lavas by continental lavas. But these processes are not as intensive and deep as in the area of island arcs. At the distance of 100 km continental influence is still felt; as if an intermixture of two classes of rocks occurs but purely oceanic conditions of melting are reestablished at a greater distance.

The data on heat flow and on the structure of the upper mantle in the area of mid-oceanic ridges are in a good agreement with peculiarities of petrochemical distribution of lavas.

A review of petrochemistry of volcanic rocks in the area of the Atlantic ocean and adjacent parts has confirmed the author's former conclusion to the effect that volcanism is directly connected with the Earth's upper mantle; petrochemical peculiarities of lavas reflect main heterogeneities in composition and structure of the upper mantle (Fig. 4). The data on the Mid-Atlantic ridge appeared to be of a specific interest.

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Discussion

H. U. SCHMINCKE: The chemical composition of the alkalic rocks from Tenerife is not representative of the Canary Islands as a whole. The composition of the Miocene hawaiites and rocks of pantelleritic affinities on neighbouring Gran Canaria — an island close to the continent of Africa — is similar to the rocks on Ascension an Bouvetøya — island close to the Midatlantic Ridge.

G. S. GORSHKOV: For Canary Islands I used data which were published in the *Catalogue of the Active Volcanoes.* In the Guidebooks there are much more new analyses. I shall recalculate them and it is possible that some data will be changed. In this case I shall make an appendix to my report.

J. G. SCHILLING: I found your paper very interesting and stimulating. I have been working along similar lines (contrasting continental versus oceanic areas) considering the geochemistry of the rare earth series. The results show striking differences that can be interpreted in similar ways than what you just presented us. I would like to ask you whether you have applied the same treatment to published analyses of submarine tholeiitic basalts associated with mid-ocean ridges and the more alkaline basalts of seamounts?

G. S. GORSHKOV: Tholeiitic basalts from mid-ocean ridges are similar in petrochemical respect to those from the other parts of ocean bottoms. But they are quite different from continental tholeiites. On my opinion oceanic tholeiites reflect primary magma and alkaline basalts of seamounts are secondary rocks derived from tholeiites. it is quite clear from the data published by G. A. Macdonald and Katsura. Some details will be published in my book which will be published by Plenum Publishing Co., New York, USA.

S. HERNANDEZ PACHECO: The projection of the origin of the sectors representing the rocks of the Tenerife island, that fall in the field ASB of the Zawaritszki diagram, is a line showing a sharp inflection towards the A axis, i.e. towards alkalinity. To which volcanic formation do the rocks of the first and second part of the variation line belong?

G. S. GORSHKOV: I used averages recalculated from the data published in the *Catalogue*. Now I have a possibility to use new data from the Guidebooks.

K. YAGI: I think your approach to the problem is very interesting. I made a little different way of approach. I calculated the ratio K_2O/K_2O+Na_2O in the alkalic rocks from the continents and from the oceans, and have found this ratio is always higher in the continental alkalic rocks, even when they are free from any assimilation by sialic materials, than in the oceanic alkalic rocks. From this I calculated that the upper mantle under the continents may be slightly richer in K_2O than that under the oceans.

What kind of chemical difference have you found in your model of the two kinds of upper mantle?

G. S. GORSHKOV: One of my important conclusion is that the volcanism reflects inhomogeneity of the upper mantle. Under oceans and continents not only structure but the composition of the mantle are different. Volcanism is an indicator of composition and state of subscrustal parts of our planet.

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