

*Titania and alumina content of oceanic and
circum-oceanic basalt*

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Summary. Most circum-oceanic basalts contain less and most oceanic basalts considerably more than 1.75% of TiO₂. The difference of TiO₂ averages is large enough to require rejection of the hypothesis that circum-oceanic basalt results from the assimilation of sial by oceanic basalt.

IT has long been recognized that there is a marked chemical distinction between the salic lavas of the oceanic and circum-oceanic environments. In the latter there is nearly always a molar excess of alumina over alkalis and, again in molar terms, $(\text{SiO}_2 - \text{XO}) \gg 6\text{Y}_2\text{O}$. In eu-crystalline rocks these inequalities assure the absence of feldspathoids and peralkaline ferromagnesian minerals; their normative expression is the absence of *ne*, *lc*, and *ac*. In this respect the circum-oceanic Cenozoic lavas resemble the overwhelming bulk of plutonic rocks, for it is a petrographic commonplace that in magmas of all ages—and in metamorphic rocks as well—alumina and silica are usually present in sufficient abundance to fix all alkali as feldspar.

In oceanic salic lavas, on the other hand, an insufficiency of silica is the rule rather than the exception, and a molar excess of alkalis over alumina is not uncommon. In Shand's terminology, the salic lavas of the oceanic environment are characteristically undersaturated and not infrequently peralkaline.

In both environments basalt is abundant, but there appears to be no marked qualitative chemical distinction between oceanic and circum-oceanic basalt similar to that between the salic lavas. Oceanic basalts are on the whole poorer in silica and alumina than circum-oceanic ones and richer in magnesia and iron. Despite these fairly clear group differences, however, there is so much compositional overlap with regard to major constituents that attempts to distinguish between individual basalts of the two environments—attempts dating back almost to the birth of microscopical petrography—now rely heavily or wholly on

mineralogy rather than bulk chemistry. The subject is obviously one of prime importance to petrology; a review of its development would be presumptuous in a volume dedicated to one of its acknowledged masters.

The purpose of this note is to direct attention once more to differences in bulk composition. The work described here is part of a study of Cenozoic volcanism based entirely on published analyses. At the time the frequency distributions described below were tallied, the collection included 1837 relevant analyses, 1003 of specimens from the circumoceanic environment and 834 from the oceanic. A bibliography of source references will be included in the full report, which is now nearing completion.¹ That report will also contain an extended and, I hope, satisfactory rationalization of the use of the terms 'oceanic' and 'circumoceanic'. Here it will suffice to remark that in the analyses used for this note the term 'circumoceanic' refers exclusively to lavas collected on the immediately shoreward borders of the great troughs which margin the open ocean, while the term 'oceanic' is used to denote lavas from islands either separated from shore or shallow seas by such trenches or lying in deep water remote from them and apparently also unconnected with continental land masses.

Readers familiar with the complex geography of Cenozoic volcanism will realize that a classification as simple as this must lead to omissions and assignments open to considerable question. The omissions are largely of rocks petrographically similar to the circumoceanic type but failing to qualify for inclusion either because they do not lie along the edge of a contemporary trough in the ocean floor (e.g. the Taupo series of New Zealand, the Medicine Lake volcanics of California) or because the trough along whose edge they lie does not margin the open ocean (e.g. the lavas of the Ryukyu Islands). The doubtful inclusions, on the other hand, are mostly of oceanic lavas lying uncomfortably close to land (e.g. Fernando Noronha, Cape Verde). Neither inclusion of analyses now omitted nor deletion of those included would appreciably affect the argument of this note.

Although lavas containing less than 54 % silica are sometimes called andesite, those with more than 54 % silica are almost never called basalt. If we select from our sample all analyses containing not more than 54 % of silica and characterized by Thornton-Tuttle indices of less than 50, we shall include nearly every specimen which has been called basalt and a small number which have been described as andesite. The distribution of titania in these analyses is shown in table I and fig. 1.

¹ Journ. Geophys. Res., 1964, vol. 69, p. 1593.

TABLE I. Distribution of TiO_2 in analyses with $\text{SiO}_2 < 54\%$ and Thornton-Tuttle index < 50

Upper class mark	Observed frequency		Upper class mark	Observed frequency	
	Circum- oceanic	Oceanic		Circum- oceanic	Oceanic
0-35	10	0	3-85	1	51
0-70	31	2	4-20	1	41
1-05	154	5	4-55	0	21
1-40	84	7	4-90	0	18
1-75	49	15	5-25	1	10
2-10	15	51	5-60	0	5
2-45	4	61	5-95	0	3
2-80	8	78	6-30	0	3
3-15	2	65	6-65	0	1
3-50	0	59	7-00	0	1
			No. analyses	360	497
			Average	1.14	3.06

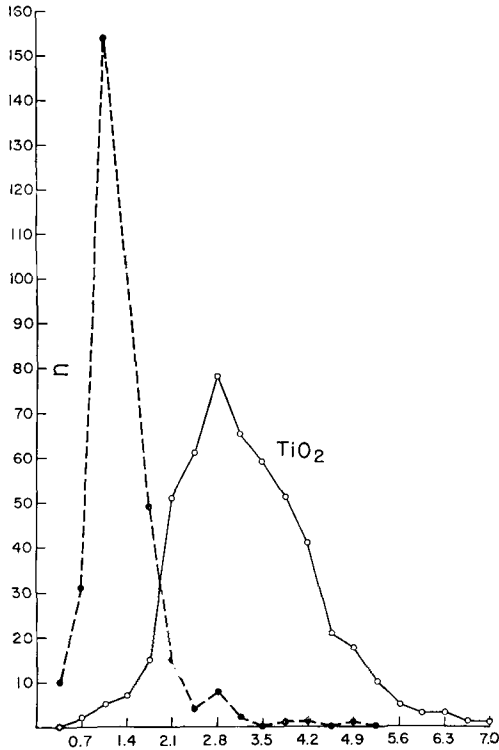


FIG. 1. Histogram showing distribution of TiO_2 in oceanic and circumoceanic lavas with $\text{SiO}_2 < 54\%$ and Thornton-Tuttle index < 50 . (Circumoceanic—dashed line with solid circles; oceanic—solid line with open circles.)

The suggestion that oceanic basalts contain more TiO_2 than circumoceanic ones is far from novel, but I believe that neither the abundance of TiO_2 in the former nor the magnitude of the difference has been generally recognized. Most circumoceanic basalts contain less than 1.5 % and most oceanic basalts more than 2.0 % of TiO_2 . There is overlap, of course, but far less than for any other major constituent. As table II shows, TiO_2 is less than 1.75 % in 91 % of the circumoceanic basalt analyses of the collection and exceeds this value in 94 % of the oceanic ones.

TABLE II. Frequency of basalt analyses containing more and less than 1.75 % of TiO_2

	$\text{TiO}_2 \leq 1.75$	$\text{TiO}_2 > 1.75$
Circumoceanic	328	32
Oceanic	29	468

TABLE III. Distribution of Al_2O_3 in analyses with $\text{SiO}_2 < 54$ % and Thornton-Tuttle index < 50

Upper class mark	Observed frequency		Upper class mark	Observed frequency	
	Circum-oceanic	Oceanic		Circum-oceanic	Oceanic
7.75	0	14	16.00	41	40
8.50	0	8	16.75	35	34
9.25	0	21	17.50	40	26
10.00	0	16	18.25	57	15
10.75	0	21	19.00	50	11
11.50	1	25	19.75	39	4
12.25	5	39	20.50	32	1
13.00	2	37	21.25	6	2
13.75	5	63	22.00	5	1
14.50	9	60	> 22.00	3	1
15.25	30	58			
			No. analyses	360	497
			Average	17.46	13.60

Table III and fig. 2 record, for the same sets of analyses, the observed distributions of Al_2O_3 , by no means the most extreme example of the greater overlap shown by other major constituents. By making a cut at 14.50 % Al_2O_3 , for instance, one could put 6 % of the circumoceanic analyses in a 'low' alumina and 94 % in a 'high' alumina class, but the first class would contain 61.2 % and the second 38.8 % of the oceanic analyses. Similarly, a cut at 17.5 % Al_2O_3 would throw 93 % of the oceanic analyses into a 'low' and 7 % into a 'high' alumina class, but the first class would contain 46.7 % and the second 53.3 % of the circumoceanic analyses. Results for subdivisions on the basis of other essential oxides are considerably less efficient.

Most of us tend to think of TiO_2 as a minor constituent, but the difference between the TiO_2 averages for the two basalt groups is of the same order as their difference in Al_2O_3 . As a *group* property, half the difference in alumina is compensated by the titania difference. This of course tells nothing at all about individual analyses; an oceanic basalt high in

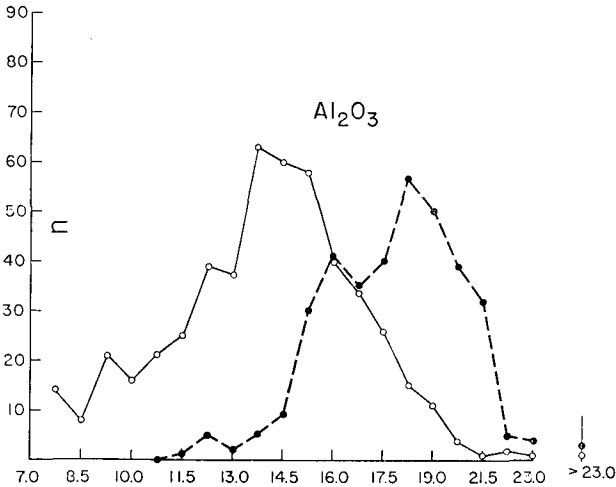


FIG. 2. Histogram showing distribution of Al_2O_3 in oceanic and circumoceanic lavas with $\text{SiO}_2 < 54\%$ and Thornton-Tuttle index < 50 . (Circumoceanic—dashed line with solid circles; oceanic—solid line with open circles.)

alumina may or may not be low (or high) in titania. The very fact that one of these oxides provides a rather efficient discriminant and the other does not implies that the relationship between them is far from simple.

It is worth remembering, however, that in taxonomic and descriptive petrography, and also in the conception and planning of experimental work, average values play an important role. In work of both types we are continually obliged to make simplifying assumptions, but if we persist in ignoring significant variables we must expect that some of our simplifications will prove to be oversimplifications.

What is the possibility, for instance, that circumoceanic basalts, closely associated with andesites for which a syntectonic origin has often been suggested, may result from the assimilation of sial by oceanic basalt? The geographic distribution of the two types of basalt is on the whole favourable to this suggestion and the differences between mean values of major constituents other than CaO are compatible with it.

The difference in TiO_2 mean values, on the other hand, appears to require outright rejection of the hypothesis. For if we are to reduce an initial TiO_2 content of 3.06 % to 1.14 % by assimilation, each gram of our average magma must combine with at least 1.68 grams of diluent, and more if the latter is not entirely free of TiO_2 . An hypothesis which seems perhaps not unreasonable if we ignore TiO_2 becomes little short of fantastic if we eliminate this oversight.
