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The oceanic basalt–trachyte relation in general and in the Canary Islands

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Abstract

Abundant data from the Canary archipelago confirm an earlier suggestion based on scattered data from volcanic islands as a whole that, among published analyses of specimens from the oceanic basalt–trachyte association, trachytic materials are considerably more numerous than those of compositions intermediate between basalt and trachyte. Frequency distributions of SiO_2, CaO, and Thornton-Tuttle index for the Canaries data are strikingly similar to those for the earlier worldwide collection. In the Canaries, as in most oceanic and many other examples of the basalt-trachyte association, trachyandesitic materials are probably considerably less abundant than trachytic materials. The relation is not readily explained by crystal fractionation but seems readily explicable by fractional melting.

In his memoir on Ascension, Daly (1925) suggested that, in oceanic island assemblages, rocks intermediate in composition between basalt and trachyte were markedly less abundant than trachytes. Unlike most of his petrological generalizations, this one seems to have attracted little immediate attention. Even such devoted contemporary students of the alkaline rocks as Bowen and Shand had nothing to say about it; indeed, Daly himself does not mention it in his own text (Daly, 1933). It was taken up and considerably strengthened by Barth *et al.* (1939), who alleged, even then not quite unexceptionably, that lavas with silica content in the range 53–58 percent were "entirely lacking" in the Pacific basin; this marks its first appearance in a major text. Barth's position is accepted and generalized by Turner and Verhoogen (1960, p. 199), who go so far as to say that "in the oceanic basalt association there is complete chemical gradation from olivine basalt to oligoclase basalt *but transitional types between the latter and trachyte are rare or altogether absent*" (italics added). In the successor volume (Carmichael *et al.*, 1974, p. 423), however, the whole question is mooted, and Daly is credited only with drawing attention to "the intimate field association between basalt and trachyte on Ascension and other islands," a rather curious case of throwing the baby out while preserving that "somewhat puzzling feature," the bath water.

Although Daly's better known dictum about the relative abundances of granitic plutonic and basaltic volcanic rock types was based entirely on planimetric estimates of map areas underlain by various petrographic units (for a review, see Chayes, 1975), he nowhere specifies the basis for his inference about the relative abundance of intermediate and trachytic materials in the basalt-trachyte association of the oceanic islands. In view of the amount and quality of information then available about the oceanic islands, it could not have been based on such estimates; even now, despite extensive studies of many island groups in the past two decades, this would be possible for only a few islands.

In 1963 I recorded the results of an extensive literature search indicating that materials intermediate in composition between basalt and trachyte were indeed much less abundant than trachyte *among published chemical analyses* of specimens from all the known basalt–trachyte associations of the oceanic islands. This point could be made from frequency distributions either of raw oxides or of appropriate normative components, whether prepared from the whole data array or from subsets filtered in various ways to eliminate hydrated or oxidized materials. The relation also seemed to hold in numerous marginal and nonoceanic occurrences of the association.

There was of course no binding assurance that what was true of the literature was also true of the lithosphere. From what seemed to me a fair and thorough review of conventional objections, however, I concluded there was no persuasive reason to suspect persistent systematic biases toward under-representation of materials of intermediate composition among analyzed specimens. The burden of evidence was—and is—to the effect that these materials are indeed less abundant than trachyte in the basalt–trachyte association of the oceanic islands.

The conclusion was disconcerting both intrinsically and because of the way in which it was reached. Among proponents of crystal fractionation it is rather generally agreed (*per contra* see Mukherjee, 1967) that the amount of residual liquid decreases monotonically in the course of fractionation. One would not expect that trachytes generated in this fashion would be more abundant than the trachy-andesites regarded as their immediate parents. And if one were sufficiently persuaded of the overriding importance of crystal fractionation in the oceanic volcanic dispensation, one would not welcome such a conclusion, however it was reached. Recent developments in petrology, discussed below, should greatly weaken objections of this kind.

Nothing has happened, however, to lessen the force of objections based on the way in which the conclusion was reached. The procedure was bound to affront some petrologists, for it ignored entirely such matters as rock identification, mode of occurrence, areal distribution, stratigraphic position—in sum, the whole complex of concepts and operations involved in making and interpreting geological maps. Reaction was not long in forthcoming, and there have been numerous notes restating objections I thought had been fairly discussed and dispassionately dismissed in the original paper.

Harris (1963), for instance, argued that trachytes are characteristically "oversampled" because they are "unusual" and frequently intrusive, that "trachy-andesites were probably much less overcollected as they more closely resemble basalts in the field and in hand specimen," and that ratios of specimens collected are likely to "represent" relative areal abundances "only if an island has been subjected to a thorough field study and detailed mapping." Cann (1968) doubled this in spades, finding that intermediate rocks are overlooked not only because they look like other rocks but more importantly because of their "extreme petrographic (and hand specimen) dullness" and "monumental lack of interesting features," characters they somehow do not share with the rocks from which they cannot be distinguished. Whereas Harris evidently presumes that specimen counts comparable to relative areal abundances would be desirable, Cann thinks that even the latter might give "a very poor representation of the relative volume proportions of the rock types present." Baker (1968) agrees heartily with Cann's position *re* the misleading character of both specimen counts and areal abundances and with both Cann and Harris about the nonexistence of the Daly gap. Unlike them, however, he finds that on *his* island (St. Helena) the "distinctive field characters (coordinated with petrographic and geochemical studies)" of intermediate rock types "permitted a detailed investigation of their distribution to be made." The decisive field characters are, *mirabile dictu,* that (1) trachyandesite tends to occur in thick massive flows that "weather to flat discs of fresh rock in a characteristic orange material" whereas "trachybasalts form numerous thin flows that . . . could be mistaken for basalts in many cases but not for trachyandesites" and (2) "trachy-andesites are medium to dark green in color with a distinctive shimmer or platiness" whereas "trachybasalts are fine-grained black, purple, dark grey or rarely very dark green rocks often with a distinct sheen (*not* a platiness)"![1]

Read separately these notes are rather less than persuasive. Considered together they have about them a distinct air of special pleading; despite marked and quite evidently irreconcilable differences about the field characteristics of the all-important trachy-andesites and even about the possibility of identifying them, as well as about appropriate procedures to be used in estimating their abundance in the event they could be identified, the authors are nevertheless firmly agreed that trachyandesites are indeed more abundant than trachyte. How this agreement has been reached is not explained and seems quite inexplicable.

There is, of course, no question at all that basalt is by a very large margin the dominant rock of the oceanic islands, and in many islands and island groups rocks of any other kind are either very rare or lacking. Such groups can hardly be expected to provide decisive information about the relative abundance of trachyte *vis-à-vis* rocks intermediate in composition between trachyte and basalt. Macdonald (1963) points out, for instance, that trachytes are exceedingly rare in the Hawaiian archipelago, and it would hardly be surprising if in Hawaii, as he asserts, trachytes were in fact less abundant than hawaiites and mugearites. It is to be recalled, however, that

[1] Italics and parentheses in original.

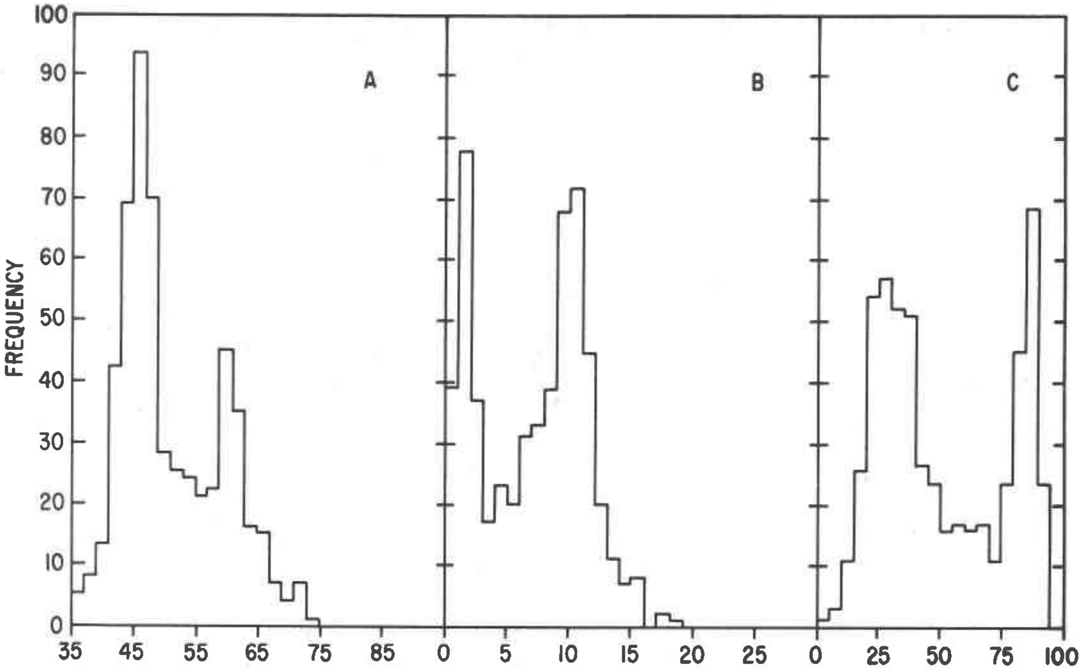

Fig. 1. Distribution of SiO_2 (A), CaO (B), and Thornton-Tuttle index (C) in analyses of 551 specimens of the basalt–trachyte association of the oceanic islands, worldwide. (Redrawn from Figs. 1A-3A of Chayes, 1963.)

in SiO_2 content and Thornton-Tuttle index, Hawaiian hawaiites are basaltic, and so too are most Hawaiian mugearites; that is to say, they are essentially alkaline basalts or trachybasalts, not trachyandesites. Trachytes do seem to be exceedingly scarce in the Hawaiian Islands, but so too are rocks compositionally intermediate, in any realistic sense, between basalt and trachyte; published evidence suggests that on the whole the Hawaiian archipelago, like some other island groups, is not a favorable site for study of this problem.

The situation is quite different in the Canaries, in which trachytes and phonolites abound, and there is even a considerable development of highly siliceous peralkaline ignimbrites. Despite the abundance and notoriety of these materials, however, opinion about the existence and significance of the Daly gap in the Canaries is divided and confused. In 1969 Schminke concluded that "the Bunsen-Daly gap is very real in Gran Canaria. . . . There are no flows of intermediate composition between the underlying 'basalts' (up to 54% SiO_2) and the rocks of the lower and middle units (SiO_2 above 67%), despite flow-by-flow sampling in many profiles across the contact." Nevertheless, in 1970 Ridley, though concerned to stress his fundamental agreement with the position of Harris, Cann, and Baker, announced that "Tenerife is the first Atlantic island described that shows the bimodal distribution of rock types that was postulated from chemical data by Chayes." One would hardly guess from this that Gran Canaria and Tenerife are neighboring islands in a small archipelago, or that the "Bunsen-Daly gap" is the very one "postulated from chemical data by Chayes." Without mention either of Schminke's conclusion that Gran Canaria is an excellent example of the Daly gap in the Canaries or of Ridley's later assertion that the nearby island of Tenerife is the first example of it found in the whole Atlantic, Fuster (1975) maintains that the Daly gap is "not well defined" in either Gran Canaria or Tenerife, or in La Palma, but "is frequently found" in the rocks of Fuertaventura, Gomera, Hierro, and Lanzarote.

In view of this confusion, now twice confounded, it may be helpful to summarize Canaries data currently in the public domain, for this archipelago is by far the most closely studied and densely sampled of the Atlantic oceanic island groups, and perhaps of all such groups, and has the further advantage of containing considerable amounts both of trachyte *and* of material intermediate in composition between basalt and trachyte.

The literature search leading to my own article on the Daly gap unearthed 551 published analyses of

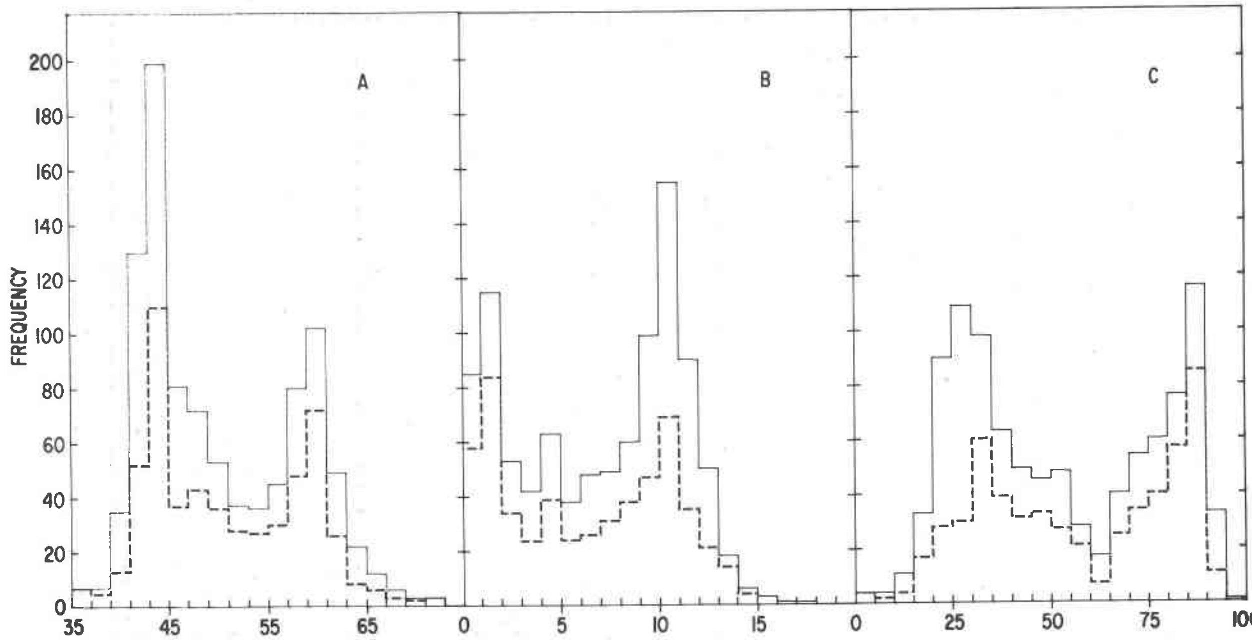

Fig. 2. Distribution of SiO_2 (A), CaO (B), and Thornton-Tuttle index (C) in analyses of volcanic rocks of the Canary Islands. Solid line—979 specimens from all islands; broken line—556 specimens from Gran Canaria, Tenerife, and La Palma only.

specimens from all known clearly oceanic examples of the basalt–trachyte association.[2] Thanks largely to the efforts of Fuster, his students, and his colleagues, there are now considerably more than that many from only the three Canary islands in which he considers that the Daly gap is not well defined. Fuster cites 610 of these in his current discussion, all made in the laboratories of his department, and 105 still unpublished as of this writing.

A literature scan, kindly undertaken two years ago by Fuster's coworker J. Brändle, yielded 1094 published analyses of rocks from the Canaries. These are now included in the data base currently maintained at the Geophysical Laboratory. As shown in Figures 1 and 2, the distributions of key variables in the Canaries data are remarkably similar to those found earlier in the "world" sample of oceanic island basalt–trachyte associations.

Salic rocks as a whole seem far more abundant in the central Canaries than in any other known oceanic islands, and among the salic rocks of the Canaries the incidence of phonolite is extraordinarily high. It nevertheless seems to be true that even here, as shown in Figure 2, the number of published analyses of volcanic rocks intermediate in composition between basalt and trachyte is markedly less than the number of published analyses of trachyte.

It is sometimes said that trachytes tend to be sampled more frequently than trachyandesites simply because they are more alkaline and petrologists prefer to study alkaline rocks, but phonolite—the characteristic "intermediate" of the Canaries assemblage—is richer in alkalies than is the associated trachyte. It is frequently asserted that trachytes are oversampled relative to trachyandesites because trachytes tend to form conspicuous, well-defined plugs or sills and trachyandesites characteristically form flows not readily distinguishable from basalt. However, detailed studies of the islands of the archipelago, by the Madrid group and others, do not suggest that trachyte intrusives are more common than phonolite intrusives, that nonintrusive trachytes are less common than nonintrusive phonolites, or that phonolites look more like basalts than do trachytes. It is sometimes alleged that trachytes are oversampled relative to trachyandesites because the former mantle and the latter are interlayered with the dominant basalts, but published accounts record very little difference in the modes of occurrence of the trachytes and phonolites of the Canaries, and there seems to be almost no

[2] Ninety-one of these were from the Canaries, all taken from an early tabulation by Fuster. The tally for the Canaries should have been higher even then; the papers of Hausen were overlooked in the initial search, but his data are included in reductions reported here. Most of the Canaries analyses used in the original compilation are very old and have not been retained in the current data base.

trachyandesite in the archipelago.[3] Finally, it is often said that trachytes have been oversampled simply because they are extremely rare, but most of the work in the Canaries has been done very recently by petrologists thoroughly familiar with the controversy over the Daly gap and fully aware that, among carefully described and analyzed specimens of the oceanic basalt-trachyte association, materials intermediate in composition between trachyte and basalt are considerably rarer than trachytes.

In sum, there is no reason to suppose that this particular sampling is biased, by either geological or psychological factors, in such fashion as to underestimate the relative abundance of intermediates. The relative paucity of analyses of such specimens in published information about the Canaries strongly suggests that materials of this kind are indeed less abundant than trachytes in that archipelago, as they usually seem to be, though often less markedly so, throughout the basalt–trachyte association of the oceanic islands and in many of its nonoceanic occurrences.

From this discussion, as from its predecessor, it seems reasonable to conclude that where trachyte occurs at all in the oceanic islands it usually occurs in amounts greater than would be anticipated as a consequence of fractional crystallization of a basaltic parent. Is it nevertheless possible that crystal fractionation of basalt is indeed the only process essential to the formation of trachyte, and that its anomalous abundance is a consequence of independent controls—presumably tectonic—over the eruptive process, controls which operate to insure that more trachyte than trachyandesite is brought to the surface? This is perhaps not impossible, but it is surely a slender and unlikely reed to lean upon. For why, throughout Cenozoic time and at sites widely scattered over all three oceans, should tectonic processes unrelated to fractionation operate on magma chambers in about the same way *and at about the same point in the fractionation process?*

It seems much more likely that some process other than crystal fractionation is responsible. In 1963 I suggested that trachyte might be generated by partial fusion of previously crystallized alkali basalt, supposing, perhaps incorrectly, that if the final residue of fractional crystallization of such a basalt were indeed of trachytic composition the same might be true of the first liquid generated in the remelting of an incompletely fractionated basalt of this type. This would of course require that a rather devious thermal history be repeated as often as required. There must first be enough heat to generate basalt magma; at some level in the lithosphere enough heat must then be dissipated so that this magma may cool and crystallize; the crystallized magma must next be reheated sufficiently to produce a "first" or early melt. Finally, melting must be checked before reaching the stage at which the composition of the liquid fraction is no longer trachytic, yet the temperature must remain high enough so that the melt fraction can be separated from the solid residue before it crystallizes, a condition which then seemed arbitrary and very difficult to satisfy.

A much better understanding of the remelting process now indicates that this last step is not nearly so difficult as it then seemed, but may also eliminate the need for the whole procedure. Basing his argument on the elegant graphical analysis of partial fusion by Presnall (1969) and experimental data on the melting of hydrous silicate charges and rocks, Yoder (1973, especially p. 165–167) has recently suggested that basalt and rhyolite might be generated from a common parent in a *single* fractional melting episode. Rhyolite would be formed first and expelled from the chamber; whether or not rocks intermediate in composition between basalt and rhyolite were generated would depend on whether or not the crystallization of the subsequently formed basalt magma was fractional. Yoder argues that similar relations probably hold for undersaturated materials.

Indeed, Presnall (1969, p. 1193) had already suggested, albeit rather gingerly and with appropriate obeisance to the Anglican establishment view discussed above, that the Daly gap might be explained by fractional melting.. The parsimony of the scheme is very attractive, for it is hardly to be doubted that there is indeed one fractional melting episode in the history of every basalt, but it is difficult and usually impossible to establish that any particular basalt has undergone more than one. In this scheme salic alkaline magmas would be generated at and perhaps above the lowest "invariant point," and expelled from the magma chamber before the second such point was reached. If sufficient early-formed magma were expelled in this fashion, melting of the solid residue would cease until the second point was reached; further melting would then generate

[3] The base contains 116 analyses of volcanic rocks with $53 < SiO_2 < 57$; of these, 16 are called trachybasalt, 63 phonolite, 25 trachyte, 3 basalt, 4 tahitite, 3 trachybasanite, 1 tephrite. One analysis is recorded in the file as a trachyteandesite and none as a trachyandesite.

magma(s) of basaltic composition, which, in turn, would be expelled from the chamber. Whether or not lavas of intermediate composition were generated would depend on whether, and to what extent, the crystallization of these later-formed magmas was fractional. The probability of a central minimum in the frequency distribution of rock composition would be very high, for even if the crystallization of the later-formed basalt magma(s) was perfectly fractional, the amount of trachyte generated by the whole process would be greater than could be yielded by fractional crystallization alone, unless, of course, the early-formed trachyte magma did not escape from the magma chamber until the second "invariant point" was reached.

Whether this apparently reasonable explanation is indeed correct only time, and perhaps not even that, will tell. The evidence reviewed here, however, seems to me to establish beyond reasonable doubt that an explanation is in fact required; the Daly gap can neither be explained away in the fashion proposed by its recent detractors nor satisfactorily accounted for as a consequence of pure crystal fractionation of basaltic magma.

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(Readers wishing a bibliography of sources from which data summarized in Figure 2 were obtained are invited to request it via the rock information system RKNFSYS, a User's Manual for which is available from the author.)

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