PETROGENESIS OF OCEANIC GRANITES FROM THE AVES RIDGE IN THE CARIBBEAN BASIN

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Bruce M. Walker

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PETROGENESIS OF OCEANIC GRANITES FROM THE AVES RIDGE IN THE CARIBBEAN BASIN

Bruce M. WALKER, Thomas A. VOGEL and Robert EHRLICH
Department of Geology, Michigan State University, USA

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A genetic model proposed for granitic rocks dredged from the Aves Rise involves a sodium-enriched hydrothermal fluid phase, shallow emplacement, and significant derivation of components from the upper mantle. Megascopic observations of serially slabbed sections of the rock samples show that aggregates of plagioclase phenocrysts concentrate into channel-like mats. The presence of a late-stage, hydrothermal fluid is suggested by crystal-lined cavities in the plagioclase aggregates.

With progressively decreasing pressure, this low density, sodium-rich, hydrous fluid phase unmixed from the silicate melt and entrained the plagioclase aggregates as it rose. Reaction between this sodium-rich hydrous phase and the plagioclase produced albite rims. Genetic independence of the plagioclase aggregates and the granitic groundmass which surrounds them is implied by the results of a chi square test. Thus, the system consisted of three distinct components – the early-formed calcic plagioclase, a sodium-rich hydrous fluid phase, and a granitic-silicate fluid phase.

Shallow intrusion (less than 15 km) is indicated by the structural state of K-feldspars and presence of miarolitic cavities. $^{87}Sr/^{86}Sr$ values, which correspond to ratios obtained from oceanic basalts, suggest that the granitic rocks are primitive and most likely from the upper mantle.

1. Introduction

In 1969, Dr. Bruce C. Heezen of Columbia University, aboard Duke University's R/V Eastward, attempted to sample an anomalous 6.0–6.3 km/sec crustal layer [1] that underlies most of the Caribbean Basin area. Samples were obtained by dredging across an escarpment near the southern end of the Aves Rise, which separates the Venezuela Basin from the Grenada Trough 450 km north of Venezuela [2]. Two dredge hauls, located within 10 km of each other, contained a combined total of 3500 kg of granitic rocks.

These rocks range in size from small cobbles to a 600 kg boulder. The granitic rocks are coarse-grained and fractured. Some of the larger fragments appear to have been broken directly from outcrop by the dredge. Fossil encrustations and up to several centimeters of manganese oxide coatings [2], indicate that they were exposed to sea water for considerable time. Tests on the rock samples under a confining pressure equivalent to 6–10 km depth gives a compressional wave velocity ranging from 6.0 to 6.4 km/sec, and the velocity versus pressure curves are similar to those of continental granites [2].

The present study on these dredge samples was begun during the latter part of 1970. This paper presents a genetic model of the Aves Rise granitic rocks, based upon a synthesis of the textural and compositional variations observed from the dredge fragments.

2. Megascopic features

Slabbed sections of the rock samples from both dredge hauls showed specific compositional and textural variation not observable on a smaller scale. The largest sample available (30 × 20 × 15 cm) from the two dredge hauls was slabbed serially in each of two directions at right angles to one another in order that variation in three dimensions could be observed. Ten smaller samples were also slabbed and were studied to test the consistency of textural relationships from sample to sample.

Four petrogenetically important features were identified on the slab level:(i) Aggregates of plagioclase forming bleb-like particles, (ii) Crystal-lined vugs, (iii) Groundmass material surrounding the aggregates of plagioclase, and (iv) Granophyric matrix material.

The first three features are common to all clasts. Granophyric matrix is confined to two samples.

2.1. *Plagioclase aggregates*

All of the rock samples that were slabbed exhibit bleb-like aggregates of plagioclase. These aggregates have varying spatial relationships (figs.1 and 2), and in some instances they approximate a close-packed arrangement with interstitial groundmass, whereas in other instances they appear to be suspended in

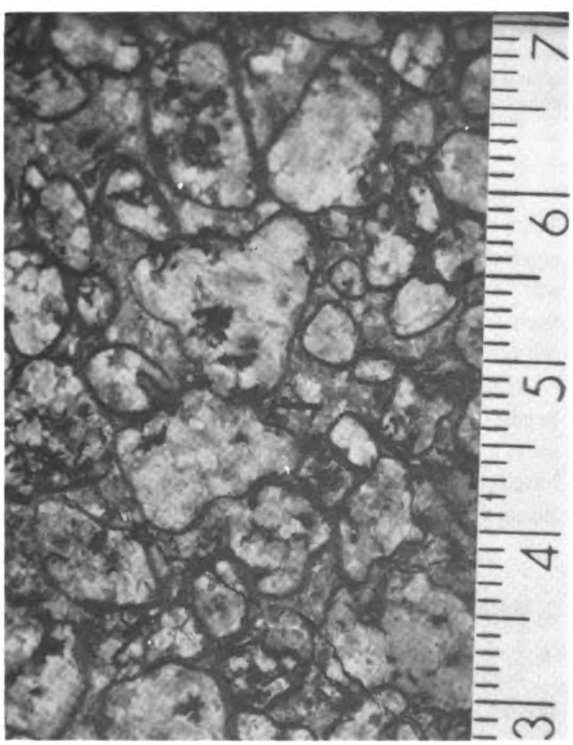


Fig. 1. Plagioclase aggregates (outlined) surrounded by groundmass material. Scale is in centimeters.

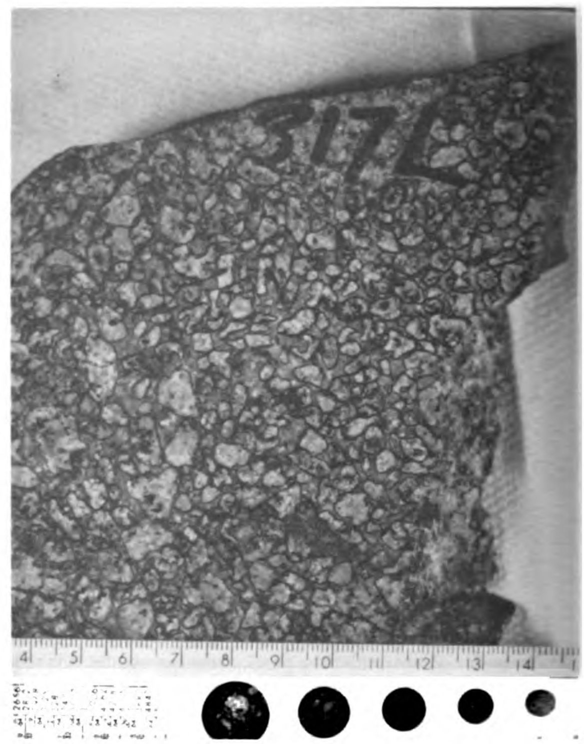


Fig. 2. Slab exhibiting varying spatial relationships of outlined plagioclase aggregates. Scale is in centimeters.

groundmass (see below). The size and shape of the aggregate vary considerably throughout each slab.

The combined effect of the above textural characteristics is to produce aggregate-rich zones separated by aggregate-poor zones. The rocks were slabbed serially to study the spatial character of these zones. In all cases segregations of plagioclase aggregates occur in channel-like features roughly circular in cross-section, a few centimeters wide extending through the sample. In some instances these channel-like features were observed to bifurcate. In fig. 3.a chevron-like effect within a very dense mat of plagioclase represents an extreme condition of such a channelway. The presence of chevron-like lineaments in this very dense clot of plagioclase aggregates provides direct evidence for relative movement along these channels.

These features, plus the association of plagioclase aggregates with vugs, as discussed below, indicate that the channel-like, aggregate-rich masses accumu-

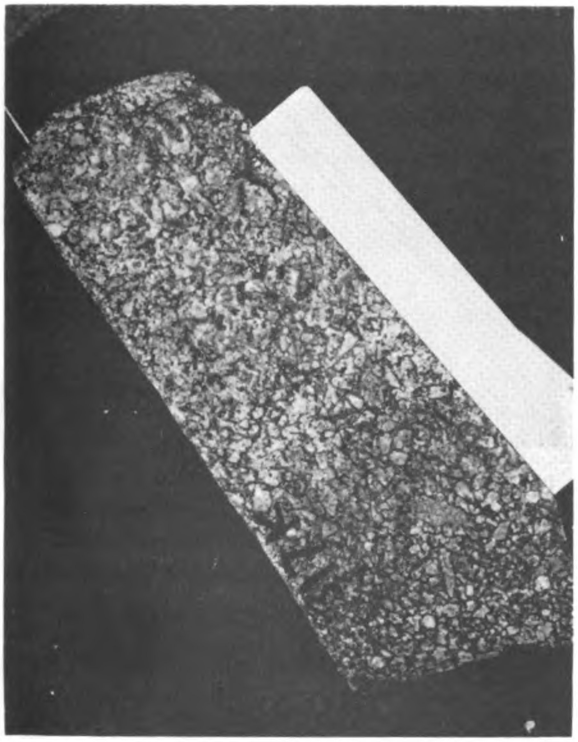


Fig. 3. Photograph displaying mat-like features of plagioclase. Plagioclase aggregates are poorly defined in the light area in the center of the photo, which is almost entirely plagioclase. The dark zone just to the right of this light area has chevron lineations of plagioclase suggesting relative movement of the aggregates in the rock before crystallization.

lated in actual channelways during the movement of solid and fluid phases.

2.2. *Vugs*

Scattered through the larger rock samples are vugs lined with crystals of feldspar and epidote that comprise less than one percent of the rock volume. The vugs are always found in association with aggregates of plagioclase. In most cases they occur within the aggregate; in a few cases they occur near the point of contact of two plagioclase aggregates. In general, the number of vugs in a sample is proportional to the size of the sample and no particular importance is placed on an apparent absence of vugs in some of the smaller sized samples.

2.3. *Groundmass*

Surrounding the plagioclase aggregates (except in the two granophyric samples) is a groundmass which is comprised principally of various proportions of generally finer-grained quartz, potassium feldspar, amphibole-chlorite, and plagioclase not included in the aggregate population. It is possible that, due to the irregular surfaces of the plagioclase within the aggregates, some of the plagioclase in the groundmass may be part of an aggregate. Volumetrically, however, this effect must be minimal, since the single grains of plagioclase in the groundmass in many cases can be observed as separate entities and not corners of plagioclase within the aggregates.. The shapes of the aggregates would have to be extremely irregular in order to produce the amounts of groundmass plagioclase that are present in the rock samples. Such is not the case.

2.4. *Granophyric matrix*

Two samples have a fine-grained, granophyric matrix. Information obtained from microprobe and petrographic data is more pertinent than can be obtained on this slab scale and will be discussed below.

3. Selected mineralogic relations

The dredged samples are composed principally of plagioclase, quartz, and K-feldspar, with lesser amounts of hornblende, chlorite and opaques. Modal analyses of five samples are given in table 1. As will be demonstrated in a later section, the plagioclase aggregates were not derived from their immediate groundmass; and, therefore, in table 1 each analysis is presented in two ways: column 1 gives the total modal analysis of the thin section; column 2 gives the modal composition of only the matrix. According to the classification scheme of Streckeisen [3] the plots of the modal analysis of the whole rock fall near the boundary of granodiorites and granites, but in the granodiorite field. The matrix of these rocks would fall in the middle of the granite field.

The plagioclase are extremely zoned in all cases. Well over fifty zones were counted in large plagioclase phenocrysts from the aggregates and an estimated 100 zones appear in a few cases. Plagioclase com-

Table 1

Modal analyses of five samples dredged from the Aves Rise. Column (1) for each sample is the modal analysis of all the minerals present in the sample. Column (2) is the modal analysis of the matrix; that is, the plagioclase in the blebs have been subtracted from the bulk modal analysis. The mineral category labeled 'Other' is chlorite, hornblende and opaques.

	7A8		7–Cb1		7A1		Cb15		319–C9	
	1	2	1	2	1	2	1	2	1	2
Plagioclase	56	20	43	16	44	21	50	13	40	14
K-Feldspar	18	31	23	34	19	27	16	27	22	32
Quartz	20	36	22	33	30	42	26	44	29	41
Other	7	13	11	17	7	10	9	15	8	12

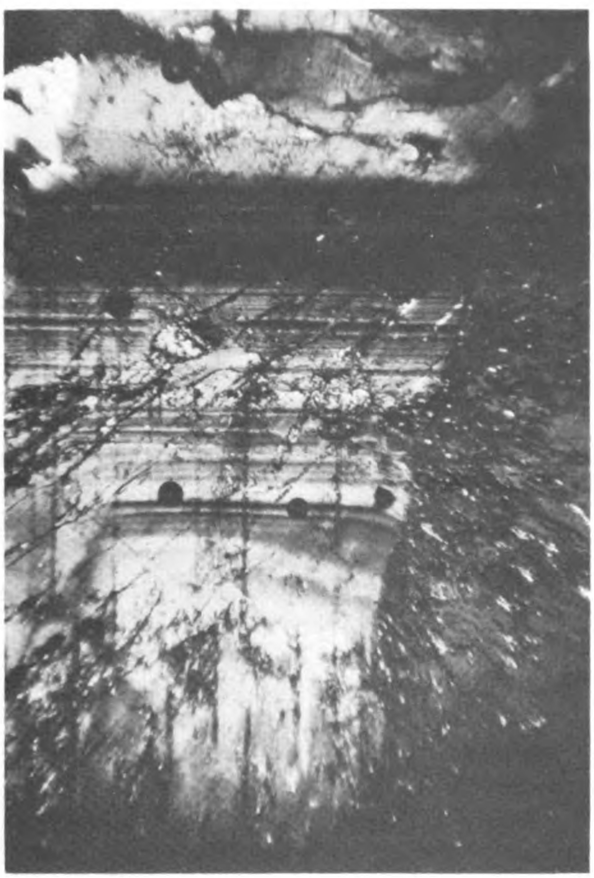


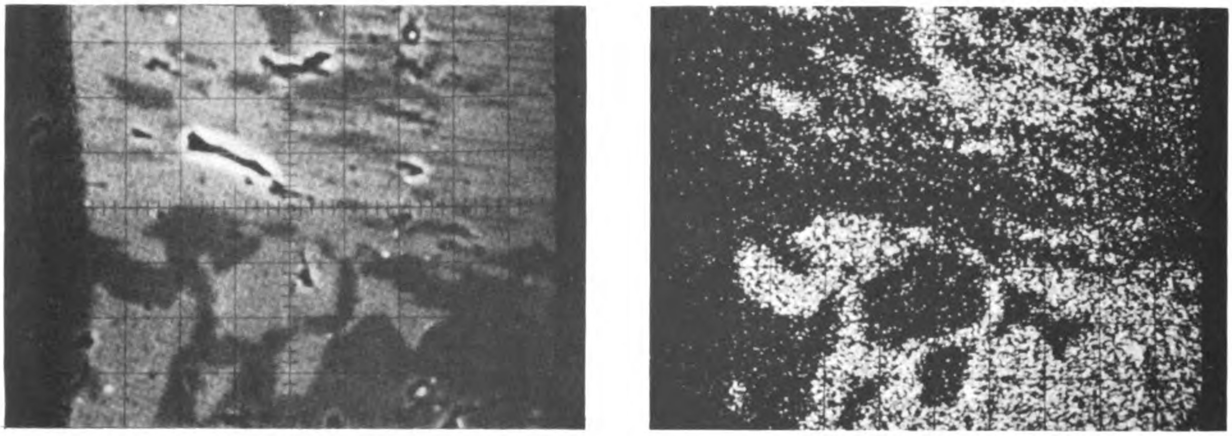
Fig.4. Plagioclase aggregate phenocryst showing oscillatory zoning from core to rim. Light area bounding the extinct zone of the phenocryst in an albite rim. Short dimension of the photograph is 1.6 mm.

position in the aggregates ranges from An 70 in the core and decreases continuously, or in an oscillating manner to An 20 – 25, and is mantled by pure albite. These mantles generally show a sharp discontinuity in composition with respect to the inner zones (fig. 4). In contrast, the groundmass plagioclase lacks this clearly defined albite rim. Clearly, these plagioclase were subjected to many changes in pressure, temperature, and composition.

Microprobe analyses of the granophyre shows abundant albite in the matrix and that nearly pure K-feldspar is surrounded and embayed by this albite (fig. 5). Perthitic development within single K-feldspar crystals varies from large areas that contain no albite to areas that are nearly completely replaced by this albite with only small remnants of K-feldspar.

Using X-ray techniques described by Wright and Stewart [4] and Wright [5], structural state and compositional analyses of potassium feldspar were made on feldspars from the same thin section sites used in the chi square study (see below) and on granophyric samples. The samples yielded potassium feldspar having a structural state and composition analogous to the Spencer B type (low sodium-intermediate microcline) used by Wright [5]. The granophyric samples also yielded Spencer U or Spencer B type low sodium-intermediate microclines. The low amounts of albite in solid solution in these intermediate K-feldspars is further evidence that much of the sodium present is a late event rather than associated with silicate melt and the crystallizing K-feldspars.

The pattern of late-stage crystallization of albite and the presence of vugs implies the existence of a



(A) (B)

Fig. 5. (A) Microprobe sample current photograph of granophyric material and a perthitic K-feldspar. Each division is 10 microns. (B) Microprobe photograph of sodium K_{α}X-ray of the same area as in fig. 5 (A). Albite (light areas) appears as a matrix in the granophyre and as included areas in the K-feldspar phenocryst.

sodium-rich, hydrous fluid phase which has separated from the silicate liquid. The solubility of water in a granitic liquid has been shown by Luth and Tuttle [6] to be greatly increased upon the addition of sodium disilicate and that the solubility of albite in the fluid phase decreases markedly with decreasing pressure and temperature. The Aves Rise granitic rocks were affected by a late, highly sodic fluid as shown by the albite rims on the plagioclase within the bleb-like aggregates and by the K-feldspar-albite relationships. It is concluded that the late stage emplacement of the albite probably is a response of the fluid phase to decreasing pressure and/or temperature.

4. Relationship of plagioclase aggregates to groundmass

In a system where there is a significant temperature range between the first-formed phases and later phases it is most likely that these early phases will be separated from the liquid from which they crystallized. Most shallowly emplaced granitic rocks probably exhibit relationships similar to those discussed here, but have not been subjected to the same type of textural analysis.

In the Aves Ridge granites the independence between plagioclase aggregates and groundmass appears to be obvious because of the channelizations and inhomogeneities of the plagioclase aggregates. This independence was tested quantitatively by a chi square test of a contingency table array. The specific classification tested in the contingency table was the plagioclase aggregate to groundmass ratio per thin section versus total plagioclase counts per thin section. The results of this test, $\chi^2_{18\,d.f.} = 24.7 \ll \chi^2(P.05)$, imply independence between the plagioclase aggregates to groundmass ratio and total plagioclase counts in thin sections. Thus, the observed variation in plagioclase counts can occur at any and all of the observed plagioclase aggregate to groundmass ratios. This implies, as would be predicted from the nature of the phases, that the plagioclase aggregates were not derived from their immediate groundmass.

5. A genetic model of the Aves Rise granites

The following observations are significant for construction of a genetic model for the Aves Rise granites.

(1) Volumetric concentrations of plagioclase aggregates forming channel-like features within the rock samples;
(2) Presence of crystal-lined vugs within plagioclase aggregates;

(3) Genetic independence of plagioclase aggregates and their immediate groundmass;
(4) Presence of albite rims around highly zoned calcic cores on plagioclase crystals in the aggregates;
(5) Albite mantling potassium feldspar grains and forming replacement perthites;
(6) Presence of granophyric matrix in some samples;
(7) Structural state, X-ray diffraction analyses of K-feldspar showing them to be a low sodium, intermediate microcline;
(8) The rocks are dredged from the anomalous 6.0–6.3 km/sec layer in the Caribbean Basin [2];
(9) Absence of muscovite and biotite.

These results must also be interpreted in the light of the $^{87}Sr/^{86}Sr$ ratios of these samples determined by Spooner (personal communication) to be discussed more fully, with the rare-earth element abundance patterns, in a later paper. Values for $^{87}Sr/^{86}Sr$ of 0.7038, 0.7046 and 0.7080 (all ± 0.001) were found for samples of fresh granite, an inclusion in the granite and a granophyre, respectively. In view of the young ages encountered (K/Ar = 57–89 my) [2], the isotopic ratios measured are effectively initial ratios, especially since the Rb/Sr ratios for these specimens are low (0.31 ± 0.18***). The initial $^{87}Sr/^{86}Sr$ values are lower than those generally encountered in crustal granites and are similar to values found in oceanic basalts presumably derived from the upper mantle. Further, all the ratios measured are lower than that of present-day sea water indicating little or no equilibration with common strontium.

The following genetic conditions can be derived directly from the above observations. (1) The existence of a three component system consisting of early formed calcic plagioclase, a granitic silicate melt phase and a sodium-rich, hydrous fluid phase. (2) All textural components – aggregates, groundmass and granophyre – have $^{87}Sr/^{86}Sr$ ratios reflecting an upper mantle origin. (3) Early formation of basic plagioclase phenocrysts. (4) Disequilibrium conditions existing between calcic plagioclase and granitic groundmass. (5) Aggregate formation, channelization and transport of early formed plagioclase by the sodium-rich hydrous fluid. (6) A progressive decrease in pressure implied by progressive late-stage sodium enrichment. (7) Shallow depth of crystallization (less than 15 km) is indicated by the presence of intermediate structural state of K-feldspar and absence of muscovite. The presence of vugs probably indicates crystallization at a shallower level.

Taking these observations and interpretations into account, the following conclusions can be made. The Aves Rise granites represent a primitive granite. The groundmass crystallized at its present location (less than 15 km depth) and the plagioclase aggregates probably crystallized at a greater depth.

Although the $^{87}Sr/^{86}Sr$ data indicate all of the components are derived from the upper mantle, the chi square results indicate that the plagioclase aggregates are not derived from their immediate groundmass. The plagioclase may either have formed earlier and been separated from its parent melt, or the plagioclase and the granitic groundmass reflect two separate genetic events. Because of the highly calcic cores of the plagioclase in the aggregates, the authors favor the latter alternative. A possible model is suggested if one considers the sequence of events causing heat transfer from the mantle to the crust.

It is generally agreed that the material overlying the mantle consists of low melting point products of the mantle. If a molten fluid derived from the mantle were injected into this material, the overlying material would melt along with crystallization of some of the injected material. In the Aves Rise rocks the plagioclase aggregates could arise from the mantle-derived liquid whereas the granitic groundmass could be produced by partially melting basaltic lower crust. The composition of the highly calcic plagioclase cores is consistent with crystals in equilibrium with a liquid derived by partial melting under upper mantle conditions, and similarly the granitic groundmass is consistent with liquid derived by partial melting under crustal conditions. The initial melt produced in the lower crust was probably under saturated with respect to water [7]. As this liquid, along with the early plagioclase crystals, was emplaced into higher levels in the Caribbean crust, the silicate liquid became saturated and a hydrous (sodium-rich) fluid phase separated. Total crystallization occurred soon after separation of the hydrous phase. The present textures observed are a result of the tendency for the early plagioclase crystals to agglutinate into aggregates and the entrainment of these plagioclase aggregates by the low density fluid phase as it rose in the silicate liquid.

In light of Fox et al.'s [2] velocity determination for these rocks, it is possible that the 6.0–6.3 km/sec velocity layer that underlies the Caribbean is composed, in part, of granitic rocks derived in a similar fashion to those from the Aves Rise. For this reason other granitic rocks from the Caribbean should be subjected to a similar geochemical-textural analysis. If the results are in accord with those presented here, then perhaps these rocks and the processes which formed them are analogous to primitive continental crusts, in which case the Caribbean crust is a protocontinent.

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