

36. VESICULARITY OF SHIKOKU BASIN BASALT: A POSSIBLE CORRELATION WITH THE ANOMALOUS DEPTH OF BACK-ARC BASINS

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INTRODUCTION

Highly vesicular basalt predominates at Sites 442 and 443 in the Shikoku Basin, between the Izu-Bonin and Kyushu-Palau island arcs. These basalts are far more vesicular than typical ridge tholeiites erupted at similar abyssal depths and appear to have had a much higher initial volatile content than is typical for mid-ocean-ridge basalt (MORB).

The Shikoku Basin appears to have formed by rifting of an old island arc and by formation of a new basin between the inactive remnant to the west and the still-active part to the east (e.g., Watts and Weissel, 1975; Karig, 1970). The basin has geophysical and petrologic properties similar to those of typical oceanic crust (e.g., Murauchi et al., 1968; Watts and Weissel, 1975; Scientific Party, Leg 58, 1978). Linear magnetic anomalies parallel to the basin elongation also have been identified (Watts and Weissel, 1975; Kobayashi and Isezaki, 1976). The oldest sediment above basement at all the Shikoku Basin sites is younger (14–21 m.y.; Scientific Party, Leg 58, 1978) than the oldest dated rocks in the island arc to the east (30–40 m.y.; Kaneoka et al., 1970). Both the Shikoku Basin and the Parece Vela Basin to the south, however, are 1000 meters deeper than predicted by the depth-age relation of Sclater et al. (1971) for oceanic crust of the same age (Kobayashi and Isezaki, 1976).

In this paper, I would like to suggest that the high vesicularity of many Shikoku Basin basalts may reflect hydrous remelting of old, relatively cool abyssal mantle above a subduction zone. Such melting might trigger mantle diapirism above the slab and initiate generation of basaltic magma (Wyllie, 1971). The resulting mantle convection would be at a temperature lower than that below major ocean basins, resulting in a cooler lithosphere. This may account, then, for the anomalous depth of the oceanic crust in many marginal basins (e.g., Sclater, 1972).

PETROGRAPHY

The Leg 58 pillow basalts, flows, and sills are described in detail elsewhere in this volume. At Sites 442 and 443, they resemble typical abyssal tholeiites, except for the textures peculiar to the sill units, which have not been well described elsewhere. The basalts at Site 442 are largely aphyric whereas those at Site 443 are both aphyric and phyric. Olivine is present in the majority of the basalts. The sequence of crystallization in the pillows and sills appears to be olivine and spinel → plagioclase → clinopyroxene → titanomagnetite. Olivine and

spinel are absent in some basalts where plagioclase or plagioclase and clinopyroxene occur as microphenocrysts in glassy chill zones. Textural gradations from a glassy rim to a nearly holocrystalline core are typical for abyssal pillow basalts. Glassy chill zones are rare in the sill sequences where the contacts tend to be fine grained or cryptocrystalline rather than glassy. The sills and massive flows grade from fine-grained basalt at their margins to diabase in the middle of the thicker units.

At Site 444, also drilled in the Shikoku Basin, the basalts are more alkaline and much less vesicular than those at Sites 442 and 443. The upper of two sill units consists of alkali olivine basalts (teschinite) which contain analcite, potassium feldspar, kaersutite, and biotite. The lower units appear petrographically to be typical abyssal basalts, but their plagioclase shows a definite potassium-enrichment trend which is not typical of abyssal tholeiites (Dick et al., this volume).

VESICULARITY

The amount and size of vesicles in 127 relatively crystalline basalt samples representative of the entire basement section at Sites 442, 443, and 444 were estimated visually through the petrographic microscope (Table 1). These estimates were checked and corrected for a slight systematic bias in visual estimation by point-counting 21 of the samples (see Dick et al., this volume). In addition, thin sections of 25 glassy chilled margins were also examined.

Vesicles are abundant in the Site 442 pillow lavas (avg. 17.6 vol. %) and sills (avg. 15.6 vol. %), somewhat less abundant in the Site 443 pillow lavas (avg. 7.9 vol. %), and absent or present only in small amounts in the Site 443 and Site 444 sills. Vesicle diameter averages 0.22 mm in the pillow basalts and 0.55 mm in the sills and flows. Many of the basalts contain a second size

TABLE 1
Vesicularity of Shikoku Basin Basalts^a

	Volume of Vesicles (%)				Vesicle Diameter (mm)			
	Pillows		Sills		Pillows		Sills	
	avg.	1σ	avg.	1σ	avg.	1σ	avg.	1σ
Site 442	17.6 ± 7.0 (18)		15.6 ± 7.6 (33)		0.20 ± .12 (18)		0.47 ± .22 (21)	
Site 443	7.9 ± 5.2 (18)		1.3 ± 2.5 (23)		0.25 ± 1.6 (17)		0.68 ± .35 (13)	
Site 444								
alkali basalt	—		0.0 (7)		—		—	
tholeiite	—		1.8 ± 4.3 (17)		—		1.22 ± .80 (5)	
All Sites								
Aphyric Basalts		13.8 ± 7.5 (70)				0.31 ± 0.21 (56)		
Phyric Basalts		0.9 ± 2.6 (57)				0.83 ± 0.55 (18)		

^aNumber of samples in parentheses.

population of nearly circular vesicles averaging 1.2 mm in diameter (Plate 1, Figures 1-4), and a third size population of more irregularly shaped vesicles and vugs of varying size (up to 1 cm across). Pipe vesicles and concentric zones of vesicles occur in many pillows (Plate 2); similar vesicle-rich zones parallel the contacts of some sills.

The highest measured vesicularity is 36.8 volume per cent in a Site 442 pillow basalt containing fine vesicles 0.2 mm or less in diameter, evenly distributed through the rock. Such high vesicularity and such small vesicles give many of the rocks a foam-like appearance (Plate 1, Figures 1-4). Often the rocks are almost entirely crystalline, and the vesicles either occupy the interstices between plagioclase laths and pyroxene grains (diktytaxitic texture), or the groundmass crystals have grown around and are embayed by somewhat rounder vesicles (Plate 1, Figures 1-4).

The abundant small vesicles are evenly distributed through the rock on the scale of a thin section or hand specimen, and are also evenly distributed on the scale of an individual cooling unit except at chilled margins. Between units, the degree of vesicularity may vary sharply. The larger vesicles, however, are not evenly distributed through individual samples or units, and are frequently concentrated in zones (often near the top of individual sills); they appear to predate the generally more abundant smaller vesicles.

The glassy chill zones of the Site 442 and 443 pillow basalts, flows, and sills contrast remarkably with the more-crystalline interiors, because the chill zones rarely contain more than 1 to 2 per cent vesicles. The transition from a highly vesicular foam-like basalt to massive glass is abrupt, usually occurring over a distance less than a centimeter (Plate 3, Figures 1-3). The walls of those few vesicles present in the glass are often decorated with small, evenly spaced sulfide blebs (see Moore and Schilling, 1973). This indicates that, while the amount of free volatiles in the melt was small at the time of eruption, the volatiles were saturated with respect to sulphur (Plate 3, Figures 1-3).

Of the 25 clear, glassy chill zones examined from Sites 442 and 443, only five contain more than 1 to 2 per cent vesicles. These few were all "evolved" pyroxene or pyroxene-plagioclase microphyric glasses containing up to 10 per cent unusually large (avg. 1-2 mm) vesicles.

It is evident from the non-vesicular glasses that most of the volatiles exsolved from the melt after eruption onto the sea floor. The formation of highly vesicular basalt within a centimeter of the glassy zone and the small size, abundance, and frequent overgrowth of vesicles by groundmass crystals suggest that the gas exsolved before most groundmass crystallization. A very high rate of degassing is indicated by the great number and small size of the vesicles, just as a great number of small crystals in a basalt indicates rapid cooling. This is consistent with the much larger average diameter of vesicles in the coarser-grained, more slowly cooled, massive sills and flows than in the pillow basalts (Table 1).

Phenocryst-rich basalts, unlike the aphyric basalts from the Shikoku Basin, generally have a very small ves-

icle content (Table 1). Those vesicles present, however, have a relatively large diameter. This is consistent with the shallow magma chamber implied by abundant phenocrysts. Extensive degassing in the chamber prior to eruption may explain the low vesicularity of the phyric basalts, while slow cooling and consequent exsolution of volatiles could explain the large vesicle size. Some lavas erupted near the top of the chamber might contain substantial amounts of relatively large vesicles due to vesicle accumulation while the majority contain few or none. This may explain the abundance of large vesicles in the glassy chill zones of a few relatively evolved pyroxene-microphyric basalt samples, and their near absence in the remainder.

It is unlikely that the source of the volatiles in the vesicles could be sea water or sediment. The absence of vesicles in the chilled glassy margins of the basalts demonstrates that such contamination would have had to occur late, while it is evident petrographically that the exsolution of volatiles actually occurred very rapidly following eruption of the basalt. Further, the near absence of vesicles in the vast majority of abyssal ridge basalts, all erupted in a similar environment, strongly argues against significant contamination of deep-sea basalts by sea water prior to freezing.

VESICLES IN MID-OCEAN-RIDGE BASALTS

Mid-ocean-ridge basalts are typically erupted at depths of 3000 to 4000 meters and are the least vesicular of any known basalt type (Moore, 1970). Moore and Schilling (1973) found that basalt vesicularity along the Reykjanes Ridge decreased systematically with depth, from an average of about 40 per cent at 100 meters to about 5 per cent at 1000 meters (see also Jones, 1969). Radially elongate and concentric zones of vesicles are absent at depths greater than about 700 meters, in contrast to the Shikoku Basin basalts. The average vesicle diameter is 1 to 2 mm (much larger than in the Shikoku basalts), and there is only a small decrease in vesicle abundance from core to rim (Moore, pers. comm., 1979). Moore (1970) suggests that the sharp increase in vesicularity with decreasing water depth (above 1000 m) may represent the confining pressure at which the basalt becomes saturated with water-dominated gases, which exsolve to form abundant vesicles. The gases in basalt vesicles from greater depth, then, may be dominated by sulphur and carbon compounds (Moore, 1970).

The depth of crystallization of the Shikoku Basin basalts can be inferred from the overlying sediment at the three sites, which appears to have been deposited near the carbonate-compensation depth (see site chapters, this volume). In conjunction with the curve of Ramsay (1977), this indicates a water depth in the vicinity of 3400 meters (0.35 kb) for intrusion and extrusion of the Shikoku Basin basalts. Unless there has been dramatic and sudden subsidence following crystallization of the basalt, for which there appears to be no evidence in the sedimentary sections, the high vesicularity of the Shikoku Basin basalts cannot be attributed to a shallow depth of crystallization. Therefore, the basalt liquids must have held a higher volatile content than normal mid-

ocean-ridge basalts. Similar high vesicle contents have also been reported from back-arc basalts from the Scotia Sea, which Saunders and Tarney (1979) believe are also due to high volatile contents.

While mid-ocean-ridge basalts generally have low water contents (avg. $\sim 0.18 \pm 0.1$ wt. %; Delaney et al., 1978) and Reykjanes ridge basalt glass contains only about 0.3 weight per cent H₂O (Moore and Schilling, 1973), significant water contents have been reported in back-arc basin basalts. Delaney et al. (1978), for example, report high water contents, near saturation for a basaltic magma, in Mariana back-arc-basin basalt glass (1.4 ± 0.3 wt. %), an observation consistent with the high vesicularity and postulated volatile contents of Shikoku Basin back-arc-basin basalt.

VOLATILE COMPOSITION

The composition of the volatiles in the Shikoku Basin basalts is a subject of some interest. The principal components of the gas phases are likely H₂O, CO₂, and SO₂. At the relatively high temperatures and low pressures of extrusion of the Shikoku Basin basalts, the behavior of volatiles, particularly H₂O (see Burnham et al., 1969), is nearly ideal. Accordingly, using the ideal-gas law, we can roughly calculate the amount of gas required to produce 20 volume per cent vesicles, which is typical of many Shikoku Basin basalts, for each of the above species (SO₂ = 1.8 wt. %; CO₂ = 1.2 wt. %; H₂O = 0.5 wt. %).

From this, we can eliminate both SO₂ and CO₂ from consideration as the major gas species in the vesicles. The solubility of sulphur in melts is low compared to that of other volatiles (Mysen, 1977a; Haughton et al., 1974); therefore, evolved SO₂ likely did not contribute significantly to the gas phase at 0.35 kb. Similarly, the solubility of CO₂ in basaltic melt at 1 kb is about 0.35 weight per cent (Khitarov and Kadik, 1973, fig. 1a). If the melt was saturated with respect to CO₂ it could not evolve half the required CO₂ after eruption, even if it retained all the gas phase over a 3-kb (10-km) pressure drop prior to eruption.

The solubility of water in basaltic melt at 1 kb, however, is over 3 weight per cent (Figure 1). Extrapolating the data of Hamilton et al. (1964), a pressure drop of only about 200 bars (0.56 km) would be required to evolve the 0.5 weight per cent H₂O required to produce 20 per cent vesicles in a water-saturated melt. Thus, while CO₂ and H₂O likely were present in the volatile phase, the large volume of vesicles in the Shikoku Basin basalts appears to require a relatively large proportion of water in the magma.

Water in a basaltic magma can reduce the viscosity and density of the magma and hence greatly decrease its ability to carry crystals in suspension (Mysen, 1977b). Scarfe (1973) found, for example, the viscosity of a water-saturated basaltic magma at 1 kb is three eighths of its 1-atmosphere anhydrous viscosity. This is consistent with the large difference in vesicularity between the aphyric (13.8 vol. %) and phyruc (0.9 vol. %) basalts from the Shikoku Basin.

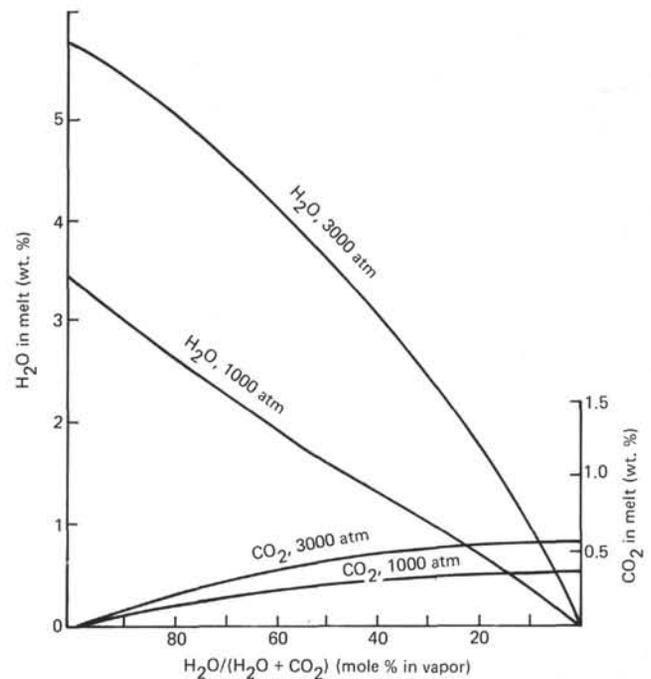


Figure 1. Solubility of water and CO₂ in basalt at 1200°C and pressures of 3000 and 1000 atmospheres (from Khitarov and Kadik, 1973).

An indication of a high water content can also be seen in the vesiculation pattern of the Shikoku Basin basalts. The small quantity of vesicles in the glassy chill zones and the large quantity of very small vesicles in the interiors of many of these basalts indicate very rapid separation of volatiles from the melt after eruption. This pattern contrasts with that of the Reykjanes Ridge basalts, where the vesicles are larger (1–2 mm) and there is not such a large difference in vesicularity between pillow rim and interior. These differences are consistent with a relatively small amount of CO₂-dominated volatiles in the Reykjanes Ridge basalts, and a larger amount of H₂O-dominated volatiles in the Shikoku Basin basalts.

As seen in Figure 1, a small amount of CO₂ in a basaltic melt has a profound influence on both the solubility of H₂O and the total volatile content. In particular, this affects both the pressure at which volatiles will separate and their composition. For example, a basic melt containing 1.5 weight per cent H₂O will boil first at 250 bars, but if it contains an additional 0.25 weight per cent CO₂, it will boil first at 1200 bars, with an H₂O/CO₂ ratio in the vapor 10 times that of the melt (Khitarov and Kadik, 1973). Delaney et al. (1978) found that while MORB glasses are very undersaturated with respect to pure H₂O they are approximately saturated with respect to pure CO₂ (0.12 wt. %). Thus, while MORB glasses contain only a small amount of volatiles, the presence of a significant amount of CO₂ explains the occurrence of vesicles in MORB from great depths, as found by Moore (1970). On the other hand, since the total quantity of dissolved volatiles is small, a small drop in pressure accompanying eruption will not greatly increase the ves-

icularity of the magma. Thus, unlike the Shikoku Basin basalts, there is little difference in vesicularity between the glassy rim and the interiors of most abyssal basalts.

For a water-rich basalt magma, this is not the case. Water has not only a much greater solubility than CO_2 (Figure 1), but also a much greater molar volume. Accordingly, a relatively small pressure drop in a water-saturated magma should cause considerable water vapor to exsolve rapidly and numerous vesicles to form. This would account for the small size and abundance of the vesicles in the Shikoku Basin basalts, and the sharp increase in vesicle content away from the chilled margin. The low vesicle content of the glassy chill zone may reflect the ease with which gas escapes from a water-rich, low-viscosity melt prior to eruption and quenching of the glassy rim. Alternatively, the melt may have degassed prior to eruption, perhaps in a shallow magma chamber, and failed to exsolve substantial volatiles prior to quenching of the glassy chill zone. Whatever the case, it is clear that the Shikoku Basin basalts underwent a dramatic second boiling following eruption — not reported for typical MORB — consistent with a high water content in the melt.

Kennedy (1955) has pointed out that water-rich magmas consistently appear to have high $\text{Fe}^{3+}/\text{Fe}^{2+}$ ratios. Kennedy suggested that water might act as a reservoir for O_2 by dissociation ($2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2$), thus promoting the reaction $2\text{FeO} + \frac{1}{2}\text{O}_2 \rightarrow \text{Fe}_2\text{O}_3$. Gerlach and Nordlie (1975) have studied gas compositions from high-temperature volcanic fumaroles and have noted that “gas compositions indicate that gases are commonly buffered by their magmas.” It is evident from Gerlach and Nordlie’s study that these buffers shift the gas phase toward oxygen-poor compositions in the quadrilateral O–S–H–C, with a distinct deficiency in oxygen such that the proportions of these species plot below the stoichiometric plane $\text{H}_2\text{O}-\text{CO}_2-\text{SO}_2$. Such a change in composition of the gas phase could be effected reasonably by the reaction $\text{FeO} + \frac{1}{2}\text{O}_2 \rightarrow \text{Fe}_2\text{O}_3$. Thus, basalts with initially water-rich gases will, with crystallization and cooling, have higher $\text{Fe}^{3+}/\text{Fe}^{2+}$ ratios than those poor in water-rich volatiles.

Roeder and Emslie (1970) studied the distribution of iron and magnesium between melt and olivine for a variety of basalt compositions. They found that the distribution coefficient

$$K_D = \frac{X_{\text{Mg}}^{\text{Ol}} \times X_{\text{Fe}^{2+}}^{\text{melt}}}{X_{\text{Mg}}^{\text{melt}} \times X_{\text{Fe}^{2+}}^{\text{Ol}}} = 0.3$$

is constant and relatively independent of P , T , and composition effects. Thus, they suggested that it would provide a convenient method for determining the Fe^{3+} content of a liquid at the time of olivine crystallization. To do this requires measurement of total iron in a glass coexisting with olivine. Measurement of the iron in such pairs yields apparent distribution coefficients,

$$K'_D = (X_{\text{Mg}}^{\text{Ol}} \times X_{\text{total Fe}}^{\text{melt}}) / (X_{\text{Mg}}^{\text{melt}} \times X_{\text{total Fe}}^{\text{Ol}}),$$

of about 0.27 for most abyssal basalts (e.g., Dungan et al., 1977). The apparent distribution coefficient measured for Sites 442 and 443 olivine–glass pairs is about 0.227, clearly reflecting unusually high $\text{Fe}^{3+}/\text{Fe}^{2+}$ ratios and correspondingly high water content at the time of eruption.

SUMMARY

High volatiles contents at the time of eruption are necessary to explain the vesicularity of Shikoku Basin basalts. A water-rich volatile composition is also indicated by four independent lines of evidence: (1) the large volume of gas required, as opposed to the low solubility of gas species other than water in the melt; (2) the vesicle pattern, atypical of most abyssal tholeiites, which indicates a rapid second boiling on eruption, apparently requiring water-rich volatiles; (3) the high $\text{Fe}^{3+}/\text{Fe}^{2+}$ ratios indicated by the apparent K'_D for Mg and Fe between olivine and melt; and (4) the absence of significant amounts of phenocrysts in the highly vesicular basalts.

DISCUSSION

High water contents were first suggested for back-arc-basin basalts by Gill (1976) on the basis of some data from the Lau Basin. Since that time Delaney et al. (1978) and Garcia et al. (1979) have reported water contents in excess of 1 per cent in Mariana back-arc-basin basalt glass. Dick et al. (1978) and Saunders and Tarney (1979) have suggested that the high vesicularity of Shikoku and Scotia Sea back-arc-basin basalts also indicates high primary volatile contents. These observations and the high vesicularity of the Shikoku Basin basalts appear to make high water contents a characteristic feature of back-arc basins. Any model for the origin of such basins must take into account the notably higher water contents of these basalts compared to typical mid-ocean-ridge basalt. On the other hand, it is important to note the gross chemical and petrographic similarity of back-arc-basin basalts to typical abyssal tholeiites (e.g., Hawkins, 1977; Gill, 1976; Hawkesworth et al., 1977). In some cases, however, back-arc-basin basalts tend to be somewhat more enriched in large-ion lithophile elements and to have higher $\text{Sr}^{87}/\text{Sr}^{86}$ ratios than typical abyssal tholeiite (e.g., Tarney et al., 1977; Hart et al., 1972), and they may be transitional between ocean-floor and island-arc tholeiites (e.g., Gill, 1976).

The source of the volatiles in the Shikoku, Mariana, or Lau Basins is likely not the underlying mantle. First, each of these basins appears to have formed by rifting of a pre-existing island arc already resting on oceanic crust, without the complication of the involvement of a continental margin. The underlying mantle must have been involved previously in at least one, and possibly two, prior melting events: the generation of the abyssal oceanic crust on which the pre-existing island arc was built, and the formation of the island-arc magmas themselves. During melting, water is very strongly fractionated into the melt (e.g., Mysen, 1977a), and the removal of any melt must leave the residual mantle strongly de-

pleted in water. Second, the concentration of volatiles in the marginal-basin basalts, being much higher than that of typical abyssal tholeiites, requires a special source of volatiles; thus, it is unlikely that the old abyssal mantle beneath a back-arc basin alone could be the source of new water-rich magma. The only logical source for the water, then, appears to be the subduction zones underlying the basins (Dick et al., 1978; Saunders and Tarney, 1979). This water could be carried into the mantle either in high-pressure hydrous phases, such as phlogopite, or in hydrous melt formed during or after breakdown of the hydrous minerals and trapped interstitially in the slab. At any rate, the required depth of transport is initially no deeper than that to form the arc volcanic rocks themselves, which preceded basin formation immediately before rifting.

The effect of release of water from the descending slab would be to induce melting in the overlying, hotter mantle (e.g., McBirney, 1965; Wyllie, 1971). This may in turn trigger upward mantle diapirism driven by the resulting density contrast between partially molten and surrounding anhydrous mantle (Wyllie, 1971). In fact, the density of the solid residue from melting may have a 2 to 10 per cent lower density than the original peridotite (O'Hara, 1975), which in addition to the buoyant melt fraction would further drive mantle diapirism. Melting of the mantle due to the addition of water would proceed in the divariant field of hydrous melt plus crystals, to a point where equilibrium was reached somewhere between the anhydrous and water-saturated solidi of the peridotite. As it ascended, driven by the density contrast, the peridotite would continue to melt because of adiabatic decompression in the divariant melting field (Figure 2), until the adiabatic curve intersects the water-saturated solidus (e.g., Rumble, 1976). According to the large depression of the water-saturated solidus of various peridotite nodules (e.g., Boettcher et al., 1975), this would not occur until relatively low pressures were reached.

This scheme has been used previously to explain the generation of basalts beneath island arcs (e.g., Wyllie, 1971); given the hydrous nature of back-arc-basin basalts, it appears to be applicable to the formation of back-arc-basin basalts, and it may play a critical role — in addition to mantle counterflow above the descending slab — in inducing convection and back-arc-basin formation in an arc terrane. Inasmuch as this same process may play a role in island-arc magmatism, there may be a continuous gradation from early arc formation to rifting of the arc and basin formation, which may account for the transitional nature of some back-arc-basin basalts (e.g., Gill, 1976).

The effect on the composition of the basalts may be very small; this process is seen as more of a triggering mechanism than as a major contributor to the melt — most of which would be produced by the resulting adiabatic decompression. It is possible, however, that the slight differences between back-arc-basin basalts and typical MORB — notably, slightly higher Sr^{87}/Sr^{86} ratios — may reflect an isotopic contribution, in addition to water, to the melt from the subduction zone. Even if

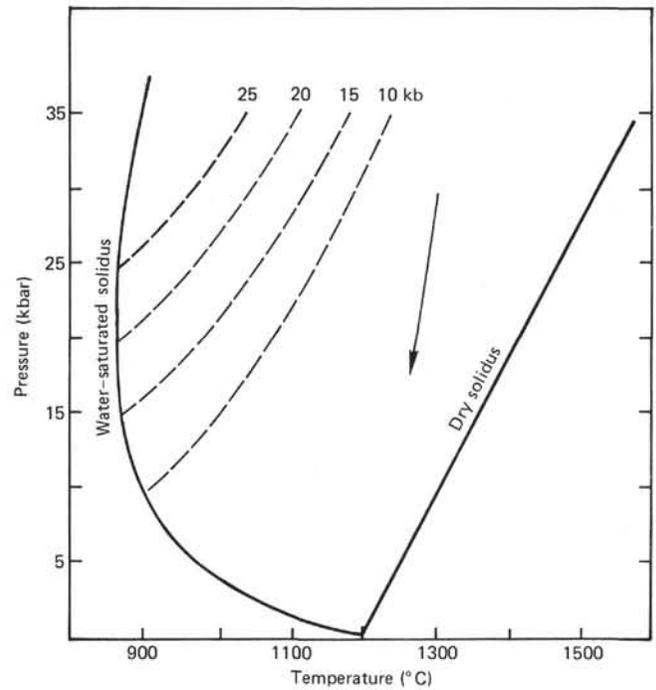


Figure 2. Water-saturated and anhydrous solidi for peridotite (modified after Mysen and Boettcher, 1975). Dashed lines indicate the slope of the water-undersaturated solidi in the divariant melting field of peridotite- H_2O . Arrow shows a hypothetical P-T path for a rising mantle diapir containing trapped hydrous melt. Because the water-undersaturated solidi all have a positive slope, such an ascending mantle diapir would melt continuously, the water content of the melt decreasing as the proportion of melt increased, until the water-saturated solidus was reached.

the major carrier of water from the subduction zone into the mantle is a silicate melt, such melts at high pressures can dissolve very large quantities of water. For example, a diopside melt can dissolve close to 30 weight per cent H_2O at 30 kb, and an albite melt close to 90 weight per cent at 20 kb (Mysen, 1977a). If the source of the water (or hydrous melt) were hydrated abyssal basalt or peridotite in the descending slab, the net effect on the composition of the back-arc-basin basalt may be negligible.

It appears reasonable that the topographic anomaly across ocean ridges and the increasing depth of oceanic crust with age are basically the results of the thermal anomaly created by mantle upwelling beneath mid-ocean ridges (e.g., Sclater et al., 1971). It is therefore reasonable that the topographic anomaly created by inducing a secondary convection cell in the old, relatively cool mantle above a subduction zone should be smaller — and therefore produce a deeper basin — than that created by deep mantle convection beneath an ocean ridge.

It is also to be expected that the initial heat flow at a back-arc-basin spreading center will be the same as at a mid-ocean ridge, because the temperature of upwelling

mantle is in effect buffered by the presence of rock and melt together. Until the entire solid residue is eliminated, the temperature is constrained to that of the liquidus of the basaltic melt in equilibrium with the rising mantle. As low pressures are reached, this temperature becomes crudely similar for both anhydrous and hydrous melts. So while the temperature of the mantle at the depth at which convection is initiated in a back-arc basin may be lower than below a mid-ocean ridge, the final temperature immediately below the ridge is expected to be roughly the same.

Thus, the same initial heat flow (driven by the temperature gradient) can be expected in both areas. It might be expected, on the other hand, that the heat flow might decay somewhat more rapidly in a marginal basin than at a mid-ocean ridge, because the ratio of melt to rock — and therefore the heat content of the underlying mantle — would be lower.

SPECULATION

If the preceding arguments hold, then one might expect that as a marginal basin grew and the depth to the subduction zone from the spreading center increased, assuming symmetric spreading, the character of the basin and the chemistry of its basalts would evolve toward those of a typical ocean basin. If water from the subduction zone is critical not only in inducing convection, but also in maintaining it, progressive dehydration of the slab with depth might lead to the death of the cell and the formation of a new cell closer to the trench and arc. In fact, this may be what is occurring today in the formation of the trough between the Izu-Bonin Arc and the Iwo Jima Ridge, in front of the apparently extinct Shikoku Basin spreading center. On the other hand, progressive dehydration of the slab (therefore less water available to drive convection at depth) may explain strongly asymmetric spreading in a marginal basin.

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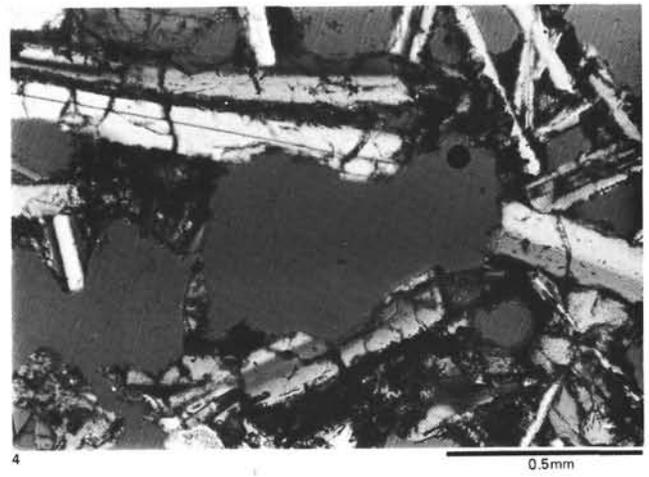
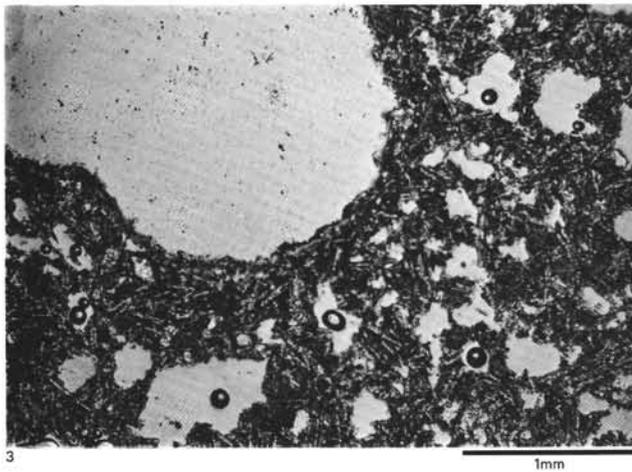
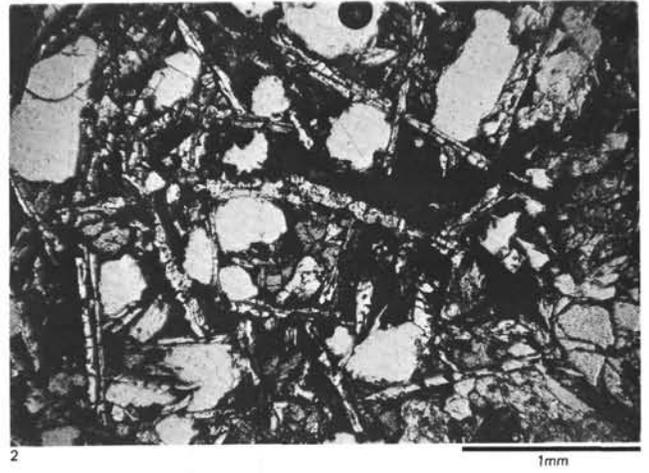
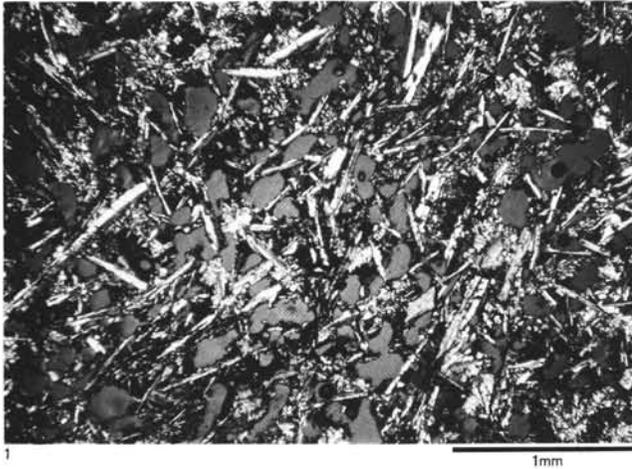
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PLATE 1



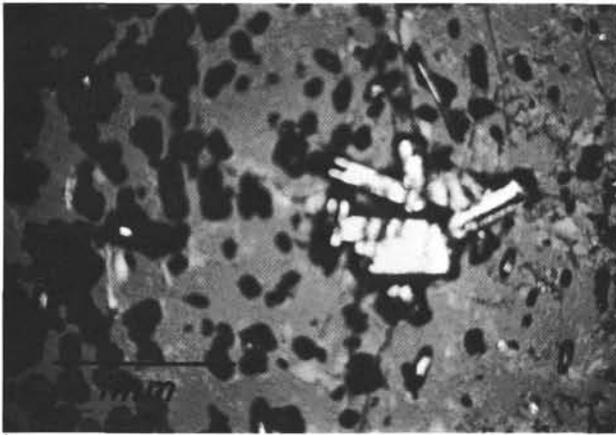
- Figure 1 Vesicular pillow basalt, Hole 442B, unit 3, Sample 18-1, 8-10 cm.
- Figure 2 Vesicular diabase with medium-grained plagioclase and pyroxene in an intersertal groundmass from a sill, Hole 442A, Sample 32-2, 62-64 cm.
- Figure 3 Vesicular pillow basalt with two generations of vesicles: one large population of round vesicles 1-3 mm in diameter, and a second generation of small (0.05-0.5 mm), irregularly shaped vesicles. Unit 2, Hole 442B, Sample 16-1, 34-37 cm.
- Figure 4 Vesicular diabase from a sill with plagioclase growing around and embayed by early-formed vesicles. Hole 442A, Sample 33-1, 8-10 cm.

PLATE 2

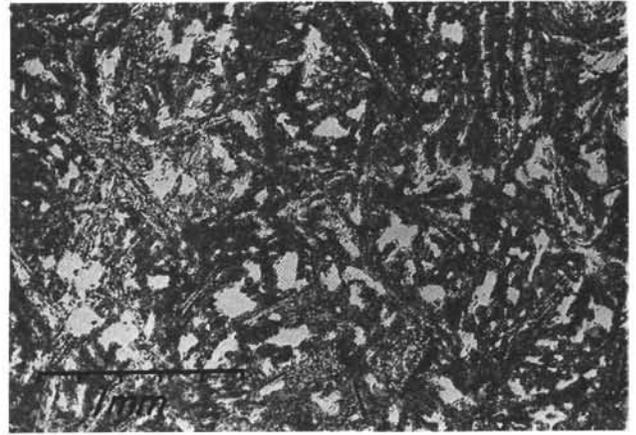


Top of a pillow basalt in Hole 442B, showing absence of vesicles in glassy chill zone, a zone of large pipe vesicles below the chill zone, and a generation of relatively large (1-2 mm), round vesicles. The majority of the vesicles in these basalts are much smaller, occupying the interstices of the groundmass plagioclase, as can be seen in Plate 1, Figure 1 (too small to be seen clearly in this photograph).

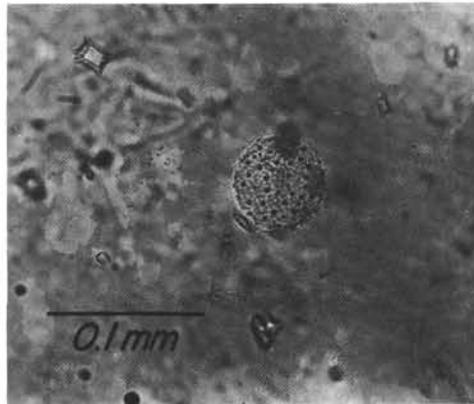
PLATE 3



1



2



3

- Figure 1 Glassy chill zone, Hole 442B pillow basalt, Sample 11-3, 6-10 cm. No visible vesicles from edge of pillow to beginning of the variolitic zone.
- Figure 2 Vesicular pillow basalt from the variolitic zone near the pillow margin. Note the sheaf-like aggregates of clinopyroxene and plagioclase and the numerous very small vesicles.
- Figure 3 Decorated vesicle in the glassy chilled margin of a Hole 442b (unit 3) pillow basalt, Sample 20-1, 57-61 cm. Evenly spaced blebs are probably sulfides condensed on the vesicle walls from the trapped gas during cooling.