29. AUTOCLASTIC SUBMARINE BRECCIAS IN HOLE 410, LEG 49, AND OTHER DSDP SITES

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INTRODUCTION

Deep-sea drilling and dredging have shown that the oceanic crust consists predominantly of basaltic lava flows. The frequent occurrence of glassy selvages, observed in some cores — but absent in others — shows that at least two volcanological types are common: pillow lava sequences and more homogeneous lava flows.

If the basaltic crust consisted of a continuous sequence of homogeneous lava flows or pillow, then relatively constant physical properties would be encountered during drilling. Results of DSDP cruises show that this is generally not so, and that although diagnostic measurements are lacking, considerable variations occur in the basaltic sequences; easily drilled sections alternate with hard rocks that drilled slowly. On Leg 49, we could in several cases correlate slow drilling with compact flows and fast drilling with either interlayered sediments or volcaniclastic products (hyaloclastites or breccias). (See site summary chapters, this volume.)

The aim of this paper is to emphasize the possible importance of these volcaniclastic layers in the oceanic crust. This has consequences for volcanic processes operating in submarine environments, geophysical interpretations of the oceanic crust (in terms of density, velocity), and geological processes (circulation of fluids, alteration, etc).

Such layers are particularly well developed in Hole 410, where the whole sequence consists of volcaniclastic products. Detailed observations of this core allow us to define the geological processes responsible for the formation of these breccias. Comparison with other occurrences, either outcropping in some areas (volcanic islands, Afar) or found by drilling in some atolls (e.g., Mururoa or Fangataufa in the Pacific), show that the occurrence of such products is not uncommon in the oceanic environment and may be rather frequent, not only in volcanic island substrata and in guyots or seamounts, but also in normal oceanic crust.

OCCURRENCE OF AUTOCLASTIC BRECCIAS AND AUTOCLASTITES ON PREVIOUS DSDP LEGS

Results in *Initial Reports* volumes for previous DSDP cruises show that breccias are not uncommon in the basaltic basement. Almost every cruise dealing with oceanic crust has encountered such formations, which may be named differently or interpreted in various ways, according to the authors: talus formation, tectonic breccia, hyaloclastite tuffs, or volcanic breccias.

The following occurrences have been checked from original color photographs or direct observations of the core:

Leg 6	Hole 54
Leg 7	Hole 66
Leg 11	Holes 103 and 117A
Leg 12	Hole 122
Leg 14	Holes 136 and 137
Leg 18	Hole 171
Leg 19	Holes 172 and 173
Leg 20	
Leg 25	Holes 246 and 248
Leg 26	Holes 253, 254, and 257
Leg 28	Hole 274
Leg 29	Holes 280A and 282

Of these, some are definitely not breccias of direct volcanic origin, but are either reworked basalts or basaltic hyaloclastites or breccias, or glassy fragments produced by exfoliation of pillow rims. The core sections that are breccias or hyaloclastites of direct volcanic origin are listed in Table 1.

This table indicates that a consequent proportion of the basaltic crust is made up of volcanic breccia. Detailed study of the Hole 410 breccia and comparison with other occurrences allow us to define the structure and origin of these rocks.

DESCRIPTION OF BRECCIAS AT HOLE 410 (FIGURE 1)

Except for two small segments of compact basalts recovered from Cores 39 and 41, the entire basement section recovered at Site 410 is composed of breccias.

a) The upper part of the section (Sample 37-1, 0 cm to Sample 38-1, 30 cm) was originally called "limestone-basalt breccia" (see Site summary chapter, 410A). It consists of fragments of basalt (4 to 10 cm in diameter) frequently rimmed with volcanic glass. Fragments are angular when microcrystalline, and tend to become more rounded when glassy rims occur. Smaller fragments (0.1 to 2 cm) of glass are also present; they are frequently altered to palagonite. Volcanic fragments are cemented by a matrix of carbonates and zeolites.

b) A short interval in Section 38-1 (30 to 65 cm) is composed exclusively of fine, deformed glassy basaltic fragments cemented by a limestone matrix.

c) From Sample 39-1, 65 cm to Sample 38-2, 65 cm, the breccia consists of angular fragments, 0.1 to 10 cm in dimension. These fragments are cemented by a limestone matrix; only a few glassy shards were observed. This interval was originally considered a cold talus pile, although magnetic data show consistent values indicating little displacement between blocks since the Curie temperature was reached.

d) In Core 39, the entire Sections 1 and 2 and Section 3 down to 47 cm consist of a breccia where basaltic fragments vary in size from 20 cm to some few millimeters. Small

TABLE 1
Occurrence of Autoclastic Breccias and Hyaloclastites for DSDP Cruises Covered in Published Initial Reports

Leg	Site	Sample (Interval in cm)
6	54	8-1, 0-95
11	105	19-1, 0-95
11	105	19-2, 0-150
11	105	19-3, 0-150
11	105	19-4, 0-150
11	117A	11-1, 80-125
14	137	17-1, 20-150
17	171	27-3, 100-150
17	171	27-4, 0-150
17	171	28-1, 50-150
17	171	28-2, 1-50
25	246	10-2, 70-150
25	248	15-1, 0-150
25	248	17-2, 0-150
25	248	17-2B, 25-90
26	253	52-4, 0-150
26	257	13-1, 90-130
26	257	13-4, 75-150
26	257	12-3, 0-150
29	280A	23-3, 0-150
29	282	18-1, 50-150
29	282	18-2, 0-150
29	282	18-3, 0-150
29	282	19-1, 100-150
29	282	20-1, 80-150
29	282	20-2, 0-150
29	282	20-3, 0-150
31	290	8-1, 59-150
31	290	8-2, 0-150
31	290	8-3, 0-150
31	290	8-4, 0-150
31	290	8-5, 0-150
31	293	18-1, 80-140
	293	19-1, 100-150
	293	20-1, 0-150
	293	21-1, 0-90
	293	21-2, 0-150

fragments (1 to 5 mm) are composed of glassy shards, whereas larger fragments consist of vesicular fine-grained basalt (Figure 2). The very large pieces are vesicular basalt with glassy margins (Figure 3). All intermediates occur between microcrystalline vesicular basalt, constituting the largest pieces, and glassy shards, constituting the smallest pieces. Progressive separation of fragments from major pieces occurs either for glassy shards departing from glassy margins or for angular fragments departing from already microcrystalline but still deformable basalt (Figure 4). Evidence indicates that vesiculation was partly contemporaneous with brecciation; some small fragments (2 to 10 mm) are highly vesicular and constitute basaltic pumiceous fragments with irregular contours, detached while expanding and fracturing from major basalt pieces (Figure 5).

e) In the lower part of Section 3, in Section 4, and in the upper part of Section 5 (interval 0-60 cm) in Core 39, the breccia is composed of angular basalt fragments. The lava is microcrystalline and slightly vesicular, and the texture is relatively coarse grained if compared with (d) in Figure 6. No glassy margin or shard is evident, and the texture of the lava is rather constant, regardless of the dimensions of the blocks (Figure 7). Only a limited amount of displacement between fragments occurred in this sequence (e), and observations (Figure 8) indicate that fracture was nearly an *in-situ* phenomenon.

In fact, no clear break occurs between (d) and (e), and these correspond to a progressive sequence showing various steps in the brecciation.

f) A petrographic break occurs in the lower part of Section 5, Core 39, marked by a glassy selvage, and another breccia unit occurs in the interval between Samples 39-5, 60 cm and 39-7, 35 cm. It consists of a relatively vesicular (vesicles up to 1 cm in diameter) basaltic breccia composed of angular microcrystalline basalt fragments, ranging in size from a few millimeters to 20 cm. Glassy shards or chilled margins are not present, except in the two pieces at the extremes of the sequence. All intermediates occur between an only slightly fractured lava flow, with almost no displacement after fracturing (Figures 9A and 9B), and more disturbed areas where fragments were subjected to some translation and rotation (Figures 10A and 10B). Textural evidence indicates (Figure 9A) that fragmentation was contemporaneous with vesicle segregation and deformation during flowage. The process occurring in this sequence (f) is very similar to the one observed in (e). However, no progressive transition is apparent here as in (d) to (e) toward fragmented glassy margins: the unit is limited by a single glassy selvage without development of glassy shards.

g) A single piece (#5) (at the bottom of Section 39-7) of typical hyaloclastites was cored (Figure 11). It probably corresponds to the only recovered piece of a thicker unit made of glassy and vesicular fragments of basalts, ranging in size from 0.1 mm to 10 mm and cemented by a limestone matrix. It may be the result of the eruption of this clastic product from a nearby vent.

h) In Core 40 (one section recovered) and in the upper part of Core 41 (Section 1, interval 0-40 cm), another type of breccia occurs. Although the rocks are more altered, a progressive sequence is present: fragmented glassy margin of small pillows in the upper part (Sample 40-1, 0-50 cm, Figure 12), highly vesicular microcrystalline basalt fragments without glassy shards in the intermediate part (Figure 13), and fragmented pillow margins with glassy shards in the lower part (Sample 41-1, 20-40 cm). This sequence thus appears to be a rather symmetrical brecciated flow unit.

i) The lower part of the sequence recovered at Site 410 (Sample 41-1, 40 cm to Sample 42-2, 85 cm) is made up of a typical pillow sequence, with glassy margins frequently associated with glassy shards and microcrystalline fragmented pillow interiors.

Proposed Interpretation of the Breccias

Observations at Site 410 are exceptionally good because of the excellent recovery (38%), compared with average DSDP oceanic crust drilling.

Other continuous coring in volcanic breccias has been carried out in several oceanic islands or seamounts. Comparison with cores from Fangataufa and Mururoa, where several thousands of meters of cores with breccias

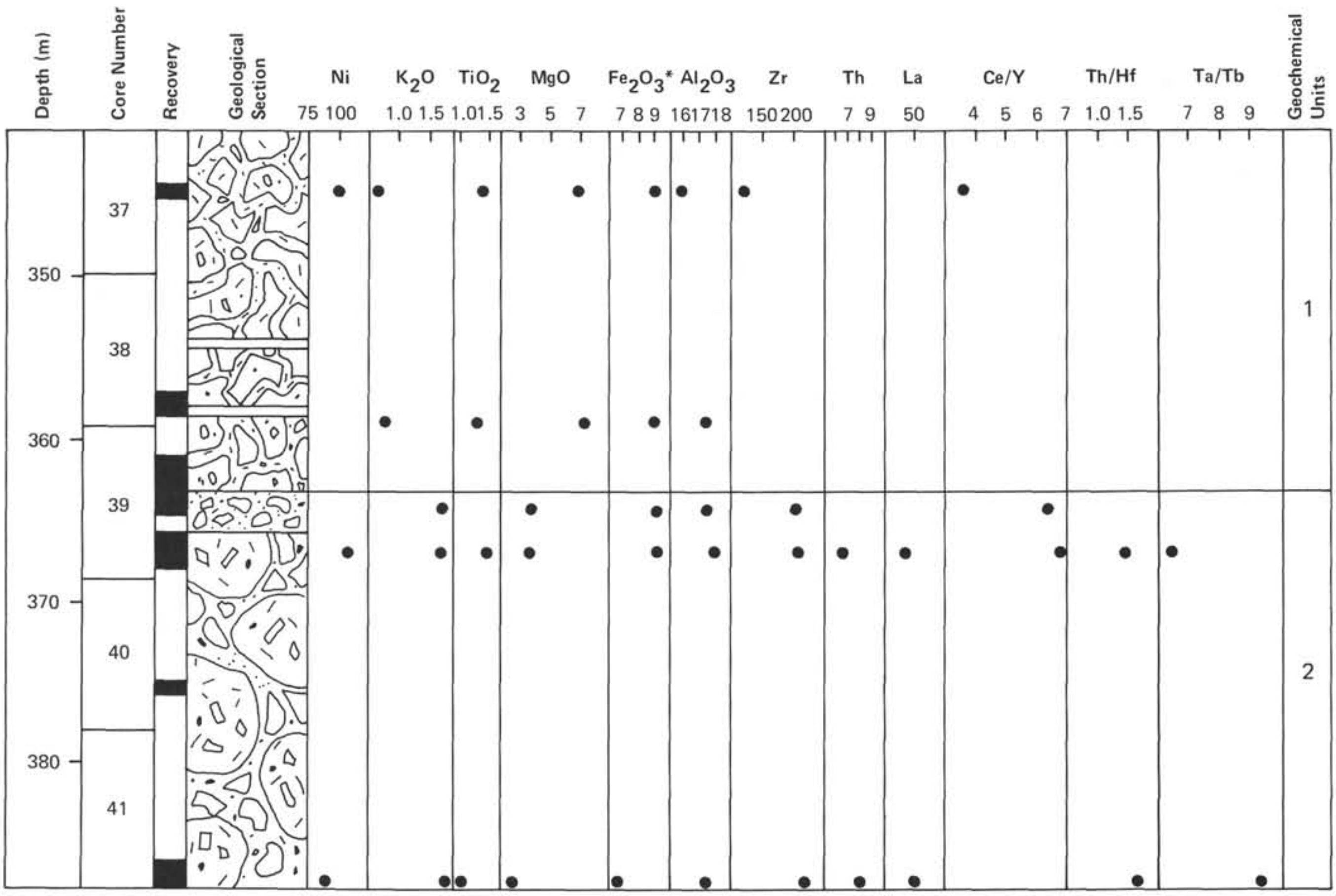

Figure 1. *Detailed lithostratigraphic section of Hole 410. Source of data: Wood et al. (this volume).*

have been made available to the authors, enables us to propose a classification of the submarine breccias and an explanation of their origin.

Submarine breccias can be classified as the intermediate terms between two end members:

1) Pahoehoe submarine flows with glassy margins, constituting piles of lava flows with no intercalated clastic products.

2) Hyaloclastite layers (submarine volcanic ash).

Six major types can be distinguished between these two extremes:

1) Pillow lavas breccias (PtB) (Figure 14)

These generally consist of non-vesicular or slightly vesicular rounded or elongated pieces of lava, the diameter of which varies from some decimeters to some meters.

Pillow lavas are formed, when the lava is erupted, flowing within conduits of cooled and solidified lavas to form elongated lobes or more round-shaped "pillows" (Rittman, 1958; Moore et al., 1971). These lobes extend by rupture and spreading of the thin weak quenched margins of lobe fronts.

A progressive increase in the degree of crystallization and size of minerals is evident from glassy rim (except for porphyritic rocks) to holocrystalline pillow center (Bryan, 1972). While the pillow interior is still deforming, the rigid glassy pillow margin separates from the pillow, constituting glassy clastic shards between the pillows.

These clastic products, called hyaloclastite by Rittman (1962), but which we prefer to call "pillow shards" to avoid confusion with hyaloclastite of direct clastic origin (i.e., fragmented at the vent), vary in proportion within a pillow unit from a few per cent of the total pillow unit to 30 or even 50 per cent (Figure 15).

Therefore, pillow units vary from "compact" to "rich in glassy shards." In extreme cases, it becomes difficult to distinguish in a drilled core — and particularly if the recovery is limited — a pillow unit rich in glassy shards from autoclastic breccias.

2) Brecciated microcrystalline flows (B.M.F.) (Figure 16A)

Brecciated microcrystalline flows are also derived by fragmentation of basaltic flows of the pahoehoe type, but instead of fragmentation occurring mainly by quenching and while the lava is fluid, as in pillow lavas, sets of cracks develop within an already microcrystalline and partly solidified flow interior. The result is a breccia, with angular fragments of centimeter dimension. Displacement between blocks is either limited, with calcite or zeolites filling millimeter cracks, or significant, with larger blocks included in a matrix of angular fragments of smaller

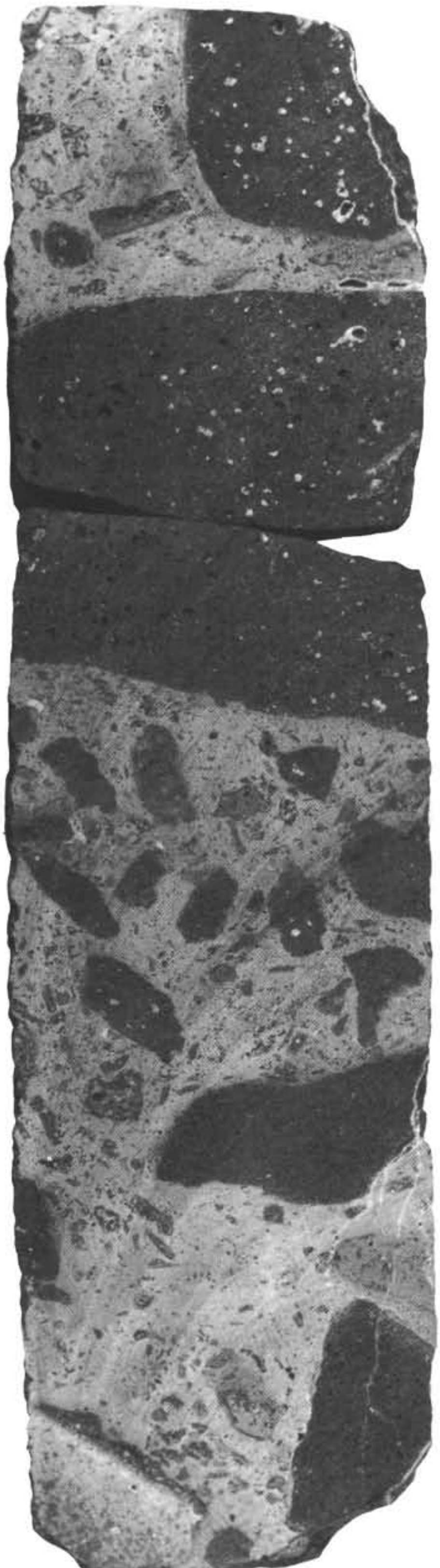

Figure 2. *Detailed photograph of a section of 410-39-2, piece 10, showing a piece of autoclastic breccia with microcrystalline angular fragments and smaller glassy fragments with a limestone matrix.*

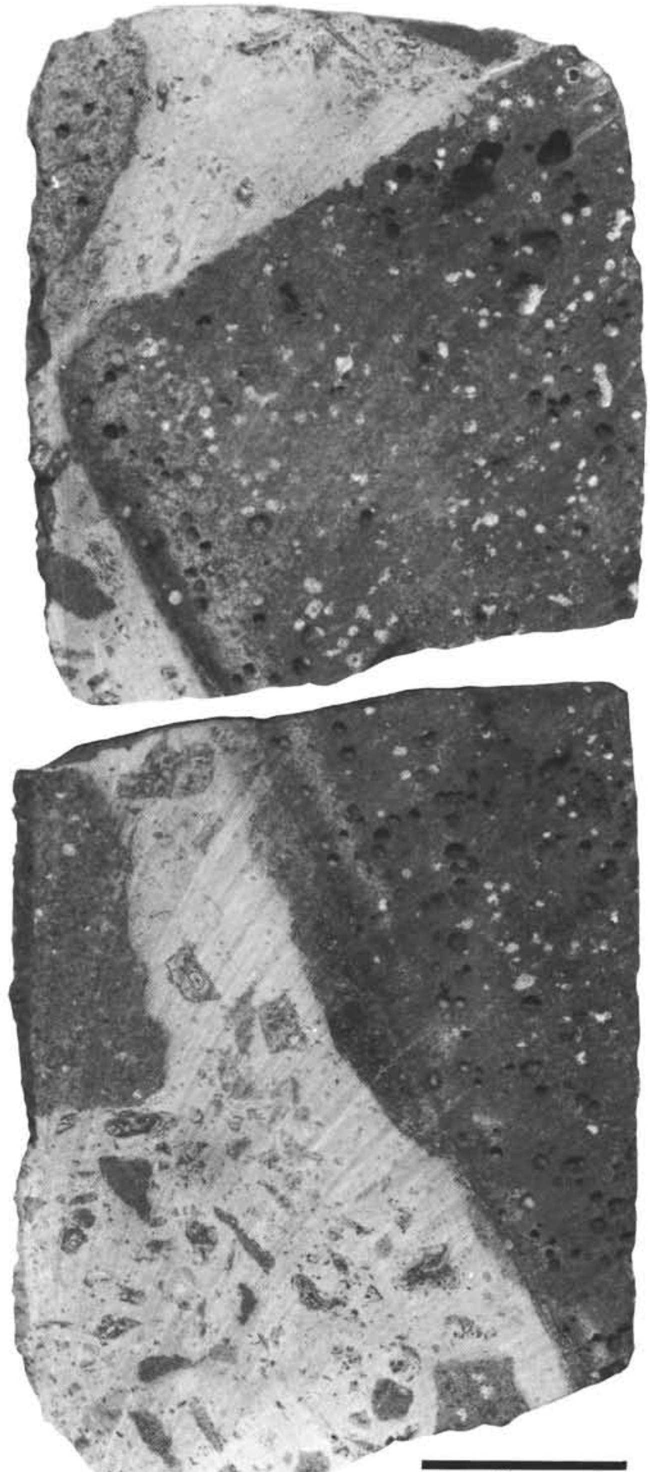

Figure 3. *Detailed photograph of a section of 410-39-2, piece 1, showing a breccia containing a large microcrystalline vesicular fragment with a glassy margin.*

dimension (Figure 10B). In some cases, blocks are undeformed, and it could be possible to reconstitute the puzzle by translation or rotation of fragments. In other cases, blocks have been subject to plastic deformation during and after fragmentation (Figure 17).

Figure 4. *Detailed photograph of a section of 410-39-2, piece 3, showing deformation of fragments during fragmentation.*

Figure 5. *Detailed photograph of a section of 410-39-2, piece 2, showing vesiculation of fragments during brecciation.*

Figure 6. *Detailed photograph of a section of 410-39-4, piece 3. Fragments are microcrystalline and angular.*

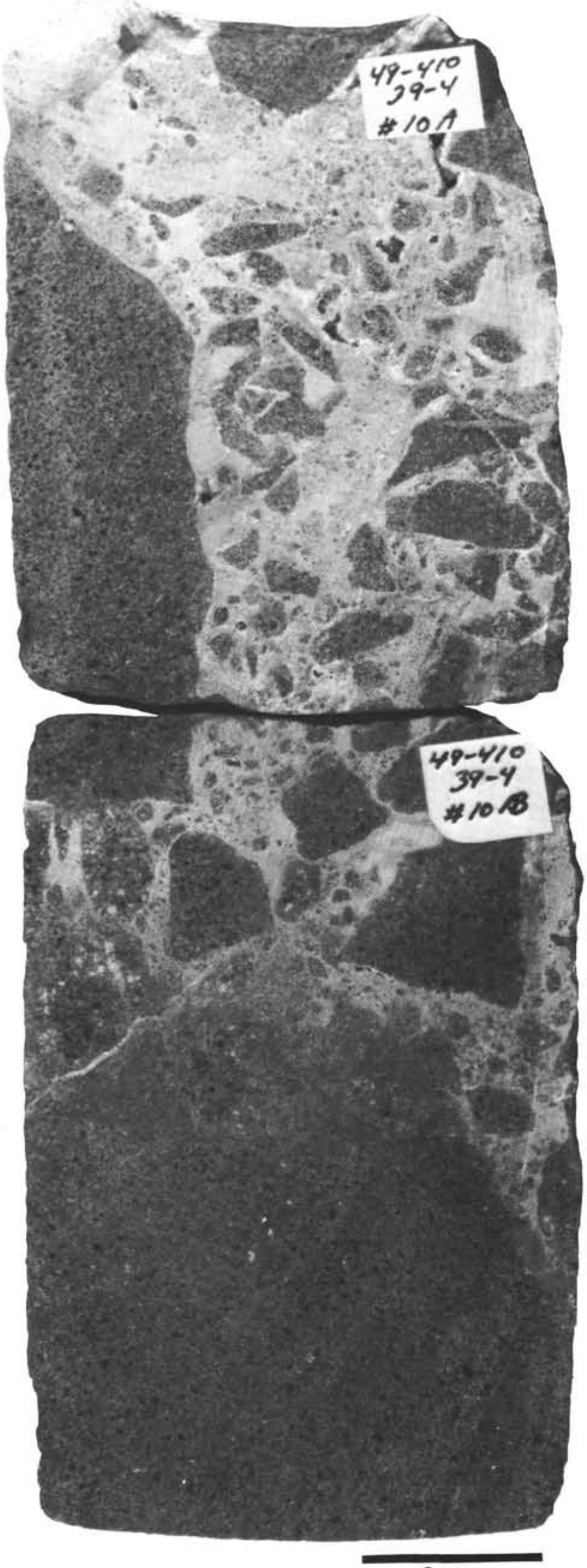

Figure 7. *Detailed photograph of a section of 410-39-4, piece 10.*

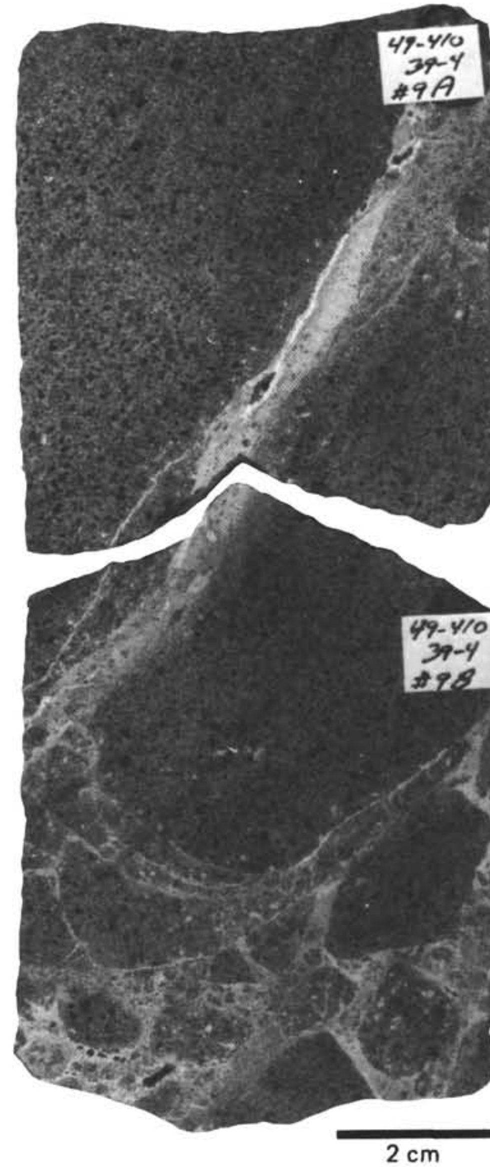

Figure 8. *Detailed photograph of a section of 410-39-4, piece 9.*

3) Autoclastic flow unit (A.F.U.) (Figure 16B)

As in subaerial volcanic activity, subaqueous flows are not always of the pahoehoe type: flows analogous to scoriaceous lavas of Aa type apparently also occur (Moore et al., 1973; Solomon, 1969). (Table 2 offers a tentative comparison of subaerial and subaqueous volcanic products.) Of course, since quenching phenomena are more important in subaqueous conditions, flow boundaries of submarine flows tend to differ from subaerial flows. Vesicular glassy fragments are developed at the flow margins. The result is a coating of glassy to microcrystalline fragments surrounding the top and bottom of flows. The thickness of the coating may be of the same dimension as the flow interior (0.5 to 3 m in most cases). Fragments are angular basalt ranging in size from a millimeter to a decimeter, and are generally cemented by later calcite or zeolite (Figure 18).

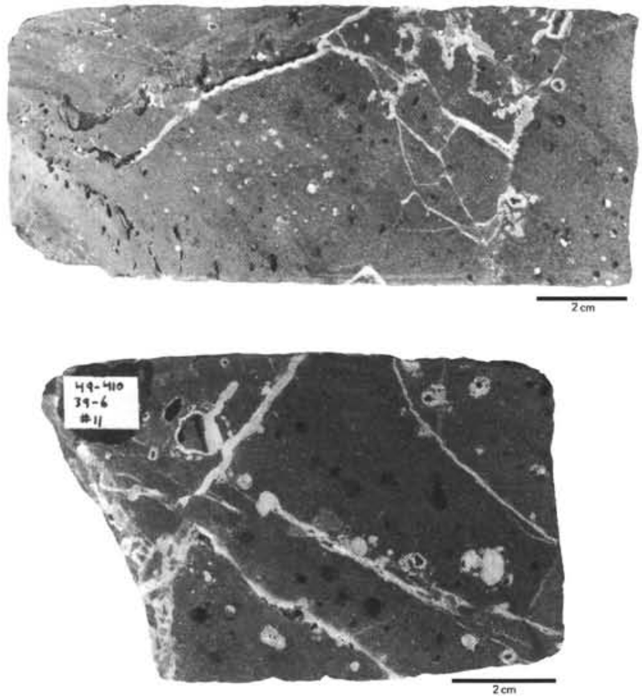

Figure 9. *Detailed photographs of sections of 410-39-5, piece 9, and Section 39-6, piece 11. Very slight displacements occur within this microcrystalline brecciated flow unit.*

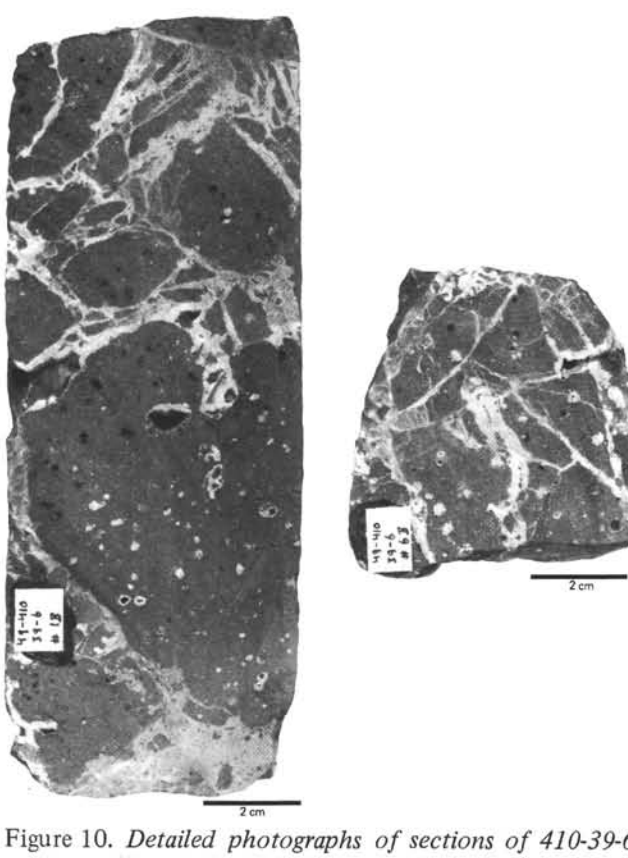

Figure 10. *Detailed photographs of sections of 410-39-6, pieces 1B and 6B. Vesicular microcrystalline brecciated flow.*

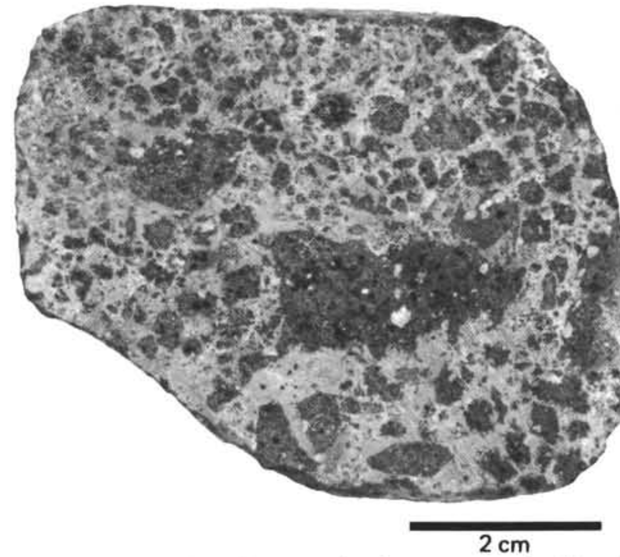

Figure 11. *Detailed photograph of a coarse-grained hyaloclastite. Section of piece 5, Section 7, Core 39, Hole 410.*

Figure 12. *Detailed photograph of a microbrecciated pillow fragment section of piece 3, Section 1, Core 40, Hole 410.*

4) Autoclastic breccia unit (A.B.U.) (Figure 16C)

Some submarine brecciated units seem to have been erupted as an already brecciated product during outpouring from the vent. Such formations are known from subaerial observations, but have not been described as in submarine environments (Darwin, 1892; Upton and Wadsworth, 1969, McKelvey and Fleet, 1974). These are the block-lavas, the breccias, and "nuée ardente" products, and are generally produced by gas-rich and often relatively viscous magmas. In submarine environments, volcanic units consist exclusively — or almost exclusively — of fragments of common petrographic nature, but vary in size from a millimeter to a decimeter, and in texture from glassy to microcrystalline. The size of fragments generally increases

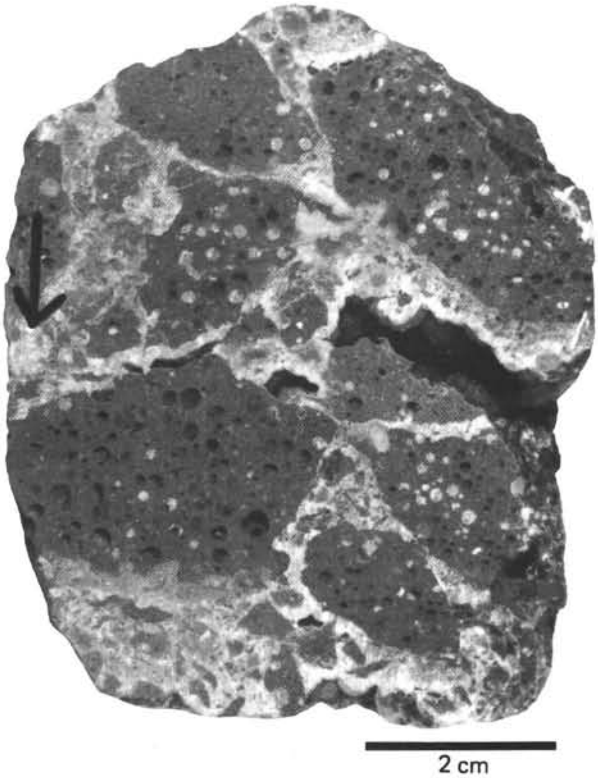

Figure 13. *Detailed photograph of a vesiculated microcrystalline breccia section of piece 2, Section 1, Core 41, Hole 410.*

Figure 14. *Deep-sea-bottom photograph of a pillow lava breccia (144°59'W, 56°07'S, depth 1416 m). Cruise Eltanin NSF 15.*

Figure 15. *Deep-sea-bottom photograph of autoclastic rims around pillow fragments (115°02'W, 56°02'S, depth 1720 m).*

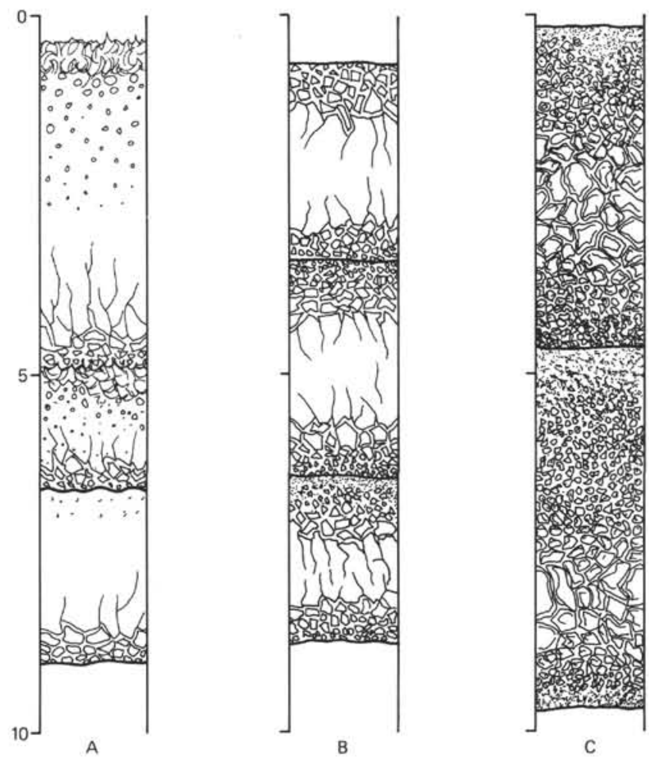

Figure 16. *Sections of various types of autoclastic flows from core drilled in atolls of Tuamotu Archipelago. Scale is in meters. A = Autobrecciated microcrystalline flow; B = Autobrecciated flow units; C = Autoclastic breccia units.*

toward the unit interior, where an unbrecciated part may be observed. Similarly, fragments tend to become more angular and more microcrystalline (Figure 19).

5) "Popcorn" Breccia (PCB)

In some cases the magma tends to expand, probably through hydration, in submarine conditions. The rock is glassy and frequently has spherulitic textures in these sections. Fragmentation is contemporaneous and both phenomena result from magma-water interaction. The rock is generally of low density, and water percentage varies from 15 to 20. In some cases, vesiculation was contemporaneous with hydration, and the resulting product is a pumiceous hydrated breccia. The physical character of these rocks allowed us to name them "popcorn breccia." As for autoclastic breccia units, this volcanological feature

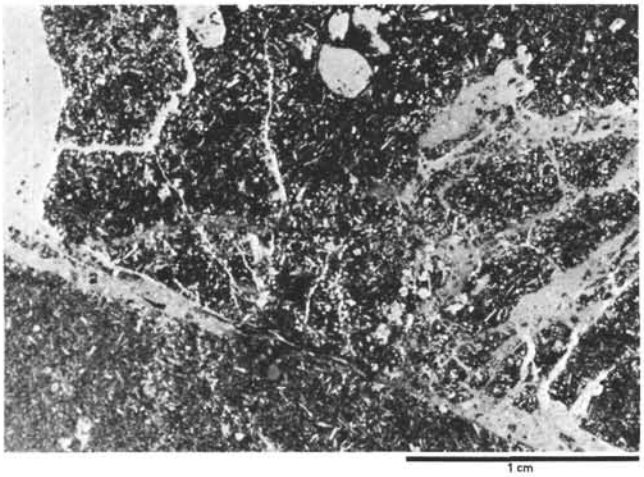

Figure 17. *Thin section of autoclastite flow unit (scale = 1 cm) (Sample 410-39-6, piece 1B).*

TABLE 2
Tentative Comparison of Subaerial and Subaqueous Volcanic Products

	Subaqueous	
Subaerial	Flat Surface	Significant Slope
Pahoehoe	"paving stone" lava or pahoehoe (figure 20)	Pillow lavas (when near to vent), brecciated microcrystalline flow (when far from vent) (Figure 21)
Aa Flow	Autoclastic flow unit	
Block-lavas and breccias	Autoclastic breccia unit, "popcorn" breccia	
Scoria	Coarse hyaloclastite	
Cinder	Fine hyaloclastite	

seems to be characteristic of magmas of relatively "evolved" nature, such as hawaiites or mugearites.

6) Hyaloclastites (HYL)

We propose to limit the term *hyaloclastites* to basaltic breccias resulting from fragmentation of the magma while it erupted from the vent in submarine conditions. The synchronism of formation of such products was described in detail by Tazieff (1972), Bonatti and Tazieff (1970), and Nayadu (1964). In this sense, these are the equivalent of basaltic cinder and scoria in subaerial volcanism. Such products are known from shallow subaqueous volcanic activity, and have been described in Afar, in Iceland, and in various volcanic islands (Cotton, 1969; Muecke et al., 1974; Honnorez, 1963; Tazieff, 1972; Barberi and Varet, 1970). These products are characterized by low seismic velocities which range from 4000 to 4500 cm/s, and have been recognized in many Pacific atolls under coral layers (Dobrin and Perkins, 1959; Raitt, 1957; Hochstein, 1967; Shor, 1968).

ORIGIN OF BRECCIAS OF HOLE 410 AND OTHER DSDP HOLES

Part a: Autoclastic breccia unit, with no recovered massive interior. It probably resulted from near-to-vent fragmentation and a flow relatively rich in gas. Degassing, fragmentation, and quenching were subcontemporaneous phenomena.

Figure 18. *Photograph of a section through a core of autoclastite flow unit. (Tuamoto Archipelago).*

Part b: Coarse hyaloclastite produced by explosive eruptions of magma with sedimentation on the sea floor after eruption.

Part c: Interpreted as a cold talus pile, but probably composed of blocks coming from an autoclastic flow unit.

Parts d and e: Typical section of an autoclastic flow unit, with the highly fragmented upper boundary (d) and the coarser and more compact flow interior (e).

Part f: Brecciated microcrystalline flow, probably resulting from the quiet eruption of a thick flow on a relatively flat surface. Fragmentation occurred while the flow was moving and the lava already partly crystalline but still in motion.

Part g: Coarse hyaloclastite. The process is similar to (b), although both units are clearly distinct.

REVISION OF THE NATURE AND ORIGIN OF SOME VOLCANIC BRECCIAS FROM OTHER DSDP SITES

Leg 6, Site 54, Core 8 Section 1 (1-95 cm)

A progressive transition is apparent in this core, from a compact lava (60-85 cm) toward an autoclastic breccia made of angular centimeter to decimeter fragments of microcrystalline basalt cemented by calcite (60-30 cm).

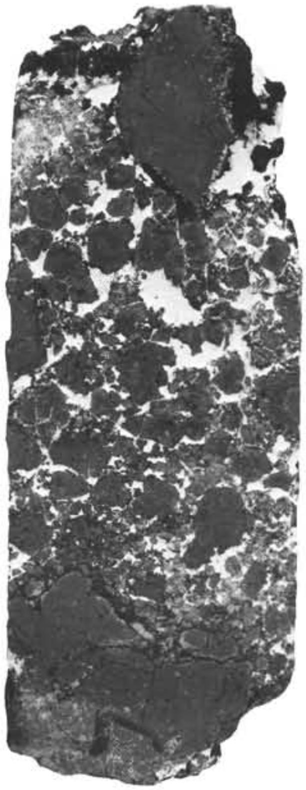

Figure 19. *Photograph of a section through a core of autochastite flow unit. (Tuamoto Archipelago).*

Figure 20. *Surface of pahoehoe flow. Galapagos (47°N-86° 09'W, depth 2500 m). Lonsdale,* Marine Geology.

Between 30 and 20 cm, the breccia is made up of centimeter fragments with a glassy margin, cemented by white calcite. This is the upper part of a typical autoclastic flow unit.

Leg 11, Site 105, Sections 1 to 4

Consolidated breccia, possibly reworked basaltic flows or breccias.

Leg 11, Hole 117A, Section 1 (80-125 cm)

Typical sequence of autoclastic flow unit; fragmentation occurs toward top and bottom of flow. Glassy fragments or microcrystalline fragments with glassy margins are more abundant toward the extremities (80-96 and 107-120 cm), and are cemented with calcite. Toward the center, the rock is compact or only affected by fractures, with slight displacement between blocks.

Figure 21. *Pillow lavas Galapagos (047°N–86°09'W, depth 2500 m) Lonsdale,* Marine Geology.

Leg 14, Site 137, Section 1 (20-150 cm)

Compact basaltic flow, fragmented in the upper part — only slight displacement occurred between fragments. Fragments are angular and microcrystalline, with no visible glassy margins. Cement is dark, and probably mainly smectite (130-140 cm). Interstices are filled with late calcite. This is a typical brecciated microcrystalline flow.

Leg 17, Site 171, Core 27, Secitons 1-3

Slightly brecciated microcrystalline flow. The flow is predominantly compact, and brecciated only in the 10 cm near the bottom, in contact with hyaloclastite (Section 3, 90-100 cm). The glassy part is limited to a few millimeters at the contact with hyaloclastites.

Leg 17, Site 171, Core 27, Section 3, 100 cm to Core 27, Section 2, 50 cm

Typical hyaloclastite sequence, with various types of textures.

Core 22, Section 3, 100-150 cm

Coarse hyaloclastite, with relatively large blocks of various shapes (2 to 5 cm diameter).

Core 27, Section 4, 0-70 cm

Hyaloclastite with vesicular glassy fragments and angular lava and limestone blocks (1 to 3 cm diameter) cemented by a pale yellow matrix and later calcite.

Core 28, Section 4, 70-150 cm

Hyaloclastite with abundant lava blocks. This may be an autoclastic breccia unit erupted on the slope of a submarine volcano.

Core 28, Section 1, 50-150 cm to Section 2, 0-50 cm

Fine hyaloclastite with millimeter to centimeter fragments, glassy as well as microcrystalline.

Leg 25, Site 246, Core 10, Section 2 (70-150 cm)

Fine stratified hyaloclastite.

Leg 25, Site 246, Core 11, Section 1 (78-98 cm)

Stratified hyaloclastite, coarser grained.

Leg 25, Site 253, Core 52, Section 4 (0-150 cm)

Fine, black hyaloclastites; fragments are millimeter size toward top and tend to become centimeter size toward the bottom.

Leg 26, Site 254: cf. Site 253

Leg 26, Site 257, Core 13, Section 1, 90 cm to Section 4, 150 cm

Section through a typical autoclastic flow unit. Top (Section 1, 90-130 cm) and bottom (Section 4, 75-150 cm) are made up of angular fragments filled by calcite, whereas the interior is compact. Fragments in the uppermost breccia are frequently glassy.

Leg 28, Site 274, Core 44, Section 2, and Core 45, Section 1

Autoclastic flow unit. Fragmentation progresses from top and bottom toward flow center. Fragments toward margins are more rounded, vesicular, and glassy, and tend to become microcrystalline and angular toward center. Fragments are altered and cemented by smectites and calcite.

Leg 31, Site 290, Core 8, Sections 1 to 5

Sequence of hyaloclastite becoming coarser toward bottom (Sections 4 and 5). Fragments are more angular when microcrystalline, and are more abundant toward the bottom, reaching 5 cm in diameter. The uppermost part of the section is fine-grained hyaloclastite (fragments less than 1 mm in diameter).

CONCLUDING REMARKS

Volcaniclastic products are abundant in the submarine environment. The sea floor is not made up exclusively of piles of compact lava flows and pillows, but also contains abundant clastic layers, produced either directly at the vent or during eruption or movement of the lava on the ocean floor.

Apart from hyaloclastites, already known from previous literature, this study emphasizes the importance of autoclastites, which have been classified into five types:

1) brecciated pillow lava
2) brecciated flow unit
3) autoclastic flow unit
4) autoclastic breccia unit
5) "popcorn" breccia.

Breccias described on previous cruises, as well as breccias from Hole 410, could be assigned to one of these five types. The phenomenon of vesiculation and brecciation is certainly related to depth of eruption (pressure), as well as to topography, as emphasized by various authors (Hawkins et al., 1971; Herzer, 1971). It is also related to the viscosity and gas content of the magma, both linked with the magma composition. More alkaline and differentiated magmas clearly tend to produce autoclastic breccias and hyaloclastites. Hence, the development of these volcanic products in guyots and central volcanoes is justified not only by topography and depth, but also by the petrologic differences between these magmas and "typical" mid-ocean ridge tholeiites.

It is certainly not coincidental, therefore, that the products from Hole 410 have these volcanological characteristics, since the magma types here are both more alkaline and more fractionated than at any other sites cored to date by DSDP in the North Atlantic (Day, Wood, et al., this volume).

Hole 410 shows that conditions appropriate to the development of submarine breccias and hyaloclastites may occur in the mid-ocean ridge environments. Other occurrences in DSDP sites show that such conditions are found elsewhere on normal sea floor, and that hyaloclastites and volcanic breccias constitute a significant part of the sea floor. Taking into account the low recovery of these products relative to compact basaltic flows, it is possible to guess that the sea floor may be composed of as much as 20 to 40 per cent of autoclastic breccias and hyaloclastites. Further statistical work on these products may allow us to define their importance and their relation to magma types and geological environments.

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