

10. PETROGRAPHY OF VOLCANIC ASHES IN DEEP-SEA CORES NEAR JAN-MAYEN ISLAND: SITES 338, 345-350 DSDP LEG 38

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INTRODUCTION

The purpose of this study is to determine the petrographic characteristics of volcanic ashes in deep-sea cores obtained from DSDP drill cores near Jan-Mayen Island. The ultimate objective is to work out, if possible, a more complete volcanic history of the island than is known from subaerial field studies of the island itself (Fitch, 1964).

Forty-six samples of volcanic ashes were collected for this study by the shipboard party of *Glomar Challenger* from seven of the Leg 38 drill sites. The locations of the sites with respect to Jan-Mayen are shown in Figure 1. The samples range in age from late Eocene to Pleistocene; the sampled intervals are shown in Figure 2.

METHODS AND TERMINOLOGY

All samples were studied optically in whole-rock smear slides with a Caedex mounting medium, and in X-ray diffraction patterns of whole-rock powders. Percentages of constituents were estimated from the smear slides and are approximate.

The problems inherent in identification and estimation of the amounts of constituents in volcanic ashes have been discussed by Donnelly (1975); however, the constituents of most samples in this study are remarkably fresh, so that alteration poses only minor problems.

Sampling was not comprehensive and coring was not continuous at all sites (Figure 2); thus a complete volcanic record cannot be established at this time for individual sites, and correlations among sites are virtually precluded. Future studies will include acquisition of material from other ash beds from these sites, as well as chemical characterization of glass and selected mineral phases with an electron microprobe.

The terminology and genetic interpretations in the following sections follow those given by Heiken (1975). Age assignments are taken from the Initial Core Descriptions compiled for Leg 38.

PETROGRAPHY

Nearly all samples consist of well-sorted, fine-grained, highly angular basaltic and felsitic glass and mineral fragments. They suggest an explosive hydrovolcanic origin and dispersal as wind-borne rather than pumice- or ice-rafted debris. The ashes and their altered products can be separated broadly into three types: basaltic ash, felsitic ash, and bimodal basaltic and felsitic ash.

The constituents in the two samples of middle Oligocene age from the outer Vøring Plateau (Site 338) and

in the three samples of Oligocene and late Eocene age from the Lofoten Basin (Site 345) are dissimilar to each other and to those from the other sites. The differences probably reflect different sources. The constituents of all samples are given in Table 1. Representative textures are shown in Plate 1.

Black Glass

Tachylyte (submicrocrystalline opaque black glass of basaltic composition) is ubiquitous in all basaltic and basaltic-felsitic ashes. The grains are blocky, equant to irregularly polygonal in shape, with rounded corners and hackly surfaces. In a few samples, the surfaces of tachylyte grains are liberally sprinkled with tiny (1-2 μm) pyrite rhombs. Rarely are microphenocrysts imbedded or attached to the grains. Grain sizes range from about 50 μm to 600 μm ; from 100 μm to 200 μm is average.

Brown Glass

Sideromelane (light- to dark-brown translucent volcanic glass of basaltic composition) is present in most basaltic and basaltic-felsitic ashes (Table 1). It has a refractive index greater than Caedex. Commonly the grains are blocky, subequant or irregular polygonal fragments with smooth conchoidal fracture surfaces; the glass is homogeneous; microlites are rare; and vesicularity ranges from low to moderate. All of these features are characteristic of hyaloclastic ashes of hydrovolcanic eruptions (Heiken, 1975). Round droplets, indicative of a subaerial magmatic origin, are present, sparingly, in some of the basaltic-felsitic ashes (348-6-4, 46 cm; 348-6-4, 75 cm; 348-8-1, 145 cm; 348-8-2, 30 cm; 348-9-4, 76 cm; 349-1-1, 63 cm; 349-2-4, 75 cm; 350-10-3, 12 cm; 350-10-3, 39 cm; 350-12-3, 25 cm), and exclusively in 349-2-5, 55 cm (Plate 1, Figure 5).

Sideromelane is strongly altered in samples of late Oligocene and older ages; it is partially palagonitized in 346-4-5, 128 cm and in 346-8-5, 38 cm.

Clear Glass

Clear isotropic glass has a refractive index less than Caedex, indicating a rhyolitic, or more broadly, felsitic composition. At sites on the Jan-Mayen Ridge and the Icelandic Plateau, it is present chiefly as water-clear, nonporphyritic, highly angular, irregularly shaped platelets ranging in size from about 50 μm to as much as 800 μm in maximum dimension. Typically less than half of the clear glass is pumiceous, with highly streaked bubbles. Black spherulites about 5 μm in diameter speckle the surfaces of blocky grains in 348-7-3, 37 cm. The glass in samples from the outer Vøring Plateau (Site 338) is quite fine grained (average 50 μm), and less

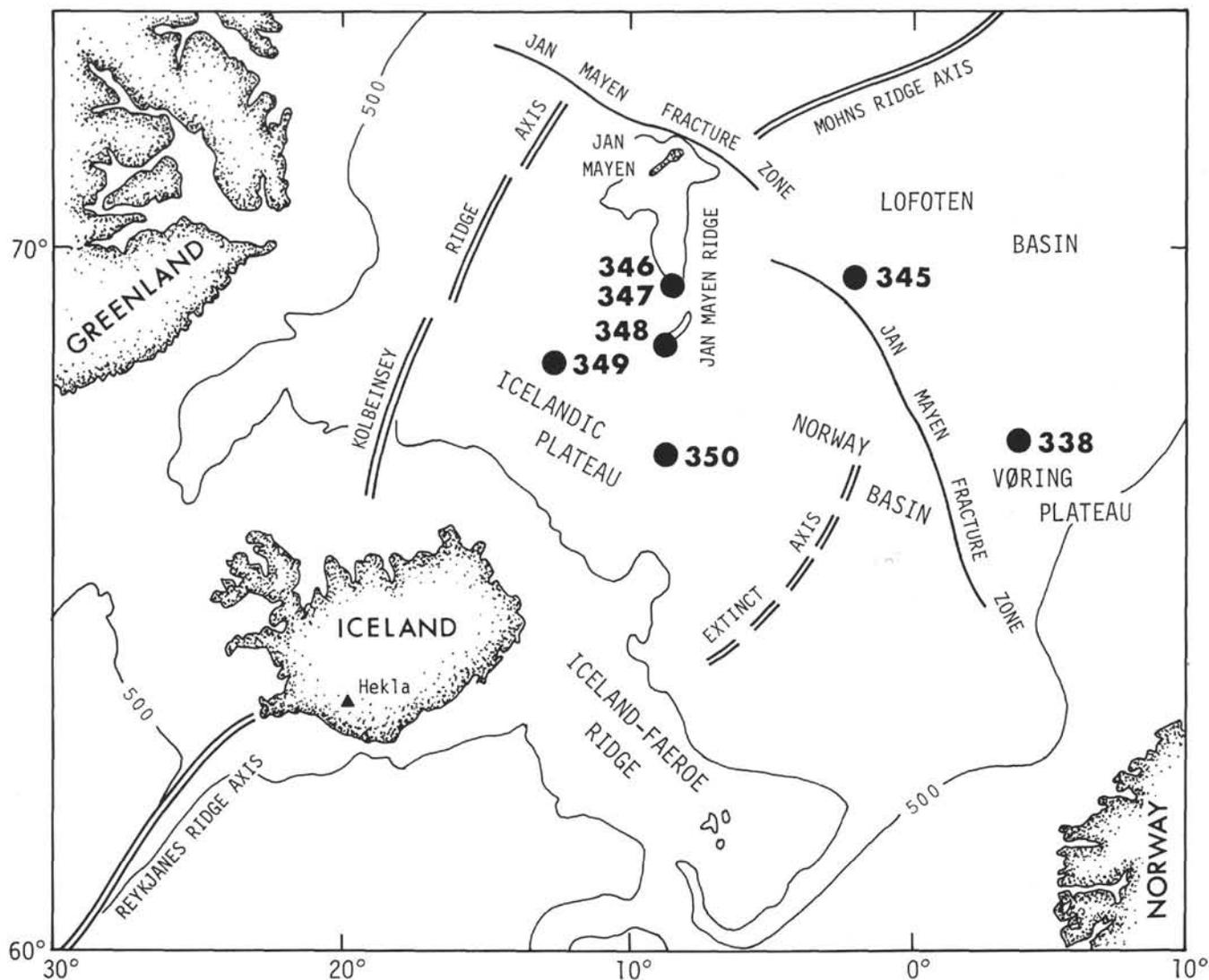


Figure 1. Index map showing locations of DSDP drill sites and principal tectonic elements of the Norwegian-Greenland Sea. Submarine contours are in fathoms. Adapted from Initial Core Descriptions for Leg 38.

than one-fourth of the grains are pumiceous (Plate 1, Figure 1).

Microcrystalline Glass

Clear glass with a pale brown turbidity in transmitted light and which is charged with tiny, lath-shaped microphenocrysts visible under crossed polarizers is abundantly present in basaltic-felsitic ashes containing otherwise undevitrified sideromelane, tachylite, and clear glass (Table 1). Its index is less than Caedex and is present in equant subrounded grains equivalent in size to that of the other glass constituents. The tinge of color suggests that it is intermediate in composition between the basaltic glasses and the more common clear, isotropic glass.

Plagioclase

Plagioclase crystal fragments and euhedral microphenocrysts comprise minor fractions (usually less than 1%) of all samples with two notable exceptions: 1) at Site 345, subhedral lath-shaped crystals up to 500 μm in length constitute as much as 30% of the ash sample (Plate 1, Figure 2), and 2) euhedral plagioclase phenocrysts up to 300 μm long constitute approximately 15%

of Sample 348-8-2, 3 cm, and 10% and 8%, respectively, of samples directly beneath. These plagioclase-rich samples are provisionally correlated with a unique plagioclase-rich lava on Jan-Mayen as will be described later. Plagioclase in basaltic ashes have broader twin lamellae and higher refractive indices (equal to or slightly less than Caedex) than those in felsitic and basaltic-felsitic ashes.

Clinopyroxene

Subhedral to anhedral crystal fragments of clinopyroxene constitute from a trace to as much as 2% of basaltic and basaltic-felsitic ashes from sites on the Jan-Mayen Ridge and Icelandic Plateau (Table 1). It is invariably pale green to pale brownish green, nonpleochroic, and has a refractive index much greater than Caedex. The grains are equant with conchoidal fracture surfaces, and are rarely larger than 300 μm in the longest dimension.

Orthopyroxene

A few rectangular prisms of orthopyroxene were identified in only two samples (348-6-5, 30 cm; 348-8-3, 131 cm). They are readily distinguished by the distinc-

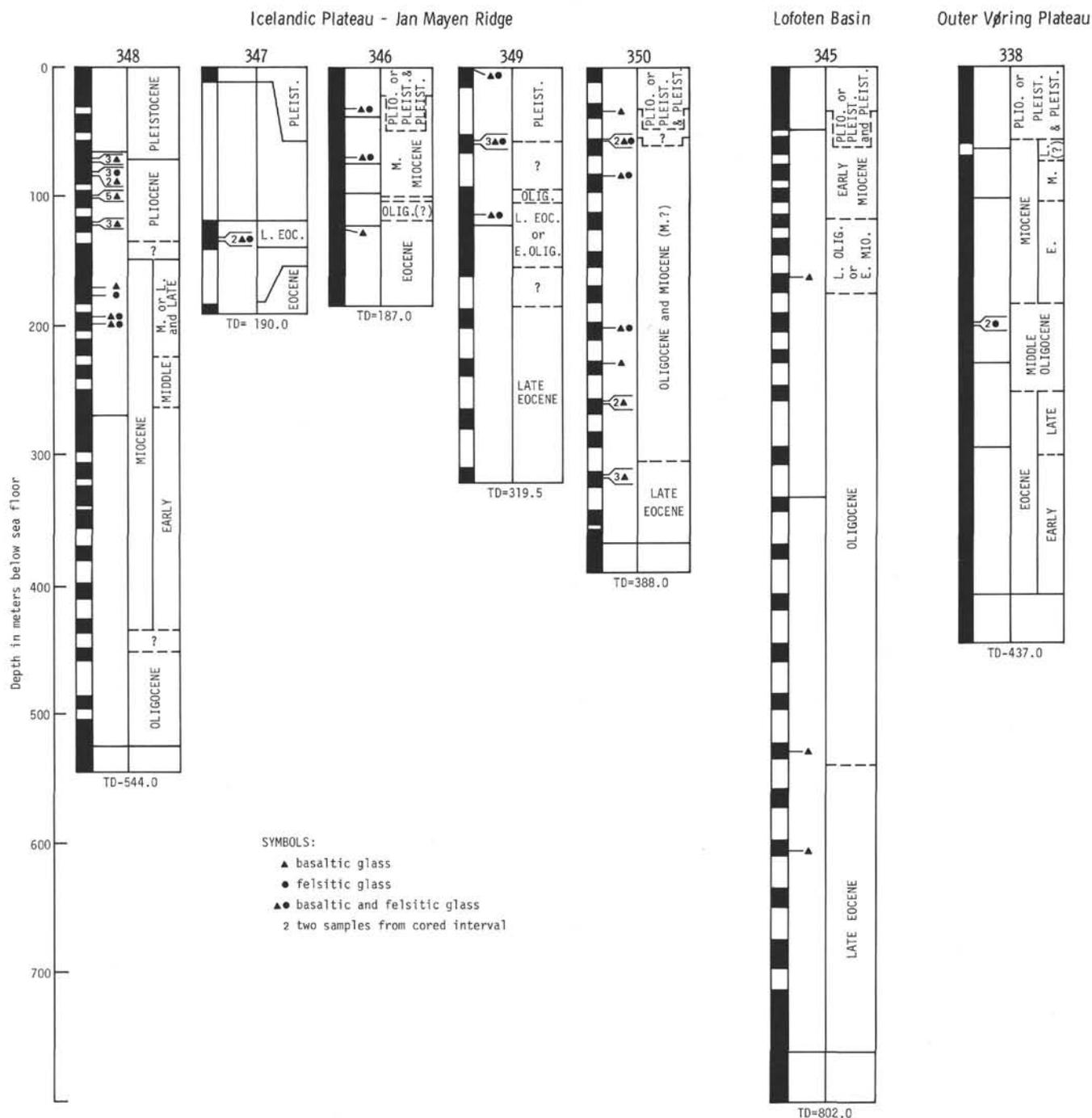


Figure 2. Diagrammatic columnar sections showing sampled intervals for this study, number of samples for given interval, and predominant lithologic type of ash. Adapted from Talwani et al. (1975).

tive pink-blue-green pleochroism and straight extinction. The prisms range in length from 100 μm to 200 μm .

Biotite

Biotite is present exclusively and abundantly only in samples from Cores 21 and 23 of Site 345 (Plate 1, Figure 2). Predominantly basal sections of the mineral were observed, owing to the smear method of slide preparation, but its presence is confirmed in X-ray powder diffraction patterns. It is distinguished in thin

section from coexisting tachylite by its subhedral crystal form, its faint translucence in transmitted light, and by its birefringence in grains that are not oriented perfectly normal to the microscope axis. Cleavage platelets are subequant, and are approximately from 150 μm to 200 μm across.

Hornblende

A few tiny (50 μm to 80 μm) crystal fragments tentatively identified as hornblende, are present in four ash samples (Table 1). They are lath-shaped with irregular

TABLE 1
 Constituents Distinguished in Volcanic Ash Samples from Deep-Sea Cores: Sites 338, 345-350, DSDP Leg 38

| Sample (Interval in cm) | Age | Tachylite (%) | Sideromelane (%) | Clear Glass (%) | Micro- crystalline Glass (%) | Plag (%) | Clpx (%) | Other |
|---|------------------------------|------------------|---------------------|-----------------------|---------------------------------------|-------------|-------------|----------------------------|
| Site 338: Outer Vøring Plateau | | | | | | | | |
| 20-3, 54 | M. Olig. | | | 85 | | 3 | | Py (12), green Hb |
| 20-3, 100 | M. Olig. | | | 85 | | 3 | | Py (12), green Hb |
| Site 345: Western Lofoten Basin | | | | | | | | |
| 11-1, 33 | L. Olig. or E. Mio. | 5 | 80A | | | 15 | | |
| 21-4, 77 | Oligocene | 25 | 10 | | 30 | 20 | | Dk brn Bi (15) |
| 23-6, 86 | L. Eocene | 25 | 5 | | 35 | 25 | | Dk brn Bi (10), Zr |
| Site 346: Northern Jan-Mayen Ridge | | | | | | | | |
| 4-5, 128 | M. Miocene (?) | 20 | 60A | 10 | | 10 | tr | Qtz (tr) |
| 8-5, 38 | M. Miocene | 30 | 13 | 50 | | 2 | | Py (5) |
| 14-4, 14 | Eocene(?) | 25 | 50A | | | 5 | | Qtz (20), Chlor |
| Site 347: Northern Jan-Mayen Ridge | | | | | | | | |
| 3-3, 100 | Eocene | 10 | 80A | | | 3 | | Qtz (7), Chlor, Microcline |
| 3-3, 148 | Eocene | 15 | 55A | | 12 | 3 | | Qtz (15), Chlor, green Hb |
| Site 349: Central Jan-Mayen Ridge | | | | | | | | |
| 1-1, 63 | Pleistocene | 15 | 10 | 75 | | tr | tr | Qtz (tr) |
| 2-3, 60 | Pleistocene | 5 | 5A | 25 | 60 | 3 | | Qtz (2) |
| 2-4, 75 | Pleistocene | 30 | 49A | 20 | | 1 | tr | Qtz (tr), grn Clay |
| 2-5, 55 | Pleistocene | 53 | 40A | 5 | | 2 | tr | Qtz (tr) |
| 5-3, 73 | E. Oligocene or L. Eocene | 30 | | 48 | | 7 | | Qtz (tr), Py (15) |
| Site 348: Icelandic Plateau | | | | | | | | |
| 6-4, 46 | Pleistocene | 30 | 15 | 55 | | tr | tr | Py |
| 6-4, 75 | Pleistocene | 40 | 25 | 35 | | tr | tr | Py |
| 6-5, 30 | Pliocene | | 90A | | | 7 | | Qtz (3), green Hb |
| 7-3, 37 | Pliocene | | 10A | 65 | 25 | tr | | |
| 7-4, 48 | Pliocene | | | 48 | 48 | 3 | | Py (1) |
| 7-4, 114 | Pliocene | | 2A | 45 | 50 | 3 | | |
| 7-5, 91 | Pliocene | 60 | 35 | | | 4 | 1 | |
| 7-5, 131 | Pliocene | 50 | 45 | | | 4 | 1 | |
| 8-1, 145 | Pliocene | 35 | 60A | | | 3 | 2 | |
| 8-2, 3 | Pliocene | 35 | 50A | | | 15 | tr | |
| 8-2, 30 | Pliocene | 50 | 40A | | | 10 | tr | |
| 8-2, 52 | Pliocene | 75 | 5 | | | 8 | 2 | Py (10) |
| 8-3, 114 | Pliocene | | | 92 | 5 | 3 | | |
| 8-3, 131 | Pliocene | 20 | 70A | 10 | | tr | tr | Orpyx |
| 9-4, 41 | Pliocene | 10 | 90A | | | tr | tr | |
| 9-4, 76 | Pliocene | 37 | 60A | 5 | | 2 | 1 | |
| 9-5, 129 | Pliocene | 10 | 28A | 60 | 20 | 1 | 1 | |
| 13-1, 105 | L. Miocene | 5 | 95A | | | tr | | |
| 13-3, 140 | L. Miocene | | | 80 | | | | Clay (20) |
| 14-3, 60 | L. or M. Miocene | 15 | 80A | 5 | | tr | | |
| 14-5, 110 | L. or M. Miocene | 65 | 15 | 10 | | 10 | | Clay, py |
| Site 350: Southern Jan-Mayen Ridge | | | | | | | | |
| 2-5, 10 | Plio. or Pleistocene | 35 | 15 | 50 | | tr | | Olivine (?) |
| 3-1, 110 | M. Miocene | 35 | 60 | 5 | | tr | | |
| 3, CC | M. Miocene | 40 | 50A | 7 | | 3 | | Green clay |
| 4-1, 2 | Undated | 40 | 50A | 10 | | tr | | |
| 8-3, 149 | Oligocene (?) | 40 | | 45 | | 5 | | Py (10), Green clay |
| 9-2, 97 | Oligocene | 35 | 20A | | | 2 | | Py (3), Qtz, Calcite (40) |
| 10-3, 12 | Oligocene | 30 | 40A | | | tr | | Calcite (30) |
| 10-3, 39 | Oligocene | 40 | 50A | | | tr | | Clay (10) |
| 12-3, 25 | L. Eocene | 35 | 55A | | | tr | | Py (10), Clay |
| 12-3, 39 | L. Eocene | 50 | 50A | | | tr | | Py, Clay |
| 12-3, 134 | L. Eocene | 35 | 60A | | | 5 | | Py, Clay |

Note: A indicates constituent is altered.

terminations, dark green in color, and extinguish in polarized light at moderately low angles to the elongation. The refractive index is greater than Caedex.

Calcite

Fine-grained calcite constitutes as much as 30% of samples in Core 9, and in the younger of the two samples in Core 10 from Site 350. However, it is completely lacking in all other samples.

Quartz

Small, irregularly shaped crystal fragments of quartz are sparingly present in basaltic ashes from Sites 346 and 347. It is probably detrital.

Opaque Minerals

Pyrite, magnetite (titanomagnetite?), and hematite are the only opaque minerals observed. Magnetite and hematite, which has formed by oxidation of magnetite, together rarely constitute more than 1% of any of the samples. Pyrite, however, constitutes from 0 to 5%, and is abundantly present both in samples from Site 338 and in Core 8-2 (Plate 1, Figure 1), from Site 348. In the latter samples, the surfaces of tachylyte and sideromelane grains are almost covered by tiny (1-2 μm) pyrite rhombs.

Clays

X-ray diffractograms show that clay minerals are abundant in a few samples, particularly those that are most strongly devitrified (Table 1). No attempt was made at this time to identify the clay minerals.

Biogenic Components

Sponge spicules, diatoms, radiolarians, and silico-flagellates are present, sparingly to abundantly, in samples ranging in age from middle Miocene to Pleistocene at sites on the Icelandic Plateau and Jan-Mayen Ridge. Traces of radiolarians are present in ash from Site 338; ash samples from Lofoten Basin (Site 345) are barren.

DISCUSSION

Transportation and Deposition

The highly fragmented, blocky grain morphology and low vesicularity of basaltic glasses indicate that most of the ash samples are products of hydrovolcanic eruptions. This is a typical mode of eruption for basaltic magmas in the Iceland region as shown not only by the recent eruptive activity of Surtsey (Thorarinsson, 1967a, b), but also by the petrography of basaltic tuffs of Glacial age, the bulk of which were erupted from beneath a thick glacial ice cap (Kjartansson, 1967). According to Heiken (1975), hydrovolcanic eruptions are caused when hot magma encounters and is suddenly quenched by ground water, seawater, or glacial meltwater, resulting in violent steam eruptions and consequent fragmentation of glass, crystals, and lithic inclusions. In explosive magmatic eruptions, the ascending magma is turned into a froth by rapid expansion of coalescing gas bubbles exsolving from the magma; this yields, upon eruption, droplets

and pasty clots of magma whose shapes are controlled by the combined effects of surface tension, acceleration, and air resistance.

The well-sorted character of all the ash samples suggests dispersal as wind-borne, rather than pumice-rafted, debris. Because this region of the sea is commonly covered by pack ice during much of the year, it is also possible that some of the ashes were temporarily deposited on a raft of sea-ice before ultimate deposition upon the sea floor. Such a process may have delayed the deposition of ash for as long as a year or so, but hardly longer. Because of the relatively high frequency of eruptive activity in this region, one would expect that ashes from several lithologically distinct and geographically separate volcanic centers could have accumulated together over a period of years upon the ice, only to be mixed during settlement to the sea floor when the ice melted. In such cases, the ashes in deep-sea sediments should be rather poorly sorted, in contrast to those of this study. Without chemical data to establish that these ashes represent mixtures from separate volcanic centers, it seems reasonable to conclude that ice rafting has not played a significant or at least, detectable, role in the depositional history of these ashes.

Aeolian differentiation may be invoked to account for the lack of olivine or its alteration products in these remarkably fresh ashes, as well as the relatively low amount of magnetite. Both of these heavy minerals are common in basalts in Iceland and Jan-Mayen, which are the two most likely source areas for these ashes.

Pyrite, which is abundantly present in some of the samples, may be authigenic in origin, but alternatively, it may be primary, having been deposited on the surfaces of grains by sublimation from the eruption cloud during atmospheric transport. This hypothesis is suggested by the report of pyrite-covered sulfur droplets in the recent fine-grained wind-borne ejecta from Mt. Baker, Washington (David Frank, University of Washington, personal communication, 20 June, 1975).

Correlation and Sources

Correlation of specific ash layers among the drill sites is precluded at this time by the fact that not all of the encountered volcanic ash layers were sampled for this preliminary study, by the lack of forthcoming chemical analyses of the ashes, and by the gross nature of the available paleontologic age assignments for the sampled intervals.

Some of the ashes may be correlated provisionally with probable sources, however, particularly those of late Cenozoic and Recent ages from the Icelandic Plateau and Jan-Mayen Ridge (Sites 346, 347, 348, 349, and 350). These ashes are petrographically similar to volcanic rocks of comparable ages in the nearby volcanic centers of Iceland and Jan-Mayen. However, the few samples of early Cenozoic age from the outer Vøring Plateau (Site 338) and the Lofoten Basin (Site 345) differ so markedly from one another and from those of the other sites (Table 1) that it is reasonable to conclude that they were derived from separate and, as yet, unknown sources.

The most likely sources of ashes on the Icelandic Plateau-Jan-Mayen Ridge are Iceland and Jan-Mayen

Island which have well-documented records of volcanic activity throughout late Cenozoic and Recent times. It is also possible that some of the material may have originated from presently submerged portions of the Kolbeinsey and Mohns ridges, perhaps even the Iceland-Faeroe Ridge. However, this will be difficult to establish with the available data.

The felsitic ashes almost certainly originated from volcanic centers in Iceland where about 10% of the exposed volcanic rocks are acidic and intermediate lavas and pyroclastic deposits. Hekla (Figure 1), for example, is one of six central volcanoes in Iceland characterized by eruption of acidic and intermediate lava and tephra in addition to the more preponderant volumes of basalt (Sigurdsson, 1967). Thorarinsson (1967a, b) has shown that windborne tephra from several historic eruptions of Hekla has been carried northward across Iceland toward Jan-Mayen Island. Moreover, the tephra is often composite, composed of rhyolitic ash from an initial Plinian explosive phase followed by eruption of intermediate lava and tephra. Such an eruptive cycle may account for the mixture of felsitic and basaltic glass in the bimodal ashes of this study, as well as the presence of ash of intermediate (?) composition in some of the samples.

The clinopyroxene-bearing basaltic ashes, all but one of which are Pliocene or Pleistocene in age, were probably derived from Jan-Mayen Island where clinopyroxene, specifically chromian diopside and salite (Hawkins and Roberts, 1972; Weigand, 1972), is a characteristic mineral phase in the ankaramitic basalts and trachybasalts that comprise most of the subaerial portion of the island. However, it is lacking or rare in most Icelandic volcanic rocks (S. Jakobsson, written communication, 1975).

Of particular interest are the modal variations in the sequence of clinopyroxene-bearing basaltic ashes in Cores 7 and 8 of Site 348 (Table 1), because they are very similar to the general modal variations among lavas of comparable age on Nord Jan. There predominantly ankaramitic lavas of the Nordvestkapp and Tromsøyrggen formations are separated by the Sentralkrater Formation, a distinctive glomeroporphyritic plagioclase basalt (Fitch, 1964), and the only one of its kind known on Jan-Mayen. Ash Samples 348-8-2, 3, 30,

and 52 cm are rich in plagioclase phenocrysts in contrast to all other samples of comparable age of this study, and for this reason they are provisionally correlated with the Sentralkrater Formation. If this correlation is confirmed by chemical analyses, it indicates that the subaerial portion of Jan-Mayen Island is at least as old as early (?) Pliocene, which is somewhat older than suggested by radiometric ages (Fitch et al., 1965), or volume-eruption frequency calculations (Sylvester, 1975).

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PLATE 1

Representative textures of volcanic ashes. Plane light.
Bar scale is 100 μ m long.

- Figure 1 Vitric felsitic ash. Very fine grained, platy felsitic glass shards and cubiform pyrite. Middle Oligocene; Outer Vøring Plateau; Sample 338-20-3, 54 cm.
- Figure 2 Biotite-bearing, vitric crystal basaltic ash. Irregularly shaped opaque tachylite, large platy biotite crystal fragments (upper left corner), and large, clear plagioclase crystal fragments. Oligocene; Lofoten Basin; Sample 345-21-4, 77 cm.
- Figure 3 Vitric basaltic-felsitic ash. Irregularly shaped opaque tachylite, partially opaque sideromelane shards with low to moderate vesicularity, and clear glass shards. Middle Miocene; Icelandic Plateau-Jan-Mayen Ridge; Sample 346-8-5, 38 cm.
- Figure 4 Vitric felsitic ash. Clear platy glass shards, forked sponge spicule fragment. Pliocene; Icelandic Plateau-Jan-Mayen Ridge; Sample 348-8-3, 114 cm.
- Figure 5 Vitric basaltic ash. Droplets of opaque tachylite and partially opaque, partially devitrified sideromelane, dusty and clear glass shards, blocky clinopyroxene crystal fragments; broken rod-shaped sponge spicules. Pleistocene; Icelandic Plateau-Jan-Mayen Ridge; Sample 349-2-5, 55 cm.
- Figure 6 Vitric basaltic-felsitic ash. Irregularly shaped opaque tachylite, partially opaque, incipiently devitrified sideromelane, clear glass shards and pumice. Pliocene or Pleistocene; Icelandic Plateau-Jan-Mayen Ridge; Sample 350-2-5, 10 cm.

PLATE 1

