18. CENOZOIC ASH LAYERS ON THE VØRING PLATEAU (ODP LEG 104)\(^1\)

P. R. Bitschene, H.-U. Schmincke, and L. Viereck\(^2\)

ABSTRACT

Numerous fresh ash layers comprise about 0.3% by volume of Neogene to Holocene sediments drilled at Leg 104 Sites 642 and 643 (Vøring Plateau, North Atlantic). Median grain sizes of the ashes are about 100 \(\mu\)m and maximum grain sizes range up to 1200 \(\mu\)m. Rhyolitic pumice shards dominate, with minor bubble wall shards. Basaltic shards are poorly vesicular and blocky or round. Phenocrystic plagioclase, zircon, and clinopyroxene occur in the rhyolitic, plagioclase, and clinopyroxene phenocrysts and basaltic lithics in the basaltic tephra. Quartz, amphibole, clinopyroxite, and rutile are interpreted as xenocrysts. All ash layers are well-sorted and represent distal fallout from major explosive eruptions. Most ashes are rhyolitic (high-K and low-K) in composition, some are bimodal (tholeiitic and rhyolitic). Early Miocene tephra is dominantly basaltic.

Iceland is inferred to be the likely source region for most ashes. Late Miocene high-K rhyolites may have originated from the K-rich Jan Mayen magmatic province. One Quaternary layer with biotite and alkali feldspar phenocrysts may have been derived from Jan Mayen Island. Four individual Pliocene to Holocene ash layers from Sites 642 and 643 can be correlated fairly well. Upper Miocene layers are tentatively correlated as a sequence between Sites 642 and 643. Average calculated layer frequencies are about three layers/m\(y\) through the Pliocene and Pleistocene and five to eight layers per m\(y\) through the middle and late Miocene, suggesting rather continuous volcanic activity in the North Atlantic. Episodic magmatic activity during Neogene epochs in this part of the North Atlantic, as postulated in the literature, cannot be confirmed.

INTRODUCTION

Numerous ash layers encountered in the sedimentary sequence of the Vøring Plateau, northeast Atlantic Ocean, drilled during Leg 104 at Sites 642, 643, and 644 (Fig. 1), provide a unique record of Cenozoic explosive volcanism in the North Atlantic (Eldholm, Thiede, Taylor, et al., 1987). A basement high, upon which Site 642 is located with a northeast-trending linear escarpment, divides the Vøring Plateau into the inner plateau to the east and the outer plateau to the west (Fig. 1). Site 643 is located at the base of the western slope of the outer Vøring Plateau, and Site 644 lies within the inner Vøring Plateau. Ash layers are not abundant in Pliocene to Holocene sediments from the latter site and were not studied in detail.

Fifty-four distinct ash layers were identified within Holes 642B, 642C, and 642D. Hole 643A contained 56 distinct ash layers; only five ash layers were recovered in the Pliocene to Holocene section of Site 644 (Eldholm, Thiede, Taylor, et al., 1987).

Excellent core recovery (79%–98%) and freshness of the glass made a study of distinct tephra layers promising. The aim of our study is to help unravel the stratigraphy of Sites 642 and 643 by using geochemical and mineralogical compositions of prominent tephra layers. Also, an attempt is made to infer potential source regions for the ash, and to draw some conclusions regarding possible episodic volcanic activity during the Neogene and Quaternary.

METHODS

Based on shipboard descriptions, 16 fresh and representative samples were selected for detailed study. The ash layers studied are listed in Figure 4. Grain size and sorting of glass shards, morphology, color, and crystal and lithic components and their abundances were studied in smear slides and thin sections. Between 20 and 50 grains in each thin section were measured using calibrated ocular scales.

Major-element compositions of individual glass shards and mineral grains were determined with a CAMEBAX automated electron microprobe using natural mineral and glass standards. Raw data were corrected using the program CORREX (CAMEBAX). Operation conditions: Accelerating voltage 15 KV, beam spot size 5X5 \(\mu\)m and beam current of 14 nA. Na\(_2\)O concentrations measured are lower by ca. 1%-2% by weight, when compared with compositions of rhyolitic shards and rocks from the North Atlantic and Iceland (Table 1). This could be due to selective sodium loss during diagenesis or, more likely, during microprobe analysis. K\(_2\)O concentrations are slightly higher than in rocks of similar bulk compositions from Iceland (Walker, 1966; Jorgensen, 1980; Schmincke et al., 1982).

RESULTS

Stratigraphy and Lithology

The ash layers comprise about 0.3% of the sediments and occur within Neogene and Quaternary sediments of the Vøring Plateau (Fig. 2). They represent the most complete succession of Cenozoic ash layers so far recovered in the North Atlantic. At Site 642, the Neogene sequence rests upon an Eocene massive, glauconite-rich, volcaniclastic mass flow deposit with an erosional unconformity (Fig. 2). At Site 643, the Oligocene to Holocene section overlies an Eocene volcaniclastic sequence with a basal conglomerate unit consisting of reworking basalts.

Tephra occurs as discrete (sharp base and gradational top; \(L\) in Fig. 4) or disseminated (no sharp base and up to 80% ooze or fissiliferous mud; \(D\) in Fig. 4) ash layers. Enriched layers (\(E\) in Fig. 4) often overlie discrete or disseminated layers by as much as 100 cm and contain only 5%-10% ash. Ash pods are distributed throughout the cores. A complete list of all ash layers and their corresponding raw data is given in Eldholm, Thiede, Taylor, et al. (1987).

Most ash layers are Miocene in age, and are particularly abundant between 113 and 137 meters below sea floor (mbsf) at Site 642 and 90 and 110 mbsf at Site 643. Only 12 layers are preserved within the uppermost 110 m of Site 642, and 11 layers are

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\(^1\) Eldholm, O., Thiede, J., Taylor, E., et al., 1989. Proc. ODP, Sci. Results, 104; College Station, TX (Ocean Drilling Program).

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preserved within the uppermost 90 m at Site 643, representing Pliocene to Holocene volcanic activity.

Tephra layers from Site 642 are mostly between 2 and 4 cm thick, but range from less than 1 to as much as 11 cm in thickness (Fig. 3). Site 643 ash layers are, on the average, thinner than those at Site 642 (Fig. 3); one layer, however, is 11 cm thick. Color and thus inferred chemical composition do not correlate with ash layer thickness.

All ash layers consist dominantly of vitric ash with few crystals and lithic clasts. Many are white to gray, but can be dark gray to black when surface pyritized (e.g., interval 104-642D-7-6, 62-74 cm). They are well-sorted with an average median grain size of approximately 100 ± 40 μm (fine sands to coarse silts). Maximum grain sizes (3 largest shards), however, differ significantly and range from about 240 μm to as much as 1200 μm (Section 104-642B-13, CC, 9-13 cm). Colorless shards are larger than brown glass clasts in the same layer. Maximum grain size is grossly related to the colorless shards (Fig. 4).

Different shard types can be distinguished by color, refractive index (R.I.), and dominant shape: colorless to light-greenish shards with an R.I. < 1.54 consist of angular tubular pumice and minor platy and cusparse shards (vesicle walls and vesicle
juctions); light-brown shards with R. I. > 1.54 consist of tubular pumice and blocky, platy, and cuspate shards; deep-brown shards with R. I. > 1.54 have round (droplets) and blocky, platy shapes and few but round vesicles. Additional glass phases consist of altered, ore-spotted and/or hydrated glasses and opaque tachylite. Shipboard studies of color and R. I. suggest the following magma types: rhyolite (colorless glass), icelandite (light brownish glass), and basaltic to andesitic varieties (brown glass). However, brown shards with low R. I. in rhyolitic tephra layers are also rhyolitic in composition based on microprobe data (Table 2).

Colorless glass populations show up to 80% (Sample 104-642C-15-2, 111-112 cm) angular, tubular pumices with parallel alignment of elongate vesicles. The remaining 20% are made up of platy and cuspate shards with smaller grain size and lack of bubbles. Light-brown glass mostly occurs as fibrous tubular pumice and minor blocky, vesicle-free shards. Deep-brown shards are blocky, platy to cuneiform, often round droplets with spheri-

### Table 1. Compilation of chemical data on North Atlantic rhyolitic ashes (Sigurdsson and Loebner, 1981), first three columns, and Iceland rhyolitic rocks (middle three columns), in comparison with Leg 104 rhyolitic ash.

<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
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<td>High-K</td>
<td>High-K</td>
<td>Low-K</td>
<td>High-K</td>
</tr>
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<td>72.57</td>
<td>73.61</td>
<td>73.50</td>
<td>73.69</td>
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<td>1.97</td>
<td>2.00</td>
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<td>Fe₂O₃</td>
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<td>1.70</td>
<td>4.45</td>
<td>3.21</td>
<td>3.62</td>
</tr>
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<td>MgO</td>
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<td>0.10</td>
<td>0.00</td>
<td>0.33</td>
<td>0.28</td>
</tr>
<tr>
<td>CaO</td>
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<td>0.77</td>
<td>0.13</td>
<td>1.64</td>
<td>0.84</td>
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<td>Na₂O</td>
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<td>0.10</td>
<td>0.00</td>
<td>0.33</td>
<td>0.28</td>
</tr>
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<td>K₂O</td>
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<td>4.67</td>
<td>4.16</td>
<td>5.13</td>
<td>4.97</td>
</tr>
<tr>
<td>Sum</td>
<td>96.58</td>
<td>97.46</td>
<td>97.10</td>
<td>99.78</td>
<td>99.65</td>
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</tbody>
</table>

Figure 2. Stratigraphic position of tephra layers in Holes 642B, 642C, 642D, and 643A (data from Eldholm, Thiede, Taylor, et al., 1987; new stratigraphic summary after Goll, this volume).
Ash layers are thought to be detrital. Plagioclase is always twinned. Very rare rutile is brownish orange, elongate, and probably detrital. Clinopyroxene is light greenish gray in brown glass and shows rare twinning and cleavage. Blue to greenish pleochroic amphiboles (alkali-amphiboles) and brownish pleochroic amphiboles are very rare.

Lithics, composed of clusters of glomerophytic plagioclase in a devitrified matrix, occur in layer 104-643A-15-4, 147-149 cm. Unique mineral assemblages cannot be assigned to specific layers except for the biotite-rich layer 104-642B-6-1, 131-132 cm (Fig. 4).

**Geochemistry**

One prominent upper Miocene rhyolitic ash layer from each hole, three in total (104-642B-13-CC, 9-13 cm; 104-642C-15-2, 110-114 cm; and 104-643A-11-1, 104-105 cm), was selected for chemical analysis. Based on shipboard interpretation (Eldholm, Thiede, Taylor, et al., 1987), the layers are thought to correlate well between Holes 643A and 642B and 642C/642D, the distance being only 450 m between the Holes 642B and 642C/642D. Compositions of plagioclase were also determined.

All shards analyzed from these layers, including brown shards, are rhyolitic in composition (Table 2, Fig. 5). The brown color of some rhyolitic shards is probably due to the oxidation of iron. Each analyzed layer has a characteristic composition significantly different from the other two layers in their SiO$_2$, Al$_2$O$_3$, FeO, and CaO concentrations (Table 2, Fig. 5). Glasses from layers 104-642B-13-CC, 9-13 cm and 104-642C-15-2, 110-114 cm are K-rich alkali rhyolites with K$_2$O concentrations > 3.8% by weight. In contrast, layer 104-643A-11-1, 104-105 cm is low in K$_2$O (< 2.9 wt%), except for a single grain, but higher in FeO and CaO concentrations (Table 2, Fig. 5).

The more calcic plagioclase (andesine) is found in the more K-rich magma (Table 3), whereas the more sodic plagioclase (oligoclase) is found in the K-poor magma.

The basaltic shards from layer 104-642C-10-6, 5-7 cm, exhibit high MgO (6.07-6.63 wt%), CaO (11.97-12.50 wt%), and FeO (12.62-13.45 wt%), intermediate TiO$_2$ (2.39-2.66 wt%), and low SiO$_2$ (48.20-48.54 wt%), and K$_2$O (0.27-0.34 wt%) concentrations. The shards are uniformly tholeiitic (medium-Ti basalts) and differ from the more evolved tholeiites (high-Ti basalts) from layer 104-643A-7-3, 66-67 cm (Fig. 6), which are lower in MgO (4.63-5.19 wt%) and CaO (9.70-10.03 wt%) but distinctly higher particularly in TiO$_2$ (3.39-4.21 wt%), FeO (13.90-15.37 wt%), K$_2$O (0.60-0.72 wt%), and P$_2$O$_5$ (0.37-0.51 wt%). The more evolved basaltic glasses from layer 104-643A-2-3, 74-75 cm, have SiO$_2$ concentrations between 48.62 and 50.13 wt% and MgO concentrations between 4.10 and 4.34 wt%. They are high-Ti basalts (3.23-3.43 wt% TiO$_2$) with high FeO (13.06-14.03 wt%) and K$_2$O (0.75-0.83 wt%) concentrations (Fig. 6, Table 2).

The major element concentrations of the basaltic shards analyzed are similar to the composition of basalts from Iceland (e.g., Schmincke et al., 1982; Flower et al., 1982) and can be divided into more primitive, medium-Ti basalts and more evolved high-Ti basalts with markedly higher FeO and K$_2$O concentrations.

The SiO$_2$-rich (73.69-76.90 wt%) rhyolitic shards found in two layers (Table 2) are enriched in FeO (2.44-3.60 wt%) and CaO (1.07-2.13 wt%). Preliminary analyses of some rhyolitic shards from layer 104-643A-2-3, 74-75 cm show high CaO (1.24-1.45 wt%) and FeO (2.74-3.16 wt%) concentrations. The major-element compositions of the rhyolitic shards from these layers clearly differ from those of rhyolitic shards from purely rhyolitic ash layers 104-642B-13CC, 9-13 cm, 104-642C-15-2, 110-114 cm, and 104-643A-11-1, 104-105 cm (Table 2). More data, however, are needed to decide whether rhyolite shards from bimodal ash deposits differ systematically from those of purely rhyolitic ash layers or not.
**CENOZOIC ASH LAYERS ON THE VØRING PLATEAU**

### DISCUSSION

Neogene sediments from the Vøring Plateau in the North Atlantic contain a unique record of interbedded ash layers. The ash layers investigated from Sites 642 and 643 of Leg 104 have similar median grain sizes and mineral assemblages but differ in the composition of the glass (basaltic and rhyolitic, some bimodal compositions).

**Eruption, Transport, and Sedimentation**

Most glass clasts are colorless pumice and bubble wall shards. The light-brown shards are also highly vesicular pumices with elongate vesicles; deep-brown shards are mostly bubble-free, blocky, and platy shards. The vitric ashes are interpreted as distal fallout products of powerful Plinian eruptions because of the well-sorted character of all ash samples, although a few large grains possibly indicate minor contributions from pumice rafting.

Brown, basaltic glasses are common in lower to middle Miocene ash layers, which consist of brown, blocky shards and round droplets. Cracked, bubble-free glass and phenocrysts in layer 104-642D-7, 6, 70-74 cm, are most likely caused by shock-cooling in contact with cold water (or ice?) and subsequent cracking (Fisher and Schmincke, 1984). These ash layers are in-

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### Figure 4. Petrographic description and position of prominent tephra layers.

<table>
<thead>
<tr>
<th>Hole</th>
<th>Sample</th>
<th>Depth [mbsf]</th>
<th>Lithologic unit</th>
<th>Ash lithology</th>
<th>100% c Relative abundance of colorless (a) and brown (b) shards</th>
<th>Maximum grain size [μm]</th>
<th>Abundance [%] of crystal fragments</th>
<th>Mineral assemblages</th>
</tr>
</thead>
<tbody>
<tr>
<td>642 B</td>
<td>6-1-131-132</td>
<td>41</td>
<td>I</td>
<td>L</td>
<td>•</td>
<td>X</td>
<td>•</td>
<td>B, Kf, Cpx, Zr, Op, Q, Pl</td>
</tr>
<tr>
<td>9-3-95-96</td>
<td>71</td>
<td>II A</td>
<td>L</td>
<td>•</td>
<td>X</td>
<td>•</td>
<td>O, Pl, Cpx, Cz, Zr, Op, Ca</td>
<td></td>
</tr>
<tr>
<td>9-3-106-107</td>
<td>71</td>
<td>II A</td>
<td>E</td>
<td>•</td>
<td>X</td>
<td>X</td>
<td>O, Pl, Cpx, Op, Co, Ru</td>
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<tr>
<td>13 CC-10-12</td>
<td>114</td>
<td>II C</td>
<td>L</td>
<td>•</td>
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<td>Q, Pl, Cpx, Op, Zr, Kf</td>
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<tr>
<td>10-6-5-7</td>
<td>71</td>
<td>II A</td>
<td>L</td>
<td>•</td>
<td>X</td>
<td>•</td>
<td>Q, Pl, Cpx, Op, B</td>
<td></td>
</tr>
<tr>
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<td>L</td>
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<td>X</td>
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<td>Q, Pl, Zr, Op, Cpx, Kf</td>
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<td>15-2-111-112</td>
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<td>II C</td>
<td>D</td>
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<td>•</td>
<td>Q, Pl, Zr, Op, Cpx</td>
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<td>19-3-71-76</td>
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<td>L</td>
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<td>Q, Pl, Cpx</td>
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<tr>
<td>642 C</td>
<td>7-6-70-76</td>
<td>247</td>
<td>III</td>
<td>P</td>
<td>•</td>
<td>X</td>
<td>•</td>
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<td>I</td>
<td>L</td>
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<td>L</td>
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<td>X</td>
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<td>X</td>
<td>•</td>
<td>Q, Pl, Cpx, Am, Op, Zr</td>
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</table>

Note: L = Discrete ash layer  
E = Ash-rich layer  
D = Disseminated ash  
P = Ash pods  
B = Biotite  
Pl = Plagioclase  
Kf = K-feldspar  
Q = Quartz  
Cpx = Clinopyroxene  
Am = Amphibole  
Zr = Zircon  
Ca = Calcite  
Cz = Clinozoisite  
Op = Opaques and tachylite  
Gl = Glauconite  

O rare, < 2%  
@ common, 2-5%  
• abundant, >5%  

FIGURE 4. Petrographic description and position of prominent tephra layers.
Table 2. Microprobe analyses of glass shards from Holes 642B, 642C, and 643A (total Fe as FeO).

<table>
<thead>
<tr>
<th>Sample</th>
<th>SiO2</th>
<th>TiO2</th>
<th>Al2O3</th>
<th>FeO</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na2O</th>
<th>K2O</th>
<th>P2O5</th>
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<tr>
<td>642B-13C-9-13</td>
<td>72.52</td>
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<td>3.09</td>
<td>3.95</td>
<td>0.10</td>
<td>95.62</td>
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<td>643A-7-3, 66-67</td>
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<td>0.15</td>
<td>0.79</td>
<td>3.15</td>
<td>4.32</td>
<td>0.01</td>
<td>95.85</td>
</tr>
</tbody>
</table>

Interpreted as being formed by hydrovolcanic/phreatomagmatic eruption mechanisms.

Colorless, rhyolitic pumice shards are larger than brown, icelandic to tholeiitic shards and typically exceed phenocrysts in size. These size patterns might be explained by two processes. First, highly vesicular, low-density rhyolitic pumice is erupted to greater height than basaltic glass and can thus be transported farther downwind. Second, during eolian sedimentation, dense nonvesicular lithics, crystals, and basaltic glass fragments are deposited closer to the source than less-dense rhyolitic pumice.
Eruption from zoned magma columns is suggested by the bimodal ash compositions, for instance in layers 104-642C-10-6, 5–7 cm, and 104-643A-7-3, 66–67 cm, and by the occurrence of slight chemical and color zonation of thick rhyolitic ash layers, although we cannot exclude the less likely simultaneous eruptions from different but nearby sources.

Correlation and Sources

Correlation of the prominent layers from Sites 642 and 643 help establish a regional stratigraphy and may provide tiepoints for calibration of the Neogene time scale. Individual Pliocene to Pleistocene ash layers can be correlated based on petrographic analysis (median and maximum grain size, shape, and color of glass, mineral assemblages) and stratigraphic position as suggested by Eldholm, Thiede, Taylor, et al. (1987):

Correlation of individual Pliocene and Pleistocene ash layers

<table>
<thead>
<tr>
<th>Sample from Site 642</th>
<th>Sample from Site 643</th>
</tr>
</thead>
<tbody>
<tr>
<td>104-642C-2-4, 88–98 cm and 104-642C-3-3, 72–75 cm</td>
<td>104-643A-2-3, 72–75 cm</td>
</tr>
<tr>
<td>104-642C-5-3, 92–94 cm and 104-642C-7-1, 133–140 cm</td>
<td>104-643A-5-2, 107–114 cm</td>
</tr>
<tr>
<td>104-642B-9-3, 96–98 cm</td>
<td>104-643A-6-3, 24–27 cm</td>
</tr>
<tr>
<td>104-642A-7-3, 66–67 cm</td>
<td>104-643A-7-3, 66–67 cm</td>
</tr>
</tbody>
</table>

Correlation of single Neogene ash layers, as based on shipboard data (Eldholm, Thiede, Taylor, et al., 1987), was tested by geochemical means. Individual upper Miocene rhyolitic ash layers cannot be correlated between drill sites, because the compositions of all shards and plagioclases analyzed differ significantly between these layers (Tables 2 and 3; Fig. 5). Layers 104-642C-10-6, 5–7 cm and 104-643A-7-3, 66–67 cm have bimodal compositions (Table 2; Fig. 5), have the same maximum grain size (280 μm), and show similar proportions of colorless to brown glass shards (Fig. 4), but the glass compositions again differ significantly. The proposed correlation between these layers (Eldholm, Thiede, Taylor, et al., 1987) is thus not tenable, even though the ash layers analyzed have close magmatic relationships and some may have originated from very similar sources.

The petrographic similarity and abundance of ash layers in the upper Miocene intervals between 113 to 137 mbsf (Site 642) and 90 to 110 mbsf (Site 643), however, suggests that these could be correlated as a group (Fig. 2) even though individual layers cannot yet be matched between sites. Correlation of layers older than late Miocene is difficult for several reasons: disturbed sedimentary record with some hiatuses; no unique mineral assemblages in single layers; insufficient geochemical data.
and Ninkovich, 1980; Sigurdsson and Loebner, 1981). Single ash layers, however, have yet to be correlated throughout the North Atlantic Ocean Basin.

Possible ash sources lie somewhere to the south and west of the Voring Plateau. The volcanic islands of Iceland and Jan Mayen, the Jan Mayen Ridge, and continental Greenland (even if Neogene volcanism is not yet reported there) are the most likely source areas, as they have well-documented records of Cenozoic volcanic activity. Iceland is a likely source area because of its proximity, basaltic to rhyolitic magmatism, and common explosive eruptions (e.g., Sigurdsson and Loebner, 1981; Schmincke et al., 1982). Median grain sizes of about 100 μm, average layer thicknesses of 1-4 cm, basaltic and rhyolitic compositions of the Neogene tephra, and prevailing wind directions (Donn and Ninkovich, 1980) also suggest Iceland as the likely source area for most ashes. Historical eruptions and the distribution of volcanic ash in surface sediments show that stratospheric transport is dominantly to the northeast and east of Iceland (Sigurdsson and Loebner, 1981).

Until now, only Quaternary K-rich rhyolitic rocks have been reported from Iceland (Sigurdsson and Loebner, 1981; Schmincke et al., 1982). Both high-K and low-K compositional series are present in the ash layers from the Voring Plateau. Sigurdsson and Loebner (1981) distinguished high-K and low-K rhyolites among Leg 38 ash layers from the North Atlantic (Fig. 7, Sites 338 and 342), both associated with rifting and opening of the Norwegian and Greenland Seas. They inferred igneous activity on the East Greenland continental margin or near the Ice­land-Faeroe Ridge as possible sources for middle Oligocene high-K silicic ashes. Only Eocene to early Miocene high-K ashes can be attributed to these provinces, because the youngest east Greenland igneous activity with high-K rhyolites is early Mio­cene in age (Gleadow et al., 1979) and volcanic activity on the Faeroe Islands ceased until middle Miocene. High-K magmatism from Jan Mayen Island, on the other hand, is at least as young as Pliocene-Pleistocene (Fitch et al., 1965; Sylvester, 1975; Maaloe et al., 1986). Thus, late Miocene K-rich rhyolitic ashes described here cannot have originated in either Jan Mayen Island, Greenland, or Iceland. We suggest that the entire area encompassing the Iceland–Jan Mayen Ridge was a possible source for late Miocene K-rich silicic explosive eruptions (Fig. 7), even though individual volcanic centers are unknown so far. We speculate that during the late Miocene large rhyolitic eruptive centers in what may be called Jan Mayen magmatic province, which is characterized by K-rich alkalic magmas, were active since the Pliocene-Pleistocene. The unique nature of the K-rich Jan Mayen area, when compared with other volcanic areas in the Atlantic Ocean north of the Azores, was noted previously (Schmincke,
1973). Jan Mayen Island is a possible source for Quaternary alkali-rich layers with K-rich mineral assemblages (biotite- and feldspar-rich layer 104-642B-6-1, 132-133 cm) based on the Pliocene-Pleistocene age of its magmatism. Sylvester (1978) reported well-sorted ashes with average grain sizes between 100 and 200 μm from DSDP drill sites (Leg 38) near Jan Mayen Island. He inferred sources for the ashes in Iceland and Jan Mayen Island, but also suggested separate and yet unknown sources. The basaltic ashes analyzed are very similar in their major-element concentrations to basalts from Iceland and are therefore related to sources in Iceland, although we cannot definitively rule out other, yet unknown sources.

Continuous or Episodic Neogene Volcanism in the North Atlantic?

Sylvester (1978), Donn and Ninkovich (1980), and Sigurdsson and Loebner (1981) interpreted changes in the abundance of ash layers in Neogene sediments from the North Atlantic as reflecting corresponding variations in eruption frequency and therefore magmatic productivity and, in some cases, changes in spreading rates. Leg 104 Sites 642 and 643 allow a more detailed evaluation of possible volcanic episodicity because of excellent core recovery and a rather continuous sequence of Neogene sediments with an exceptionally well-preserved ash layer record.

Donn and Ninkovich (1980) used piston-core and DSDP-core ashes to infer rates of explosive volcanism in the North Atlantic during the Cenozoic. The ashes were thought to have derived from eruptions in Iceland. They make certain reservations, however, regarding their data because of poor core recovery and serious hiatuses in the sedimentary record. After interpolation for missing data and corrections for wind effects and regional plate motions, high volcanic activity was inferred for the middle Eocene and the Pliocene (Fig. 8).

In contrast, Sigurdsson and Loebner (1981), using ash layers from Leg 38, inferred four episodes of abundant explosive volcanism: middle Eocene, middle Oligocene, early to middle Miocene, Pliocene to Pleistocene (Fig. 8). These authors also caution against overinterpreting their data because of poor core recovery during Leg 38. For instance, their inferred late Miocene decline in explosive volcanic activity is based on very poor core recovery (4%). On the other hand, spreading rates in the North Atlantic increased in the late Miocene (Talwani and Eldholm, 1977; Sigurdsson and Loebner, 1981) and accumulation rates of basalt in Iceland increased abruptly (Saemundsson et al., 1980) at that time, contradicting the minimum in volcanic activity suggested by Sigurdsson and Loebner (1981).

The oldest ash layers from Leg 104 sites are early Miocene and are tholeiitic to icelandic. Basaltic ashes in the North Atlantic can form widespread layers (e.g., Pedersen et al., 1975), possibly resulting from highly explosive shallow submarine or subglacial eruptions.

In the middle Miocene sequence, up to 21 ash layers were counted. Adoption of a 3.2-m.y. hiatus, as suggested by Goll (this volume) in the upper middle Miocene section, would raise the ash layer number to about 40 and frequency to 6 to 8 layers per m.y. Spreading rates and magmatic productivity in the North Atlantic increased at that time (Talwani and Eldholm, 1977; Saemundsson et al., 1980; Sigurdsson and Loebner, 1981).

Within the uppermost 110 m of Site 642 and the upper 90 m of Site 643, only 11 (Site 642) and 12 (Site 643) Pliocene and Holocene layers are preserved. Either volcanic activity decreased through that period or unfavorable wind and sedimentation conditions prevented ash deposition. If we combine the increase in sedimentation rate (16 to 50 mm/Ka using shipboard downhole patterns in remnant magnetization polarity, and time scale after Berggren et al., 1985; see also data from Caston et al., 1976) with the onset of glacial conditions somewhere between 2.4 Ma (Shackleton et al., 1984) and 4 Ma (Eldholm, Thiede, Taylor, et al., 1987), a possible ice cover and ice rafting and a Pliocene hiatus (Goll, this volume) may explain low ash sedimentation on the Voring Plateau during Pliocene to Holocene times.

The pronounced peaks in Pliocene (Donn and Ninkovich, 1980) or middle Miocene (Sigurdsson and Loebner, 1981) volcanic activity in the North Atlantic cannot be confirmed from the Voring Plateau ash layers (Fig. 8). The apparent low ash layer frequency of Sigurdsson and Loebner (1981) in the late Miocene actually corresponds to vigorous volcanic activity shown by 26 ash layers in Leg 104 sites (Fig. 8).

CONCLUSIONS

1. The ash layers studied have fairly uniform median grain sizes (about 100 μm) but very different (280 to 1200 μm) maximum grain sizes, related to the rhyolitic glasses. Unique mineral assemblages are lacking except in one distinctive, biotite-bearing layer.

2. Bimodal geochemical compositions are indicated by rhyolitic shards in dominantly basaltic layers, whereas some brown
shards in the rhyolitic layers are also rhyolitic. The basaltic glasses analyzed are tholeiitic and can be divided into primitive medium-Ti and more evolved high-Ti basalts. The latter cannot be derived from the medium-Ti basalts by simple fractional crystallization, but all basaltic shards are compositionally similar to basalts from Iceland. The rhyolites comprise both low-K and high-K types with distinctive feldspar phenocrysts. Except for a few Pliocene to Holocene ash layers, no correlation between previously correlated ash layers in different Leg 104 drill sites can be established.

3. Iceland is the most likely source for the basaltic and the low-K rhyolitic ashes. The K-rich Jan Mayen magmatic province is inferred as source region for late Miocene, high-K rhyolitic ashes and for Quaternary, biotite-bearing ash layers. The ashes deposited on the Voring Plateau probably resulted from powerful Plinian eruptions and possibly some pumice rafting.

4. The particularly well-preserved record of Neogene to Holocene ash layers does not support the highly episodic volcanic activity advocated for this part of the North Atlantic (Norwegian-Greenland Sea) by previous authors.

Average calculated ash layer deposition rates are between 5 and 8 layers per m.y. for Neogene epochs, and around 3 layers per m.y. for Pliocene to Holocene times. The latter number, however, is obscured by the unknown influence of an ice cover precluding fallout sedimentation onto the ocean floor.

ACKNOWLEDGMENTS

R. Goll, U. Bleil, R. Henrich, and G. Bohrmann provided valuable stratigraphic information. Some of the polished sections were obtained through the kind help of J. P. Huijsmans. Many thanks to W. Schnetter Köhler, A. Freundt, and U. Bednarz, who assisted us with the microprobe work, and W. Lehmann, who helped with the drafting. A first version of this paper was substantially improved by the reviews of G. Kohler, A. Freund, and U. Bednarz, who assisted us with the microprobe work, and W. Lehmann, who helped with the drafting. A first version of this paper was substantially improved by the reviews of G. Kohler, A. Freundt, and U. Bednarz, who assisted us with the microprobe work, and W. Lehmann, who helped with the drafting.

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Date of initial receipt: 29 January 1988
Date of acceptance: 4 August 1988
Ms 104B-129