42. PALEOMAGNETISM OF THE VOLCANIC SEQUENCE IN HOLE 642E, ODP LEG 104, VÖRING PLATEAU, AND CORRELATION WITH EARLY TERTIARY BASALTS IN THE NORTH ATLANTIC

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ABSTRACT

Paleomagnetic data from a 907-m thick volcanic sequence from Hole 642E on the Vöring Plateau, Norwegian Sea, are presented. NRM, susceptibility, Q-ratio, stable inclination, and polarity values were determined for 520 samples obtained from 118 flows, 7 dikes, and 12 volcaniclastic units. Declination values were also estimated from AF demagnetization analysis on suitable samples.

The magnetic polarity in the upper 778-m thick series of tholeiitic lavas and sediments is reversed throughout while the polarity of the 136-m, more silicic lower series is interpreted to be predominantly normal with widespread reversed component overprint caused by dike intrusions. A strong contrast in magnetic properties between the upper and the lower series reflects the different primary and secondary petrological features of the series.

The reverse upper series is correlated with chron 24r of the magnetic polarity time scale, with an age of ca. 54 Ma. This timing matches well with other areas of the North Atlantic Volcanic Province and indicates a common age for the surge of voluminous volcanic activity before the onset of spreading. The inclination record of the upper series indicates an extremely fast rate of extrusion that possibly exceeds growth rates of lava piles like those in Iceland by an order of magnitude. The normal polarity of the lower series is correlated with chron 25, indicating a hiatus between the two series. Comparison of paleolatitudes from the North Atlantic basalt province confirms a northward component of movement of some 15° in the last 55 m.y. for the Vöring Plateau.

INTRODUCTION

During ODP Leg 104 five holes were drilled at Site 642 on the outer Vöring Plateau in the Norwegian Sea (Fig. 1). The deepest one, Hole 642E, penetrated 138 volcanic flows, 7 dikes and a large number of intercalated volcanioclastics between 327 and 1229.4 m below the seafloor (mbsf). This volcanic sequence was divided into a tholeiitic upper series and a more silicic lower series (Eldholm, Thiede, Taylor, et al., 1987). Shipboard magnetic results showed a dramatic decrease in natural remanent magnetization (NRM) and magnetic susceptibility at the upper/lower series boundary at 1087 mbsf. Polarity was predominantly reversed throughout the core, although there was some uncertainty about the lower series inclination due to rather unstable or erratic behavior of pilot samples during AF-cleaning.

On the ship a total of 307 cube samples were measured for NRM and AF-demagnetized in 5-mT peak AF fields. From these samples a further 89 samples were AF-demagnetized in peak fields up to 100 mT and stable inclination and median destructive fields were determined. In many cases multicomponent remanence was recognized, and careful analysis of data, as well as many more measurements, were required to determine the primary magnetization. In addition, further analysis might help to estimate the mean declination values assuming that one of the magnetic components was of a viscous type acquired during the last magnetic chron (Brunhes).

A clear paleomagnetic record for the basalts, the dipping reflector series, and the underlying lower series is important with regard to correlation with results from other areas of the North Atlantic Volcanic Province (Larsen and Watts, 1985; Abrahamsen et al., 1984). Therefore a rather extensive sampling, over 500 new samples, was performed during Leg 104 to provide the material for shore-based laboratory studies.

For the upper volcanic series, these samples are sufficient for detailed investigation of the stable inclination record. For the lower series, the glassy nature of many of the flows and the degree of alteration made it more difficult to obtain a sufficient number of suitable samples. In view of extensive remagnetization effects by both chemical and thermal alteration and by dike intrusions, the stable inclination results are therefore more interpretive for the lower series than for the upper series.

Nevertheless, with the samples obtained we could attempt to contribute to the following problems: the correlation of polarity zones of the volcanic series with the magnetic polarity scale, reconstruction of paleolatitude and, perhaps, the duration of volcanic activity at Site 642. These samples, together with other geophysical and geological information from the Vöring Plateau and other key areas of the North Atlantic Volcanic Province, may help to decipher the early stages of rifting and spreading of the area.

METHOD

The 520 samples investigated were taken from 118 flows, 7 dikes, and 12 volcaniclastic units. On the ship, samples were drilled perpendicular to the core axis after a fiducial mark for the vertical orientation was drawn. In the laboratory, samples were measured for remnant magnetization on a Digico spinner magnetometer and for susceptibility on a sensitive low field 1-kHz susceptibility bridge. All specimens were further remeasured after AF-demagnetization in peak fields of up to 100 mT. From these data median destructive fields (MDF) and stable inclinations were determined. Thermal demagnetization was performed for 12 samples at temperatures up to 690°C, to evaluate secondary components of NRM.

RESULTS

The magnetic results are summarized in Figure 2, showing stable inclination, MDF variation, NRM, susceptibility, and Q ratio as mean values with error bars for each unit investigated.
The strongest variation in all the properties (except the Q ratio) occurs at the boundary between the upper and lower series at about 1100 m.

This boundary was magnetically recognized by a drop of about two orders of magnitude of both NRM and susceptibility. The contrast between the volcanic series is confirmed by the present study. MDF and stable inclination unit mean values below the boundary exhibit considerably larger standard deviations. In Figure 3 stable inclination, NRM, and Q-values across the boundary are shown on a larger scale. Below volcanlastic unit S43, the inclination record is highly irregular with two small zones of normal inclinations at about 1115 and 1190 mbsf, respectively. With the exception of dike unit D5, NRM values beneath unit S43 are less than 0.12 A/m.

The larger scatter of low-amplitude remanence and susceptibility values for the lower series cannot be explained by larger measurement errors in connection with the lower amplitudes of remanence and susceptibility, as all magnitudes were well above the noise level of the instruments involved.

From careful examination of demagnetization curves (both thermal and AF) it is obvious that the nature of multicomponent magnetization is different between the upper and lower series. In Figure 4 examples of demagnetization behavior throughout the volcanic section are given using Zijderveld plots and ste-
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Figure 2. Compilation of magnetic data from the volcanic sequence of Hole 642E (mean values for each unit with error bars). Depth in mbsf; flow unit number (from 1 to 121 = flows, from D1 to D7 = dikes, from S4 to S49 = volcaniclastics); stable inclination in degrees; median destructive field (MDF); natural remanent magnetization (NRM) in Gauss (= 4π SI); Q ratio. The boundary between the upper and the lower series is at 1087 mbsf.
Figure 3. Stable inclination, NRM, and Q ratio for the lower volcanic series of Hole 642E (enlarged from Fig. 2).

Reographic projections of remanence directions. Within the upper series, and for dike D5 of the lower series, two directions are typical: a stable reverse direction and a normal direction that is typically demagnetized in AF peak fields of less than 10 mT. For thermal demagnetization, temperatures of less than 300°C are sufficient to destroy the normal NRM component in the upper series.

No stable end values could be found for more than 50% of the samples in the lower series. The series is dominated by the two dikes, D4 and D5, which both have reverse polarities. From magnetic characteristics, D5 resembles the dikes and massive flows of the upper series, whereas D4 has a much lower NRM and a thermal demagnetization pattern that suggests 95% of its NRM is of viscous origin (Fig. 4). From petrological and geochemical investigations (Eldholm, Thiede, Taylor, et al., 1987), the nature of D4 as a dike is now questioned. It has geochemical affinities to the flows of the lower series, and may be a thick flow. Our interpretation, however, is that it is either a dike or sill which intruded into the lower series before the formation of the upper series. The two normal-polarity zones are 15 m and 6 m from the upper and lower contacts of the two dikes, respectively (Fig. 3), and the reverse field flows and volcaniclastics between exhibit shallower inclinations than the dikes. Shallower reverse inclinations occur also for units S44 and F115, sandwiched between the two dikes. From these observations we argue that the lavas between the present normal zones may have been originally normally magnetized until the intrusion of dike D4. This dike possibly fed a flow within the uppermost part of the lower series, and D5 fed a flow in the upper series. Although the thickness of the dikes is not known, evidence from grain-size distributions as well as from magnetic characteristics indicates a width of a few meters. Dikes of this size may be a sufficient heat source to activate water within adjacent sediments and to cause alteration and introduce secondary stable magnetization. For example, from highly altered basalts in eastern Iceland Schönharting and Gisler (1982) reported that remagnetization can affect different parts of flows in highly variable ways and that it can completely mask primary magnetizations. The multicomponent NRM with strongly varying inclination values within the flows and volcaniclastics around dikes D4 and D5 supports the case for remagnetization.

With this assumption we arrive at a normal polarity interval in the lower series of between 1113 and 1194 mbsf. This interval may in fact reach deeper, as the presence of dikes D6 and D7
Magnetic Polarity and Age

A main objective of this study was to clarify the polarity record at Site 642 and to provide a record of stable inclination values to help in correlating the Voring Plateau dipping basalts with the others of the early Tertiary North Atlantic volcanic Province. The upper volcanic series of Hole 642E is of reversed polarity and the lower series is normal between 1113 and 1194 mbsf and possibly reversed above and below this interval.

Constraints on the minimum age of the reversed upper series may be obtained using marine magnetic anomalies (Hageng et al., 1983). Site 642 is situated immediately landward of anomaly 24B (Elldholm, Thiede, Taylor, et al., 1987). Assuming that this part of the magnetic source of anomaly 24B is represented by normally magnetized dipping basalts below anomaly 24B, we can arrive at an age corresponding to polarity chron 24r or older for the reversed upper series at Site 642. The validity of this constraint is strongly dependent on the assumption that the dipping basalts in a section from Site 642 seaward to the first encounter of anomaly 24B become progressively younger. This progression appears to be the case from the more or less continuous seaward thickening of the dipping reflector sequence in seismic sections of this area (Elldholm, Thiede, Taylor, et al., 1987). Therefore a minimum age for the upper series at Site 642 can be proposed within polarity chron 24r.

There are two reasons that this age may be the correct age for the upper series. First, the proximity of Site 642 to marine magnetic anomaly 24B (chron 24.2) does not leave much space to accommodate dipping basalts of chron 24r and 25r in between, allowing an age within 25r for the upper series. Second, middle Eocene and late early Eocene paleontologic ages were reported for the upper and lower series, respectively (Elldholm, Thiede, Taylor, et al., 1987). The apparent discrepancies between the magnetically and paleontologically derived ages would be further increased by assigning the upper series an age older than 24r.

Consequently, the normal polarity zone within the lower series of Hole 642E may be related to polarity chron 25, placing the lower series into the Paleocene with an age at the top of the normal polarity zone of 55.8 Ma using the magnetic polarity time scale of Harland et al. (1982) and of Berggren et al. (1985). But Tarling (1983) assigns this boundary an age of 54 Ma. The younger ages indicated by the fossil record may perhaps be due to paleontologic contamination of the core from overlying sediments. From paleomagnetic considerations alone the interpretation of the normal polarity zone of the lower series to be of chron 25 age is rather ambiguous and may be a minimum estimate.

It is of great interest to compare the ages interpreted for the upper and lower series of Site 642 with those from other areas of the north Atlantic volcanic Province. The upper part of the lower basalt series of the Faeroes, which is petrologically and geochemically similar to the upper series of Site 642, has been correlated by Smythe et al. (1983) with chron 25, while Abrahamsen et al. (1984) correlate the upper series with chron 24r and the deeper part of the lower basalt series with chron 24r. For the almost exclusively reverse polarities of the basalts from the Rockall Plateau (Roberts et al., 1984) and from east Greenland (Asperger et al., 1984), ages corresponding to chron 24r were interpreted. We agree with the interpretation by Roberts et al. (1984), who placed the first phase of voluminous effusive volcanism (the dipping reflectors) of the North Atlantic volcanic Province entirely within chron 24r.

Inclination Variation and Growth Rate of Lava Pile

The stable inclination record of Hole 642E (Fig. 2) records an almost cyclical downhole variation. A total of up to 20 cycles is observed. If one interprets these cycles as secular variations of the Earth's magnetic field and assumes an average length of one cycle to be on the order of 1,000 yr, the total period for building the lavas of the upper series would be about 10 to 100 k.y. Such rapid growth rate exceeds rates from other areas by a factor of 10 to 100. In Iceland, for example, growth rates were found to range from 0.7 km/m.y. to about 4 km/m.y. for the late Tertiary plateau basalts (summarized in Abrahamsen et al., 1984).

A more conservative, but still very high growth rate estimate can be obtained with a model that allows for intermittent lava production, separated by larger periods of quiescence. A detailed comparison between the inclination record and petrologically composite record (Eldholm, Thiede, Taylor, et al., 1987) shows some correlation of inclination cycles with petrologic properties that can be interpreted in terms of intermittent volcanic activity. Detailed rock magnetic studies are needed to pursue this issue further. At this stage, a very rapid lava production for the upper series is strongly indicated.

Cyclical variations of stable inclination have also been noted for the basaltic drilled from the Rockall Plateau (Krumbsiek and Roberts, 1984). A strong similarity for the uppermost 200 to 300 m could be indicative of similar high growth rates.

Inclination and Paleolatitude

To calculate the mean inclination, inclination statistics of Kono (1980) were applied. A mean value of $-67.5^\circ$ lies fairly close to the mean value of $-65.8^\circ$ calculated from the analysis after Stupavsky and Symons (1978). The paleolatitudes were calculated by assuming the mean field to be an axial dipole field.

Apparent paleolatitudes vs. present latitudes for the North Atlantic volcanic Province are shown in Figure 6. Mean values for west Greenland (Deutsch and Kristjansson 1974, Sharma and Athavale 1975), east Greenland (Fallar 1975, Fallar and Spear 1979, Tarling 1967, Tarling and Oulala 1972, Hallwood 1977), Faeroe Islands (Tarling 1970, Abrahamsen et al., 1984), British Isles (Irving 1964, Tarling, 1970) and Rockall Bank
Figure 4. Typical examples of AF- and thermal demagnetization results for flow units F1, F25, and F94, for dike unit D4, and for volcaniclastic unit S44: F1 (Sample 104-642E-16R-1, 131-133 cm), F25 (Sample 104-642E-23R-3, 69-91 cm), F94 (Sample 104-642E-60R-2, 46-46 cm), D4 (Sample 104-642E-100R-2, 26-26 cm), S44 (Sample 104-642E-102R-1, 46-49 cm). (A) Normalized remanence vs. AF-treatment (mT) or thermal treatment (°C). (B) Zijderveld plots. (C) Stereographic projections.
Figure 4 (continued).
Figure 5. Stereographic projection of stable directions from vector analysis of AF-demagnetization (Stupavsky and Symons, 1967). (A) Normal components, (B) reverse components, assuming that the normal component for each sample has zero declination.

(Krumspick and Roberts 1984) are included. A distinct pattern emerges with all areas displaying paleolatitudes lower by 12 to 20° compared to their present latitude. The diagonal in Figure 6 separates farsided from nearsided virtual geomagnetic poles. The farsidedness of the poles for the North Atlantic Volcanic Province cannot be explained by magnetic refraction effects or by minor but systematic dipole offsets as described by Hallowood (1977). It is difficult to visualize large deviations of the geomagnetic field from an axial field over time spans of the order 1 m.y. (Wilson, 1971). We interpret the differences between
CONCLUSIONS

The upper volcanic series of Hole 642E is found to be reversed throughout and was correlated with chron 24r. For the lower series the polarity distribution is fairly complex due to widespread remagnetization effects. A normal polarity zone is widespread throughout and was correlated with chron 25.

From cyclic variation patterns of the downhole stable inclination record a rapid growth rate of the upper series is inferred, exceeding growth rates of, for example, the late Tertiary Icelandic Plateau basalts by an order of magnitude. Further rock magnetic studies and detailed comparison with petrological results are warranted to substantiate this difference.

Polarity and age assignments for the upper series at Site 642, Voring Plateau, compare well with the Rockall Plateau, the Faeroes, and East Greenland, and substantiate that the rifting stage of the North Atlantic opening was related to a surge of voluminous volcanic activity, causing the formation of tholeiitic dipper basalts within a fairly short time span, entirely within chron 24r of the magnetic polarity timescale (Berggren et al., 1985).

Paleolatitude for the Voring Plateau upper volcanic series is about 15° more southerly than its present latitude and falls well within the range of paleolatitudes determined for other areas of the North Atlantic Volcanic Province.

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