38. THE MAGNETIC FABRIC OF NEOGENE AND QUATERNARY SEDIMENTS ON THE FENI AND GARDAR DRIFTS, NORTHEASTERN ATLANTIC, DEEP SEA DRILLING PROJECT SITES 610 AND 611[1]

E. A. Hailwood, Oceanography Department, Southampton University
R. B. Kidd, Institute of Oceanographic Sciences, Wormley, Surrey, United Kingdom
and
L. Dowling, Oceanography Department, Southampton University[2]

ABSTRACT

Determinations of the magnetic fabric of 117 samples of Neogene and Quaternary sediment from DSDP Hole 610B on the Feni Drift and Holes 611, 611C, and 611D on the Gardar Drift reveal near-horizontal magnetic foliation planes in 60% of the samples studied. These are believed to be due either to the partial preservation of original bedding surfaces or to the effects of postdepositional compaction. The majority of these samples have been affected to some extent by bioturbation, but magnetic fabric parameters suggest that the degree of disruption of the original depositional sediment fabric by bioturbation has been greater at Site 611 than at Site 610. Sediments from the three studied holes at Site 611 show highly variable magnetic lineations, probably due to the effects of bioturbation. However, a well-defined E-W magnetic lineation has been identified in upper Pliocene sediments at Site 610 on the Feni Drift, reflecting E-W preferred orientation of long axes of grains at this site. This direction of preferred grain alignment is approximately parallel with the local orientation of sediment wave crests on the surface of the Feni Drift in this region, and appears to relate to the process by which these waves develop in response to the large-scale geostrophic currents responsible for the formation of the drifts.

INTRODUCTION

The magnetic fabric of a sediment provides a measure of the degree and direction of preferred orientation of magnetic mineral grains within it. Magnetic fabric studies have been used to investigate processes operative at the time of deposition in a range of sedimentary environments. Particular styles of magnetic fabric have been shown to be associated with different depositional environments (deposition from still water, deposition in areas with bottom currents of differing strengths, deposition on a slope, etc.; e.g., Hamilton and Rees, 1970b). Ancient and modern environments have been investigated by study of sedimentary rock outcrops (e.g., Hrouda and Janak, 1971; King et al., 1970; Hamilton and Rees, 1971; Hounslow, 1985), DSDP drilled sequences (e.g., Hailwood and Sayre, 1979; Hailwood and Folami, 1985), and soft sediment cores (e.g., Rees et al., 1968; Hamilton and Rees, 1970a; Ellwood and Ledbetter, 1977). Interpretations of these data have been supported by laboratory experiments involving the measurement of samples deposited under controlled conditions in laboratory flume tanks (e.g., Rees, 1966; Hamilton, 1967; Rees and Woodall, 1975; Rees, 1983). These experiments provide some quantification of the influence of parameters such as current speed, angle of slope, grain size, and geomagnetic field influence on the resulting magnetic fabric.

Although much effort has been devoted over the past decade to the investigation of samples from DSDP drilled sequences and other sediment cores, no previous study has focused on the examination of the sediment drift deposits that characterize so much of the North Atlantic floor (Jones et al., 1970; Ruddiman, 1972; Lonsdale, 1982; Kidd and Hill, this volume). The retrieval of Neogene and Quaternary sediment cores from two major sediment drifts, the Feni and Gardar drifts in the northeastern Atlantic, during DSDP Leg 94 has provided the opportunity to carry out such a study. During this leg, use of the Hydraulic Piston Corer (HPC) in offset holes provided nearly continuous high-quality core coverage of upper Pliocene and Quaternary sediments near the crest of the Feni Drift (Site 610) and on the lower southeastern flank of the Gardar Drift (Site 611) (Fig. 1; see also Ruddiman et al., this volume, on sediment disturbance and core correlation). At each of these localities, the sediment drifts are ornamented by large-scale sediment wave fields; the waves have typical amplitudes of several tens of meters and wavelengths of several kilometers. The existence of these bedforms is believed to be related to the major contour-following ocean currents responsible for the development of the sediment drifts themselves. The nature of this relationship is not yet clear, however. At each of the DSDP sites on the Feni and Gardar drifts, holes were drilled both on a crest and in an adjacent trough of a sediment wave.

To contribute to the fine-scale stratigraphy required to realize the primary paleoceanographic objectives of Leg 94, closely spaced paleomagnetic samples were taken throughout these cores. Paleomagnetic analyses of these samples have provided a detailed magnetic reversal

[1] Ruddiman, W. F., Kidd, R. B., Thomas, E., et al., *Init. Repts. DSDP*, 94: Washington (U.S. Govt. Printing Office).
[2] Addresses: (Hailwood and Dowling) Oceanography Department, Southampton University SO9 5NH, United Kingdom; (Kidd, present address, to November, 1986) Ocean Drilling Program, Texas A&M University, College Station, TX.

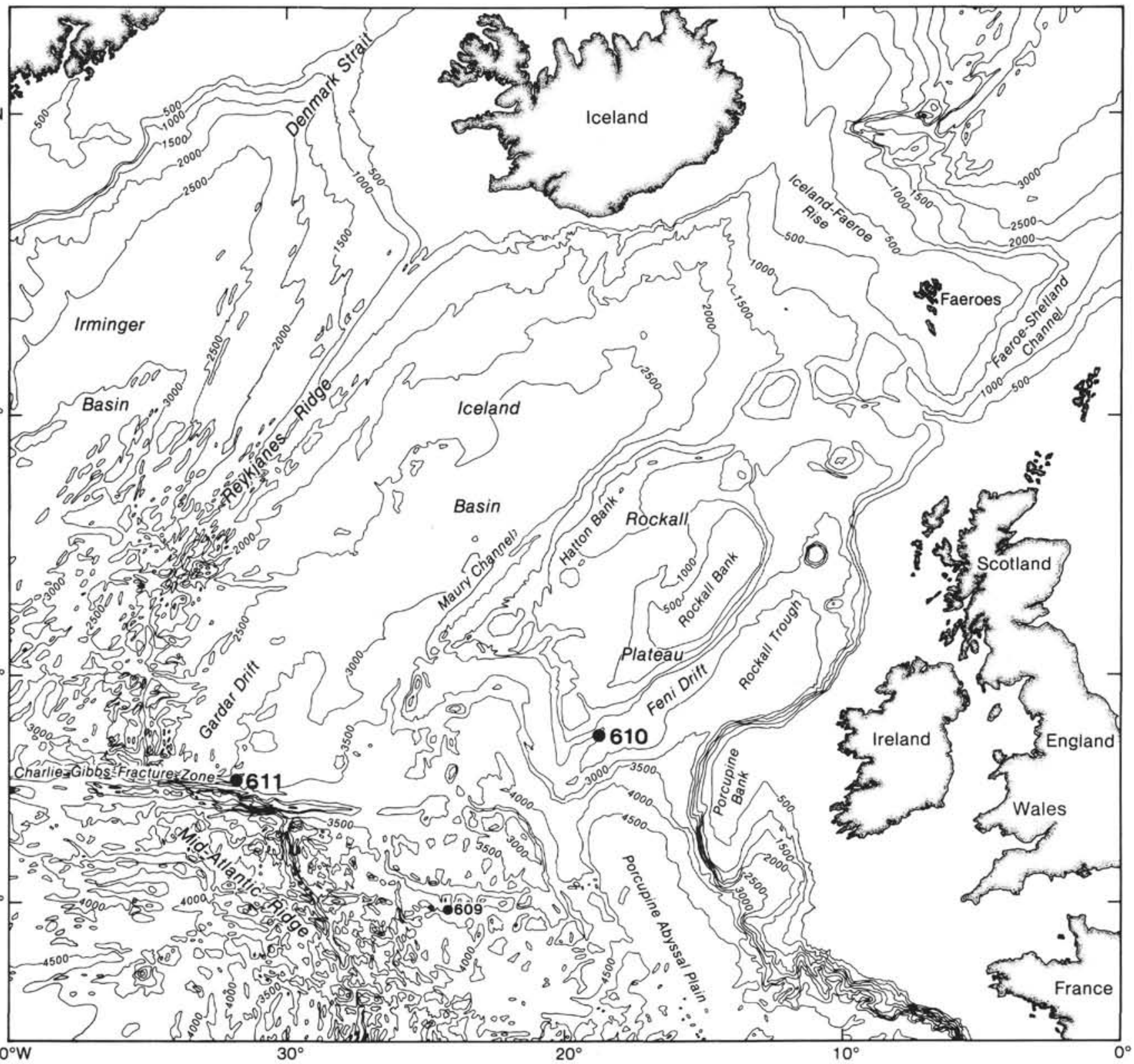

Figure 1. Locations of DSDP Sites 610 and 611.

stratigraphy (Clement and Robinson, this volume). A subset of these samples was selected for the present magnetic fabric study. Geographic reorientation of these samples has been achieved by assuming that the direction of stable remanent magnetism identified in them by Clement and Robinson provides a good approximation of the direction of geographic north at the time of deposition. This procedure for reorienting DSDP cores has been discussed by Hailwood and Sayre (1979).

The principal objectives of this magnetic fabric study were as follows:

1. To investigate whether characteristics of a primary depositional magnetic fabric can be identified in these sediments, and to determine the extent to which such a fabric might have been modified through postdepositional processes such as bioturbation.

2. To ascertain the relationship between any bulk grain-alignment trends identified and factors which might be expected to exert control on these trends, such as the local orientation of sediment wave crests, the position of the site on the wave form (at a crest or a trough), and the likely general orientation of bottom currents.

3. To compare the fabric of preglacial, glacial, and interglacial sediments at each site, and to search for possible influences due to glacially induced changes in bottom-water flow.

MAGNETIC FABRIC DETERMINATIONS

Magnetic fabric analyses provide a rapid and convenient way of specifying, in three dimensions, the bulk alignment of magnetic mineral grains within a sediment sample. Comparative studies of magnetic and optical fabric determinations (e.g., Taira and Lienert, 1979) have confirmed that the preferred alignment of the magnetic grains in a sediment usually is closely similar to that of the nonmagnetic grains (quartz, felspar, calcite, etc.). Particular advantages of the magnetic fabric method are the great speed of measurement (typically ~30 min. for a complete determination on one sample) and the fact that the magnetic fabric reflects the integrated effect of preferred grain alignment over the whole volume of the sample (typically ~10 cm^3), rather than over restricted segments of orthogonal sectioning planes.

Magnetic fabric determinations involve measurements of the variation of magnetic susceptibility with direction (susceptibility anisotropy) in the sample. These small susceptibility differences can be sensed by means of a high-sensitivity torque magnetometer (e.g., King and Rees, 1962) or a spinner magnetometer (e.g., Noltimier, 1971). For the present study a torque magnetometer has been used, operating at an applied field of approximately 10 mT. r.m.s. (milliTeslas, root mean square value).

If magnetite or other appropriate ferromagnetic iron oxide grains are present within the sediment, then any preferred shape alignment of these grains will tend to dominate the magnetic fabric, because of the relatively high susceptibilities of these grains. However, in the absence of such ferromagnetic minerals (or if their concentrations are extremely low), the magnetic fabric is likely to be controlled instead by the shape alignment of more weakly susceptible paramagnetic minerals such as chlorite and clay minerals (Hounslow, 1984 and 1985).

The magnetic fabric of a sample is conveniently expressed in terms of the shape and orientation of a triaxial susceptibility ellipsoid. The direction of the minimum susceptibility axis (K_{min}) will be parallel to the direction of preferred orientation of the short axes of the grains. The gravitational couple exerted on grains during deposition causes their long axes to lie close to horizontal and their short axes to be nearly vertical. Thus, in a sediment showing a primary (depositional) style of magnetic fabric, the K_{min} axes for different samples will tend to group close to the paleovertical. Laboratory experiments (summarized by Hamilton and Rees, 1970b) indicate that in such primary fabrics the angle between K_{min} and the vertical is normally less than about 25°.

The direction of the maximum susceptibility axis (K_{max}) of a sediment sample will be parallel to the direction of preferred alignment of the long axes of grains in that sample. Laboratory experiments indicate that, for deposition of coarse silt and sand from simple unidirectional currents, the K_{max} axes are commonly grouped close to the flow azimuth (e.g., Rees, 1961; Hamilton, 1967). However, under certain circumstances—for example, in a concentrated dispersion of grains, when the separate grains interact with each other—an alignment of K_{max} axes transverse to the flow direction may result (Rees, 1983).

The third orthogonal axis of the susceptibility ellipsoid is the intermediate susceptibility axis (K_{int}), and the relative magnitudes of these three principal susceptibility axes determine the shape of the susceptibility ellipsoid. This shape may be expressed in terms of the anisotropy quotient q, representing the ratio of magnetic linear to magnetic foliar elements, where

$$q = \frac{2(K_{max} - K_{int})}{K_{max} + K_{int} - 2K_{min}} \tag{1}$$

A further useful parameter is the percent anisotropy, $h\%$, defined by

$$h\% = \frac{K_{max} - K_{min}}{K_{int}} \times 100 \tag{2}$$

Laboratory redeposition experiments indicate that primary-style magnetic fabrics are commonly represented by fairly uniform q values in the range 0.06 to 0.67 (Hamilton and Rees, 1970b), whereas secondary-style fabrics often show more erratic q values, which are commonly outside this range.

In the present study, primary-style samples have been identified using the following two criteria: (1) K_{min} axis within 25° of the vertical; (2) q value in the range 0.06 to 0.67.

An additional acceptability criterion used was that the mean deflection on the torque magnetometer should exceed the level at which instrumental noise significantly interferes with the results. The mean amplitude (MA) of the torque curve was calculated for each measurement, and determinations for which MA $<$ 0.2 mm were rejected on the grounds of potential unreliability.

Selection of Samples

For this magnetic fabric study, samples were selected from zones in the cores which showed minimal effects of drilling disturbance (see Ruddiman et al., this volume). Primary (hydrodynamically induced) sedimentary structures are rare in these sediments, though, probably because of extensive bioturbation. Zones of heavily bioturbated sediment were avoided as far as possible, but some possibly significant biogenic modification of the original primary magnetic fabric is likely throughout much of the sequence sampled.

The distribution of samples in the four holes investigated is shown in Table 1.

Table 1. Total numbers of samples studied from each hole and numbers passing the three acceptability criteria for reliable magnetic fabric determinations (discussed in the text).

	Number of samples investigated		Number passing acceptability criteria	
Hole	Preglacial	Glacial/ interglacial	Preglacial	Glacial/ interglacial
610B	0	14	0	10
611	10	23	10	14
611C	14	12	10	7
611D	44	0	21	0

Results

It is evident from Table 1 that, despite the significant levels of bioturbation in these cores, about 60% of the samples studied satisfy the acceptability criteria already outlined. The samples satisfying these criteria all display near-horizontal (gravitationally controlled) magnetic foliations, defined by near-vertical K_{min} axes. The orientations of the corresponding magnetic lineations, defined by the azimuths of the K_{max} axes, are plotted in the form of rose diagrams (circular histograms) in Figure 2. Excepting Hole 610B, these results all show a high degree of variability, and no consistent single preferred orientation of K_{max} axes can be defined for any of the three investigated holes at Site 611. It is believed that the only hole showing a geologically meaningful preferred grain alignment is Hole 610B, for which a clear E–W trend is evident.

Histograms showing the distributions of q values and $h\%$ values for the four holes are plotted in Figure 3. A comparison of the distributions for Hole 610B with those for Holes 611, 611C, and 611D suggests two possibly significant differences:

1. A higher proportion of samples from Hole 610B show q values less than 0.67, in the range normally associated with primary-style fabrics.

2. Whereas samples from Holes 611, 611C, and 611D show percent anisotropy distributions with a peak in the range 1 to 2% and values ranging up to a maximum of 3 to 5%, the values for Hole 610B are more widely distributed and range up to a maximum of 7%.

This tendency for a higher proportion of samples from Hole 610B to show primary-style fabrics, and for the degree of anisotropy in samples from this hole to be somewhat higher than in the other three holes, is believed to reflect a generally lower level of bioturbation in Hole 610B. We conclude that the well-developed E–W magnetic lineation in this hole (Fig. 2) probably represents a primary grain alignment, produced by depositional processes, whereas the higher dispersion of magnetic lineation axes in samples from Holes 611, 611C, and 611D may be attributed to the effective destruction, by bioturbation, of any original depositional lineation in the fabric of sediments in these holes.

DISCUSSION

Owing to the apparent absence of geologically meaningful grain-alignment trends in both glacial and postglacial sediments at Site 611, it is not possible, with the existing data, to address the question of possible influences of glacially induced changes in bottom-water flow on the sediment fabric. Nor is it possible to draw mean-

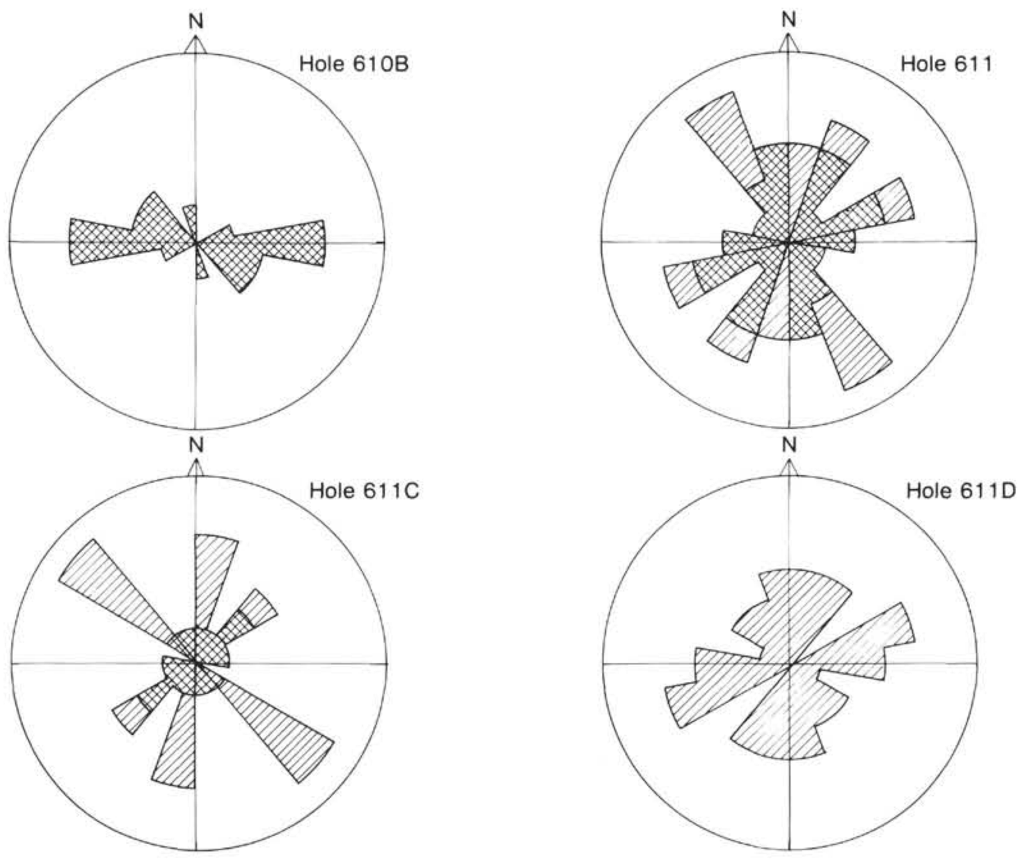

Figure 2. Rose diagrams giving the azimuthal distribution of K_{max} axes for samples showing primary-style fabrics from Holes 610B, 611, 611C, and 611D. North is determined from the stable paleomagnetic remanence in the samples. Single hachure = preglacial sediments; cross hachure = glacial sediments.

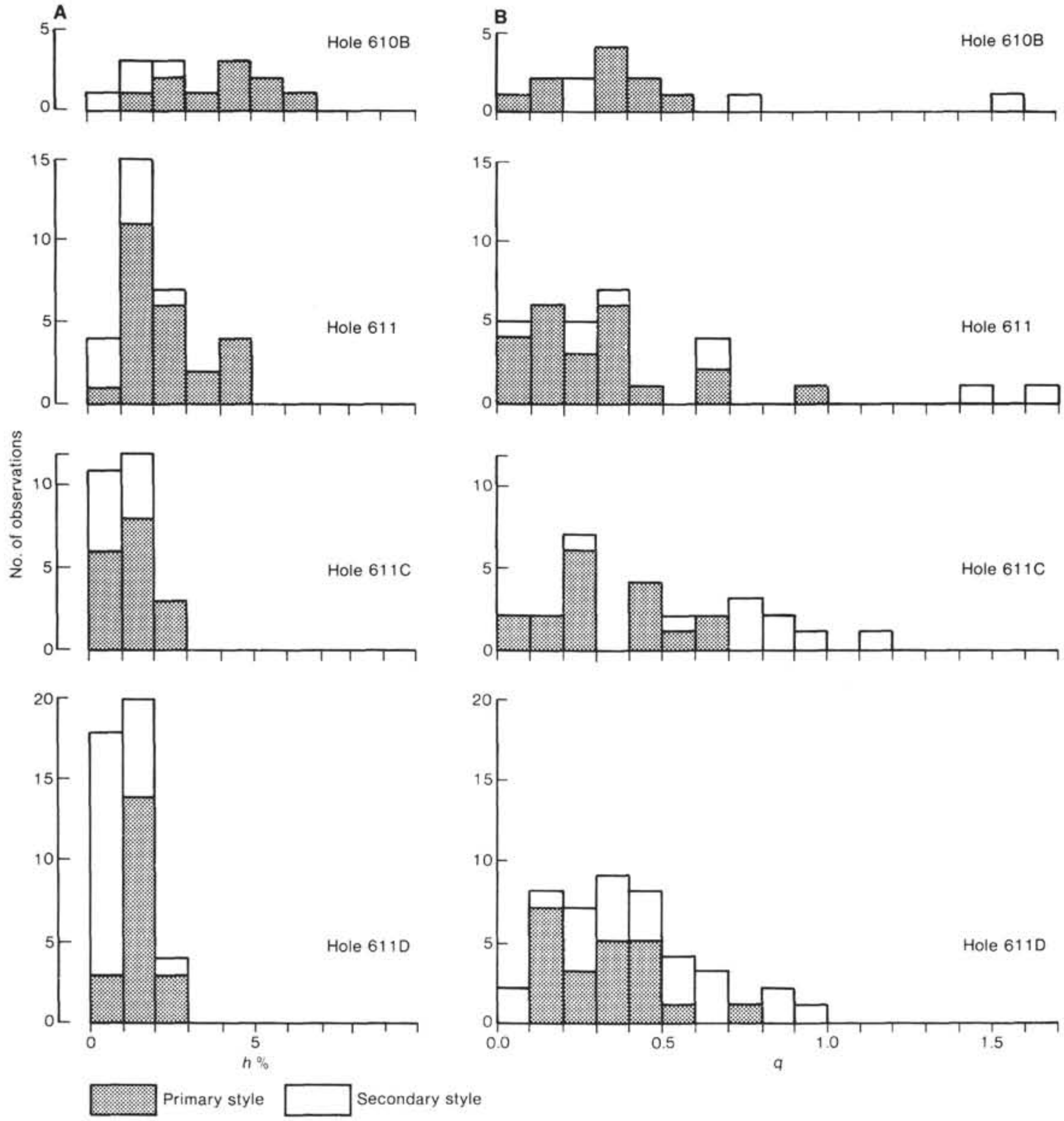

Figure 3. Histograms of (A) percentage anisotropy ($h\%$) values and (B) q values for all samples investigated, grouped according to hole.

ingful conclusions about differences between the grain alignment of sediments at the crest of a sediment wave (Hole 611) and that of sediments at a trough (Hole 611C).

The sediments from Hole 610B, in which the well-defined E-W grain-alignment trend is present, are all younger than the onset of glaciation in this area (~2.4 Ma). Consequently, as at Site 611, it is not possible to investigate influences of glacially induced water-flow changes at this site. But the E-W grain alignment in these sediments may be significant in understanding sediment transport processes within these drift deposits. The samples showing this trend in Hole 610B are mainly from Cores 13 to 15, and are of late Pliocene age. This grain-alignment trend is approximately parallel with the present axis of the sediment wave crests in the vicinity of this site. Thus, it appears that there may be a direct relationship between the trend of the grain alignment and that of the sediment waves, and that the present alignment of the wave crests may have persisted since the late Pliocene, confirming the long-term stability of the processes responsible for shaping these major sediment drifts.

Very few studies have examined grain-alignment trends within sediment waves. Recently, however, alignments transverse to inferred current flow (i.e., parallel with wave crests) have been noted for small-scale ripple marks associated with oscillatory wave motions in ancient sandstones (Hounslow, 1984). The apparent identification of a similar geometry in the much larger-scale sediment waves at the crest of the Feni Drift may be significant in explaining the relationship of these waves to the movement of the major water masses responsible for their formation. Further grain-orientation studies, both of major wave fields on sediment drifts and of smaller-scale structures possibly having a related origin, such as sand waves and mud waves on continental shelves, are called for to improve understanding of these processes.

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