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SEISMIC EVIDENCE FOR EARLY TERTIARY BOTTOM-CURRENT CONTROLLED DEPOSITION IN THE CHARLIE GIBBS FRACTURE ZONE

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ABSTRACT

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Buried, mounded and acoustically transparent sediment bodies banked up against a basement ridge at the eastern end of the Charlie Gibbs Fracture Zone are interpreted as a type of contourite drift. As they are probably of Eocene—?Palaeocene age, their origin has implications for the little-known deep circulation pattern in the NE Atlantic during this period. Possible sources for the bottom currents responsible for these drifts include Labrador Sea Water, Norwegian Sea Overflow Water, Antarctic Bottom Water or a Gulf Stream deep gyre system. The preferred source is an early development of Antarctic Bottom Water or an arm of a Gulf Stream Gyre flowing eastwards through the fracture zone.

INTRODUCTION

The present-day pattern of deep-water circulation in the northern North Atlantic (35°—65°N) is known in some detail from direct observations on the properties and velocities of water masses at specific locations (e.g. Shor et al., 1980) and by inferences drawn from the mapping of current-controlled bottom deposits (Jones et al., 1970; Stow, 1982). From the latter, coupled with micropalaeontological studies, it has been suggested that deep circulation began with a major influx of Antarctic Bottom Water (AABW) 40 Ma ago and was subsequently greatly influenced by the overflow of Norwegian Sea Water (NSOW) from about 20 Ma ago (Roberts, 1975; Schnitker, 1980; Stow, 1982).

Further back in time, circulation was probably less vigorous and the evidence for it is weaker. For much of its Mesozoic history the northern North Atlantic appears to have been too small and without access to polar-cooled waters for the development of a marked deep circulation (Schnitker,

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1980). Over the Palaeocene—Eocene period some forerunners of the present bottom currents may have been present, but there is disagreement in the literature as to the likely circulation pattern. Berggren and Hollister (1977), for instance, following many earlier workers, believe that western boundary undercurrents were flowing southwards off the United States as a result of the initial opening of the North Atlantic to the cold waters of the Arctic region, but Schnitker (1980) claims that this northern 'big flush' did not occur. Schnitker suggests, on the other hand, that there may have been deep-water supply from the south during the middle Eocene.

It is the Eocene (and ?Palaeocene) period of relatively poorly known deep circulation that concerns us here. Sedimentary features of probable Eocene—?Palaeocene age have been observed on seismic records at the eastern end of the Charlie Gibbs Fracture Zone (CGFZ; 52.3°N, 17.6°W; Fig. 2) which are interpreted as contourite drifts deposited under the influence of deep-water circulation. To our knowledge, the recognition of buried contourites on seismic reflection records has not previously been documented in the literature (Scrutton and Stow, 1981, unpublished). Such features are important for the reconstruction of deep circulation patterns in the geological past.

SEISMIC DATA AND INTERPRETATION

A survey of the eastern termination of the CGFZ carried out in 1980 from RRS "Challenger" using a 4.9 l air gun and two-channel hydrophone array revealed two large sedimentary features banked up against the major basement ridge of the fracture zone. The larger feature was crossed twice on profiles that intersect over its crest. It is also seen on an adjacent seismic profile of the Institute of Oceanographic Sciences, U.K. (D.G. Masson, pers. commun., 1982), but is not seen on the next profile to the west, 60 km away. In Fig. 1 both features are seen to be domed, 600—800 m high (assuming a velocity of 2 m ms^{-1} in the sediments), probably oval in shape with a mean width of about 6—10 km, and acoustically transparent with the seismic system used.

By analogy with the acoustic characteristics, shape and morphological setting of known modern contourites, the features are interpreted as contourite drift. Specifically, they are thought to be drifts of a type that is highly mounded, of limited linear development, and found banked up against rugged basement features such as seamounts. Such characteristics are in contrast to those of the less mounded, asymmetrically laminated type of contourite described by Sangree and Widmier (1977).

A literature search suggests that there is a spectrum of acoustic characteristics for contourite drifts that reflects bathymetric location, sediment type and current strength. Relatively weak currents carrying a low concentration of very fine grained material may construct either low-mounded, very elongate drifts far from land (e.g. Gardar, Feni and Hatton

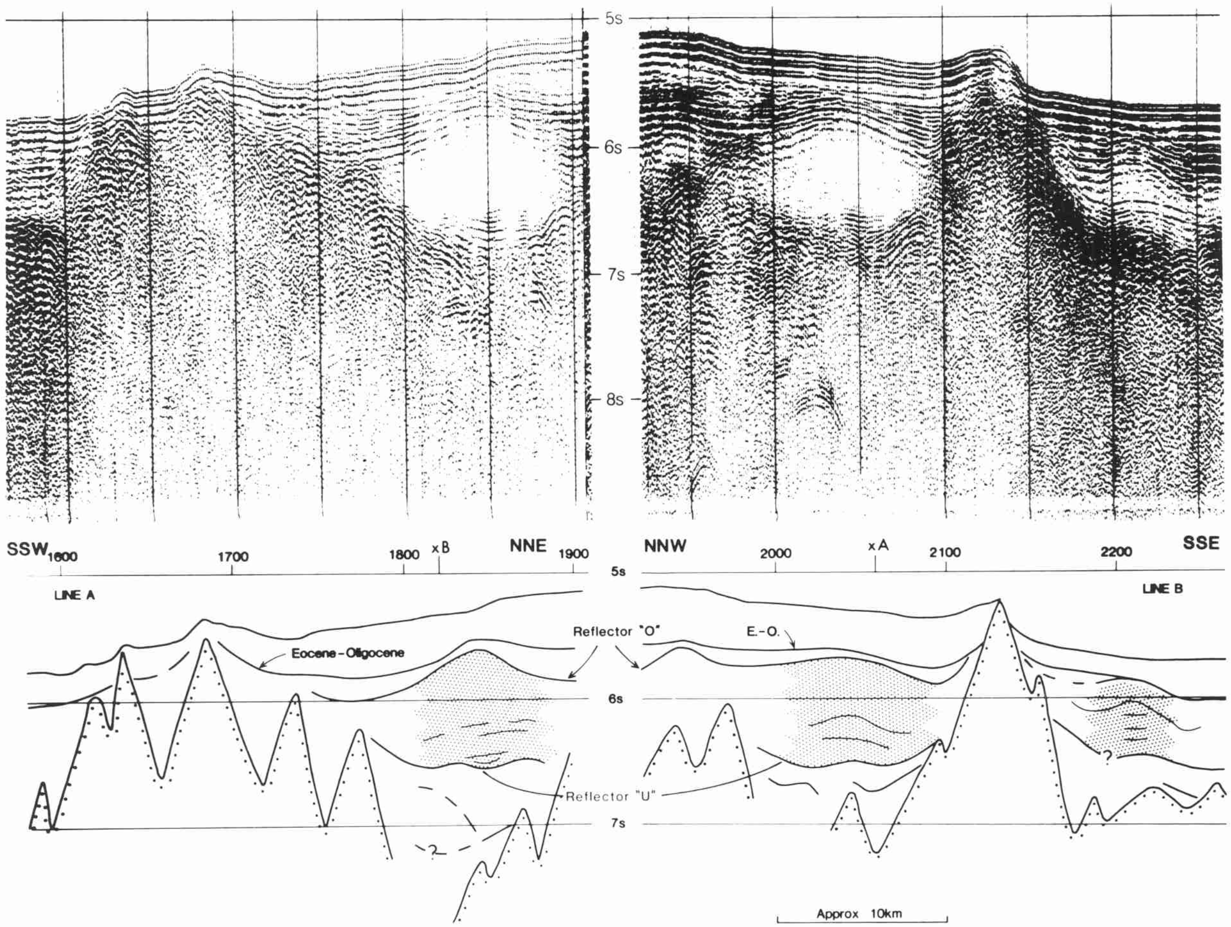
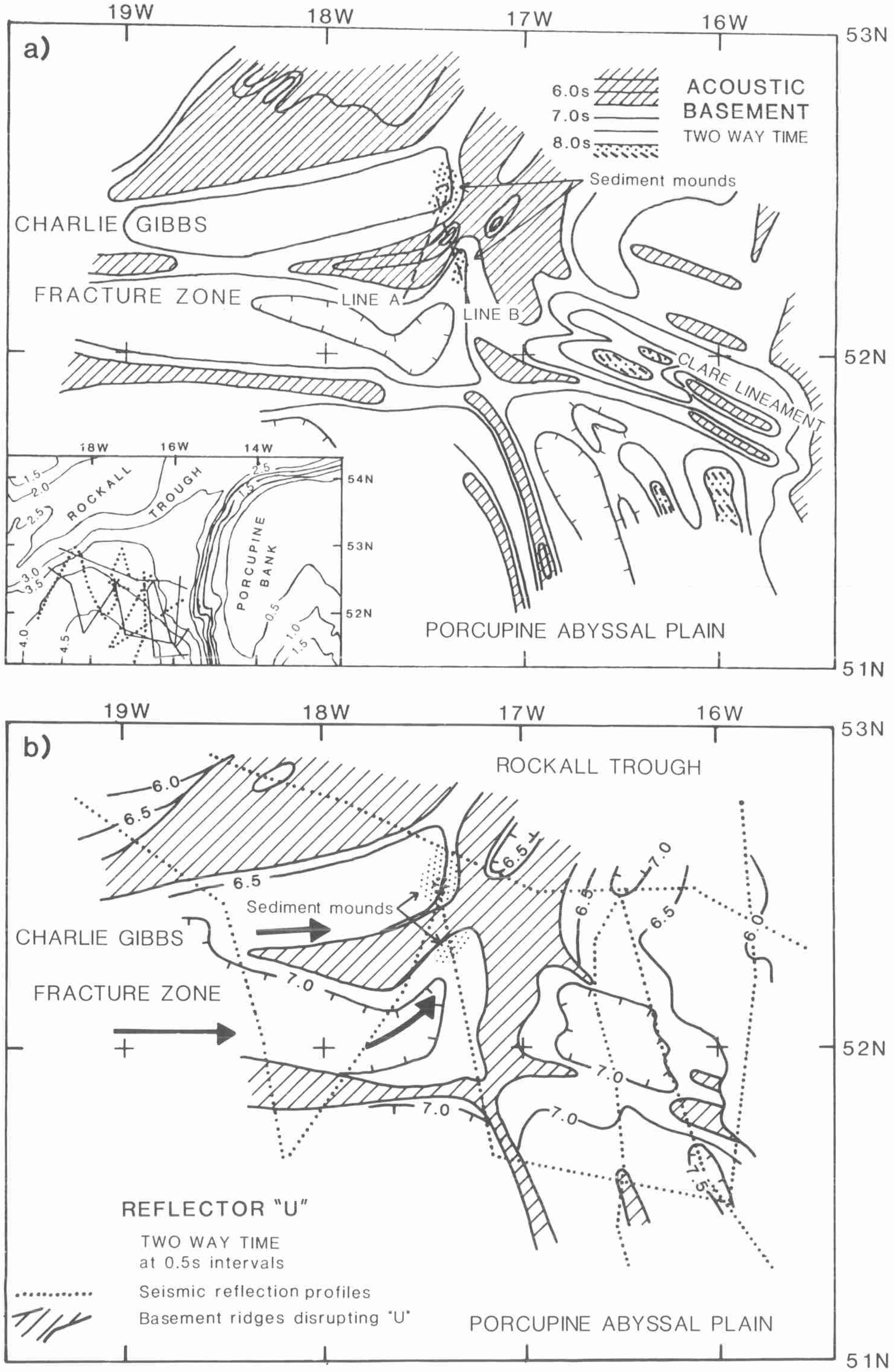


Fig. 1. Seismic reflection records and schematic interpretation of lines A and B in Figure 2a. Stippled pattern corresponds to acoustically transparent sediment mounds. Vertical scale, seconds of two-way travel time.


a)
19W
18W
17W
16W
53N
52N
51N
6.0s
7.0s
8.0s
ACOUSTIC
BASEMENT
TWO WAY TIME
Sediment mounds
CHARLIE GIBBS
FRACTURE ZONE
LINE A
LINE B
CLARE LINEAMENT
PORCUPINE ABYSSAL PLAIN
18W
16W
14W
54N
53N
52N
ROCKALL
TROUGH
PORCUPINE
BANK
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0.5
1.0
b)
19W
18W
17W
16W
53N
52N
51N
ROCKALL TROUGH
6.0
6.5
7.0
7.5
Sediment mounds
CHARLIE GIBBS
FRACTURE ZONE
REFLECTOR "U"
TWO WAY TIME
at 0.5s intervals
Seismic reflection profiles
Basement ridges disrupting "U"
PORCUPINE ABYSSAL PLAIN

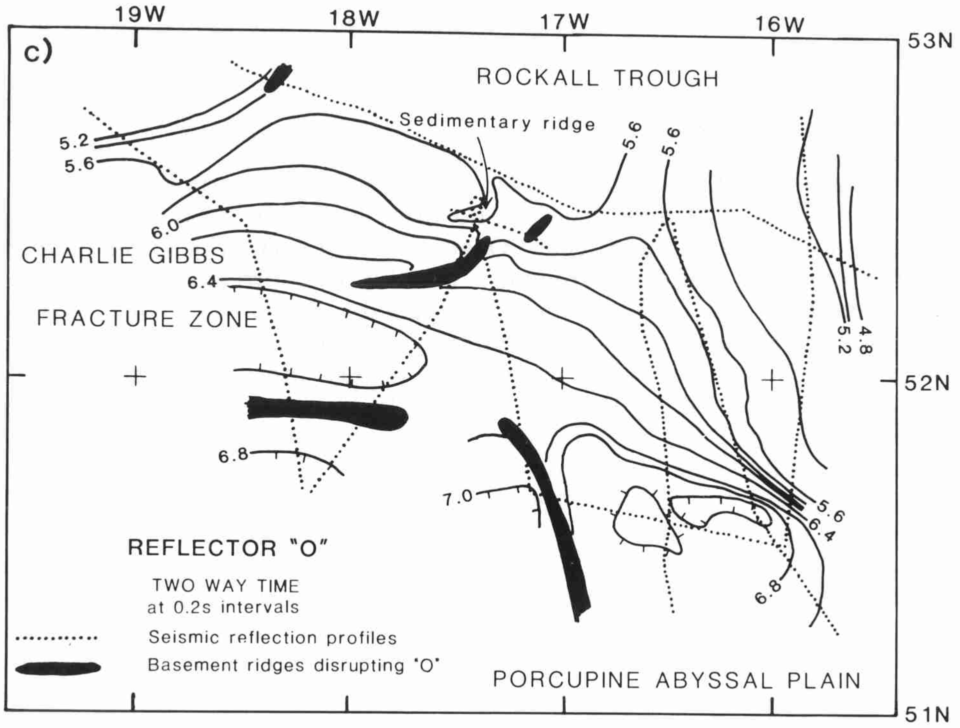


Fig. 2. *a*. Isochron map of acoustic basement at the eastern end of the Charlie Gibbs Fracture Zone, NE Atlantic. Inset shows location of area on NW European continental margin and coverage of seismic profiles used to compile the map: solid lines, Edinburgh University profiles; dotted lines, from Roberts et al. (1981). *b*. Isochron map of reflector U on which the sediment mounds (contourites) were built. See footnote in text. Heavy arrows indicate the likely flow direction of the currents forming the mounds. Dotted lines are locations of seismic profiles used to compile the map. *c*. Isochron map of reflector O, the top surface of the sediment mounds. Dotted lines are locations of seismic profiles used to compile the map.

Drifts in the NE Atlantic; Davies and Laughton, 1972), or highly domed, oval and irregular drifts where they are locally slowed by rough topography (e.g. Gilliss Seamount, NW Atlantic; Taylor et al., 1975). The latter are acoustically transparent probably due to lack of seismic velocity contrasts within the sediment or to the lack of a well-structured interior. Stronger currents of variable velocity and a higher concentration of mixed-grade sediment seem able to construct more acoustically strongly laminated drifts that are also low-mounded and elongate (e.g. Faro Drift, Gulf of Cadiz; Mougenot and Vanney, 1982; Faugères et al., 1984). Intermediate between these two types are moderately well-laminated elongate drifts that protrude from the continental margin (e.g. Blake—Bahama Outer Ridge, western North Atlantic; Hollister, Ewing et al., 1972), or that form as more irregular lobate mounds associated with narrow passageways or straits (e.g. Samoan Passage drifts; Hollister et al., 1974).

Age control on the presumed contourite drifts in the CGFZ is provided by correlating the top and bottom reflectors to seismic events of known age in the NE Atlantic. Reflector R4 (Roberts, 1975), a prominent reflector thought to be of Middle Eocene—Oligocene age, passes over the top of the drifts, and the top surface of the drifts themselves appears to be the correlative of the slightly older reflector X of Roberts et al. (1981). This event is called O here. There is no firm age for O (X) but it must be of an age also close to the Eocene—Oligocene boundary. The lower boundary of the drifts is called U here and is possibly the correlative of reflector Y of Roberts et al. (1981) which is assigned a 52—55 m.y. age, that is close to the Palaeocene—Eocene boundary. However, because of the difficulty in tracing U across basement highs, it may alternatively be the correlative of reflector Z of Roberts et al. (1981), which is probably close to the Cretaceous—Tertiary boundary. The contourite deposits are therefore most probably of Eocene age, and may be older in part.

To understand the regional setting of the presumed contourite drifts, isochron maps have been compiled for the acoustic basement, reflector U*, and reflector O (Fig. 2). The drifts are built on the northwest and southeast sides of a northwards bend in the main basement ridge of the CGFZ, where the facture zone comes to an end at 17.4°W. The ridge peaks at 5.3 s TWT (two-way time; all times quoted subsequently are two-way times), but much of it is just above the 6.5—6.6 s to the base of the contourite deposit (reflector U). The sill depth on the ridge appears to be only 6.0—6.5 s, while the sediment drifts are built to a height of 5.5—5.6 s. The continuation of the drift-building process above the sill depth may indicate that the presence of nearby shallower, complex basement topography was sufficient to slacken and/or divert the current flow and cause it to deposit its sediment load. Mapping reflector O brings out the troughs that occur between the drifts and the basement ridge, a typical feature of contourite deposits (Davies and Laughton, 1972), and suggests that the northern drift should be seen on the northernmost seismic profile included in the contouring. An inspection of this profile reveals an acoustically transparent interval at the correct depth but only a hint of the mounded shape seen clearly just to the south.

The CGFZ itself is an east—west structure of Upper Cretaceous and younger age with troughs north and south of the main basement ridge at 52.3°N. Both of the troughs are flanked on their other sides by shallower basement; to the north is a plateau area in the mouth of Rockall Trough, and to the south is a narrow ridge. Other elements of the base-

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*Note that at the sediment mounds reflector U is the top of a package of strong reflectors that is acoustically very similar to Z (ca. Cretaceous/Tertiary boundary) of Roberts et al. (1981). It is thought that it is in fact Z that is contoured in Fig. 2b but difficulty in correlating across basement ridges, particularly the one at 17°W, may mean that Z has been contoured to the east, but Y, a slightly younger event has been contoured to the west of 17°W.

ment topography are the NE—SW ridges and troughs of Rockall Trough, the NNW—SSE ridges and troughs of the Porcupine Abyssal Plain, and the WNW—ESE ridges and troughs of the Clare Lineament (Scrutton and Megson, in prep.). The drift deposits occur at the break in trend from E—W (CGFZ) to WNW—ESE (Clare Lineament).

EARLY TERTIARY BOTTOM CURRENTS

Although it is generally accepted that bottom water circulation in the North Atlantic during the late Cretaceous was negligible, due to the small size of the ocean basin and lack of marked thermal gradients (Schnitker, 1980; Cool, 1982; Barron and Washington, 1983), there is mounting evidence for the onset of thermohaline circulation during the Palaeogene. In order to explain certain palaeoceanographic features, different authors have invoked the existence of precursors to the five main present-day bottom current systems in the North Atlantic—the Norwegian Sea Overflow Water (NSOW), the Labrador Sea Water (LSW), the Western Boundary Undercurrent (WBUC), the deep Gulf Stream Gyres (GSG), the Antarctic Bottom Water (AABW) and a local Northeast Atlantic Deep Water gyre (NEADW).

Roberts (1975) noted pre-Oligocene (pre-R4 seismic reflector) sediment thickening on the Reykjanes Ridge and Jones et al. (1970) noted a similar feature in the Labrador Sea. These authors suggested an early development of the NSOW or LSW systems, while Berggren and Hollister (1977) extended this to include a proto-WBUC off the east coast of North America. However, Schnitker (1980) argues that the Labrador Sea was too far south for significant surface cooling, and the Norwegian—Greenland Seas were still isolated by a shallow sill, so that deep cold water could not escape to the south.

Schnitker (1980) favours the existence of a proto-AABW creeping northwards through the North Atlantic during the Eocene, whilst the onset of a stronger AABW system probably did not occur until the Neogene development of a significant Antarctic icecap (Ciesielski et al., 1982). The Gulf Stream is also known to have had a relatively long history with the beginning of major northeastward flow across the North Atlantic from the Paleocene—early Eocene (Pinet et al., 1981). Deep-water current gyres associated with the Gulf Stream are known from the Newfoundland Basin in the Neogene (Laine and Hollister, 1981).

In the Rockall Trough, Eocene sediment distribution suggests sediment dispersion by bottom currents flowing from the north parallel to the flank of Porcupine Bank and perhaps also along the flank of Rockall Bank on the northwest side of Rockall Trough (Dingle et al., 1982). The origin of this current system is unclear, although it may have been some kind of proto-NEADW gyre.

We suggest that the dome-shaped drifts identified at the eastern end of the CGFZ were constructed by an early Tertiary bottom current that was slowed by the change in trend of basement topography in this region. Judging from the regional setting, the current could have been flowing either southwards from Rockall Trough via the acoustic basement low at 52.7°N, 17.4°W or eastwards through the CGFZ. Each of the current systems discussed above could have extended into the area, and the oceanographic arguments for their existence seem to us equivocal. The fact that the smaller drift at 52.3°N, 17.3°W is banked up against a ridge to the north (Fig. 2b) suggests a current flow from the south or west through the CGFZ, rather than from the north via Rockall Trough. The larger drift could also have been constructed by a northern arm of the same current. Indeed, it has been suggested (Le Pichon et al., 1971) that the fracture zone is nowadays the site of eastward flowing bottom currents. If we agree with Schnitker (1980) that the Labrador Sea was too far south to act as a source of cold deep water, then the most likely current systems to find their way through the CGFZ to its eastern end are a proto-AABW or proto-GSG. Too little is known about the origin and nature of the NEADW circulation or possible eastern boundary currents at the present day (Swallow et al., 1977) to allow us to speculate on a possible Palaeogene equivalent.

CONCLUSIONS

The pre-Oligocene deep-water circulation pattern in the North Atlantic is poorly known. It is therefore noteworthy that probable Eocene—?Palaeocene contourite drifts have been recognised at the eastern end of the Charlie Gibbs Fracture Zone (CGFZ). They are of a strongly mounded, acoustically transparent type and appear to have been deposited by a bottom current flowing eastwards through the CGFZ. Possible sources of this current include Labrador or Norwegian—Greenland Sea Water, but it is more likely that a proto-Antarctic Bottom Water or deep-water gyre system associated with the Gulf Stream existed. More observations of fossil contourite drifts of this kind on seismic records would help us to further constrain paleocirculation patterns in the deep North Atlantic.

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