Middle Pleistocene glacial and glaciomarine sedimentation in the west central North Sea

MARTYN S. STOKER AND ALISTAIR BENT

BOREAS

Stoker, Martyn S. & Bent, Alistair 1985 12 01: Middle Pleistocene glacial and glaciomarine sedimentation in the west central North Sea. *Boreas*, Vol. 14, pp. 325–332. Oslo. ISSN 0300-9483.

A sequence of Middle Pleistocene (approximately early 'Cromerian Complex') sediments has been subdivided into subglacial, proximal glaciomarine, distal glaciomarine and marine facies. The subglacial facies represents lodgement till deposited during the final stages of ice-sheet advance. At the onset of ice-sheet retreat, streams deposited their load into a shallow-water glaciomarine environment; gravelly sediments immediately in front of the ice-grounding line and finer material, in suspension, to more distal areas. Ice-rafting, slumping and traction currents were also active within the glaciomarine environment. The lithofacies characteristics of this sequence are consistent with deposition from a grounded tidewater ice-sheet. The glacigenic succession is restricted to the Forth Approaches area, which implies that the ice-sheet had a limited offshore extent.

Martyn S. Stoker, British Geological Survey, Murchison House, West Mains Road, Edinburgh, EH9 3LA, Scotland; Alistair Bent, Grant Institute of Geology, University of Edinburgh, Kings Buildings, West Mains Road, Edinburgh, Scotland; 1st October, 1984 (revised 6th February, 1985).

The possible existence of pre-Weichselian Quaternary sediments in the central North Sea was first suggested by Jansen (1976). This was disputed by Holmes (1977) who, on the basis of radiocarbon age dates, assigned the bulk of the Quaternary sequence to the Weichselian glacial stage. However, more recent detailed stratigraphic work by Jansen *et al.* (1979), Jansen & Hensey (1981) and Stoker *et al.* (1983; in press a, b) has confirmed the original conclusion that a more extensive Pleistocene sequence exists in the central North Sea.

In the western part of the central North Sea, the Forth Approaches area (Fig. 1), the only previously recorded glacial and glaciomarine sediments are of late Weichselian age (Thomson & Eden 1977). In this paper we present stratigraphic and sedimentological evidence for an early Middle Pleistocene ice-sheet in the vicinity of the Forth Approaches. This combines regional stratigraphic data (Stoker *et al.* in press b) with a sedimentological analysis and facies interpretation of nine boreholes. In view of their age and spatial setting, these sediments enable us to compare the offshore extent of this ice-sheet with the Late Weichselian ice-sheet.

Stratigraphic setting

The sediments described in this paper belong to the Aberdeen Ground Formation, previously called the Aberdeen Ground Beds (Holmes 1977), which is the oldest proven Quaternary unit in the central North Sea (Fig. 2). This formation occurs mostly at subcrop below younger Quaternary formations and forms an easterly thickening wedge-shaped unit, at least 130 m thick in the eastern part of the central North Sea. Its areal extent and western subcrop limit are shown in Fig. 1.

In the west, the base of the formation rests with angular unconformity on rocks of Palaeozoic, Mesozoic and Tertiary age. To the east, as the sequence thickens, the base becomes obscured on seismic records by multiple reflections and cannot be identified at present. The top of the formation is marked by a distinct irregular erosion surface, and is unconformably overlain by the Ling Bank Formation (formerly Lower Channel Deposits of Holmes (1977)), although younger formations come on to the west.

A Lower to Middle Pleistocene age for the Aberdeen Ground Formation was suggested by a palaeomagnetic study which identified the Brunhes/Matuyama palaeomagnetic boundary in this unit (Stoker *et al.* 1983). This has generally been taken to mark the Lower/Middle Pleistocene boundary (Butzer & Isaac 1975) and has been placed towards the base of the 'Cromerian Complex' (Zagwijn 1979). Estimates of the age of this boundary vary from 0.73 Ma (Mankinen & Dalrymple 1979) to 0.79 Ma (Johnson 1982). The existence of Lower and Middle Pleistocene

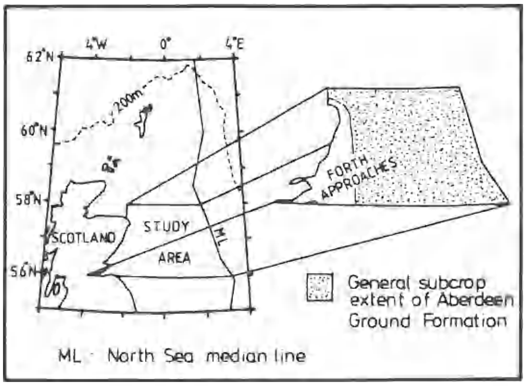

Fig. 1. Location of study area and subcrop extent of the Aberdeen Ground Formation in the central North Sea.

strata has subsequently been confirmed by amino-acid geochronology (Brigham-Grette & Sejrup 1984), and micropalaeontological data which have identified sediments as old as Tiglian in age (Stoker *et al.* in press b). The overlying Ling Bank Formation includes a rich interglacial marine fauna and flora (Stoker *et al.* in press b) and macrofossils of the freshwater plants *Potamogeton* sp. and *Azolla filiculoides* (Griffin 1984). *A. filiculoides* has not been recorded in sediments younger than Holsteinian in age in Britain or north-west Europe (Godwin 1975). The interglacial has thus been correlated with the Holsteinian and the erosion surface at the top of the Aberdeen Ground Formation is most probably of late Elsterian age.

The Lower Pleistocene part of the Aberdeen Ground Formation consists predominantly of bioturbated marine muds with occasional interbedded sands which were deposited in a temperate to boreal, inner to middle shelf environment. Just above the Brunhes/Matuyama boundary the sediments and microfossils in the upper part of the Aberdeen Ground Formation contain the earliest indications of fully glacial climatic conditions in the central North Sea. In the study area, a thin wedge of glacigenic sediments, in the west, pass eastwards into argillaceous marine sediments. It is the description and stratigraphic setting of these sediments which form the basis of our study.

Facies

Subdivision of the glacigenic sequence has been made predominantly on the basis of sediment core description, grainsize analysis of the $<2\mu m$ fraction and clast content. Sediment terminology is after Folk (1954). Palaeontological data have been included where available.

Three main facies have been identified within the glacigenic sequence and these are described separately below. A brief summary of the more normal marine facies, which forms the bulk of the Aberdeen Ground Formation, is also included as it is relevant to the general stratigraphic setting and overall facies model. The lithofacies relationships are shown in Fig. 3, which also indicates the position of the Brunhes/Matuyama palaeomagnetic boundary in boreholes 81/27 and 81/34 and provides a baseline for temporal correlation.

Subglacial facies

This facies occurs at the base of boreholes 74/10 and 74/12 and appears to form a localised mounded unit, 2 to 3 m in thickness (Fig. 3). In borehole 74/12 the base of the facies rests sharply on pyritous Lower Cretaceous shales, and may

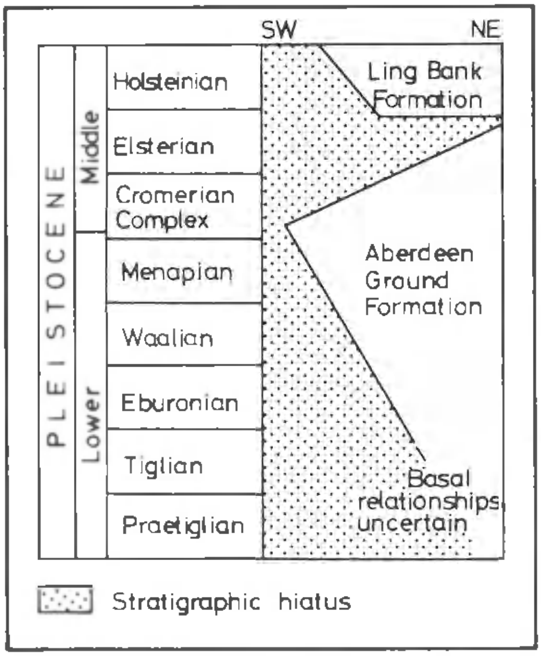

Fig. 2. Stratigraphic column of Lower, and part of Middle Pleistocene succession in the central North Sea, using British Geological Survey recommended terminology (after Stoker *et al.* in press a). Subdivision of the Pleistocene is based on the Dutch stratigraphic classification (Zagwijn 1979).

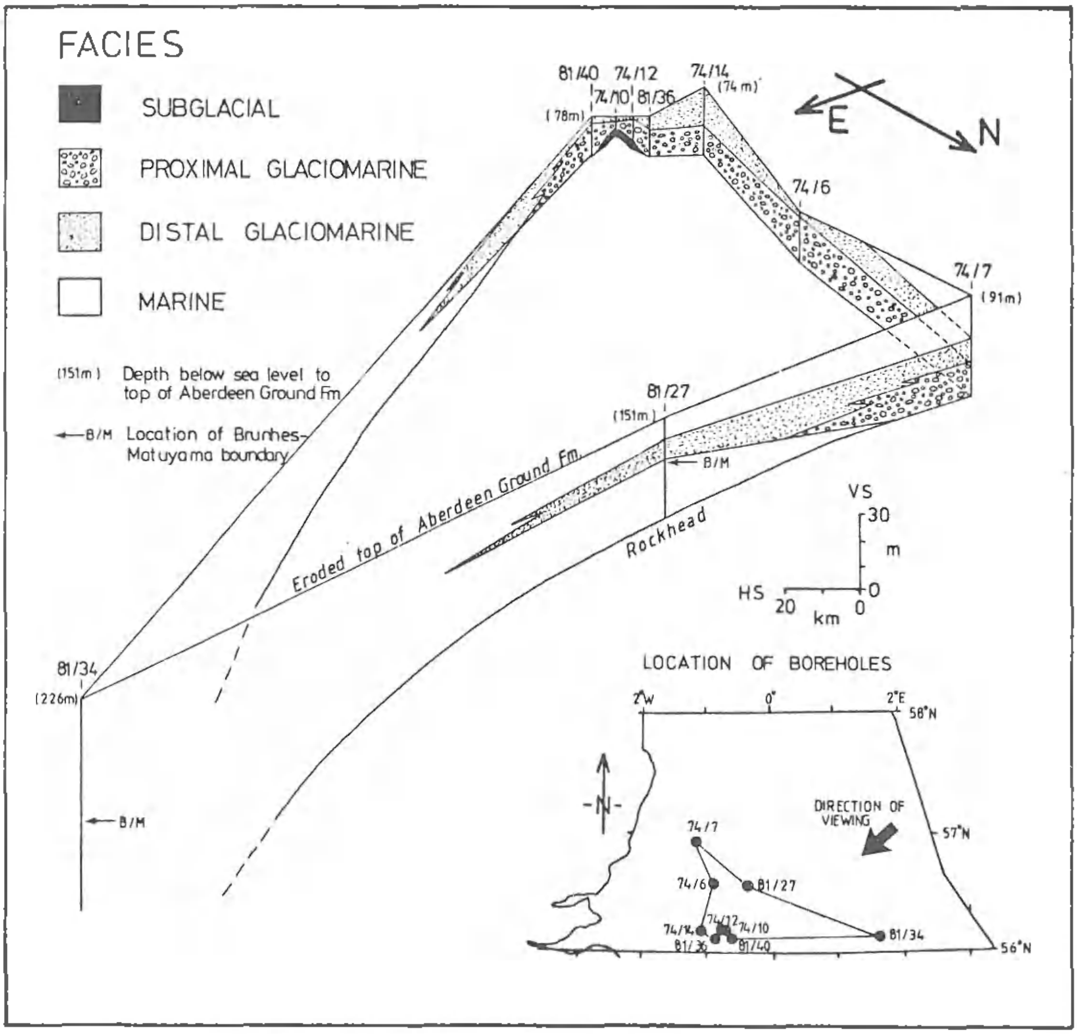

Fig. 3. Schematic fence diagram showing facies relationships. Direction of viewing is from the north-east.

be erosional as thin shale rip-up clasts are included near the base of the sequence. The top of the facies is overlain by proximal glaciomarine sediments although the exact nature of the contact is unknown.

The sediments consist of brown to olive-grey, firm, very poorly sorted, dominantly matrix-supported, gravelly sandy muds with no faunal remains. The grain-size distribution of this unit is polymodal (Fig. 4, Table 1) and texturally homogeneous (within the core). No obvious bedding structures were noted and pebble orientations varied from subhorizontal to subvertical. Clast composition is predominantly Moine/Dalradian metasediment and meta-igneous, red-purple Devonian sandstones and volcanics and grey Palaeozoic or Mesozoic sandstones, of local derivation. Fifty five percent of the pebbles were observed to be faceted and 20% displayed striations, however, only 5% had a distinctive 'bullet-shaped' appearance.

The textural homogeneity, unfossiliferous character, high clast content and locally erosive base suggest, collectively, that these sediments are of subglacial origin and represent some form of lodgement till. The sediments were probably deposited during the final stages of ice-advance and we suggest that their stratigraphic location

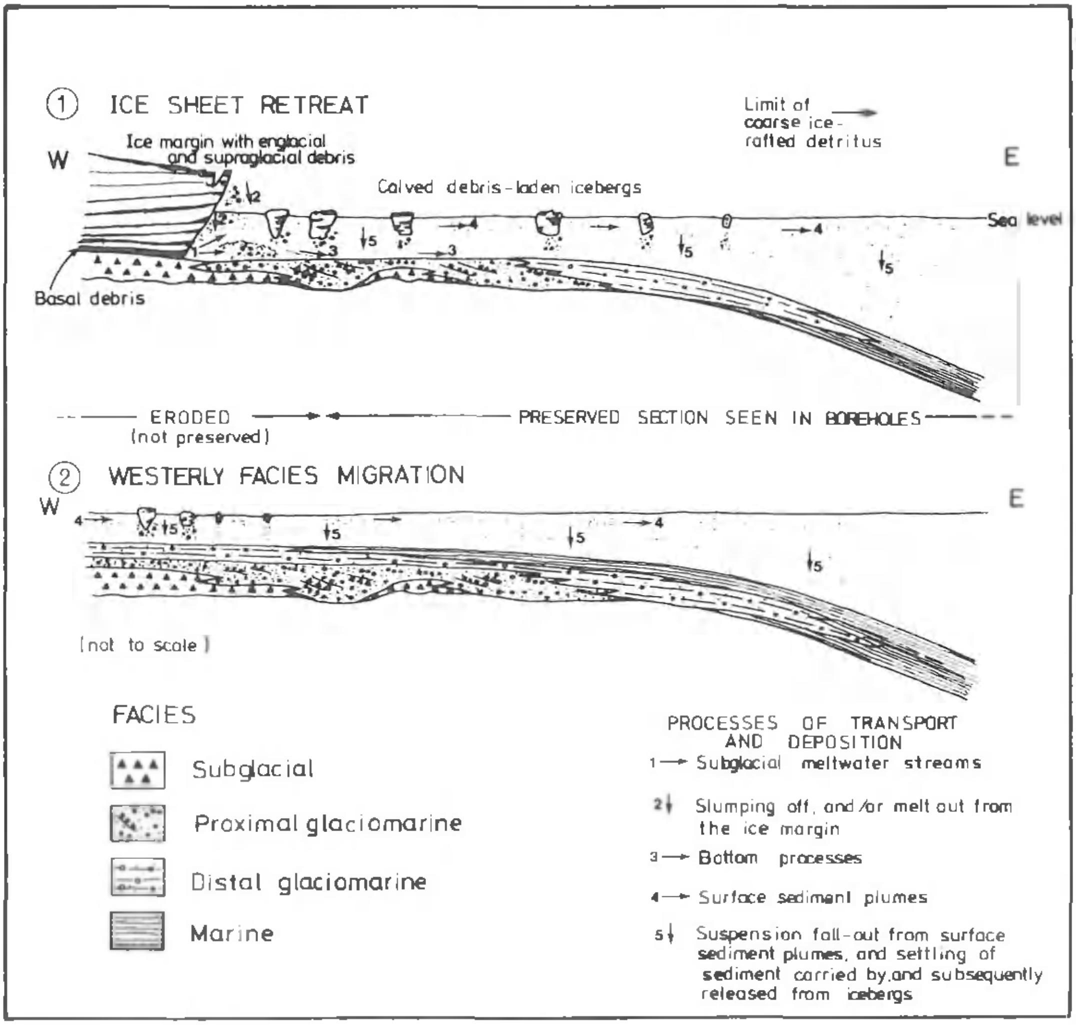

Fig. 5. Schematic model of facies development in a grounded tidewater ice-sheet environment. For explanation see text.

ed tidewater ice-sheet (cf. Powell 1984). The subglacial facies was deposited during the final stages of ice-advance while the glaciomarine facies was deposited as the ice-sheet began to melt and retreat. During ice-retreat meltwater streams discharging from tunnels beneath the ice-sheet deposited coarse proximal glaciomarine sediments immediately in front of the ice-grounding line, while the finer material was generally carried in suspension to greater distances from the ice-front, although bottom-flowing traction currents did exist. Calving of icebergs from the front of the ice-sheet carried entrapped basal and high-level debris away from the ice-margin into more distal areas, where it was eventually dumped due to melting or toppling of the iceberg and incorporated into the distal muds. Melting at the ice-front and slumping and/or melt-out of material may also have resulted in the inclusion of till-like deposits as discrete sheets or lenses within the proximal glaciomarine facies.

Overall fining of the sediments with increasing distance from the ice-front is clearly illustrated by grain-size analysis of the sand-mud fraction; the sand content clearly decreases away from the subglacial and proximal glaciomarine facies to the distal glaciomarine and marine facies (Fig. 4). A decrease in the gravel content is also appar-

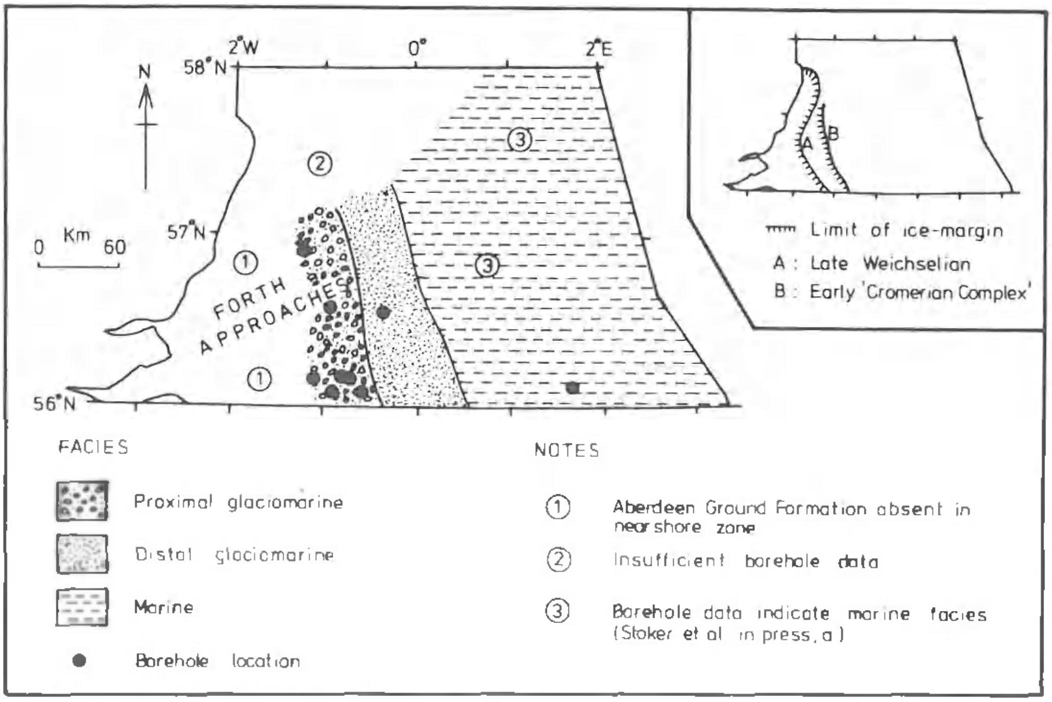

Fig. 6. Generalised palaeogeographic map of early 'Cromerian Complex' proglacial depositional environments at the onset of ice-sheet retreat. Inset shows the relative locations of the early 'Cromerian Complex' and late Weichselian ice-margins. Position of late Weichselian ice-margin after Thomson & Eden (1977) and Stoker *et al.* (in press a).

ent (Table 1). The lack of ice-rafted sandy and gravelly detritus within the marine sediments in borehole 81/34, at a level equivalent to that in borehole 81/27 (correlated by the palaeomagnetic boundary) suggests that there was a limit to the distance that icebergs were able to travel. This limit may have been due to restrictions imposed by sea ice or, as is more common under temperate tidewater conditions, to rapid melting of the icebergs (Powell 1984). Continued ice-sheet retreat led to the westerly migration of the various facies and the establishment of the overlapping facies relationships.

Correlation of the glacigenic sequence

The location of the Brunhes/Matuyama palaeomagnetic boundary in borehole 81/27 lies 1 m below the distal glaciomarine horizon. There is no evidence of any intervening erosional breaks, thus the boundary provides us with an effective stratigraphic marker for correlating the glacigenic sequence. As the Lower/Middle Pleistocene boundary is taken at the Brunhes/Matuyama boundary the sediments would appear to be of very early Middle Pleistocene age. Zagwijn *et al.* (1971) noted a correlation between the Brunhes/Matuyama boundary and the 'Glacial A' subdivision of the 'Cromerian' stage in the Dutch Quaternary sequence. The close proximity of the glacigenic sequence to the palaeomagnetic boundary suggests that these sediments may be correlatable with the 'Glacial A' subdivision, which would imply an early 'Cromerian Complex' age.

Palaeogeographic implications

The spatial distribution of the glacial and glaciomarine sediments at the onset of ice-sheet retreat is illustrated in Fig. 6. Deglaciation subsequently led to a westerly facies migration into the Forth Approaches which suggests that this area was a major outlet for glacial ice at this particular time. Clearly, however, the ice-sheet had a limited offshore extent, and the facies distribution beyond the ice-front, even at the time of maximum ice-advance, suggests that:

(1) the ice-sheet responsible for the glacigenic sequence was restricted to the UK; and,
(2) beyond the ice-margin the central North Sea was not covered by glacial ice, hence, no Scandinavian ice-sheet was involved in the deposition of these sediments.

Conclusions

A sequence of early Middle Pleistocene glacial and glaciomarine sediments has been identified in the west central North Sea, and has been tentatively dated as early 'Cromerian Complex' in age. These sediments represent, at present, the earliest indications of glacial climatic conditions in this area. They form an easterly thinning wedge of sediment, passing laterally and vertically into marine sediments, and were deposited from a grounded tidewater ice-sheet of restricted offshore extent.

The proposed location of the ice-margin is very similar to that envisaged for the late Weichselian ice-sheet (Fig. 6), and supports the growing belief that Scottish ice-sheets may have been more localised in their occurrence.

Acknowledgements. – We thank Dr. R. A. Scrutton for his comments on an early version of this manuscript. One of us (AB) acknowledges the receipt of a NERC research grant. This paper is published with the permission of the Director, British Geological Survey (NERC).

References

Brigham-Grette, J. & Sejrup, H. P. 1984: Stratigraphic resolution of amino-acid geochronology in North Sea Quaternary sediments. *In* Aarseth, I. & Sejrup, H. P. (eds.): *Quaternary Stratigraphy of the North Sea,* 30–32. Abstract volume, Symposium Univ. of Bergen.

Butzer, K. W. & Isaac, G. K. 1975: *After the Australopithecines.* The Hague.

Cheel, R. J. & Rust, B. R. 1982: Coarse grained facies of glacio-marine deposits near Ottawa, Canada. *In* Davidson-Arnott, R., Nickling, W. & Fahey, B. D. (eds.): *Research on Glacial, Glacio-fluvial and Glacio-Lacustrine Systems,* 279–293. GEO Books, Norwich.

Folk, R. L. 1954: The distinction between grain size and mineral composition in sedimentary rock nomenclature. *J. Geol. 62,* 344–359.

Godwin, H. 1975: *History of the British Flora: A Factual Basis for Phytogeography.* 541 pp. Cambridge Univ. Press, Cambridge.

Griffin, K. 1984: Plant macrofossils from a Quaternary deposit in the North Sea. *In* Aarseth, I. & Sejrup, H. P. (eds.): *Quaternary Stratigraphy of the North Sea,* 33. Abstract volume, Symposium Univ. of Bergen.

Holmes, R. 1977: Quaternary deposits of the central North Sea, 5. The Quaternary geology of the UK sector of the North Sea between 56° and 58°N. *Rep. Inst. Geol. Sci. 77/14.*

Jansen, J. H. F. 1976: Late Pleistocene and Holocene history of the northern North Sea, based on acoustic reflection records. *Neth. J. Sea. Res. 10,* 1–43.

Jansen, J. H. F. & Hensey, A. M. 1981: Interglacial and Holocene sedimentation in the northern North Sea: an example of Eemian deposits in the Tartan Field. *Spec. Publ. Int. Ass. Sediment. 5,* 323–334.

Jansen, J. H. F., Doppert, J. W. C., Hoogendoorn-Toering, K., DeJong, J. & Spaink, G. 1979: Late Pleistocene and Holocene deposits in the Witch and Fladen Ground area, northern North Sea. *Neth. J. Sea Res. 13,* 1–39.

Johnson, R. G. 1982: Brunhes-Matuyama Reversal dated at 790,000 yr BP by marine-astronomical calculations. *Quat. Res. 17,* 135–147.

Mankinen, E. A. & Dalrymple, G. B. 1979: Revised geomagnetic time scale for interval 0-5my B.P. *J. Geophys. Res. 84,* 615–626.

Powell, R. D. 1984: Glacimarine processes and inductive lithofacies modelling of ice-shelf and tidewater glacier sediments based on Quaternary examples. *Marine Geology 57,* 1–52.

Stoker, M. S., Long, D. & Fyfe, J. A. in press a: A revised Quaternary stratigraphy for the central North Sea. *Rep. Brit. Geol. Surv.*

Stoker, M. S., Long, D. & Fyfe, J. A. in press b: The Quaternary succession in the central North Sea. *Newsl. on Strat.*

Stoker, M. S., Skinner, A. C., Fyfe, J. A. & Long, D. 1983: Palaeomagnetic evidence for early Pleistocene in the central and northern North Sea. *Nature 304,* 322–334.

Thomson, M. E. & Eden, R. A. 1977: Quaternary deposits of the central North Sea. *Rep. Inst. Geol. Sci. 77/12.*

Zagwijn, W. H. 1979: Early and Middle Pleistocene coastlines in the Southern North Sea basin. *In* Oele, E., Schüttenhelm, R. T. E. & Wiggers, A. J. (eds.): *The Quaternary History of the North Sea,* 31–42. Acta Univ. Ups. Symp.

Zagwijn, W. H., van Montfrans, H. M. & Zandstra, J. G. 1971: Subdivision of the 'Cromerian' in the Netherlands; pollen-analysis, palaeomagnetism and sedimentary petrology. *Geol. en Mijnbouw 50,* 41–58.