# Climatic changes in the Norwegian Sea during the last 2.8 Ma

E. JANSEN, U. BLEIL, R. HENRICH, L. KRINGSTAD AND B. SLETTEMARK

Jansen, E., Bleil, U., Henrich, R., Kringstad, L. & Slettemark, B. 1987: Climatic changes in the Norwegian Sea during the last 2.8 Ma. *Polar Research 5 n.s.*, 329–332.

*E. Jansen, L. Kringstad and B. Slettemark, Dept. of Geology, Sect. B, University of Bergen, Allégaten 41, N-5007 Bergen, Norway; U. Bleil, Fachbereich Geowissenschaften, Universität Bremen, Postfach 330 440, D-2800 Bremen, FRG; R. Henrich, Geol. Paläontol. Inst., Universität Kiel, Olshausenstrasse 40, D-2300 Kiel, FRG.*

Prior to ODP Leg 104 no continuous paleoclimatic records older than 0.4 Ma were available from the Norwegian Sea. Only scattered information on the late Neogene and early Quaternary was provided from the sites drilled by DSDP Leg 38. No continental Plio-Pleistocene records older than the penultimate glacial (about 0.13 Ma) are known from the Scandinavian Peninsula, which has been the major accumulation area of late Cenozoic ice sheets in Europe.

## *The period 2.8–1.2 Ma*

The sedimentological record clearly shows the first major expansion of the Scandinavian Ice Sheet to have occurred at about 2.56 Ma. This is indicated by influx of ice-rafted detritus (IRD) (Fig. 2) and first occurrence of glacial type lithologies (Jansen et al. in press; Henrich in press). This is somewhat older than the age of 2.36 Ma reported for the first major IRD inputs from Site 552 in the North Atlantic (Shackleton et al. 1984). However, they also note a short pulse of ice-rafting shortly before the Gauss/Matuyama boundary, which may be correlative to the Norwegian Sea record. Except from indications of IRD at about 3.9 Ma, none of the Leg 104 sites document major Neogene glacial expansions before 2.56 Ma (Henrich in press; Jansen et al. in press), thus indicating a possible discrepancy between these records and reports of earlier glacial phases at about 3 Ma in Iceland (Einarsson et al. 1979) and in the late Miocene Arctic (Clark 1982). A re-evaluation of the magnetic time scale for the Arctic Ocean cores indicates, however, that the stratigraphy used by Clark (1982) does not extend further back in time than 2.5 Ma (Jones 1987). Thus the discrepancy between the Norwegian Sea and the Arctic Ocean records might not be real.

The relatively strong inputs of glacial material at 2.0–2.2 Ma (Fig. 2) correspond to glacial excursions seen in the North Atlantic isotope records (Shackleton et al. 1984). For the time-span 2.0–1.2 Ma, the period of relatively small IRD-inputs as seen in the coarse fraction record on Fig. 2, corresponds well to the isotope records which mainly document rather small glacial episodes. This must reflect variations of the global climate system. The Norwegian Sea experienced climatic variation and glaciation of the neighbouring mainland as seen in changing lithology and pulses of ice-rafting, but the uniform and strong carbonate dissolution during this time span (Henrich in press) indicates less variable conditions than in the late Quaternary. In contrast to late Quaternary interglacials and also in contrast to the N-Atlantic record, 'interglacials' from the Norwegian Sea during most of the Matuyama Epoch are carbonate free. Both dissolution and low carbonate productivity probably contributed to this, indicating only weak influence of warm North Atlantic surface water. This indicates that the thermal gradient between the Norwegian Sea and the North Atlantic was much stronger than at present and that the North Atlantic surface current system was deflected more to the east and south during the Matuyama. A more zonal climatic system than today would probably bring about an increased thermal gradient between the Norwegian Sea and the North Atlantic, and could also promote cooler, less saline surface waters in the Norwegian Sea. Ruddiman et al. (1986) showed that North Atlantic sea-surface temperature variations during this period are solely dominated by the 41,000 year obliquity period and that the thermal response was in phase with $\delta^{18}O$-signals and hence with ice sheet variations. Ruddiman et al. (1986) and Ruddiman & Raymo (in press) argue from results of climate models (Manabe & Terpstra 1974; Grose & Hoskins 1979) that mountain building in Himalaya and the western U.S. led to reduced zonality and promoted increased Northern Hemisphere glaciation at about 2.5 and 1.0 Ma.

Reduced ventilation rates creating more corrosive deep-waters with higher $CO_2$ content are probably necessary to explain the strong calcite dissolution in the Matuyama. Reduced ventilation and high nutrient levels of subsurface waters are indicated by more negative carbon isotope values in *N. pachyderma* during this period (Jansen et al. in press). However, the benthic carbon isotopes indicate that the deep-waters were far from anoxic. Heavier benthic oxygen isotopes than in the North Atlantic (Shackleton et al. 1984) indicate colder deep-waters in the Norwegian Sea than in the North Atlantic in the Matuyama. Some internal deep-water formation in the Norwegian-Greenland Sea/Arctic Ocean is called upon to explain this difference. Whether the Norwegian Sea in part contributed to North Atlantic Deep Water (NADW), or if deep water was formed and/or was ventilated by other and slower processes than today, is difficult to answer.

The continental record from the Netherlands shows an initial cold stage in the early parts of the Matuyama, followed by a complex series of temperate and cool stages based on pollen investigations (Zagwijn 1985). From this record there also appears to be a shift towards larger climatic variation at about

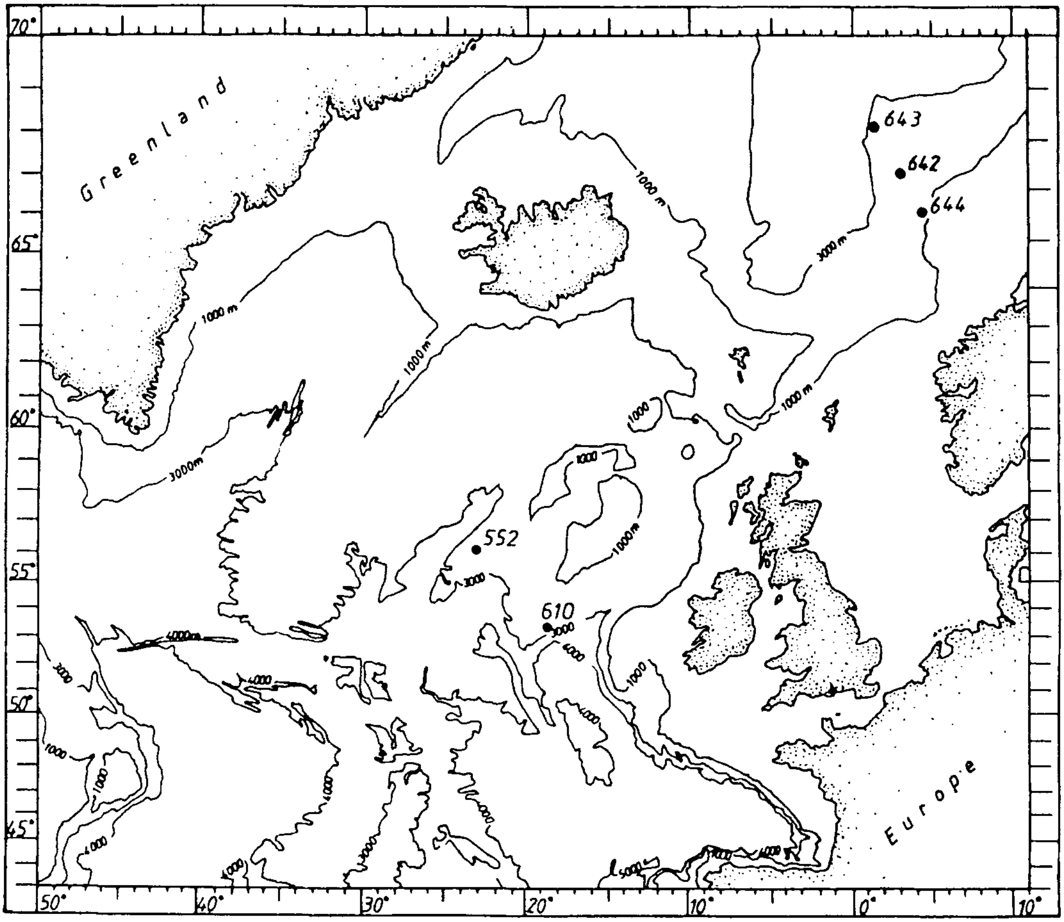


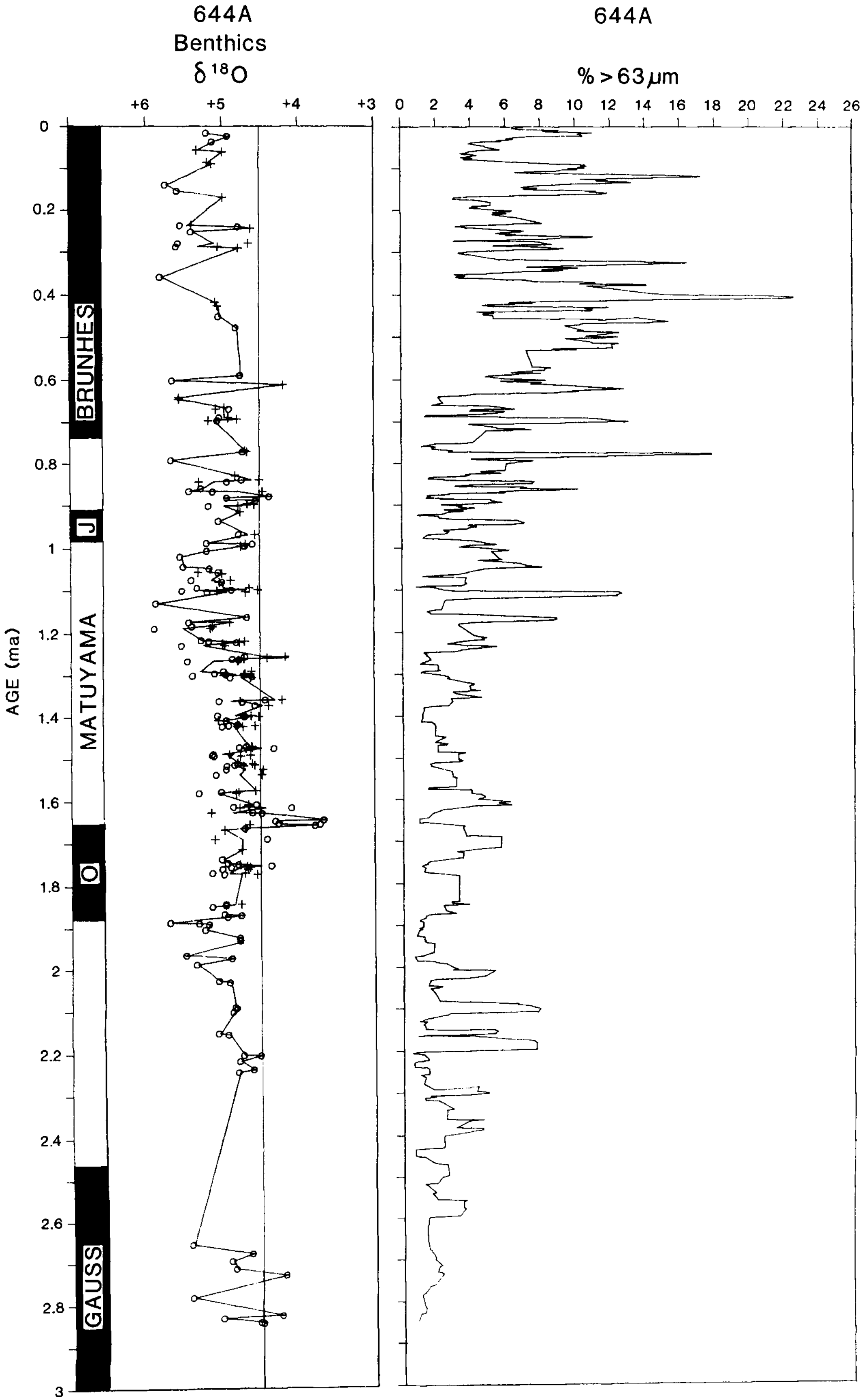

*Fig. 1.* Location of DSDP (552, 610) and ODP (642–644) drill sites referred to or used for this study.

1 Ma, after the Menapian stage, as shown by more pronounced glacials and glacial to interglacial contrasts. Land records from the circum-arctic which in parts are constrained by magnetochronology, are partly in conflict with the results of this paper. Temperate and ice free conditions in Northern Alaska and in northernmost Greenland have been deduced for a period which is supposed to belong to the early Matuyama (Funder et al. 1985; Carter et al. 1986). This evidence contrasts with the generally cold conditions deduced for the Norwegian Sea during the Matuyama. Alternatively, they may represent shortlived warm intervals where warmer waters flowed northwards and which were not discovered in our records. However, the stratigraphic resolution of both Sites 644 and 642 is better than 15,000 to 10,000 years through the Matuyama, and we have no indications of warm intervals that might correspond to the 'forested Arctic' that is shown from palynology and other studies in the sections from Kap København on the northern tip of Greenland (Funder et al. 1985).

## *The period 1.2–0.6 Ma*

Since about 1.2 Ma, inputs of IRD to the Vøring Plateau became greater than before (Fig. 2), indicating intensified glaciations in Scandinavia. Shortly after this, the monotonous carbonate dissolution diminished and the oxygen isotopic gradient between surface and deep-waters was reduced. This transition appears to have been strongest around 0.9 Ma but it continued at least to 0.6 Ma. Such an environmental shift at around 0.9 Ma is seen in many climatic time series, and it has been discussed whether this is a climatic step or a more gradual trend towards larger ice volumes and longer cycles (Pisias & Moore 1981; Prell 1982; Ruddiman et al. 1986). Remnants of the Matuyama pattern (dissolution, $\delta^{18}O$ gradient, and low to moderate IRD inputs) are seen in our records in a transition period that persisted until approximately 0.6 Ma. This is an argument for the theory that there was a more gradual shift centered around 0.9 Ma in which the climatic system needed time to adjust to new boundary

*Fig. 2.* Coarse fraction and isotope record of 644A. The filtered coarse fraction record was produced by applying a 5 point moving average filter to avoid high-frequency noise and to enhance low frequency patterns. The time scale is produced by linear interpolation between magnetic reversal boundaries.



644A
Benthics
δ18O
+6
+5
+4
+3
644A
% > 63 μm
0
2
4
6
8
10
12
14
16
18
20
22
24
26
AGE (ma)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
BRUNHES
J
MATUYAMA
O
GAUSS

conditions. Alternatively, changes in boundary conditions need time to develop, and this might be the case if the shift was caused by tectonic factors such as mountain building.

The first subpolar planktonic foraminiferal assemblages within the entire glacial sequence in the Leg 104 holes appeared at about 0.9 Ma (Spiegler & Jansen in press). This probably marks the first major incursions of temperate Atlantic water in the Matuyama.

The inputs of terrigenous coarse fraction at Site 644 increased after 1 Ma. This timing fits in with indications of a major glacial expansion into the central North Sea in the late Matuyama (Sejrup et al. 1987).

## *The period 0.6–0 Ma*

This period was characterized by environmental changes similar to those found in studies of the upper Quaternary. Short, but warm interglacials with deep-water formation and carbonate accumulation occurred between extended periods of glacial environments, with pulses of heavy inputs of IRD, especially during the decay of large ice sheets extending onto the continental shelf. Formation of dark organic rich layers during deglacial phases indicates short periods when a stable water column was formed and deep-water renewal halted, and calcite dissolution increased for short periods. The relatively continuous presence of planktic foraminifers (*N. pachyderma* (sin.)), especially in the most shallow and most landward Site 644, indicates seasonally open waters present during most of the glacial phases.

Although glaciation has been the dominant feature of North European climates for the last 2.5 Ma, it was only during the last 0.6 Ma that the ocean and climate systems operated in a manner similar to that deduced from previous studies of the last 400,000 yrs in the Norwegian-Greenland Sea.

## References

Carter, L. D., Brigham-Grette, J., Marincovitch, L., Pease, V. L. & Hillhouse, J. W. 1986: Late Cenozoic Arctic Ocean sea ice and terrestrial paleoclimate. *Geology 14*, 675–678.

Clark, D. L. 1982: Origin, nature and world climate effect of Arctic Ocean ice cover. *Nature 300*, 321–325.

Einarsson, T., Hopkins, D. M. & Doell, R. R. 1979: The stratigraphy of Tjørnes, northern Iceland, and the history of the Bering Land Bridge. Pp. 312–315 in Hopkins, D. M. (ed.): *The Bering Land Bridge*. Stanford University Press.

Grose, W. L. & Hoskins, B. J. 1979: On the influence of orography on large scale atmospheric flow. *J. Atmos. Sci. 36*, 223.

Funder, S., Abrahamsen, N., Bennike, O. & Feyling-Hanssen, R. W. 1985: Forested Arctic: Evidence from North Greenland. *Geology 13*, 542–546.

Henrich, R. in press: Glacial-interglacial cycles in the Norwegian Sea: sedimentology, paleoceanography and evolution of late Pliocene to Quaternary Northern Hemisphere climate. *Proc. ODP 104B*.

Jansen, E., Bleil, U., Henrich, R., Kringstad, L. & Slettemark, B. in press: Paleoenvironmental changes in the Norwegian Sea and the Northeast Atlantic during the last 2.8 Ma: DSDP/ODP Sites 610, 642, 643 and 644. *Paleoceanography*.

Jones, G. 1987: The central Arctic Ocean sediment record: Current progress in moving from a litho- to a chronostratigraphy. *Polar Research 5.n.s.* (this volume).

Manabe, S. & Terpstra, T. B. 1974: The effects of mountains on the general circulation of the atmosphere as identified by numerical experiments. *J. Atmos. Sci. 31*, 3.

Pisias, N. G. & Moore, T. C. 1981: The evolution of Pleistocene climate: a time series approach. *Earth Planet. Sci. Lett. 52*, 450–458.

Prell, W. L. 1982: Oxygen and carbon isotope stratigraphy for the Quaternary of Hole 502B: evidence for two modes of isotopic variability. *Init. Repts. DSDP 68*, 269–276.

Ruddiman, W. F., Raymo, M. & McIntyre, A. 1986: Matuyama 41,000-year cycles: North Atlantic Ocean and northern hemisphere ice-sheets. *Earth Planet. Sci. Lett. 80*, 117–129.

Ruddiman, W. F. & Raymo, M. in press: Northern Hemisphere climate regimes during the last 3 myr: possible tectonic connections. *Philos. Trans. Royal Soc. London.*

Sejrup, H. P., Aarseth, I., Ellingsen, K. L., Løvlie, R., Reither, E., Bent, A., Brigham-Grette, J., Jansen, E., Larsen, E. & Stoker, M. 1987: Quaternary stratigraphy of the Fladen area, Central North Sea: a multidisciplinary study. *J. Quat. Sci. 2*.

Shackleton, N. J., Backman, J., Zimmerman, H., Kent, D. V., Hall, M. A., Roberts, D. G., Schnitker, D., Baldauf, J. G., Desprairies, A., Homrighausen, R., Huddlestun, P., Keene, J. B., Kaltenback, A. J., Krumsieck, K. A. D., Morton, A. C., Murray J. W. & Westberg-Smith, J. 1984: Oxygen isotope calibration of the onset of ice-rafting and history of glaciation in the North Atlantic region. *Nature 307*, 620–623.

Spiegler, D. & Jansen, E. in press: Planktonic foraminiferal biostratigraphy ODP Leg 104. *ODP Proceedings 104B*.

Zagwijn, W. H. 1985: An outline of the Quaternary stratigraphy of the Netherlands. *Geol. Mijnb. 57*, 577–588.