With compliments
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Jörn Thiede ✓

BEELLA MEGASTOMA (EARLAND) IN LATE PLEISTOCENE NORWEGIAN-GREENLAND SEA SEDIMENTS: STRATIGRAPHY AND MELTWATER IMPLICATION

HENNING A. BAUCH

GEOMAR, Research Center for Marine Geosciences, Wischhofstrasse 1-3, D-24148 Kiel, Germany

ABSTRACT

Prior to this work, the planktic foraminiferal genus *Beella* Banner and Blow (1960) has never been described from Pleistocene sediments from the Norwegian-Greenland Sea (NGS). The general characteristics of this species agree well with the most recent emendation of the genus *Beella*. Accordingly, the described species is considered to be *Beella megastoma* (Earland). Test sizes range from 200-700 μm, but specimens are mainly confined to the 250-500 μm mesh-size fraction. Interpretations of stable isotopes, sedimentological, and other micropaleontological data indicate that this species is not simply a 'warm-water form' and, despite its low abundances, it is a species of major paleoceanographic significance. Stratigraphically, it is confined to meltwater events of Termination II, III, and VI (oxygen isotopic stage boundary 5/6, 7/8, and 15/16) and not to the ensuing interglacial maximum. Hence, these '*Beella*-events' represent a particular oceanographic phenomenon and are designated in accordance with the present numerical system of deglacial terminations as Event B_2, B_3, and B_6 respectively.

INTRODUCTION

During the past twenty years the bulk $CaCO_3$-content of sediment cores of which planktic foraminifera are major constituents has proved to be of immense importance to deciphering the marine paleoenvironment of high latitude areas such as the Norwegian-Greenland Sea (NGS). In conjunction with oxygen isotope records these data provide a sound basis for interpretation and reconstruction of past glacial-interglacial surface water circulations (e.g., Kellogg, 1975; Kellogg and others, 1978; Henrich and others, 1989; Wolf, 1991). The recognition of past oceanographic processes in conjunction with the causes of fluctuations in the modern circulation patterns is essential to understand short-term variations which are especially apparent during glacial-interglacial transitions. Due to intensive coring in the NGS during recent years, this part of the North Atlantic is probably the most studied area of the World Ocean (Fig. 1). Planktic foraminifera have been subject to investigations because of their almost continuous presence in interglacial as well as glacial times. Traditionally, all species that occur in Pleistocene or Holocene sediments of the NGS may be assigned according to their preferred latitudinal habitat either to a polar or a subpolar group (Kipp, 1976; Kennett and Srinivasan, 1983; Hemleben and others, 1989). *Neogloboquadrina pachyderma* sinistral is the only true polar species, whereas the subpolar group is predominantly made up of *Globigerina quinqueloba*, *G. bulloides*, *N. pachyderma* dextral, *Globigerinita glutinata*, *Gl. uvula*, and to a lesser degree, *O. universa*, *N. dutertrei* intergrades,

Globorotalia inflata, *Glr. truncatulinoides*, *Glr. Scitula* (Kellogg, 1984; Haake and Pflaumann, 1989). These latter species are sparse, and appear to be restricted to the southeastern part of the NGS with a strong tie to the region of North Atlantic surface water influence (Bauch, 1993). They therefore may be regarded as being not truly indigenous subpolar species in comparison to the others.

Neogloboquadrina pachyderma sin. is almost continuously present during glacial and interglacial times. This is in contrast to the subpolar species which are strongly tied to interglacial maxima only (Haake and Pflaumann, 1989; Bauch, 1993). The scope of this paper is to show a detailed stratigraphic distribution of *Beella megastoma*, a planktic foraminifera first reported from Pleistocene sediments (past 600 ky) of the NGS by Bauch (1992), and which seems to be confined in modern and past times to subtropical-temperate zones (Srinivasan and Kennett, 1975; Kipp, 1976; Holmes, 1984).

TAXONOMIC ASSIGNMENT

During the past 30 years, there has been some confusion concerning the taxonomic and stratigraphic classification of the genus *Beella*. Parker (1967) introduced *Globigerina praedigitata* for a species with a radial elongation of chambers that do not become digitate. The same features were used to describe *Beella digitata* cf. *digitata* by Blow (1969). In both cases this species was mentioned to have a stratigraphic range from Zone N16–N21. Bolli and Saunders (1985) noted that this species is undoubtedly not confined to the late Tertiary only but is also found throughout Pleistocene into Holocene times. This is supported by Holmes (1984) who carried out the most recent emendation of this genus and which is also followed in this paper. His specimens derived from surface sediments of the Rockall area, northeastern Atlantic Ocean. The samples contained both *B. megastoma* and *Beella digitata* (Brady) of which the latter is most strikingly distinguished by its digitate chambers.

The shape of *B. megastoma* and especially the position of its aperture is extremely variable. All specimens from the NGS (Pl. 1) show at least slight elongation of chambers when viewed from the spiral side. The variations of the ultrastructure of the test wall (Pl. 1, Fig. 5, 8) is probably based on different growth stages. In general, these characteristics agree well with those pointed out by Holmes (1984). It is beyond the purpose of this study to discuss taxonomy at great length but as Bolli and Saunders (1985) stated, the strong resemblance of *G. praedigitata*, and *B. digitata* cf. *digitata*, adding here also *B. megastoma*, with *B. digitata* is most likely due to juvenile growth stages. Hence, the development of digitate chambers may be a sign for optimum environment, rendering those specimens with only elongated chambers to represent phenotypic variants.
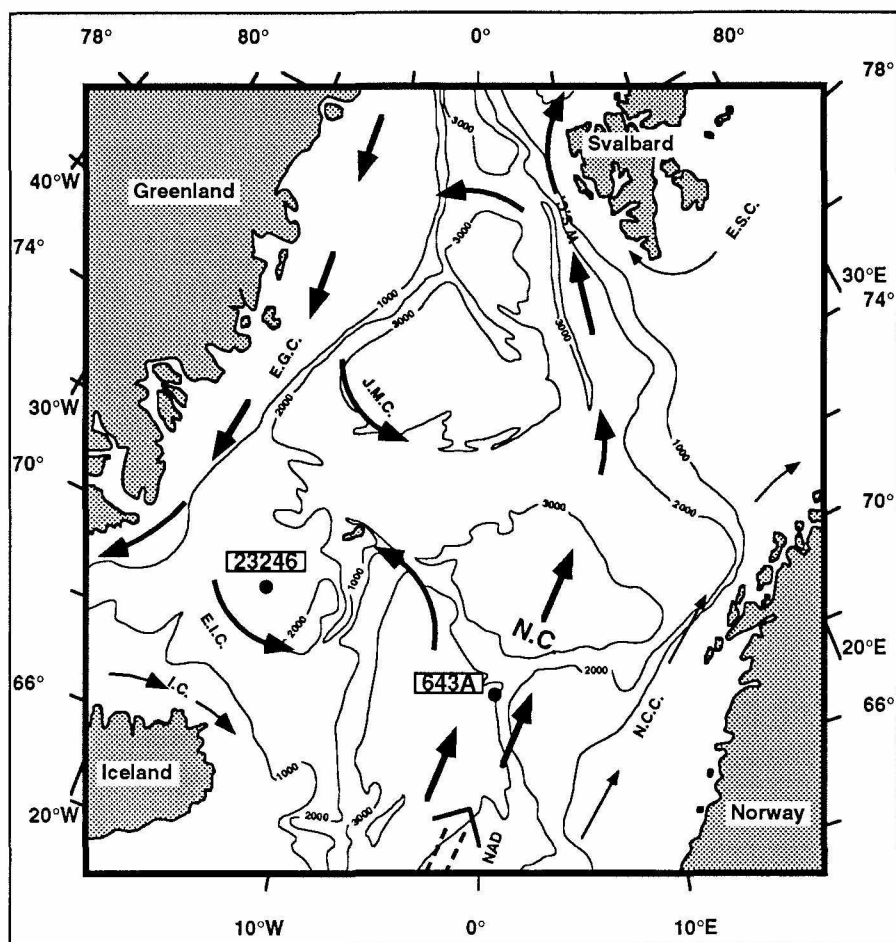
FIGURE 1.   Core position and modern large-scale surface water circulation pattern in the NGS (redrawn from Trangeled, 1974; Swift and Aagaard, 1986). E.I.C.—East Iceland Current; E.G.C.—East Greenland Current; E.S.C.—East Spitsbergen Current; I.C.—Irminger Current; J.M.C.—Jan Mayen Current; NAD—North Atlantic Drift; N.C.—Norwegian Current; N.C.C.—Norwegian Coastal Current; W.S.C.—West Spitsbergen Current.

With regard to the unusual large test sizes, *B. megastoma* is possibly a rapidly growing species such as *G. bulloides* (Kroon, 1988). This would also explain the observation that this species was primarily encountered in the >250 μm size-fractions only.

MATERIALS AND METHODS

For this investigation a gravity core 23246-4 linked to a boxcore 23246-2 from the northern Iceland Plateau has been chosen (69°23.6'N, 12°52.1'W). This core was collected during cruise ARK II on board of RV 'Polarstern' (Augstein and others, 1984). This area of the NGS has low sedimentation rates and is not prone to receive down-slope transported material as other core locations that are closer to the shelfs. A reinterpretation of previous studies by Vogelsang (1990) and Birgisdottir (1992) on O/C-isotopes, bulk CaCO$_3$ and coarse-size fraction analyses suggests that this core possibly penetrates oxygen isotope Stage boundary 15/16 (Termination VI) at about 680 cm and a corrected total length of 697 cm (Bauch, 1993). This fact is corroborated by two more stable isotope analyses that have been added to the original data set of Vogelsang (1990). Stratigraphic control of Termination VI in Core 23246 is additionally supported by correlation with Hole 643A (ODP Leg 104;

67°42.9'N, 0.1°02.0'E) as reference, using stable isotopes and CaCO$_3$-data from Wolf (1991) as well as my own observations.

Investigations were carried out on samples from ~10 cm intervals (boxcore 2 cm intervals) that have originally been dry-weighed, washed, and sieved into coarse-size fraction 63-125 μm, 125–250 μm, 250–500 μm, and 500-1000 μm. Preliminary observations revealed that the abundance of *B. megastoma* is exceedingly low in comparison to *N. pachyderma,* and that this species predominantly occurs in the 250–500 μm mesh-size. Therefore, for counting *B. megastoma* this size-fraction was left unsplit and all specimens counted. All counts are expressed as specimens per gram dry bulk sediment. In order to gain a better control of the stable isotope stratigraphic framework, particularly for correlation of Stage 15 between Core 23245 and Hole 643A, observations on the mode and kind of clastic particles as well as the occurrence of certain benthic foraminifera are considered.

RESULTS

Micropaleontological analyses of samples of Core 23246 reveal the stratigraphic distribution of *B. megastoma* (Fig. 2). These sporadic occurrences—in this study named Event
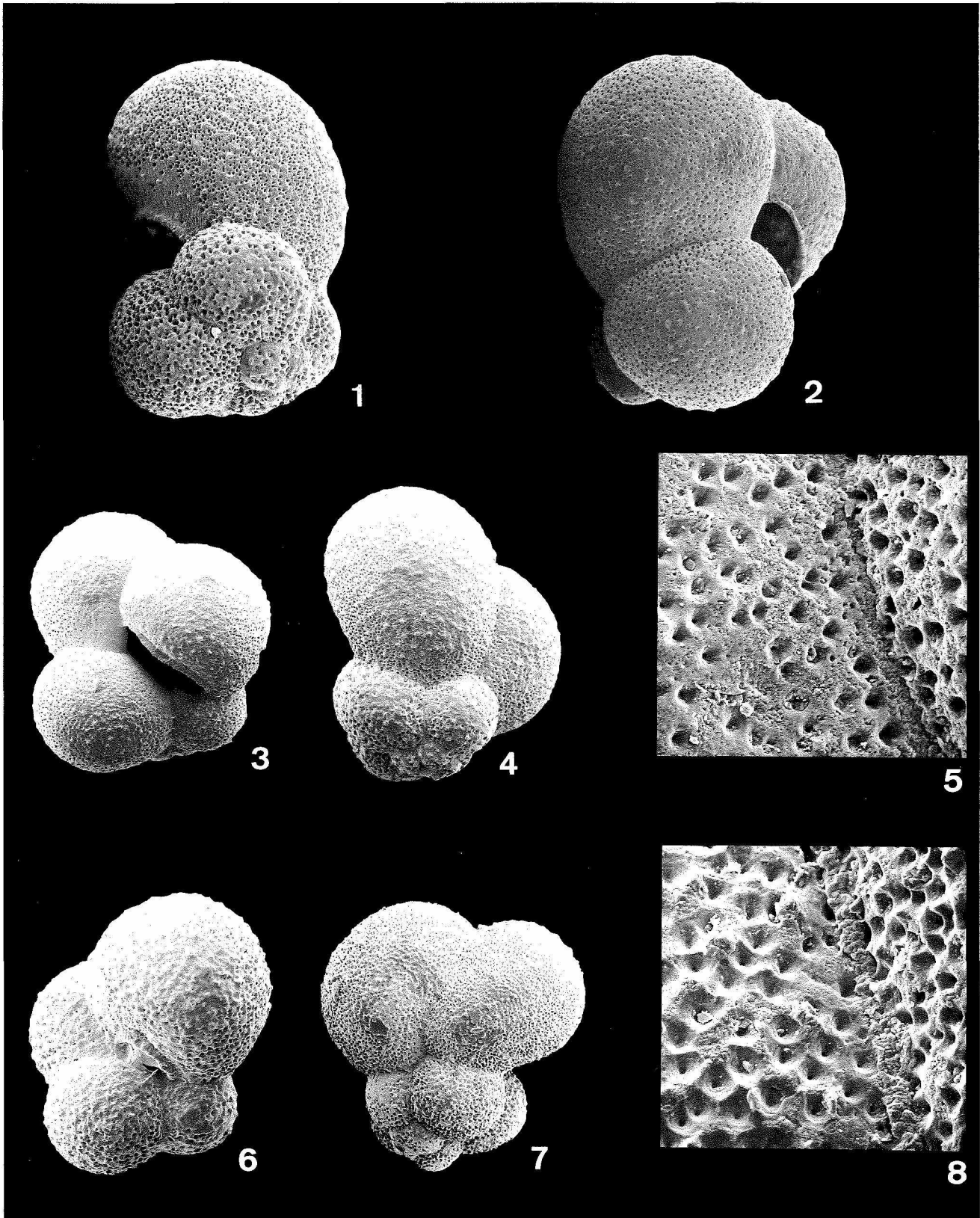
PLATE 1.

Different views of *Beella megastoma* (Earland) from Termination II: one ×190; two ×180; three ×130, umbilical view of Fig. 2; four ×150; five ×1000, ultrastructure of penultimate chamber of Fig. 3. Fig. 6 ×200; Fig. 7 ×125; Fig. 8 ×1000, ultrastructure of penultimate chamber of Fig. 7.

B_2, B_3, and B_6 in accordance with the current terminology of glacial-interglacial transitions (Sarnthein and Tiedemann, 1990)—are easily distinguished from the interglacial maxima, because in all cases in Core 23246 they coincide with light $\delta^{18}O$ and $\delta^{13}C$ values. The latter range between 0.2–0.4‰ suggesting a strong meltwater influence. By us-

ing the SPECMAP-time scales (Imbrie and others, 1984; Martinson and others, 1987) as well as the interpretation of Vogelsang (1990), Event B_2 and B_3 fall within isotope Substage 5.5 and 7.5, respectively. The stratigraphic assignment of Stage 15 is difficult to ascertain due to a somewhat irregular record of the oxygen isotopes in the lower part of
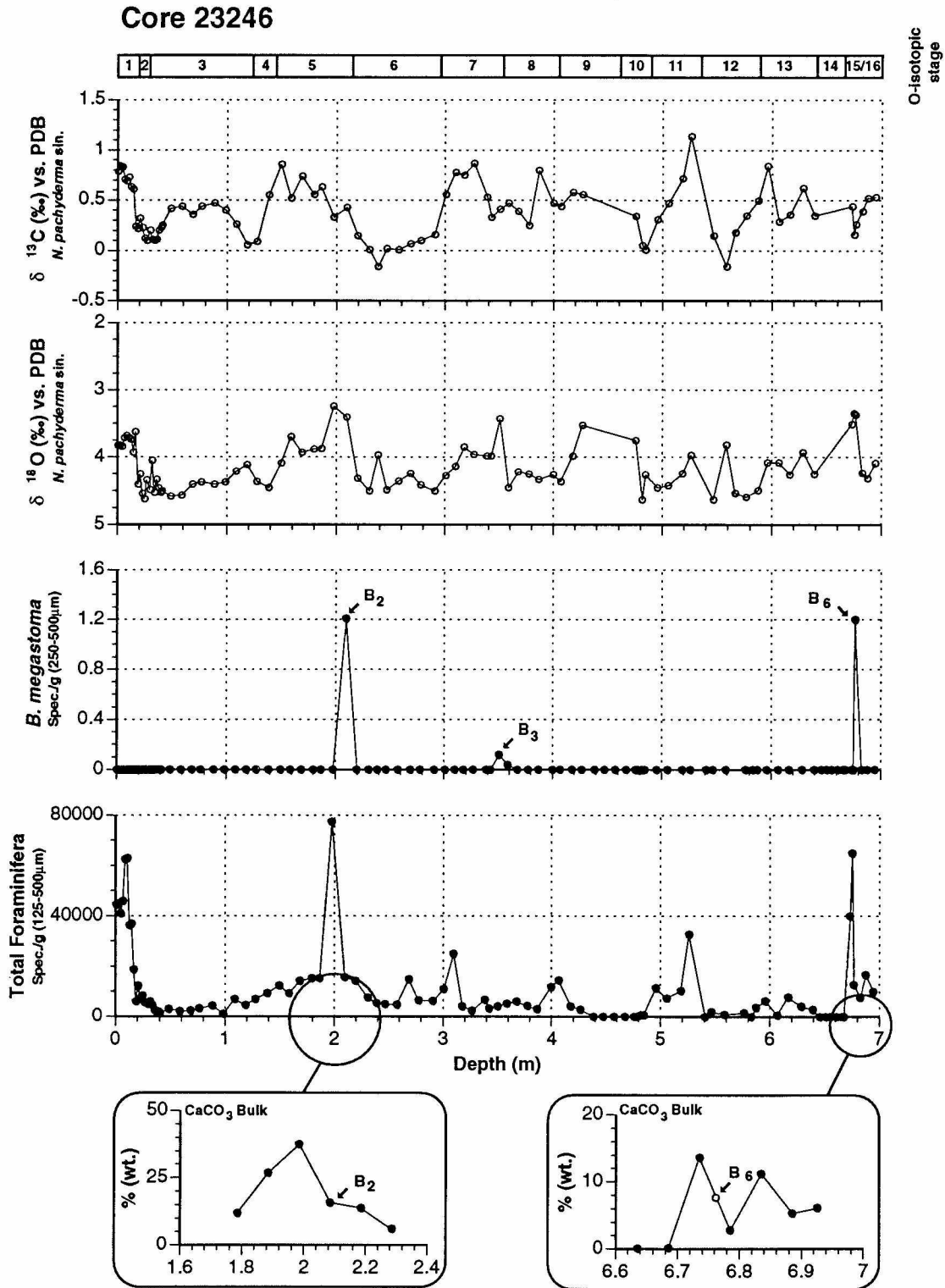

FIGURE 2. Stratigraphic distribution of *B. megastoma* in Core 23246. Due to the sampling scheme of previous workers samples for carbonate and stable isotopes do not always exactly correspond. Isotope data are essentially from Vogelsang (1990) and carbonate data are from Birgisdottir (1992).

this core. Nevertheless, by comparing the $\delta^{13}C$ curves with that of Hole 643A (Fig. 3), the identification of at least Stage 11 in Core 23246 becomes apparent. The good agreement between these two curves further downcore confirms the presence of Stage 15 in Core 23246. This is also supported by corresponding benthic foraminiferal evidence in both cores and the similarly outstanding preservation of all biogenic particles. The benthic foraminiferal assemblage shows high abundances of *Cibicidoides wuellerstorfi* (Schwager), *Epistominella exigua* (Brady), and *Pullenia bulloides* (d'Orbigny). Whereas *C. wuellerstorfi* is characteristic of interglacial Stages 1, 5, 7, 9, 13, and 15 in the NGS (Streeter and others, 1982; Haake and Pflaumann, 1989; Struck, 1992), *P. bulloides* is only present below about 1400 m water depth at distinct levels such as Substage 5.1 or 7.5 (Haake and Pflaumann, 1989; Struck, 1992), and *E. exigua* appears to be restricted to Stage 15 and the latest Holocene (Struck, 1992). Hence, *P. bulloides* and *E. exigua* are in some way indicative of rarely occurring oceanographic processes in the NGS.

The abundances of *B. megastoma* are nearly the same in Event B_2 and B_6 of Core 23246 and comparatively higher than in B_3 (Table 1). In Substage 5.5 and Stage 15 the Events predate the $CaCO_3$-maximum which is presumed

TABLE 1. Specimens per gram bulk sediment of *B. megastoma* from unsplit samples of the >250 μm size fraction.

Core/depth (corr. m)	23246-4 (spec./g)	Core/depth (m)	Hole 643A (spec./g)
2.06	30/24.74	3.11	2/11.16
3.475	3/24.6	17.00	4/6.34
3.555	1/26.38		
6.735	26/21.96		

here to represent the interglacial peak, Substage 5.51 (Vogelsang, 1990). Within Substage 7.5, *B. megastoma* is present in low concentrations only (Fig. 2). In the Stage 7 interval, the $CaCO_3$-curve does not exceed 5% (wt.) according to Birgisdottir (1992), implying that this interglacial was far less pronounced than others like Stage 5. Therefore, it is difficult to identify among Substages 7.1, 7.3 and 7.5 the actual interglacial maxima of Stage 7.

With respect to other qualitative criteria, *B. megastoma* always coincides with a distinct matrix of ice-rafted detritus (IRD) which is dominated by immature angular quartz grains and crystalline rock fragments, and which is almost devoid of any clastic sedimentary rocks. During Termination II, just prior to Event B_2, grey rounded siltstone fragments comprise most of the clasts in the coarse size frac-
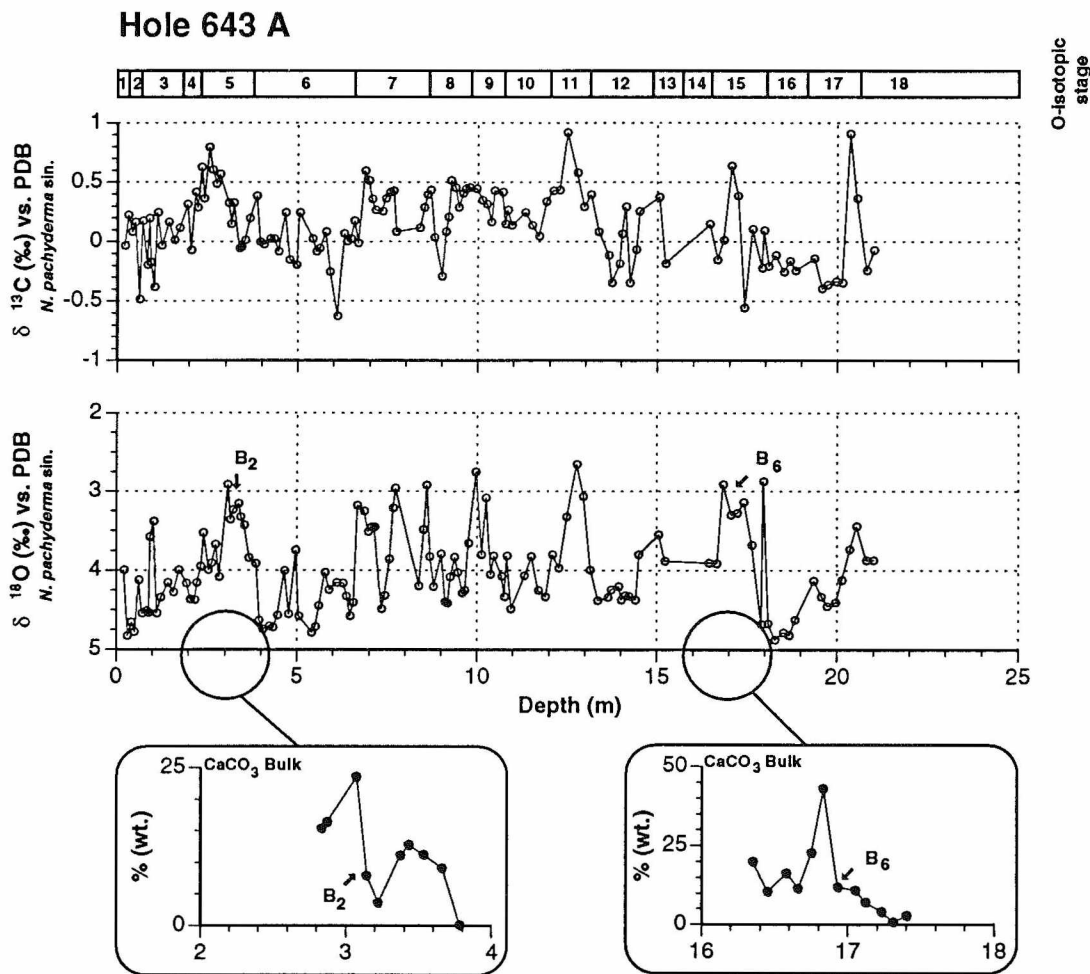

FIGURE 3. Occurrence of *B. megastoma* in Hole 643A. Only a few specimens were observed in Termination II and VI whereas Termination III did not yield any. For abundances see Table 1. Carbonate and isotope data are from Wolf (1991).

tion. Nearly the same phenomena seen in Core 23246 are reflected in Hole 643A even though the sample spacing is broader, so that it was impossible to detect Event B_3 here. Despite the sparse number of specimens and available samples (Table 1), Event B_2 and B_6 are still clearly recognizable. Again, *B. megastoma* occurs where expected: Just below the occurrence of the main bulk $CaCO_3$, coinciding with (1) immature IRD and (2) meltwater phases as indicated by stable isotopes.

DISCUSSION AND CONCLUSIONS

The sporadic stratigraphic occurrence of *B. megastoma,* coincides with the deposition of IRD and light stable isotope values. This indicates a strong linkage of all three *B. megastoma* events to meltwater phases. Reworking of *B. megastoma* from shelf-based older sediments by glacials may be precluded, because of its very delicate tests (Holmes, 1984; Bauch, 1992) which are well preserved (Plate 1). Furthermore, there are no rounded rock fragments or clasts of terrigenous origin which one would normally expect from reworked shelf sediments.

The precise definition of $\delta\ ^{18}$O-substages in Core 23246 is problematic because of low sedimentation rates and wide sampling intervals. Using Hole 643A as a guide, Event B_2 falls within Substage 5.5 or possibly 5.53 which is 123.82–125.19 ka in age (Wolf, 1991). The dominance of grey siltstones during early deglaciation of Termination II is most likely due to a decay of shelf-based glaciers which is also a striking feature of Termination IA (pers. com. R. F. Spielhagen 1993). Therefore, the appearance of immature quartz and crystalline rock fragments in conjunction with *B. megastoma* indicates a time during Termination II when the glaciers have already retreated from the shelfs onto the surrounding continental landmasses. From here, glaciers were now capable of incorporating fresh unreworked rock material and were responsible for transporting this via icebergs into the NGS.

Sarnthein and Tiedemann (1990) subdivided each of Termination I-VI into two major groups on grounds of variable deglaciation time spans: Meltwater fluxes during Termination I, IV, and V were generally of longer duration than during II, III, and VI. The latter are marked by abrupt deglaciation steps—as short as 700 years—which consequently led to rapid sea level rises (Sarnthein and Tiedemann, 1990). A link between the last deglaciations' meltwater run-off and the shut-downs of North Atlantic Deep Water formation has been recently proposed by various authors (Fairbanks, 1989; Birchfield and Broecker, 1990; Jansen and Veum, 1990; Sarnthein and others, 1992) and is a vital part to understanding the so-called 'saltwater pump' system (Birchfield and Broecker, 1990). Time resolution of the investigated cores does not allow as yet (either by lack of appropriate detailed sampling intervals or due to low sedimentation rates) to state whether the occurrence of *B. megastoma* is a direct consequence of deglaciation or is primarily related to unknown oceanic processes that accompanied and possibly strongly influenced particular ice-melting phases during the glacial/interglacial transitions. However, Event B_2, B_3, and B_6 remain puzzling phenomena. They raise the questions (1) why are there abundance spikes of a 'lower-latitude' species, (2) why are there no others warmer water species, and (3) why we do not find this rare species more often in Termination I, IV, V, and ensuing interglacial maxima for example? Detailed information especially of the life habitat of *B. megastoma* and further investigations of more core material are needed to resolve these problems.

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