DISTRIBUTION OF FORAMINIFERA AND
CALCAREOUS NANNOPLANKTON IN
QUATERNARY SEDIMENTS OF THE EASTERN
ANGOLA BASIN IN RESPONSE TO CLIMATIC AND
OCEANIC FLUCTUATIONS

by

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1. INTRODUCTION

In 1976 the Netherlands Institute for Sea Research (NIOZ) initiated a research project in the Zaire River estuary and adjacent eastern Angola Basin.

Part of the project was devoted to the Late Quaternary depositional evolution of the Zaire deep-sea fan, which has been built up by the Zaire River in front of a deep and narrow submarine canyon system extending up into the estuary. Therefore, piston cores from the ocean floor were taken in or close to the area of the deep-sea fan, on the con-

tinental rise and shelf at water depths ranging from 75 to over 5000 m. Brief core descriptions are given by JANSEN *et al.* (1984).

So far, little research has been directed towards Quaternary

Fig. 1. a. Location of the cores studied; the numbers 4, 6, 7, 8, 10 are of 1980, the others of 1978. b. Pattern of calcareous nannoplankton dissolution index; shaded area indicates anomalously high dissolution rates. c. Ratio diatoms to *Gephyrocapsa oceanica* based on the smear-slide counts of frustules and coccoliths respectively: dominance of fresh and brackish water diatoms indicated by heavy shading, dominance of *Thalassionema* frustules by light shading. d. Total numbers of Radiolaria per 10 g dry weight (>63 µm); high abundance of sand-sized *Coscinodiscus* frustules indicated by shading. e. Total numbers of planktonic Foraminifera per 10 g dry weight (>63 µm). f. Total numbers of benthic Foraminifera per 10 g dry weight (>63 µm).

sediments in the Angola Basin. A comprehensive paper by BORNHOLD (1973) and the contribution by CARATINI & GIRESSE (1979) are among the very few which can be cited in this context. Comparatively better known are Quaternary sediments from the northern Guinea Basin (THIEDE, PASTOURET & MELGUEN, 1974; KLINGEBIEL *et al.*, 1975; GARDNER, 1975; PASTOURET *et al.*, 1978). All authors, cited above, showed the impact of Quaternary climatic fluctuations on the oceanic and adjacent terrestrial environment.

This paper reports on the distributional patterns of Foraminifera and calcareous nannoplankton in cored sediments of the eastern Angola Basin. Additional data are presented on the distribution of selected non-calcareous biogenic and non-biogenic components. All these data were gathered for the purpose of designing a Middle and Late Quaternary time-stratigraphic frame and contributing to a palaeoenvironmental reconstruction of the eastern Angola Basin.

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2. MATERIAL AND METHODS

Five cores (T78-26, -46, -45, -33, -49) were analyzed for their planktonic foraminiferal and calcareous nannofloral compositions (Fig. 1). The composition of benthic Foraminifera was studied in 2 cores (T78-26, -45). All foraminiferal studies were conducted on the coarser than 63 μm fraction.

Total number estimates were made for benthic and planktonic Foraminifera and Radiolaria of the coarser than 63 μm fraction according to the procedure described earlier (ZACHARIASSE *et al.*, 1978). It is noted that total numbers of Radiolaria are uncorrected for extrapolated carbonate values. Furthermore, total numbers were estimated for sponge spicules, fish remains, and non-biogenic components such as quartz and pyritic grains. All total number estimates were converted to 10 g of dry bulk sediment.

Tops of 28 cores were studied for the present-day distribution of biogenic components (Fig. 1).

3. DISSOLUTION INDEX

Dissolution of calcareous organisms is prevalent in the core samples of the eastern Angola Basin. Both the calcareous nannoplankton and the Foraminifera show varying stages of preservation from sample to sample.

For the Angola Basin cores the state of preservation is described by a semi-quantitative nannoplankton preservation index. This index is based primarily on the preservation of the most resistant species. *Gephyrocapsa oceanica* becomes more frequent in dissolved samples because of its large size and tightly bound structure. Other species are more quickly removed in an order that depends on size and structure.

TABLE 1

Calcareous nannoplankton dissolution index as applied to the cores of the Angola Basin.

Index	Coccoliths, ratio (<i>R</i>) small/large	Proportion (<i>P</i>) of <i>Gephyrocapsa</i> <i>oceanica</i>	Preservational aspect			
			<i>Nanno-</i> <i>fossils</i>	<i>Gephyro-</i> <i>capsa</i> <i>oceanica</i>	<i>Cyclo-</i> <i>coccolithus</i> <i>leptoporus</i>	<i>Helico-</i> <i>sphaera</i> <i>carteri</i>
0	not defined	not defined	pristine; no disso- lution	well preserved	well preserved	well pre- served
- 1	$R > 1.5$	$P < 0.3$	minimally etched	badly preserved (etched shields)	mostly as whole shields	mainly well pre- served
- 2	$0.5 < R < 1.5$	$0.3 < P < 0.6$	moderate- ly etched	badly preserved (etched shields)	whole and loose shields	mixed preser- vation
- 3	$0 < R < 0.5$	$0.6 < P < 0.9$	mostly etched; resistant species prevail	badly preserved (missing bar)	mostly loose shields	rare; badly etched
- 4	$R = 0$	$P > 0.9$	very rare; mostly badly etched	rims only	few, mostly proximal shields	—
- 5	—	—	all dissolved	—	—	—

The nannoplankton dissolution index describes the relative intensity of carbonate dissolution in terms of 6 successive stages, normalized to a scale of 0 to -5 (Table 1).

A comparison of the nannoplankton index with the total numbers of both planktonic and benthic Foraminifera shows a good correlation (Figs 2 to 4). Therefore, foraminiferal total numbers are also a measure of carbonate dissolution.

4. BIOGENIC COMPONENTS IN CORE TOPS

There is an anomaly in the pattern of nannoplankton preservation indices over a large area off the Zaire River mouth (Fig. 1b). North and south of this area nannoplankton preservation is largely depth controlled by which the carbonate compensation depth (CCD) approximates the 5600 m contour (THUNELL, 1982; JANSEN *et al.*, 1984). Apparently, the anomaly in carbonate dissolution results from factors other than water depth alone.

The high proportion of fresh and brackish water diatoms (Fig. 1c), the occasionally high quartz and mica contents and the high proportion of plant remains at stations T78-30, -31, -32, and -35 point to a significant admixture of land-derived material along 6°S.

The anomalously high carbonate dissolution rates along and south of 6°S (Fig. 1b) are, therefore, thought to result from decomposition of relatively large amounts of river-borne organic matter. Carbondioxide formation by decomposition of organic matter at or below the sediment-water interface is an important cause of carbonate dissolution (BERGER, 1976) and seems especially effective in organic carbon-rich, carbonate-poor environments (DIESTER-HAASS & MÜLLER, 1979).

The extremely low numbers of Foraminifera along 6°S (Fig. 1e and f) are attributable to the combined effects of carbonate dissolution and dilution.

Surface sediments from stations T78-27, -28, -29, -44 and T80-7, -8, -10 contain frequent Radiolaria and *Coscinodiscus* frustules (Fig. 1d). In smear-slides *Thalassionema* dominates the marine diatom flora (Fig. 1c). These stations are thought to delimit a highly-productive area which extends over the continental rise south of the main canyon and adjoins a surface-water region of maximum chlorophyll *a* values (CADÉE, 1978). This chlorophyll *a* maximum may be related to phytoplankton blooms brought about by high-nutrient, low-turbidity levels nearby the shelf (CADÉE, 1978, 1984). These conditions possibly account for the high numbers of *Thalassionema* and *Coscinodiscus* frustules on the sea bed. The area of stations T78-23, -24, -25, and -26 is (almost) devoid of diatoms and Radiolaria (Fig. 1c and d). Instead,

TABLE 2

Relative abundance (%) of planktonic foraminiferal taxa in core top samples from the Angola Basin ($>63 \mu\text{m}$) (samples containing less than 100 specimens and taxa with abundances of less than 1% have been omitted from the table): *G. bulloides* (1), *G. quinqueloba* (2), *G. siphonifera* (3), *G. glutinata* (4), *G. uvula* (5), *G. ruber* (6), *G. trilobus* (7), *G. cf. anfracta* (8), *G. crassaformis* (9), *G. inflata* (10), *G. menardii* group (11), *G. scitula* (12), *N. dutertrei* group (13), *Orbulina* (14), *P. obliquiloculata* (15), *S. dehiscentis* (16).

Core	Species abundance (%)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
T78-23	15	56	1	4	12	3	0	1	2	2	1	1	1	0	0	0
T78-24	19	45	0	5	3	7	0	2	4	0	5	2	1	0	0	0
T78-25	20	37	2	4	5	11	0	1	4	5	2	2	5	0	0	0
T78-26	11	59	0	1	7	3	1	3	1	3	0	2	3	1	0	0
T78-33	12	30	2	16	1	15	2	3	1	3	3	1	3	3	0	0
T78-42	4	75	0	3	2	1	0	1	0	1	3	0	7	0	0	0
T78-44	9	45	0	11	2	10	2	4	1	4	2	2	2	0	0	0
T78-45	14	46	1	9	0	10	3	1	2	3	5	1	2	0	0	1
T78-46	10	57	1	5	9	6	1	2	0	1	0	2	2	0	0	0
T78-49	17	30	0	10	4	7	3	2	3	7	1	1	4	0	1	0
T80-7	13	45	3	13	5	5	1	3	0	1	1	3	2	2	0	0
T80-8	4	64	0	5	9	5	1	2	1	1	1	1	1	0	0	0
T80-10	9	51	1	5	7	5	2	4	2	3	1	2	0	0	0	0

planktonic Foraminifera are frequent. Contrary to calcareous skeletons, opaline ones are readily dissolved before final burial as long as there is no excessive supply of opaline remains to the bottom (DIESTER-HAASS, 1977 and references therein). Therefore, the (near) absence of biogenic opal is thought to be relatable to a lowered phytoplankton productivity due to the short residence time and high turbidity of the surface waters.

Notwithstanding the complex hydrography of the area (VAN BENNEKOM & BERGER, 1984), and the effects of carbonate dissolution, the quantitative distribution of planktonic Foraminifera in the surface sediments is fairly homogeneous (Table 2).

The associations display a mixed composition, *i.e.* species flourishing in tropical and subtropical water masses (*e.g.* *Globigerinoides trilobus*, *G. ruber*, *Globorotalia menardii* group) are mixed with species characteristic of the temperate regimes of the South Atlantic (*e.g.* *Globorotalia inflata*, *Globigerina bulloides*, *Globigerinita uvula*). This latter group of species may be seen as "southern intruders", brought northwards by the Benguela Current.

The high percentages of *Globigerina bulloides* on the shelf (stations T78-23, -24, -25, and -26) may be indicative of the penetration of Benguela Current water in this region (VAN BENNEKOM & BERGER, 1983).

5. DOWNCORE DISSOLUTION PATTERNS AND CARBONATE CONTENT

5.1. CORES FROM BELOW 4000 METRES

From a base line between 1 and 5% individual carbonate peaks range up to 25%. Because the relative spacing and amplitude of these peaks appear to be uniform in the deep cores of the eastern Angola Basin the peaks have been used as main reference points for intercore correlations.

In the cores T78-45, -49, and -33 a characteristic triplet of carbonate peaks is recognized immediately below the LOD (Last Occurrence Date) of *Globorotaloides hexagona*. Relative to this level, comparable triplets are present in the western (*e.g.* core V25-59; BÉ *et al.*, 1976) and eastern (*e.g.* core S16; PUJOL, 1980) equatorial Atlantic Ocean. According to the carbonate numbering system of BÉ *et al.* (1976) the peaks of the carbonate triplet in the eastern Angola Basin have been labelled (from top to bottom) VI, VII, and VIII (Figs 2 to 4).

Calibration of these 3 carbonate peaks with radiometrically dated Barbados terraces (BÉ *et al.*, 1976) and their close correlation with ox-

Fig. 2. Core T78-33: % CaCO₃, nannoplankton dissolution indices (dotted line represents 3-point moving average) and total numbers of planktonic and benthic Foraminifera and Radiolaria per 10 g dry weight (>63 µm) with statistical error (confidence level 95%). Dissolution events are numbered and have prefix C (coccoliths) or F (Foraminifera); preservation peaks are coded by Roman numerals according to the carbonate peak numbering system of BÉ *et al.* (1976) (preservation peaks in the climatic zone Y that are not clearly present as carbonate peaks are indicated by pr).

Fig. 3. Core T78-49: % CaCO_3 , nannoplankton dissolution indices (dotted line represents 3-point moving average) and total numbers of planktonic and benthic Foraminifera and Radiolaria per 10 g dry weight ($> 63 \mu\text{m}$) with statistical error (confidence level 95%). Dissolution events are numbered and have prefix C (coccoliths) or F (Foraminifera); preservation peaks are coded by Roman numerals according to the carbonate peak numbering system of BÉ *et al.* (1976) (preservation peaks in the climatic zone Y that are not clearly present as carbonate peaks are indicated by pr).

ygen isotope minima (*e.g.* PUJOL, 1980) demonstrate that they correspond with warm periods in the last interglacial (isotopic stage 5).

The prominent carbonate peak in the upper part of the deep cores is correlated with carbonate peak I of BÉ *et al.* (1976). In several cores (*e.g.* T78-45 and -49) this carbonate peak consists of 2 subpeaks labelled Ia and Ib by JANSEN *et al.* (1984). Radiocarbon dating indicates that the upper subpeak (Ia) is Holocene in age and that whenever the lower subpeak Ib is present its age is Late Pleistocene.

A comparison of the patterns of dissolution indices and the carbonate curves shows that higher carbonate content almost always correlates with better preservation. Sometimes, however, the preservation is much better than expected from the corresponding low carbonate content. Plotting carbonate and dissolution patterns of cores T78-45, -49, and -33 versus time, by assuming a constant accumulation rate for the interval between carbonate peak Ia (~ 6000 yBP, JANSEN *et al.*, 1984) and peak VIII ($\sim 119\,000$ yBP), and applying the same procedure to the carbonate curve of core V25-59 (BÉ *et al.*, 1976) one notices the (near)-absence of carbonate peaks II, III, IV and V in the eastern Angola Basin cores, whereas the signal is well-preserved in the nannoplankton dissolution curve (Figs 2 to 4).

Fig. 4. Core T78-45. % CaCO₃, nannoplankton dissolution indices (dotted line represents 3-point moving average) and total numbers of planktonic and benthic Foraminifera and Radiolaria per 10 g dry weight ($> 63 \mu\text{m}$) with statistical error (confidence level 95%). Dissolution events are numbered and have prefix C (coccoliths) or F (Foraminifera); preservation peaks are coded by Roman numerals according to the carbonate peak numbering system of BÉ *et al.* (1976) (preservation peaks in the climatic zone Y that are not clearly present as carbonate peaks are indicated by pr).

Because in the deep cores of the eastern Angola Basin dissolution patterns give a more detailed record of correlatable oscillations than carbonate peaks alone, dissolution depressions and preservation peaks are coded (Figs 2 to 4).

As shown in Figs 2 to 4 the pattern of dissolution indices is the least uniform in the interval between carbonate peak I and VI, which makes it difficult to designate individual events with certainty.

5.2. CORES FROM 2100 AND 600 METRES

The overall low and relatively smooth carbonate pattern in the shallow cores T78-46 and -26 follows from the higher rate of accumulation of terrigenous material.

Contrary to what one would expect from the water depth, fluctuations in the nannoplankton dissolution indices and percentages of benthic Foraminifera per total Foraminifera clearly demonstrate varying intensities in carbonate dissolution.

The dissolution indices in core T78-46 describe a staggering pattern with strongest dissolution registered in the middle part of the core (Fig.

Fig. 5. Core T78-46: % CaCO_3 , nannoplankton dissolution indices (dotted line represents 3-point moving average) and total numbers of planktonic and benthic Foraminifera and Radiolaria per 10 g dry weight ($> 63 \mu\text{m}$) with statistical error (confidence level 95%), isotopic stages (Isost. st.; after OLAUSSON, 1984) and radiocarbon datings (after JANSEN *et al.*, 1984).

5). Even the shallowest water core T78-26 contains several intervals of intense carbonate dissolution (Fig. 6).

The patterns of carbonate content and dissolution indices in the shallow cores show only little relationship among themselves and no, or hardly so, with those in comparable intervals of the deep cores. Therefore, the system of coded preservation events, designed for the deep cores, cannot be applied in the shallow cores.

Fig. 6. Core T78-26: % CaCO_3 , nannoplankton dissolution indices (dotted line represents 3-point moving average) and total numbers of planktonic and benthic Foraminifera per 10 g dry weight ($> 63 \mu\text{m}$) with statistical error (confidence level 95%).

5.3. DISCUSSION

The close correspondence between carbonate content and dissolution indices in the deep cores of the eastern Angola Basin indicates that dissolution strongly controls the fluctuations in carbonate content. These carbonate fluctuations have well correlatable counterparts in other Atlantic regions (*e.g.* BÉ *et al.*, 1976; PUJOL, 1980) and, therefore, must reflect ocean-wide changes in the "corrosiveness" of bottom water and in the position of the CCD. Furthermore, the close relationship between carbonate content and climatic oscillations indicates that the changes in the position of the CCD have been brought about by glacial-interglacial climatic contrasts and are generally linked to different modes of deep water circulation (VOLAT *et al.*, 1980).

Since carbonate peaks II and V are (almost) absent, whereas their preservational analogues (IIpr to Vpr) are well represented in the deep cores, the pattern of dissolution indices reflect in more detail the ocean-wide changes in the position of the CCD than the pattern of carbonate content in the deep cores of the eastern Angola Basin. Apparently, the consistent suppression of carbonate peaks II to V in all deep cores does not result from carbonate dissolution and, therefore, must be attributed to the combined effects of increased deposition of terrigenous material and enhanced biogenic opal production.

Carbonate dissolution in the shallow cores is readily detectable from the patterns of dissolution indices. In view of the water depth, downcore variations in the intensity of carbonate dissolution must be governed by local processes rather than ocean-wide fluctuations in the position of the CCD. The dissolution in these cores is most probably determined by the high supply of organic matter, due to the proximity of the river mouth. Higher input rates of organic matter may lead to higher carbondioxyde levels at or near the sediment-water interface, thus, increasing carbonate dissolution rates (SCHRADER, CHENG & MAHOOD, 1983).

Downcore fluctuations in the dissolution pattern and in the carbonate content of cores T78-26 and -46 may be the result, therefore, of varying fluxes of land-derived organic matter.

In summary carbonate dissolution in the deep and shallow cores is governed by different, ocean-wide versus local, processes.

6. DOWNCORE COMPOSITIONS OF PLANKTONIC FORAMINIFERA

Core-top distribution of planktonic Foraminifera in the eastern Angola Basin indicates the presence of tropical-subtropical and of

subantarctic-transitional species. This mixture is attributed to the joint effects of the northward flowing Benguela Current and the southeastward flowing South Equatorial Counter Current. Climatic changes in the oceanic environment in this region, therefore, may be read from the changing proportions of tropical-subtropical and subantarctic-transitional water mass indicators.

Carbonate dissolution, however, is a factor which seriously limits the use of planktonic Foraminifera for palaeoclimatic reconstructions in the Late Quaternary sediments of the eastern Angola Basin. In all cores well-preserved sections alternate with sections in which almost all planktonic Foraminifera have been removed by intensified carbonate dissolution. Only core T78-46 contains a complete planktonic foraminiferal record (Fig. 5).

6.1. CORE T78-46

The species composition shows a distinct change-over at 300 cm (Fig. 7). From this depth up to the core top *Globigerinoides ruber*, *G. trilobus*, and *Globigerinita glutinata* proliferate. From below 300 cm *Globigerina bulloides*, *Globorotalia inflata* and the *Neogloboquadrina dutertrei* group dominate the fauna. In addition, *Globigerinita uvula*, *Globigerina bulloides*, and *Orbulina universa* attain highest relative numbers down to about 750 cm. From 750 cm down to the bottom the frequency of the latter species drops, whereas *Globorotalia scitula* and the *Neogloboquadrina dutertrei* group attain maximum percentages.

Present-day biogeographical patterns of the South Atlantic Ocean shows that *Globorotalia inflata* is closely bound to the Subtropical Convergence Zone and is an excellent indicator of the Benguela Current (e.g. BÉ & TOLDERLUND, 1971). On the whole, the frequency pattern of the *Neogloboquadrina dutertrei* group correlates with that of *Globorotalia inflata* suggesting a relationship between the *Neogloboquadrina dutertrei* group and the Benguela Current. Such a relationship agrees well with the flourishing of *N. dutertrei* in present-day boundary current systems (e.g. CLIMAP, 1976; BÉ & HUTSON, 1977) due to its high food requirements (e.g. COULBOURN, PARKER & BERGER, 1980). The highest frequencies of *Globigerina bulloides*, *Orbulina universa*, and *Globigerinita uvula* are registered in and south of the Subtropical Convergence Zone (e.g. BÉ & HUTSON, 1977) and in coastal upwelling regions, such as those off south-west Africa (e.g. BÉ & TOLDERLUND, 1971).

Therefore, the distributional patterns of *Globorotalia inflata*, *Orbulina universa*, *Globigerina bulloides*, *Globigerinita uvula*, and neogloboquadrinids in the Late Quaternary of the eastern Angola Basin may serve as indicators of fluctuations in the northward transport of cool

Fig. 7. Core T78-46: quantitative distribution or presence (●) of planktonic foraminiferal taxa ($>63 \mu\text{m}$), and isotopic stages (after OLAUSSON, 1984). (*Orb.* is *Orbulina*, *uv.* *uvula*, *scit.* *scitula*, *tril.* *trilobus*, *glut.* *glutinata*, *cras.* *crassaformis*, *men.* *menardii* group, *trunc.* *truncatulinoidea*, *obliq.* *obliquiloculata*, *Sph.* *Sphaeroidinella*).

water by the Benguela Current.

Consequently, the fauna change-over at 300 cm documents the weakened influence of the Benguela Current and the concomitant greater influence of the South Equatorial Counter Current as a result of which higher numbers of the (sub)tropical species *Globigerinoides trilobus*, *G. ruber*, and *Globigerinita glutinata* are introduced into the eastern Angola Basin. This fauna change-over and the inferred change in surface water circulation pattern is attributed to the climatic amelioration which terminates the Weichselian stadial III (beginning of the Bölling-Alleröd warm climatic phase; cf. OLAUSSON, 1984) and is radiocarbon-dated at about 14 000 yBP (JANSEN *et al.*, 1984).

At 225 cm, percentages of "southern intruders" are high again, whereas the group of (sub)tropical species almost vanishes from the record. This faunistic signal suggests a temporal reinforcement of the Benguela Current and corresponds to the Weichselian IV (Younger Dryas) cold climatic event. The reintroduction of high percentages of (sub)tropical species immediately above 225 cm corresponds with the Pleistocene-Holocene boundary, the age of which is fixed at about 10 000 yBP (OLAUSSON, 1982, 1984).

Maximum percentages of "southern intruders" occur in the core sections from 300 to 750 cm. During this interval surface waters in the eastern Angola Basin were significantly influenced by the cool

Benguela Current, indicating global climatic cooling. Below 750 cm the average percentage of *Globigerinita uvula*, *Globigerina bulloides*, and *Orbulina universa* decrease, whereas those of *Globorotalia scitula*, the *Neoglobobadrina dutertrei* group and, to a lesser extent, those of *Globigerinoides ruber* and *Globigerinita glutinata*, increase. This faunistic change at 750 cm indicates a slightly weakened influence of the Benguela Current in the eastern Angola Basin due to a slight climatic amelioration.

The faunistic changes are nicely recorded in the oxygen isotopic signals of the planktonic foraminifer *Globigerinoides ruber* and the benthic species *Uvigerina peregrina* and *Bulimina aculeata* (OLAUSSEN, 1984). The maximum faunal difference, which is recorded between the 325 and 150 cm levels, may correspond with a (local) surface water temperature difference of about 3°C (OLAUSSEN, 1984).

The boundary between isotopic stages 1 and 2 is placed at 225 cm and coincides with a level where the *Globorotalia menardii* group starts to increase in frequency (Fig. 7). The latter event has been used as boundary between the Z and Y zones (ERICSON & WOLLIN, 1968). The boundary between isotopic stages 2 and 3 is placed at 750 cm (OLAUSSEN, 1984) and indicates the beginning of the Weichselian III stadial.

Fig. 8. Core T78-33: quantitative distribution or presence (●) of planktonic foraminiferal taxa (>63 μm), open sections represent intervals of strong carbonate dissolution (Orb. is *Orbulina*, infl. *inflata*, uv. *uvula*, scit. *scitula*, tril. *trilobus*, glut. *glutinata*, cras. *crassa-formis*, men. *menardii* group, hex. *hexagona*).

6.2. CORES T78-33, -49, -45, AND -26

The planktonic foraminiferal curves for the deep cores (Figs 8, 9, and 10) are fragmentary. The preserved signal correlates with carbonate preservation peaks, which, in the Atlantic Ocean, correspond with warm periods. Consequently, the potential compositional differences between warm and cold periods is obliterated in the cold cycle. Therefore, positioning of the boundaries of the climatic zones of ERICSON & WOLLIN (1968) must be based on matching the planktonic foraminiferal distribution patterns with the carbonate content and dissolution curves.

The Z-Y boundary has been placed at the top of the first downcore interval devoid of planktonic foraminifera. At this level the *Globorotalia menardii* group is quantitatively present.

The presence of *Globorotaloides hexagona* in the deep water cores indicates that the X zone has been penetrated. This stenothermic species disappeared in the Atlantic Ocean at or shortly after the X-Y zonal boundary (e.g. KENNETT & HUDDLESTON, 1972; GARDNER & HAYS, 1976). The X-Y boundary has been defined by the drop in abundance of the *Globorotalia menardii* group and corresponds with a drastic climatic deterioration that heralds the last glacial period (Weichselian). Because the *G. menardii* group is (almost) absent in the higher part of the X zone (i.e. carbonate peak VI), the highest occurrence of

Fig. 9. Core T78-49: quantitative distribution or presence (●) of planktonic foraminiferal taxa (>63 μm), open sections represent intervals of strong carbonate dissolution (Orb. is *Orbulina*, scit. *scitula*, tril. *trilobus*, glut. *glutinata*, cras. *crassaformis*, men. *menardii* group).

Fig. 10. Core T78-45: quantitative distribution or presence (●) of planktonic foraminiferal taxa ($>63 \mu\text{m}$), open sections represent intervals of strong carbonate dissolution (*Orb.* is *Orbulina*, *scit.* *scitula*, *tril.* *trilobus*, *anf.* *anfracta*, *cras.* *crassaformis*, *men.* *menardii* group, *hex.* *hexagona*, *obliq.* *obliquiloculata*, *trunc.* *truncatulinoidea*).

Globorotaloides hexagona has been used to discriminate between the X and Y zones.

The inflection point below carbonate peak VIII has been taken as the X-W boundary. In cores T78-45 and -33 this point correlates with the temporal downcore disappearance of *G. hexagona*. In core T78-49, this species is too scanty to be of much use. The reintroduction of *G. hexagona* in the lowermost section of core T78-33 together with appreciable numbers of the *Globorotalia menardii* group mark the local V-W boundary.

The planktonic foraminiferal associations of the deep cores are too distorted by dissolution for further palaeoecological conclusions. In the shallow core T78-26 preservation lows, from which most planktonic Foraminifera have been removed, alternate with well-preserved sections (Fig. 11). The record is too fragmentary to discern climatic zones.

Fig. 11. Core T78-26: quantitative distribution or presence (●) of planktonic foraminiferal taxa ($>63 \mu\text{m}$), open sections represent intervals of strong carbonate dissolution (*infl.* is *inflata*, *dut.* *dutertrei* group, *uv.* *uvula*, *scit.* *scitula*, *tril.* *trilobus*, *glut.* *glutinata*, *cras.* *crassaformis*, *men.* *menardii* group, *trunc.* *truncatulinoidea*, *obliq.* *obliquiloculata*).

7. DOWNCORE COMPOSITIONS OF BENTHIC FORAMINIFERA

7.1. CORE T78-26

Of core T78-26 10 samples have been examined for benthic Foraminifera. In the samples *Bolivina dilatata* dominates with percentages varying from 38 to 87. Quantitatively important are also *Epistominella smithi* (2 to 29%), *Uvigerina peregrina* (3 to 16%), *Cassidulina carinata* (0 to 15%), *Bulimina marginata* (0 to 15%), *Bolivina albatrosi* (0 to 8.5%), and *Planulina ariminensis* (0 to 6.5%).

The dominance of *Bolivina dilatata* and *Bulimina marginata*, together with high total numbers of benthic Foraminifera (Fig. 6), numerous faecal pellets and the highly mottled structure of the sediments indicate that bottom waters were nutrient-rich and well oxygenated. The nutrient concentration at or near the bottom must be attributed to the input of terrestrial organic matter, which, together with its bacterial flora, serves as an important food source for benthic organisms.

7.2. CORE T78-45

In the deep core T78-45 benthic foraminiferal associations are dominated by the species *Epistominella*? *pusilla* and *Cibicides wuellerstorfi*. Amongst both species *Epistominella*? *pusilla* seems to be the one particularly susceptible to carbonate dissolution. Strongly fluctuating frequency patterns are shown by the species *Epistominella exigua*, *Osangularia*? *umbonifera*, *Astrononion* sp., *Melonis barleeanus* and *Uvigerina peregrina* (Fig. 12). *Epistominella exigua* shows high relative frequencies in the Holocene section of the core. Similar or higher frequencies at 600 cm and 800 to 850 cm, correspond with carbonate peaks VI and VIII of the X zone (substages 5a and 5e of the standard isotopic stages). Noteworthy is the presence of *Osangularia*? *umbonifera* in the upper part of the Holocene and in the lower part of the X zone (substage 5e) where it is quantitatively important (15%). A pattern more or less congruent with that of *Epistominella exigua* is shown by *Astrononion* sp. and *Melonis barleeanus*. *Uvigerina peregrina*, instead, shows an independent series of peak occurrences.

From the present species distribution it can be concluded that *Epistominella exigua* is characteristic of Arctic Bottom Water (SCHNITKER, 1974, 1979, 1980) and "younger" North Atlantic Deep Water (STREETER, 1973; STREETER & SHACKLETON, 1979). On the other hand, *Osangularia*? *umbonifera* seems to be the dominant element in the Antarctic Bottom Water (STREETER, 1973; SCHNITKER, 1974, 1979,

1980; LOHMAN, 1978; CORLISS, 1979). In terms of recent species distributions, Holocene bottom waters in the Angola Basin must have been made up of an admixture of North Atlantic Deep Water and Antarctic Bottom Water just as it is today (VAN BENNEKOM & BERGER, 1984). The joint dominance of *Epistominella exigua* and *Osangularia? umbonifera* in isotopic substage 5e points to nearly identical bottom water conditions. This is not surprising because the climate during substage 5e was at least as warm as it is today. Also for substage 5a bottom water composition may have been comparable to that during the Holocene. A parallel with modern bottom water conditions during substage 5e has been reported also for the North Atlantic Ocean (SCHNITKER, 1974; STREETER & SHACKLETON, 1979).

In core T78-45, the *Epistominella exigua* - *Osangularia? umbonifera* association has been largely suppressed or is absent for most of the last 160 000 years. Instead, *Uvigerina peregrina* dominates frequently. Its present distribution in the Atlantic Ocean largely follows the low oxygen levels of the Antarctic Intermediate Water and the Antarctic Circumpolar Water (SCHNITKER, 1974, 1980; STREETER & SHACKLETON, 1979). The recurrent peak frequencies of *U. peregrina*, therefore, may reflect intermittent periods of less oxygenated bottom waters in the Angola Basin. If true, these peaks may document periods in which the deep water circulation in the Angola Basin and possibly in the entire

Fig. 12. Core T78-45: quantitative distribution of selected benthic foraminiferal taxa (>63 μm) compared to % CaCO₃ and pattern of nannoplankton dissolution indices (dashed lines based on less than 200 counts).

ocean was slower than today. Ocean-wide weakening of the deep water circulation has been postulated in various models of glacial-interglacial deep water circulation (*e.g.* WEYL, 1968; WORTHINGTON, 1968; OLAUSSON & JONASSON, 1969; SACHS, 1976).

8. DOWNCORE TOTAL NUMBERS OF NON-CALCAREOUS BIOTIC AND ABIOTIC COMPONENTS

8.1. RADIOLARIA

Numbers of sand-sized Radiolaria were estimated in cores T78-33, -45, -49, and -46 (Figs 2 to 5) and compared with total number estimates of BJØRKLUND & JANSEN (1984) which are based on carbonate-free residues coarser than 44 μm . Because of the low carbonate content numbers based on bulk sediments do not differ significantly from those estimated on a carbonate-free basis.

Downcore radiolarian numbers fluctuate strongly and parallel to some extent the patterns of planktonic foraminiferal total numbers. A prominent radiolarian minimum is registered at and below carbonate peak VIII (isotopic stage 5e) in cores T78-33 and -49. In core T78-45 Radiolaria are even absent in this interval. A comparable high-amplitude drop in radiolarian numbers is recorded across the Y-Z boundary.

8.2. PYRITIC GRAINS, QUARTZ GRAINS, SPONGE SPICULES AND FISH REMAINS

Except in the uppermost part of the cores, where aerobic conditions prevail, sand-sized pyritic grains occur throughout the cored sediments. The grains consist largely of framboid lumps and burrows. The pyritic infilling of many Foraminifera and the preservation of the delicate burrows suggest an authigenic origin for the pyritic grains.

A pronounced peak in sand-sized pyritic grains is recorded at the base of the X zone in all deep water cores (Fig. 13) and coincides with the (near) absence of Radiolaria. X-ray diffraction analyses of bulk sediments show no peak concentrations in this interval (VAN DER GAAST & JANSEN, 1984).

The number of sand-sized quartz grains fluctuates randomly in all deep water cores (Fig. 13). The sands must have been transported from the shelf area, as their average size seems too large to be transported by wind.

The number of sponge spicules and fish remains (Fig. 13) also show a nondescript pattern. For both a slight drop in numbers is shown across the W-X and Y-Z boundaries of the deep water cores.

Fig. 13. Total number estimates of selected biotic and abiotic components per 10 g dry weight (>63 μm) a. Core T78-33. b. Core T78-49. c. Core T78-45.

8.3. DISCUSSION

The (near) absence of Radiolaria across the W-X boundary (Figs 2 to 4) may be explicable in terms of present-day radiolarian distribution. In today's inner plume area low phytoplankton productivity results from the short residence time and high turbidity of the surface waters (CADÉE, 1978; 1984; VAN BENNEKOM & BERGER, 1984). As postulated earlier, the (near) absence of Radiolaria in the surface sediments on the shelf off the Zaire estuary follows from the low phytoplankton productivity. If radiolarian production is lowered, the skeletons are more readily dissolved, which in turn reduces the chance of being preserved in the sediments. Likewise, increased runoff across the W-X boundary may have lowered primary production, leading to the drop in radiolarian numbers. In that case turbid and low salinity water must have spread over an area far larger than today. Increased runoff across the W-X boundary is strongly supported by the diatom data provided by MIKKELSEN (1984).

The peak in sand-sized pyritic grains across the W-X boundary (Fig. 13) may be due to the increased porosity of the sediments. If runoff raised the accumulation rate across the W-X boundary, the randomly fluctuating quartz grain numbers suggest that mainly fine-grained terrigenous material accumulated. This material would not increase the porosity. Otherwise, higher accumulation rates of fine-grained terrigenous material and associated higher food supply could have raised the number of burrowing organisms whose traces are clearly detectable on X-ray photographs. The preservation of these burrows may have increased porosity, thereby allowing the finely dispersed pyrite to accrete to coarser aggregates. The slight drop in combined numbers of sponge spicules and fish remains across the W-X boundary (Fig. 13) fits in well with the postulated higher accumulation rate in this interval.

It is possible that a number of features across the Y-Z boundary can be explained in almost the same way as those across the W-X boundary. Again, radiolarian numbers in the deep water cores T78-33 and -49, as well as in the shallow core T78-46, show a significant drop. MIKKELSEN (1984) reports a distinct lowering in diatom preservation and abundance of total diatoms in core T78-33. Also the patterns of sponge spicules and fish remains show a depression at the transition from the Y to the Z zone in the deep water cores (Fig. 13). As is the case of the W-X transition in core T78-45, diatoms and Radiolaria are absent from the Y-Z boundary upwards.

9. SUMMARY

The impact of the Zaire River on the oceanic environment is clearly illustrated in the surface sediments by anomalously high carbonate dissolution rates over a large area off the river mouth. This anomaly results from the high supply of terrestrial organic matter brought into the Angola Basin by the outflowing river water.

Carbonate dissolution indices demonstrate that downcore fluctuations in carbonate content are strongly controlled by carbonate dissolution processes. In the deep water cores variations in the rate of dissolution follow from changes in the position of the CCD. Variations in carbonate dissolution in the shallow cores are of local origin, and are linked to differences in the flux of land-derived organic matter.

Associations of planktonic Foraminifera in the cored sediments of the eastern Angola Basin consist of tropical-subtropical and transitional-subantarctic species. The latter are considered as "southern intruders" brought northward by the Benguela Current and are potentially useful for deciphering changes in surface-water circulation during the Quaternary. Unfortunately, in almost all cores the planktonic foraminiferal signal in the "cold" periods has been obliterated by dissolution. The compositional pattern (in core T78-46) indicates that the Benguela Current had a stronger influence during the last glacial than it has today.

High joint percentages of *Epistominella exigua* and *Osangularia? umbonifera* (in core T78-45) during the Holocene and Emian I document periods in which bottom waters were made up of an admixture of North Atlantic Deep Water and Antarctic Bottom Water just as they are today. Recurrent peak frequencies of *Uvigerina peregrina* may reflect intermittent stages of oxygen-poor bottom water.

A distinct drop in radiolarian numbers across the W-X and Y-Z zonal boundaries is attributed to a periodically increased discharge of river water, which lowered primary productivity due to the short residence time and high turbidity of the surface water. The resultant diminished supply of biogenic opal to the bottom prevents the opaline skeletons from being preserved in the sediments.

10. RÉSUMÉ

DISTRIBUTION DES FORAMINIFÈRES ET DU NANNOPLANCTON CALCAIRE
DANS LES SÉDIMENTS DU QUATERNAIRE DU BASSIN ORIENTAL DE
L'ANGOLA EN FONCTION DES FLUCTUATIONS
CLIMATIQUES ET OCÉANIQUES

L'influence du fleuve Zaire sur l'environnement océanique est clairement démontré dans les sédiments superficiels par des dissolutions élevés et anormales des carbonates au large de l'embouchure. Cette anomalie est liée à un important apport de matière organique terrigène amené dans le Bassin d'Angola par les eaux du fleuve.

Les indices de dissolution des carbonates dans les carottes profondes démontrent que la profondeur de compensation contrôle fortement les fluctuations des taux de carbonates sur la verticale des carottes. Les variations de dissolution dans les carottes peu profondes sont seulement d'origine locale et sont subordonnées aux changements de flux de la matière organique terrigène.

Les associations de Foraminifères planctoniques dans les sédiments carottés du Bassin oriental d'Angola sont composées d'espèces tropicales et sub-tropicales et d'espèces de transition sub-antarctiques. Ces dernières sont considérées comme des "intrus méridionneaux" amenés vers le Nord par le courant de Benguela. Les courbes de composition montrent que le courant de Benguela a eu une influence plus forte pendant le dernier glaciaire qu'aujourd'hui.

Les pourcentages élevés associés d'*Epistominella exigua* et d'*Osangularia? umbonifera* pendant l'Holocène et l'Eémien I dans une des carottes profondes illustrent les périodes de mélanges des eaux profondes nord-atlantiques et antarctiques jusqu'à nos jours. Les pics de fréquence récurrents d'*Uvigerina peregrina* peuvent refléter des stades intermittents d'eaux profondes pauvres en oxygène.

Une diminution très nette du nombre des Radiolaires dans les niveaux de transition des biozones W-X et Y-Z est attribuée à une élévation périodique de l'effluence des eaux du fleuve qui abaisse la productivité planctonique en fonction d'un temps de résidence réduit et de la forte turbidité des eaux de surface. La faible sédimentation d'opale biogénique sur le fond empêche la conservation des tests d'opale dans les sédiments.

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