An integrated stratigraphy of the Upper Quaternary of the King's Trough flank area NE Atlantic

Quaternary
Planktonic foraminifera
Coccoliths
Oxygen isotopes
Lithology

Quaternaire
Foraminifères planctoniques
Coccolithes
Isotopes de l'oxygène
Lithologie

P. P. E. Weaver
Institute of Oceanographic Sciences, Brook Road, Wormley, Godalming, Surrey GU8 5UB, UK.

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ABSTRACT

Stratigraphic studies of Quaternary sediments from the deep ocean have usually concentrated on single fossil groups, usually from widely-spaced samples. In this study both calcareous nannoplankton and planktonic foraminifera have been examined from eight closely-spaced cores from an area north-east of the Azores. Downcore variations in the foraminiferal fauna reflect changing climates whereas the calcareous nannoplankton show evolutionary changes during the last 200,000 years as well as variations in species abundance which are not directly attributable to the climate changes. Further correlation points are provided by coiling direction variations in *Globorotalia truncatulinoides*, by oxygen isotope measurements and by lithological changes. In total, 16 correlatable horizons have been identified within the last 200,000 years and the validity of each has been tested by plotting all the correlations together on Shaw diagrams.

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RÉSUMÉ

Stratigraphie du Quaternaire supérieur des parois de la fosse de King (Atlantique nord-oriental)

Les recherches stratigraphiques concernant les sédiments quaternaires situés dans l'océan profond se limitent, en général, aux groupes de fossiles individuels provenant d'échantillons très dispersés. Au cours de nos recherches, nous avons examiné le nannoplancton calcaire ainsi que des foraminifères planctoniques provenant de huit carottes rapprochées obtenues au nord-est des Açores. Certaines différences dans la faune de foraminifères indiquent des changements de climat, tandis que le nannoplancton calcaire démontre des changements évolutifs, survenus au cours des 200 000 dernières années, ainsi que des variations dans la quantité des espèces représentées, qui ne peuvent pas être attribuées directement à des changements climatiques. Des points de corrélation supplémentaires sont fournis par les variations du sens d'enroulement de *Globorotalia truncatulinoides*, par des mesures d'isotopes d'oxygène et des variations lithologiques. Dans les sédiments des 200 000 dernières années, nous avons identifié et corrélé un total de 16 horizons, leur validité ayant été vérifiée au moyen des diagrammes de Shaw groupant tous les tracés.

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INTRODUCTION

Stratigraphic studies of Quaternary sediments have almost invariably been limited to single fossil groups (e.g. Pujol, 1980) and they have usually covered large areas using a wide spread of cores (e.g. Gartner, 1977). The work of Pujol (1980) and Pujos-Lamy (1977), however, suggests that within small areas there may be numerous correlatable events which, although of limited interregional value, are of great value for intraregional correlation. Feasibility studies for the disposal of high-level radioactive waste have led to the detailed study of several areas of the North Atlantic seabed. Investigations into sediment stability in these areas requires very detailed stratigraphic studies of closely-spaced cores. The results of one such survey are

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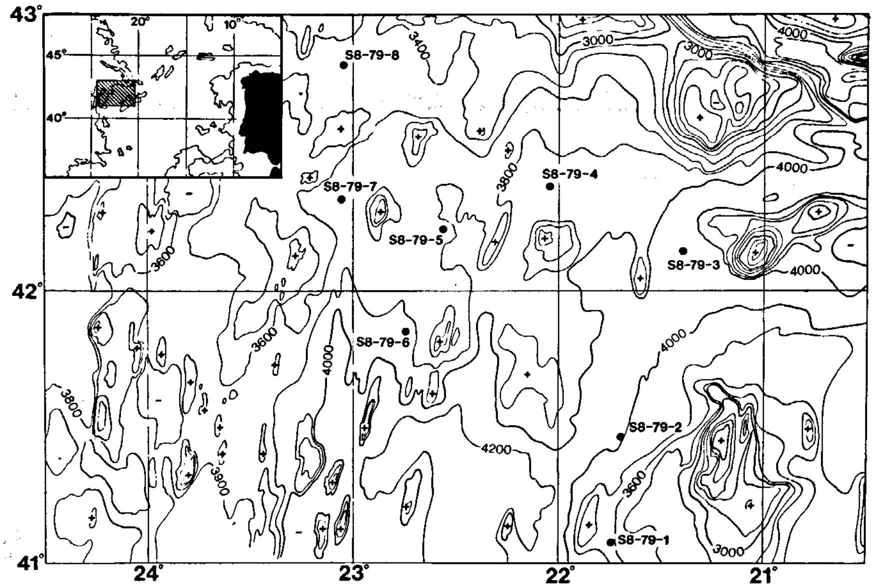

Figure 1
Bathymetry of the King's Trough Flank study area. Core positions shown by dots.

presented here. Integration of oxygen isotope, planktonic foraminiferal and coccolith data has enabled a very detailed subdivision of the cores to be made and use of Shaw diagrams has provided a check on the validity of each correlation method.

The area lies on the southern flank of King's Trough (Fig. 1) and has an average water depth of 3 800 m. It lies west of the abyssal plains and is not affected by major lateral sediment inputs such as turbidites. The sediments consist of marls and oozes which show very few signs of dissolution. Eight gravity cores from the area are discussed—two of these show repenetration features (Weaver, Schultheiss, in press), one contains a slump at its base and two contain hiatuses at their bases. The slump at the base of core S8/79/7 was recognised on sedimentological grounds but was not fully penetrated and so is not considered further. The hiatuses at the bases of cores S8/79/2 and S8/79/8 represent at least 50,000 years, since NN20 material is present beneath them. Because the other cores do not extend to NN20 no comparisons can be made and so the intervals below the hiatuses are not considered further.

STRATIGRAPHIC CORRELATIONS

Lithology

Although lithological changes do not yield positive identifications of particular oxygen isotope stages, they do very clearly indicate glacial and interglacial intervals within the cores. This is because there is a higher input of terrigenous clay during glacial periods, produced by increased erosion of the continental shelves and increased ice rafting (Ruddiman, McIntyre, 1976). Glacial intervals, therefore, stand out as having lower calcium carbonate percentages than interglacial intervals (Fig. 2). Once the glacial/interglacial cycles have been

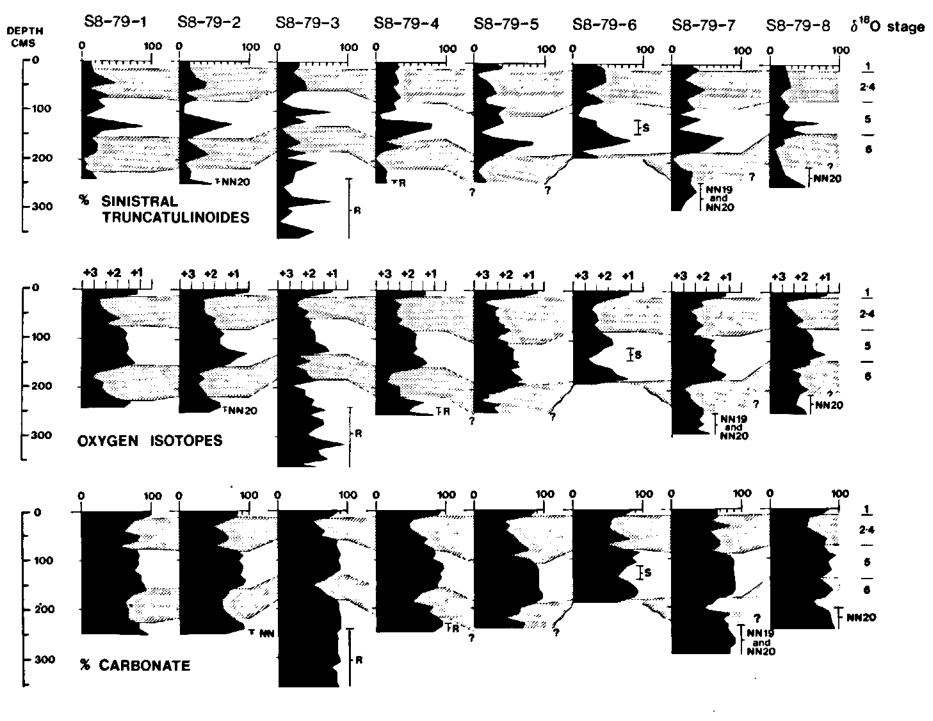

Figure 2
Percent abundance of sinistrally-coiled G. truncatulinoides, *percent calcium carbonate and oxygen isotope determinations in cores S 8/79/1-8. Stippled area represents glacial intervals as determined from the lithological changes; S = slump units, R = repenetrated units.*

dated by one or more of the methods described in later sections, the lithological changes provide very useful correlation points since they will be synchronous across relatively small areas such as the present study area. The marls are visibly distinguishable from the oozes, since they are softer and browner in colour, but a check was made by measuring calcium carbonate at 10-cm intervals with a "carbonate bomb" (Dunn, 1980). The results of this analysis are presented in Figure 2.

No evidence of strong dissolution was found in the present study and dissolution is not thought to be a significant factor in this area (Ruddiman, McIntyre, 1976). The average water depth of 3 800 metres places the area above the present-day lysocline (Biscaye *et al.*, 1976). Even if dissolution had affected the sediments the effects would be more pronounced during the glacials when Antarctic Bottom Water was produced in larger quantities (Gardner, 1975). The result of this would be to further differentiate the glacial intervals by decreasing their calcium carbonate even more.

cores S8/79/1, S8/79/2, S8/79/3 and S8/79/4 contain complete oxygen isotope records back into stage 7. The other cores all contain complete records back into oxygen isotope stage 6.

Coccoliths

All the cores belong to zone NN21 of Martini (Martini, 1971). *Emiliania huxleyi* can be found throughout, but its abundance is very low in oxygen isotope stage 7. Both zones NN21 and NN20 have been subdivided by Pujos-Lamy (1977) on the basis of a single core taken immediately to the west of the King's Trough area. Pujos-Lamy concentrated on the Gephyrocapsas and *E. huxleyi*, which are the most stratigraphically-useful coccoliths, but she did not use actual percentages when calculating relative abundances. Nevertheless, her conclusions are broadly comparable to those found here.

Figure 3 shows plots of the percent abundance of three species, namely, *E. huxleyi*, *Gephyrocapsa muellerae* and

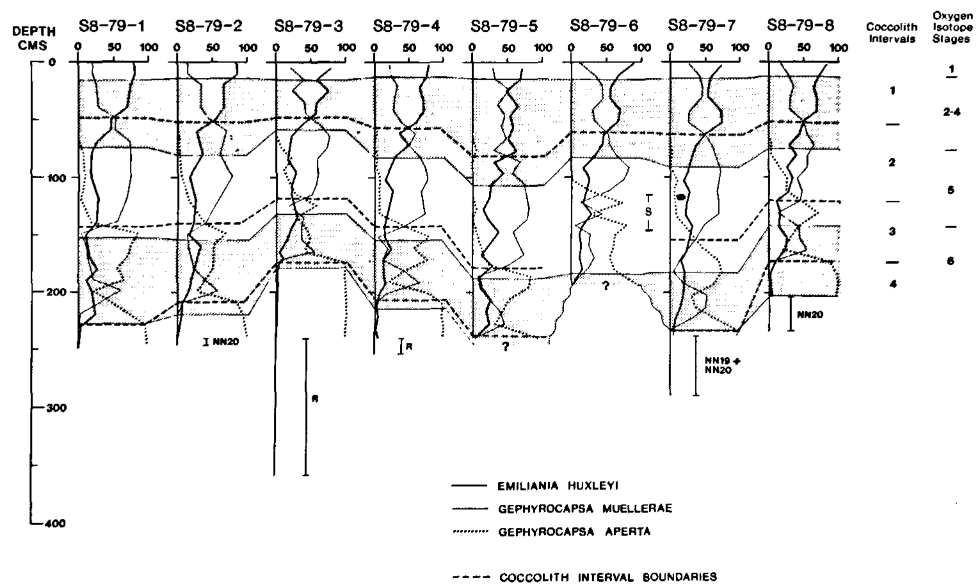

Figure 3
Percent abundance of G. aperta, G. muellerae *and* E. huxleyi *in cores S 8/79/1-8. Stippled areas as in Figure 2. NN 20 material recognised by absence of* E. huxleyi *and high percentages of* Gephyrocapsa caribbeanica.

Oxygen isotopes

Oxygen isotope determinations provide a very reliable method of determining glacial and interglacial intervals. Some stages, such as oxygen isotope stage 5, may also have unique characteristics which enable their positive identification (Shackleton, 1969), even in sediment columns which present an incomplete oxygen isotope record. Oxygen isotope determinations were made on specimens of *Globigerina bulloides* at 10-cm intervals (Fig. 2). These records clearly show stage 5 in each of the cores but the relatively low sedimentation rates (partly an artefact produced by core shortening; see Weaver, Schultheiss, in press) obscure the fine detail and make it difficult to distinguish between stages 2-4. Nevertheless, a peak on the graphs, representing isotopically light $\delta 0^{18}$ values can be seen in each core during oxygen isotope stage 3 (Fig. 2), and this provides a good correlation point. The anomalous isotopically heavy $\delta^{18}0$ values during stage 5 in core S8/79/6 are a result of a slump in this core which has introduced older glacial sediment. On the oxygen isotope evidence,

Gephyrocapsa aperta. Species other than these three were noted but not counted. In each sample about 300 specimens were counted from random traverses under the light microscope. S. E. M. analyses have been used to corroborate some of the *E. huxleyi* counts, particularly when small numbers of this species were encountered.

Following the revisions of the genus *Gephyrocapsa*, carried out by Bréhéret (1978) and Samtleben (1980), the dominant large specimens of this genus in this area in zone NN21 are assigned to *G. muellerae* and not *G. oceanica* as recorded by Pujos-Lamy (1977) or *G. caribbeanica* as recorded by Thierstein *et al.* (1977). *G. caribbeanica* is only common in pre-NN21 samples (Pujos-Lamy, 1977) whereas *G. oceanica* is very rare in this area.

The following stratigraphic intervals, beginning with the youngest, have been recognised:

1) An interval of dominant *E. huxleyi*. Base taken at the reversal of dominance between *G. muellerae* and *E. huxleyi*. This interval continues to the present day

and is known as the *E. huxleyi* acme zone (Gartner, Emiliani, 1976). *G. aperta* becomes extinct at the base of this interval although at the end of its range it constitutes less than 1% of the counted specimens and so its actual extinction point is difficult to recognise. This interval occupies oxygen isotope stages 1, 2 and most of stage 3. This is slightly younger than the stage 4 age recorded by Thierstein *et al.* (1977), but in that work the datum was taken at the point where *E. huxleyi* begins to increase in numbers and not at the actual cross-over point. As can be seen in Figure 3, the cross-over point is much easier to identify and consequently is used here in preference.

2) An interval where *G. muellerae* is dominant over *G. aperta* and *E. huxleyi.* Base marked by the youngest reversal of dominance between *G. aperta* and *G. muellerae.* Top marked by a reversal of dominance between *G. muellerae* and *E. huxleyi.* This interval occupies oxygen isotope stage 4 and most of stage 5.

3) An interval mainly dominated by *G. aperta.* Base marked by a downcore increase in its percentage to more than 90%. Top marked by the youngest reversal of dominance between it and *G. muellerae,* after which *G. aperta* declines rapidly. A correlation point within this interval is a short-lived dominance of *G. muellerae* over *G. aperta. E. huxleyi* makes up about 10-20% of the counted specimens in this interval. This interval occupies the lower part of oxygen isotope stage 5 and most of oxygen isotope stage 6.

4) An interval of dominant *G. aperta.* The base of this interval is not seen in the present cores. The top is marked by a downcore increase in the percentage of *G. aperta* to more than 90%. *E. huxleyi* is very rare in this interval. Interval 4 occupies the lowest part of oxygen isotope stage 6 and at least part of stage 7.

Planktonic foraminifera

Planktonic foraminifera were analysed from samples taken at 10-cm intervals. The samples were sieved through a 180 μ sieve and splits of 300 individuals were counted. The results of such a survey can be displayed in various ways, either as plots of individual species abundance, group species abundance (e.g. subtropical species) or as multivariant factors (Imbrie, Kipp, 1971). Here, as a first approach, plots of individual species and species groups were used since they provide adequate stratigraphic data. The more useful planktonic foraminifera are *Globorotalia truncatulinoides* and *Neogloboquadrina pachyderma. G. truncatulinoides,* a well-known subtropical species (Kipp, 1976) varies in abundance in the King's Trough area from absent during glacial periods to about 10% of the planktonic foraminiferal fauna during interglacial periods (Fig. 4). *N. Pachyderma* (sinistral), a very cold, low-salinity water indicator, shows an inverse distribution with high percentages during glacial periods (Ruddiman, McIntyre, 1981). Thus, glacial and interglacial intervals can be easily recognised in the cores. The boundaries of

Figure 4

Percent abundance of selected planktonic foraminiferal species in cores S 8/79/1-8. Stippled areas as in Figure 2.

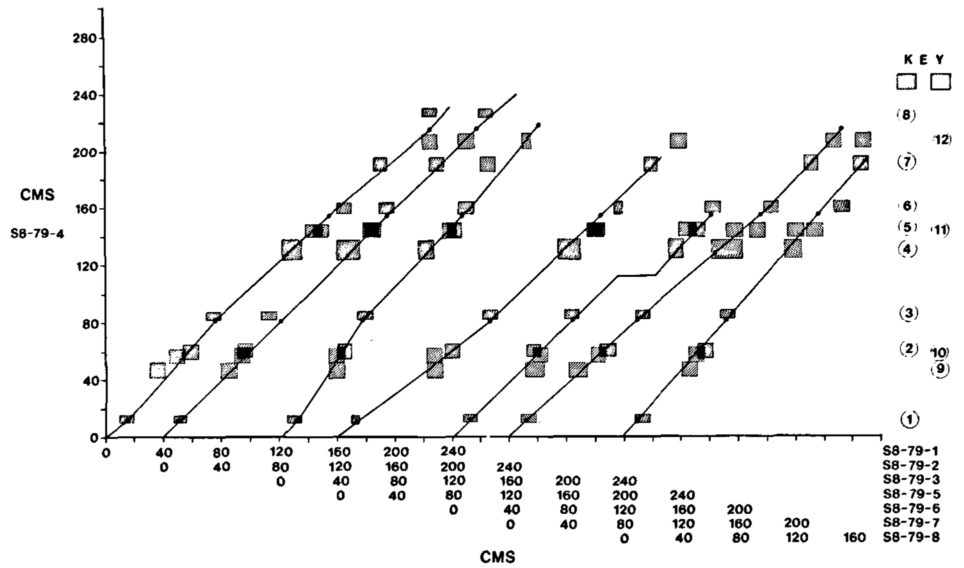

Figure 5
Shaw correlation diagram showing correlation of cores S 8/79/1-3 and S 8/79/5-8 to core S 8/79/4. Dots represent lithological changes; boxes represent distances between samples. Correlations represent: 1) oxygen isotope stage 1/2 boundary; 2) minimum value peak $\partial^{18}O$ during oxygen isotope stage 3; 3) oxygen isotope stage 4/5 boundary; 4) interval of sinistrally-coiled G. truncatulinoides; *5) low percentage of* G. bulloides, *high percentages of* G. inflata *and* G. ruber; *6) oxygen isotope stage 5/6 boundary; 7) low percentage of* G. inflata *during oxygen isotope stage 6; 8) oxygen isotope stage 6/7 boundary. Boxes with opposite shading represent coccolith interval boundaries; 9) extinction point of* G. aperta; *10) coccolith interval 1/2 boundary; 11) coccolith interval 2/3 boundary; 12) coccolith interval 3/4 boundary.*

these intervals coincide very closely with the lithological (calcium carbonate) changes with the higher carbonate intervals representing interglacials.

Other species of planktonic foraminifera show more subtle changes. Oxygen isotope stage *5e* is characterised by increased percentages of *Globorotalia inflata* and *Globigerinoides ruber* and a reduction in the percentage of *G. bulloides* (Fig.4). This reflects the warmer temperatures experienced during stage *5e* (Shackleton, 1969) and gives a useful correlation point. A further correlation point is provided by a coiling direction change in *G. truncatulinoides.* This species is dominated by the dextral form in the King's Trough area today (Kipp, 1976). However, during oxygen isotope stage *5d* there was a short-lived pulse dominated by the sinistral form (Fig. 2). Similar coiling direction changes in *G. truncatulinoides* were recorded by Ericson and Wollin (1956*a* and *b*) in cores from the equatorial Atlantic. Care must, however, be taken when correlating coiling direction changes over such long distances since Pujol (1980) has shown that in different areas of the North Atlantic they occur at different times. Such correlations can, therefore, only be relied on for intraregional correlation such as within the King's Trough area.

Correlation

To test the validity of each correlation, derived from each of the preceding methods, a "Shaw diagram" (Shaw, 1964) has been used (Fig. 5). Core S8/79/4 has been used as the vertical axis and each of the other cores is compared to this. Cores with identical sedimentation rates will produce linear correlations with 45° slopes in this type of diagram. Omissions or duplications in the sedimentary record of any one core will show up as offsets in the regression line. Changes in sedimentation rate will show up as changes in slope. Once each line has been drawn from a series of correlation points (preferably a large number) new datums can be tested to see if they fall on the same line in which case they can be regarded as reliable stratigraphic markers, at least in the area under consideration. The boxes in Figure 5 that surround the points represent the distance between samples. The correlation point can lie anywhere between two samples and so the constraint on the regression line is for it to pass through the box and not through a specific point. An exception to this is the lithological boundaries which can be accurately defined and are consequently plotted as points.

Regression lines based on lithological changes, oxygen isotope stage boundaries, foraminiferal correlations and coccolith interval boundaries are shown in Figure 5. The regression lines are remarkably straight and do not deviate significantly from a 45° slope. This shows that sedimentation has been uniform across the area during each interval but, since absolute time is not used as either axis, sedimentation rates may have varied with time. Significant deviations from a 45° slope can be seen during oxygen isotope stages 2-4 in core S8/79/3 where a reduction in sedimentation can be seen. Correlations (2), (9) and (10) in this core fall on a straight line between correlations (1) and (3), suggesting a reduction in sedimentation rate relative to core S8/79/4 rather than an hiatus which would produce an offset in the regression line. In core S8/79/5 an increase in sedimentation rate can be seen in oxygen isotope stages 1-4. Core S8/79/6 shows an increase in sedimentation between correlations (3) and (4). Unfortunately, these two points are too far apart to determine whether this is the result of an increased sedimentation rate or an added piece of sediment derived from slumping or a turbidity current. From examination of the core, however, this is seen to be a slump which is 26-cm thick. When the two segments of the regression line are drawn they have an offset of 26 cm which suggests that the slump was not accompanied by any significant erosion.

The coccolith interval boundaries all plot on the regression lines thus proving their value as stratigraphic markers. Since gravity corers are known to preferentially shorten softer (more marly) sedimentary units (Weaver, Schultheiss, in press), rates of sedimentation have not been calculated. All the cores contain similar alternations of lithologies and so the core-to-core comparisons in Figure 5 are much more meaningful for these cores than estimates of sedimentation rate.

CONCLUSION

Analysis of oxygen isotopes, lithological changes, coccoliths and planktonic foraminifera from a series of cores from the King's Trough southern flank has led to a detailed integrated stratigraphy. The cores contain complete sedimentary records back to oxygen isotope stage 7 and in this interval 16 correlatable datums can be recognised. Many of these datums cannot be used independently but are useful correlation points within a basic stratigraphic framework based on oxygen isotope stages and coccolith intervals. Relative abundances of three species of coccolith, namely, *E. huxleyi*, *G. muellerae* and *G. aperta* can be used to divide oxygen isotope stages 1-7 into four intervals. Shaw diagrams have been used to test the validity of each correlation point and to determine relative differences in sedimentation rate across the area.

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