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A CORRELATION OF LATE QUATERNARY CORES FROM SOUTH OF KING'S TROUGH, NORTH ATLANTIC

P.P.E. WEAVER

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January 1981

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF OCEANOGRAPHIC SCIENCES

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Work carried out under contract to the Department of the Environment

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INTRODUCTION

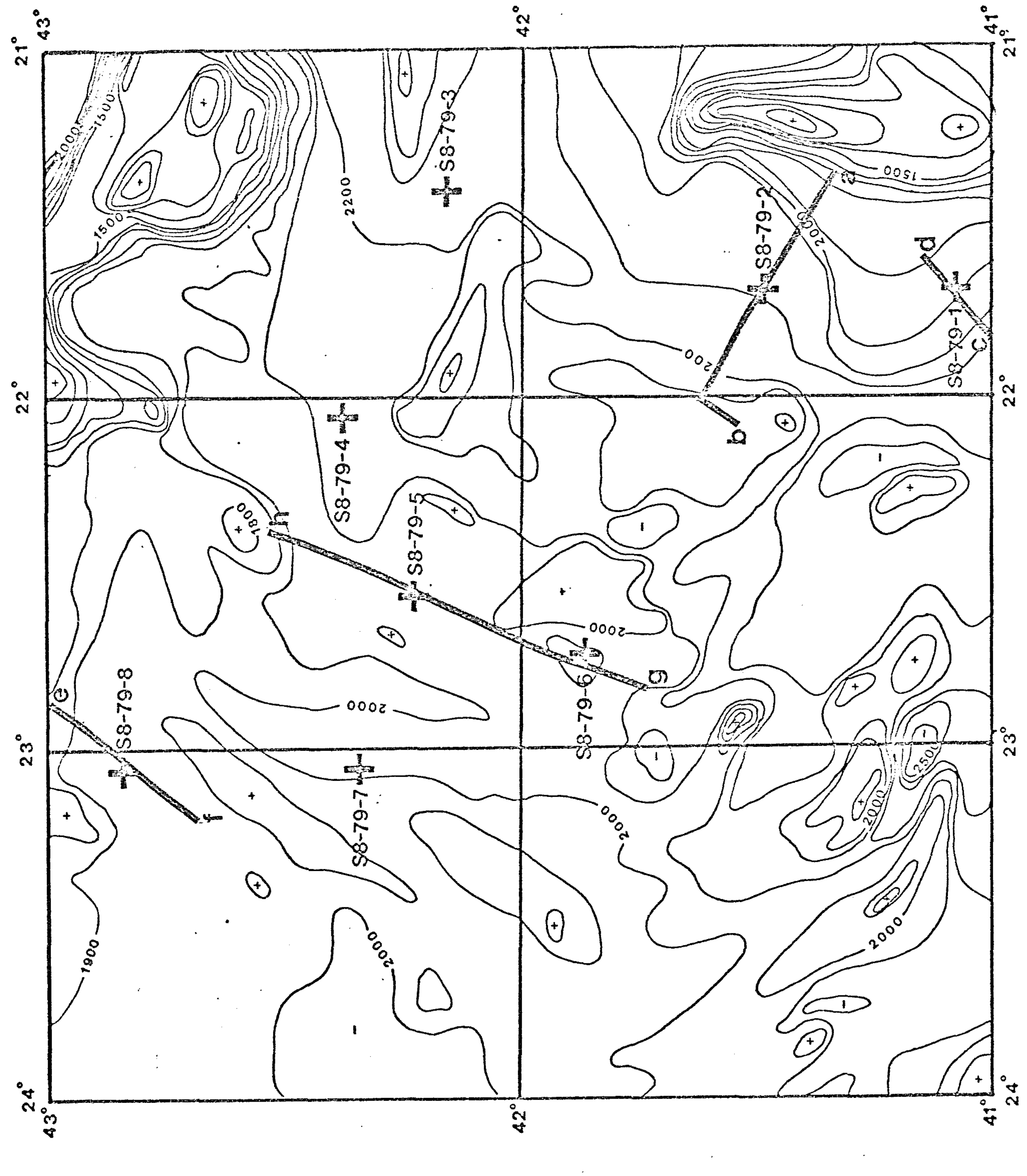
The investigation of possible disposal sites for High Level Radioactive Waste is concerned with finding a stable site where changes in sedimentation with time can be predicted and where horizontal changes within the sediments are at a minimum. It is particularly important to find a site which shows no evidence of erosion or hiatuses (IOS report no. 77). To obtain this information large numbers of cores need to be taken from each potential area and detailed stratigraphies must be determined for each core in order to provide a time framework within which sedimentological changes can be interpreted. There are numerous methods of obtaining dates on sediment cores. Absolute dating using radiocarbon (C^{14}) and uranium series (thorium Th^{230} and proactinium Pa^{231}) can be used but do not always give reliable results (Broecker & Ku, 1969). Palaeomagnetic reversal stratigraphy is very reliable but gives very few correlateable events in the Quaternary. The only major reversal occurs at 690,000 years which is well below the base of all the cores used in this study. The most reliable methods of correlating Quaternary cores are oxygen isotope measurements and palaeontological methods. Both nannofossils and planktonic foraminifera can be used to provide palaeontological data but only foraminifera are considered here. Oxygen isotope work is being carried out and this, together with the nannofossil data will be compiled later.

Quaternary sediments from the North Atlantic have been studied intensively in recent years particularly by the CLIMAP group (see Cline & Hays, 1976). Most of their attention has focussed on documenting the history of climate change over the past million years and they have relied heavily on the use of planktonic foraminifera. The CLIMAP group have used 100 cores spread throughout the whole of the North Atlantic for their study and whilst the fauna from these cores has been intensively investigated on a statistical basis they have not studied the problem of close correlation of large numbers of cores from relatively small areas. Therefore, whilst the CLIMAP methods have been very useful to this study other methods of correlation with direct application to small areas have also been sought.

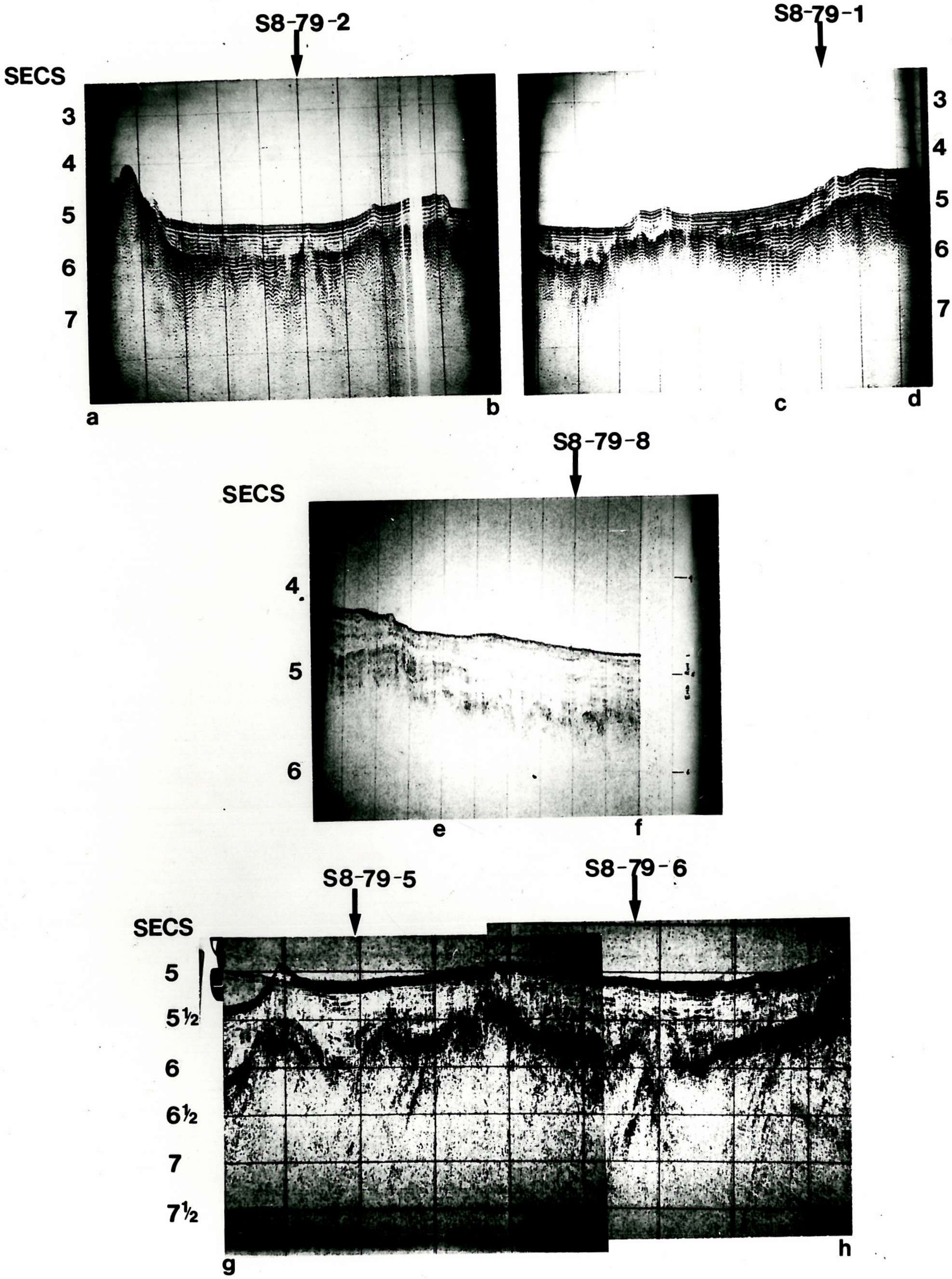
The great problem with correlating Quaternary cores is that virtually no new species evolve, or old species become extinct, during the period so that conventional methods of palaeontological stratigraphy cannot be applied. In compensation for this Quaternary ice ages have caused major changes in oceanic surface water temperature, salinity and circulation which have caused major shifts in faunal and floral distributions. By plotting these shifts glacial and interglacial periods can be recognised in deep sea cores and correlated from area to area. There is some danger in correlating cores by this method since sediment disturbance by slumping or currents could lead to undetected breaks in the record or cause duplication of parts of the record. It is therefore important to be able to recognise particular horizons which can be correlated with confidence and to use faunal fluctuations to correlate the intervals between such horizons. This time framework can then be used to correlate sedimentological events or to identify hiatuses. In correlation over relatively small distances the problem of transgressive changes in faunal distributions caused by the slow build up or decay of ice sheets should not be important.

LOCATION OF CORES

The first HLRW study area was identified on the basis of existing seismic profile lines - it lies approximately between 41-43° N and 20-23.5°W, south of King's Trough and west of the Azores-Biscay rise. This is a high carbonate area of fairly low topography and will be compared to other areas, generally more clay rich, which will be investigated on later cruises. A series of 8 cores were taken in the King's Trough study (Text - fig. 1) during cruise S8-79 of R.R.S. Shackleton. Positions of cores and water depths are given in Table 1. Some of these lie on seismic reflection profile lines (Text - fig. 2) which reveal fairly gentle topography with thick sediment cover (about 600-700 m) draped over a sometimes uneven basement.



Text - fig. 1. Location of cores with bathymetry of area (contours in fthms). Seismic reflection profile lines marked as thick black lines.

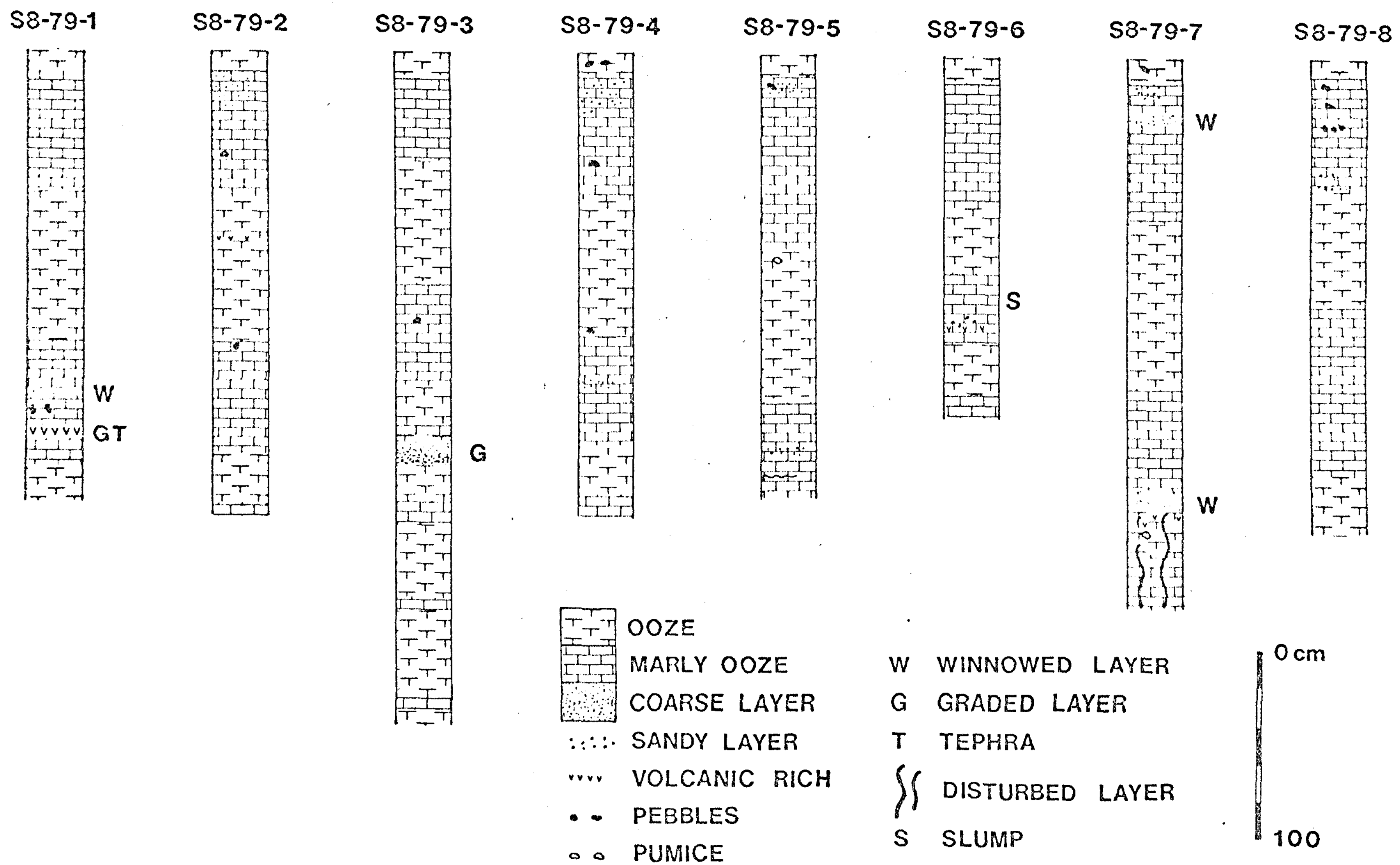


Text-fig. 2. Seismic reflection profiles across coring sites. Track lines as on text-fig. 1.

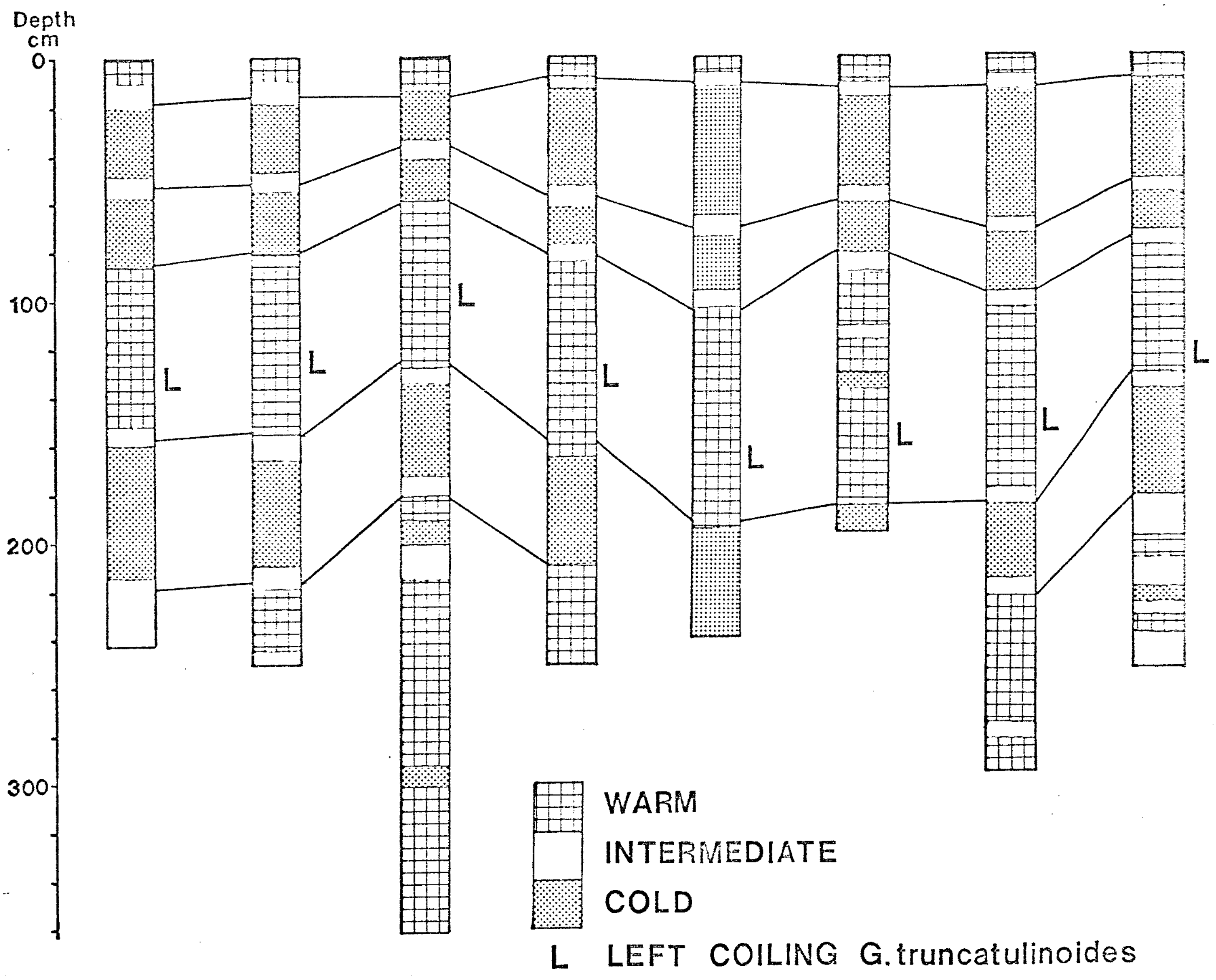
LITHOLOGY

The cores are composed of a series of carbonate ooze layers with $CaCO_3$ contents of over 80% and layers of marl and marly ooze with $CaCO_3$ contents ranging as low as 40% (Text - figs. 3 and 4). Median grain size for both ooze and marl intervals varies in the range 2-8μ although this can rise to over 160μ in the winnowed or graded sand rich layers. The distinction between the pure oozes and the marly oozes is readily discernable with the oozes being firm and white and the marly oozes varying from buff to yellowish brown and being softer and more soupy in texture. The marl ooze intervals also contain occasional small, glacial, erratic pebbles and small amounts of terrigenous sand. They correlate well with the glacial episodes and presumably represent dilution of the biogenous carbonate by clay and sand derived from icebergs, sea ice or increased wind activity during glacial periods. The macro-lithology may therefore be used as an initial guide to cold and warm intervals.

Some of the cores also contain volcanic material in the form of either pieces of pumice, tephra rich layers or, in the case of core S8-79-1, a 5cm thick layer of graded tephra. Other sedimentological features include a prominent graded layer in core S8-79-3, and winnowed layers in cores S8-79-5 and S8-79-7. The lowest 50cm of core S8-79-7 represents a disturbed unit, possibly caused during coring, and data from this level must be treated with scepticism. X radiographs of the cores were used to identify features not visible on the split core surface such as pebbles, graded layers and hiatuses. The fact that relatively few graded layers are present and that no hiatuses have been found supports the contention that these cores come from areas of quiet, continuous deposition. Hiatuses represent palaeocirculation changes and are accompanied by erosional and non-depositional intervals. Areas subject to such changes will not make good disposal sites. There is, in fact, little structural evidence of erosion in the cores other than the foram sand layers which are interpreted as resulting from current winnowing of the ooze and marly ooze layers.



Text-fig. 3. Lithology of cores.



Text-fig. 4. Preliminary estimate of cool and warm intervals with correlation lines based on later analyses. Left coiling intervals of G. truncatulinoides marked as 'L'.

The X radiographs also reveal burrows. These are fairly common in the cores and show up particularly well in the more marly intervals. This is presumably because these layers are less homogenous, so burrow infills often have a slightly different composition to the surrounding sediment. It is probably safe to assume that all the cores are bioturbated throughout and in such circumstances a sample interval of 10cm is generally regarded as giving optimum resolution of detail with minimum effect of mixing.

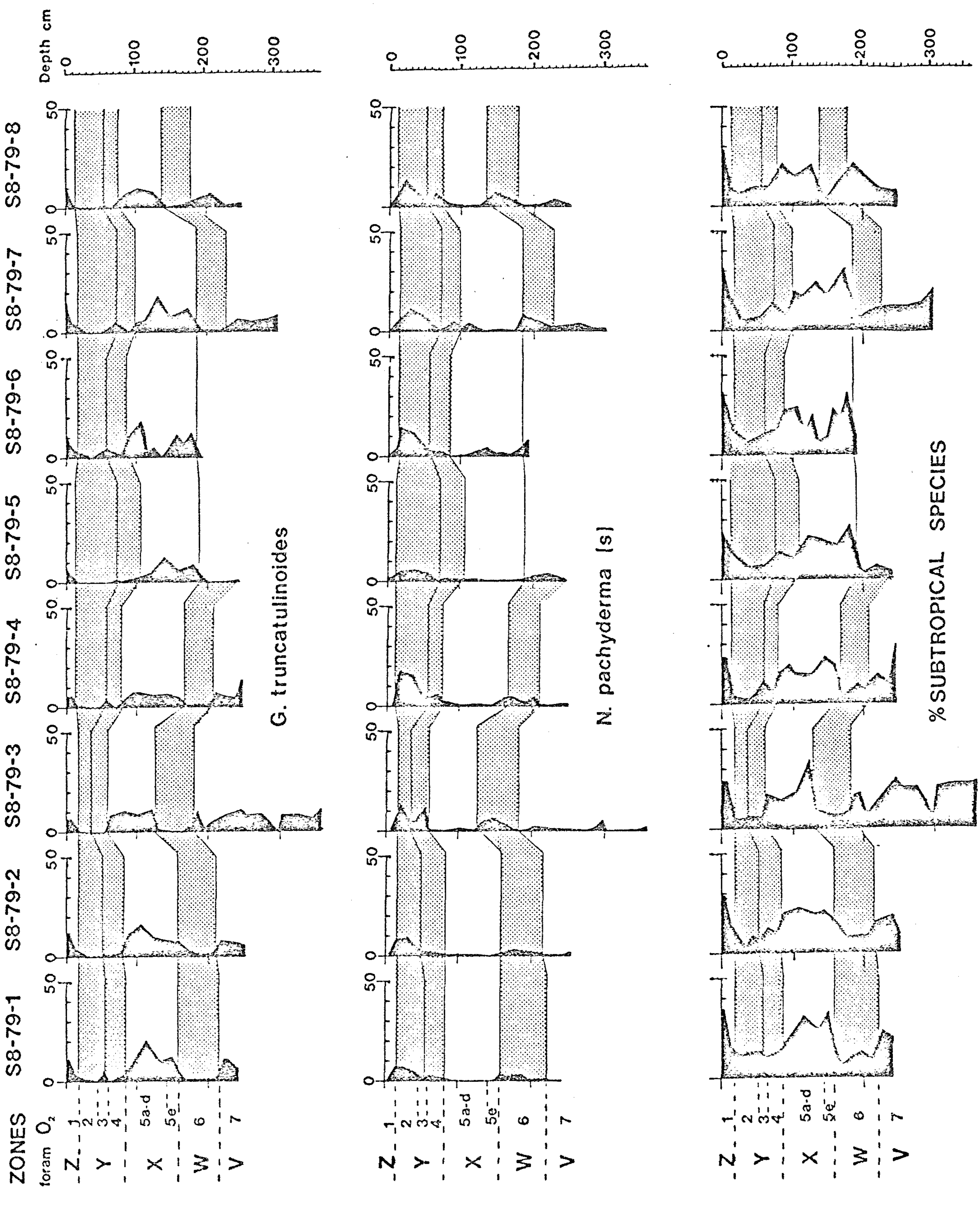
There appears to be little horizontal variability in lithology across the area, the small differences between pure oozes and marly oozes being seen down each core. Individual ooze and marly ooze layers can be correlated from core to core but the graded and winnowed layers are not correlatable and presumably represent localised events. The sand:silt:clay ratios emphasise the pelagic nature of the sedimentation, most being around 20:25:55. Much of the sand size material is foraminiferal skeletal material and much of the clay size material is, in fact, fine carbonate and quartz rather than clay minerals.

STRATIGRAPHY

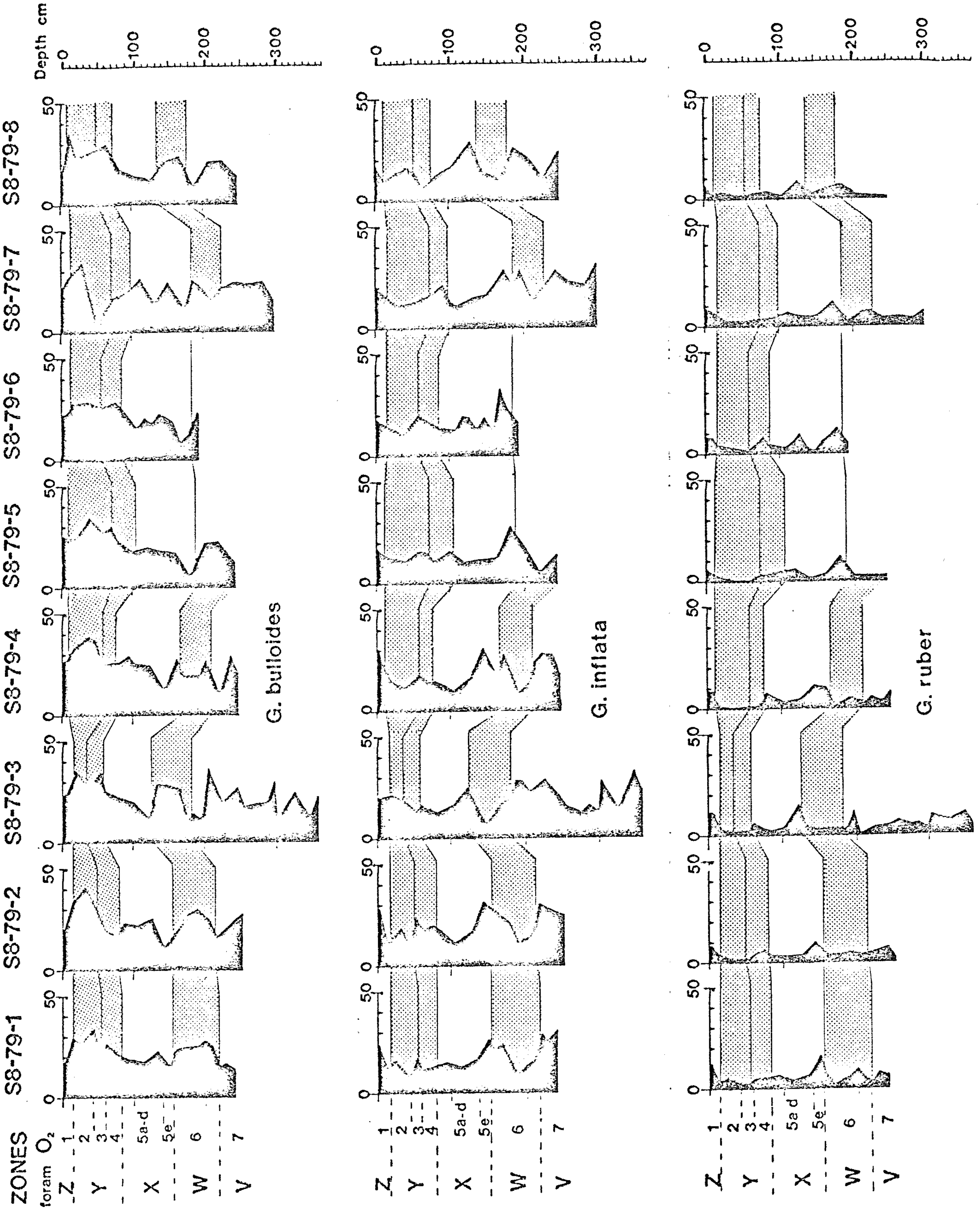
PLANKTONIC FORAMINIFERA

Samples were taken at approximately 10cm intervals down each core although this interval was sometimes altered to enable samples to be taken on either side of any major lithological changes. The samples were washed through a 63μ sieve, dried and stored in glass tubes for later examination. The residue on the 63μ sieve consists almost exclusively of the tests of planktonic foraminifera.

The results obtained here are related to the Quaternary zonal scheme of Ericson et al. (1961). These zones (Text - figs. 5 and 6) are based on the occurrence of Globorotalia menardii in tropical and subtropical areas. This species inhabits only warm water areas and almost disappears from the N. Atlantic during glacial



Text-fig. 5. Relative abundance of G. truncatulinoides, N. pachyderma (sinistral coiling) and subtropical species in each core. Stippled areas = cold intervals. Foram zones after Ericson et al. (1961); oxygen isotope zones after Shackleton (1969).



Text-fig. 6. Relative abundance of G. bulloides, G. inflata and G. ruber in each core. Stippled areas = cold intervals. Foram. zones after Ericson et al. (1961); oxygen isotope zones after Shackleton (1969).

intervals. The zones are therefore directly correlatable with the glacial/interglacial intervals. Work on oxygen isotopes (Emiliani, 1955; Shackleton, 1969) has led to the setting up of several oxygen isotope stages for the late Quaternary (Text - figs. 5 and 6. In part these correlate with the menardii zones but oxygen isotopes can be used to subdivide zone Y into three stages (stages 2, 3 and 4). Stage 3 represents a warmer interval within this generally cold period, and this interval can be recognised in the present cores by changes in the foraminifera.

1. Preliminary investigation

Before detailed analysis was carried out, each tube was examined under the binocular microscope and a qualitative estimate of a 'warm' or 'cold' origin for the sample was determined based on the following criteria - abundance of Globorotalia truncatulinoides, quality of preservation of foram. tests, abundance of large specimens. Some samples show excellent preservation with white specimens of varying size and contain large numbers of G. truncatulinoides. These are regarded as having a relatively warm water origin. Other samples contain more discoloured (often yellowish) specimens often with specks of manganese and of smaller size; these contain very few specimens of G. truncatulinoides and are regarded as having a colder water origin. Some samples are regarded as being intermediate. Thus an estimate of 'cold' or 'warm' can be obtained very quickly by this method and the boundaries of the Quaternary zones as defined by Ericson et al. (1961) can be located in each core (Text - fig. 4).

2. Analysis of total fauna

The distribution of many planktonic foraminiferal species in today's oceans is governed by temperature. Analyses of these temperature dependent groups have been used for a long time in Quaternary studies (Phleger Parker & Pierson, 1953; Ericson & Wollin, 1968; McIntyre, Ruddiman & Jantzen, 1972). With the intensified activity of the CLIMAP group Q-mode factor analysis has been used to determine quantitatively each species assemblage (Imbrie & Kipp, 1971) and the following assemblages have been identified (Ruddiman & McIntyre, 1976)

(a)	Polar	- Neogloboquadrina pachyderma sinistrally coiled
(b)	Subpolar	- Neogloboquadrina pachyderma dextrally coiled Globigerina bulloides Globigerina quinqueloba
(c)	Transitional	- Globorotalia inflata
(d)	Subtropical (Northern)	- Globorotalia scitula Globorotalia hirsuta Globorotalia truncatulinoides
(e)	Subtropical (Southern)	- Globigerinoides ruber Globigerinella aequilateralis Globorotalia crassaformis Globigerinoides conglobatus

Each sample is sieved through a 180μ sieve and about 300 specimens are split off. These are separated into species and the total number of specimens in each assemblage are counted. Each assemblage can then be plotted down core.

The present suite of cores comes from an area situated towards the southern edge of the transitional province (Bé, 1977). During warm intervals the fauna comprises transitional, subtropical (northern) and subpolar species but during glacial periods the subtropical elements are replaced by polar species. Both cold and warm intervals contain large numbers of transitional and subpolar species.

3. Analysis of individual species

Some of the species show major fluctuations in down core abundance whilst others show only minor fluctuations. To determine whether the fluctuations of a given species occur in all cores at the same time or whether they are random, plots of relative abundance of each species in each core were laid side by side and correlation lines drawn between the cores using information from methods 1 and 2. Consistent changes from core to core could then be distinguished from non-consistent changes (Text - figs. 5 & 6). By this method the following species were recognised as being useful:

Globorotalia truncatulinoides

This species is common during interglacials (zones Z, X, V) but very rare to absent during glacials (zones Y, W, U). It is probably the most useful species for determining relative water temperature in this area.

Neogloboquadrina pachyderma (sinistrally coiled)

This species shows an inverse relationship to G. truncatulinoides - it is common during cold intervals and absent during warm intervals. It is particularly common at the top of zone Y (oxygen isotope stage 2).

Globigerinoides sacculifer, Globigerinoides conglobatus

These two species belong to tropical and subtropical assemblages and their latitudinal range rarely reaches as far north as the King's Trough area. They do occur, however, in very small numbers in all eight cores in the core top samples and at the lower end of zone X (oxygen isotope stage 5e).

Globorotalia inflata

This species is always fairly common but in the lower part of zone X it always shows a marked peak in abundance.

Globigerina bulloides

Always very common but always showing reduced abundance during the lower part of zone X (oxygen isotope stage 5e).

Globigerinoides ruber

Generally present in low numbers but more common in core top and in stage 5e.

4. Coiling direction changes in G. truncatulinoides

The possibility of using coiling direction changes in G. truncatulinoides as stratigraphic markers was first put forward by Ericson, Wollin & Wollin (1954). They showed the distribution of left and right coiled varieties in core tops from the North Atlantic and how the coiling direction often changes down core. Since different coiling directions characterise different parts of the N. Atlantic today down core changes of coiling cannot be used for inter regional correlation but can be used within relatively small areas such as the present study area. Coiling of G. truncatulinoides in the present area is dominantly dextral but in every core there is a dominantly sinistral interval near the base of the X zone. This interval lasts for only 10-20 cm and gives a very reliable correlation point (Text - Fig. 4).

DISCUSSION

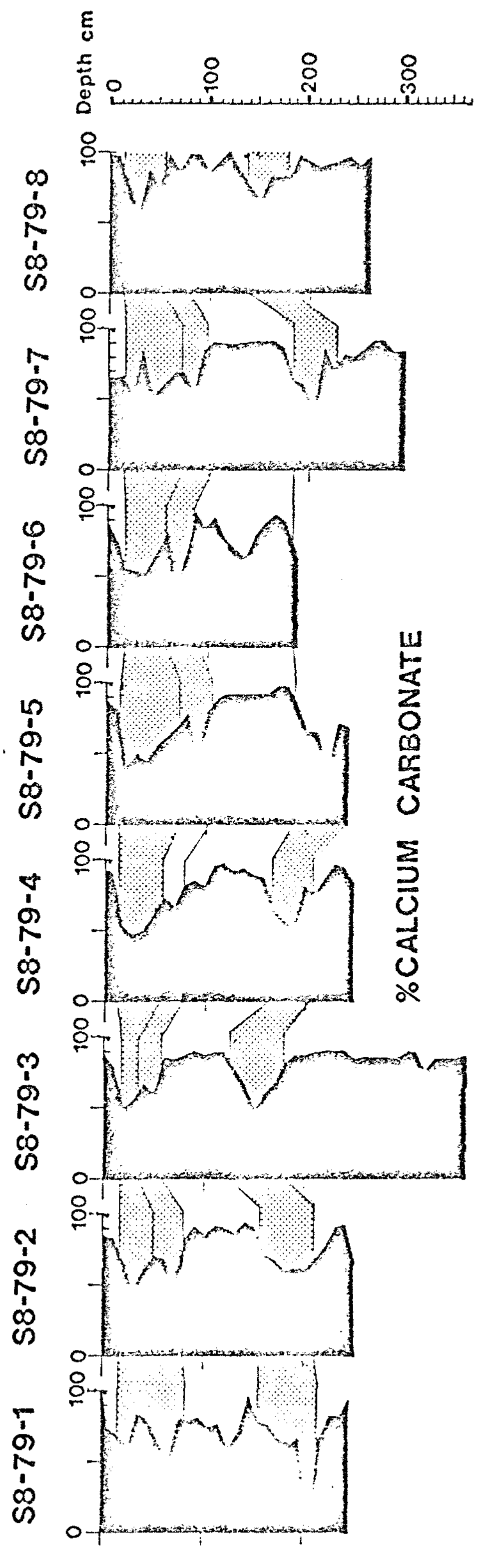
CORRELATION

There are therefore many ways in which cores from this part of the N. Atlantic may be correlated, most of which rely on plotting boundaries between glacial and interglacial intervals. Relative abundance of different species assemblages is probably the most orthodox method. This gives the most reliable results but takes the longest time since the whole planktonic foram. fauna needs to be analysed. The curves produced (Text - fig. 5) show clear divisions between 'warm' and 'cold' intervals which reflect ice advance and retreat stages. Good graphs can be obtained by looking at the relative abundances of G. truncatulinoides and N. pachyderma (sinistrally coiled). This analysis can be completed more quickly than the previous one and it appears to give equally good results. The changes in coiling direction of G. truncatulinoides give an excellent correlation point but these changes occur too infrequently to use this method on its own. Once a correlation has been obtained other species can be used to subdivide some of the intervals e.g. the low and high values of G. bulloides and G. inflata respectively in the lower part of zone X. Such changes as these are too subtle to be used in isolation but they can add to the value of the other methods.

A comparison between the preliminary investigation based on a qualitative assessment of numbers of G. truncatulinoides together with estimates of quality of preservation and abundance of large specimens with the more quantitative methods shows that the preliminary investigation is very useful. It produces a very rapid estimate of stratigraphy which has not been substantially improved by the more time consuming methods. When the foraminiferal correlation is applied to curves of percentage calcium carbonate in each core, intervals of high $CaCO_3$ are seen to compare closely with warm intervals, lower values of $CaCO^3$ compare with cooler intervals (Text - fig. 7). Although oxygen isotope information is not yet available on all the cores the results of this investigation are available for core S8-79-8. These results are in good agreement with the foraminiferal data. They show stage 2 to be particularly cold - this is the interval with the highest percentage of the polar species N. pachyderma (s). They also show stage 3 to be a short warmer interval within zone Y - this warming had been recognised in the preliminary investigation and can also be seen by a slight change of abundance in some of the species. The oxygen isotope results also show the earliest part of zone X (stage 5e) to be equally as warm as, or warmer than today. This interval can be recognised in the fauna by slight changes in abundance of some species and by small influxes of G. sacculifer and G. conglobatus at this level in all the cores.

HISTORY OF DEPOSITION

All the cores contain the Z, Y and X zones; most also contain the W zone, and core 3 in particular includes a large interval of the U zone. Within this time interval there are a number of dated horizons (Broecker & van Donk, 1970). The Z-Y boundary or Termination I is dated at 11,000 years, the Y-X boundary at 75,000 years, X-W boundary or Termination II at 127,000 years



Text-fig. 7. Percent calcium carbonate in each core. Correlation lines as in Text-figs 5 & 6. Stippled areas = cold intervals.

and the W-V boundary at 170,000 years. From these figures it is possible to determine sedimentation rates but the effects of foreshortening of the core due to the coring method must first be eliminated. The cores were taken by gravity corer and this type of instrument can cause up to 50% shortening of some sediments (Ross & Reidel, 1967). Fortunately, core RE5-34 described by McIntyre, Ruddiman & Jantzen (1972) was taken at 42°23'N 21°58'W which is less than 10 km east of core S8-79-4. RE5-34 was taken by piston corer which considerably reduces the amount of shortening. McIntyre et al. obtained a sedimentation rate of 2 cm/1000 years for this core compared to 1.2 cm/1000 years to contract the record by about 40%. Table 2 shows the calculated rates of sedimentation for the 8 cores based on depths corrected by this amount. The average sedimentation rate is fairly consistent at about 2 cm/1000 years with cores S8-79-5 and S8-79-6 having slightly higher rates and core S8-79-3 having a slightly lower rate.

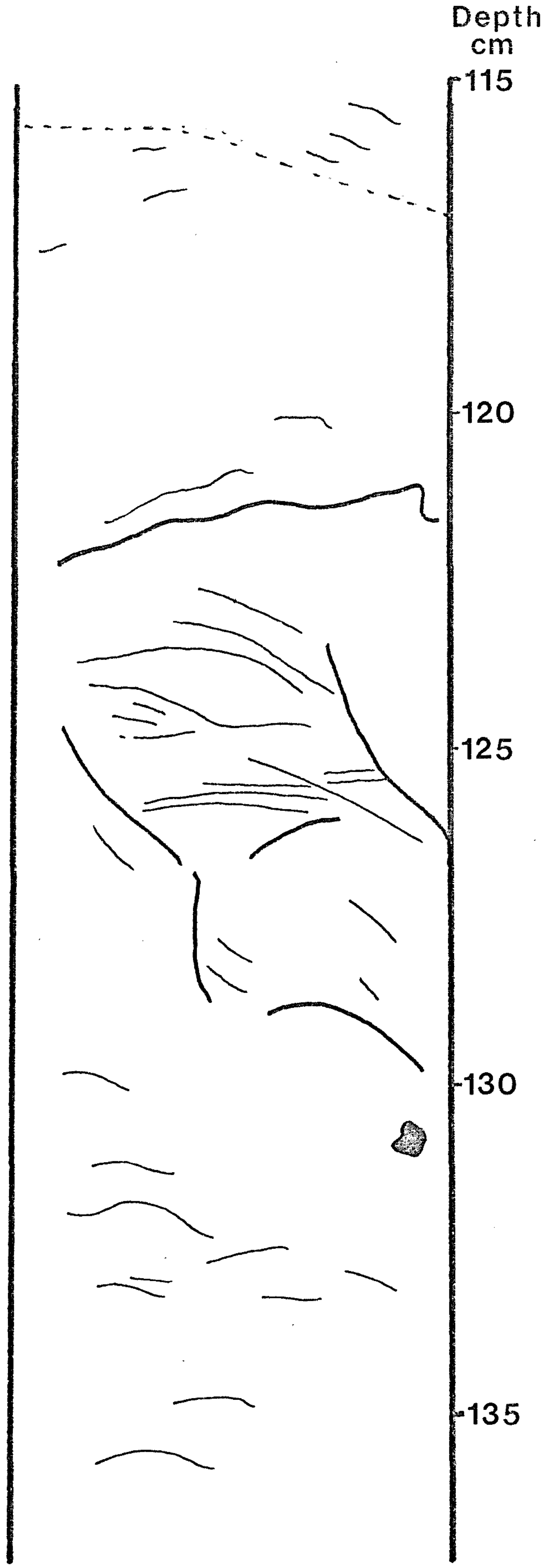
Comparison between sedimentation rates for glacials and interglacials shows that the interglacials have consistently higher sedimentation rates than glacials, even though the glacials receive more terrigenous input. This is because of the pelagic nature of this area which, even during a glacial interval, receives most of its sediment from biogenic sources (primarily skeletal remains of coccoliths and foraminifera). McIntyre, Ruddiman & Jantzen (1972) also record this difference in sedimentation rates and they have shown that the lower rates are caused by a diminution of fine coccolith carbonate (63μ), whilst the 63μ foraminiferal carbonate remains fairly constant. Coccoliths are unable to survive in polar waters whilst some species of foraminifera can survive reasonably well here.

The thicknesses of each zone are very similar in all the cores, the only interval which shows variation is the upper half of zone Y (oxygen isotope stage 2). In core S8-79-3 this interval is particularly short, whilst in cores S8-79-5 and S8-79-3 it is longer than average. These variations appear to reflect changes in local sedimentation rate since there is no evidence of slumping or hiatuses in any of the cores during this interval. Core S8-79-3 shows strong bioturbation during this interval, which may reflect the slower sedimentation rate.

The anomalous cold intervals during the X zone in core S8-79-6 are of particular interest. The anomaly in the faunal curves occurs between 116 cms and 142 cms depth. In all the other cores this part of the X zone is characterised by a warm fauna with high $CaCO_3$ values. In this core there are two intervals with cooler fauna separated by a warmer interval. On visual inspection of the split core these cooler intervals are seen to correspond to more marly layers which give the lower carbonate values on the carbonate curve (Text - fig. 7). The X radiograph of this part of the core (Text - fig. 8) reveals evidence of slumping during the interval 122-131 cms but this does not fully explain why the intervals 116-122 cms and 131-142 cms should be marly with cooler water faunas. The reasons for these anomalies are unclear but they may be related to the slumping. No evidence for a hiatus can be found in this core either in the X radiograph or the fauna; below the anomalous layer the left coiling interval of G. truncatulinoides is present as in the other cores.

CONCLUSIONS

This study has shown that the CLIMAP method of analysing the whole foraminiferal fauna enables a sound stratigraphy to be drawn up for a series of relatively closely spaced late Quaternary cores. Other methods however give equally good results and can be completed more quickly. A preliminary analysis can give a very good idea of stratigraphy and can be used to identify important levels for further investigation. Analysis of

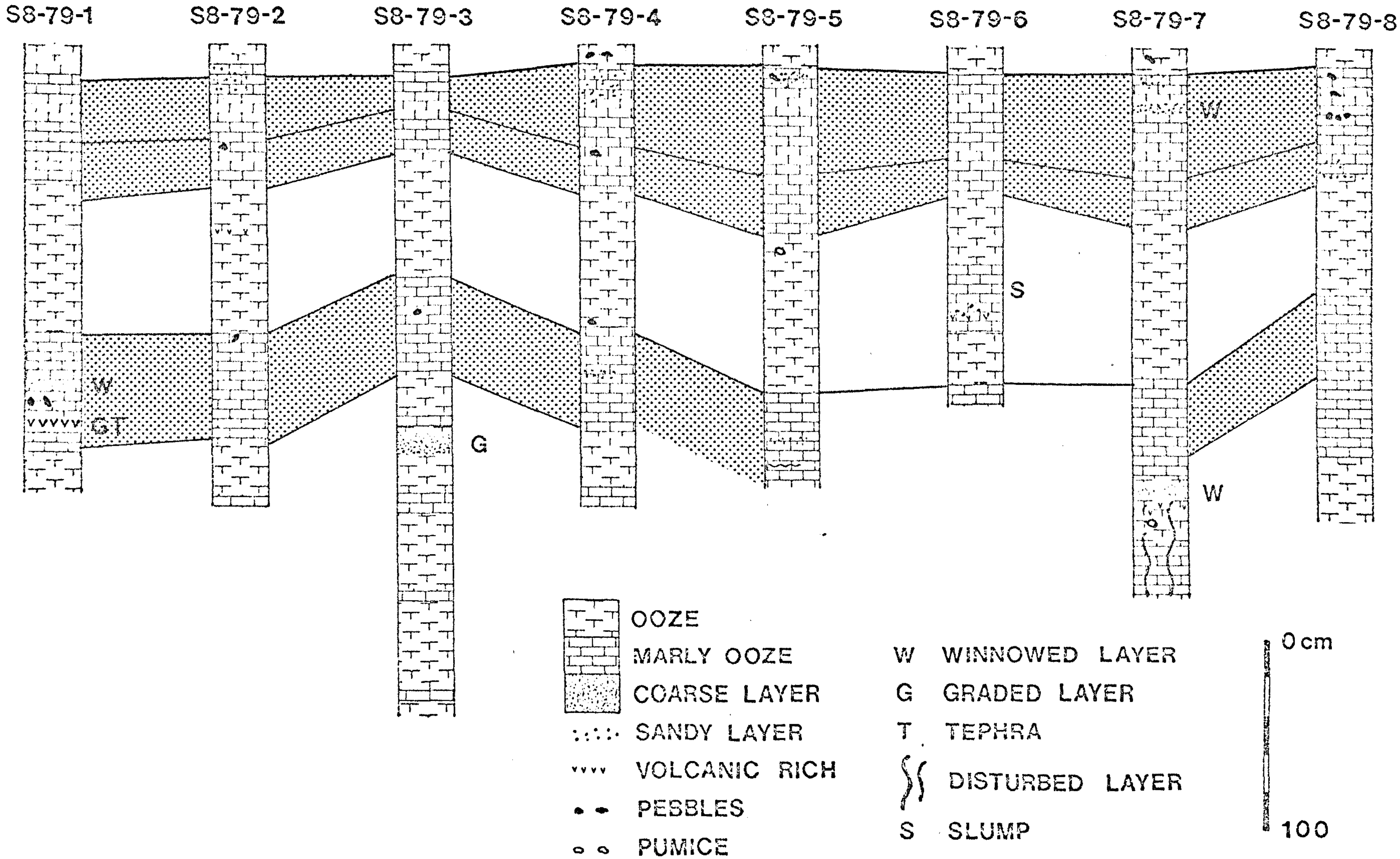


Text-fig. 8. Evidence of disturbance in core S8-79-6 as seen on the X radiograph.

G. truncatulinoides yields both an indication of relative palaeo-water temperature and changes in its coiling direction give a very good correlation point over short distances.

A knowledge of the stratigraphy enables changes in sedimentation to be analysed in detail through time and horizontally in the sediment at each particular time interval (Text - fig. 9). Sedimentation rates can be determined for successive layers in each core and any anomalous results could lead to the identification of hiatuses or current deposited material. The lateral extent of graded, winnowed and tephra layers can also be determined since the time scales on each core will reveal whether such layers in adjacent cores are part of the same widespread event or represent isolated events at different times in different areas.

The present series of cores show remarkably uniform sedimentation with most zones being of approximately equal length in each core. Sedimentation rates vary from about 1-3cm/1000 years and average about 2cm/1000 years. The interglacial intervals correlate with ooze layers whilst the glacial intervals correlate with more marly oozes, probably due to lower coccolith carbonate production. The interglacial intervals always show slightly higher sedimentation rates. The main sedimentary structures in the cores are graded and winnowed layers but these are not common and do not appear to have a great lateral spread. No hiatuses have been recognised and only one interval of slumping has been found.



Text-fig. 9. Correlation of cores. Stippled areas = cold intervals.

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Core No.	Latitude	Longitude	Depth (m)	Core Length (m)
S8-79-1	41°04'.3N	21°44'.2W	3687	243
S8-79-2	41°28'.5N	21°41'.4W	4003	254
S8-79-3	42°08'.7N	21°23'.6W	4095	360
S8-79-4	42°22'.6N	22°03'.1W	3877	253
S8-79-5	42°13'.5N	22°33'.9W	3785	244
S8-79-6	41°51'.9N	22°44'.2W	3819	196
S8-79-7	42°19'.9N	23°03'.5W	3768	298
S8-79-8	42°49'.6N	23°03'.8W	3520	260

Table 1. Location of Shackleton S8-79 cores.

CORE		S8-79-1		S8-79-2		S8-79-3		S8-79-4		S8-79-5		S8-79-6		S8-79-7		S8-79-8	
		depth cm	sed. rate	depth cm	sed. rate	depth cm	sed. rate	depth cm	sed. rate	depth cm	sed. rate	depth cm	sed. rate	depth cm	sed. rate	depth cm	sed. rate
Z	Z	0-14	2·1	0-14	2·1	0-14	2·1	0-12	1·8	0-10	1·5	0-16	2·4	0-12	1·8	0-12	1·8
O	Y	14-84	1·8	14-80	1·7	14-54	1·1	12-78	1·7	10-100	2·3	16-88	1·9	12-96	2·2	12-70	1·5
N	X	84-152	2·2	80-156	2·4	54-128	2·4	78-164	2·7	100-196	3·1	88-?184	3·1	96-182	2·7	70-138	2·2
E	W	152-210	2·2	156-210	2·1	128-170	1·6	164-204	1·6					182-222	1·6	138-180	1·6
average		0-210	2·1	0-210	2·1	0-170	1·7	0-204	2·0	0-196	2·6	0-?184	2·4	0-222	2·2	0-180	1·8
average glacial		14-84 152-210	2·0	14-80 156-210	1·9	14-54 128-170	1·3	12-78 164-204	1·6	10-100	2·3	16-88	1·9	12-96 182-222	1·9	12-70 138-180	1·6
average interglacial		0-14 84-152	2·2	0-14 80-156	2·4	0-14 54-128	2·3	0-12 78-164	2·6	0-10 100-196	2·8	0-16 88-?184	3·0	0-12 96-182	2·6	0-12 70-138	2·1

Table 2. Sedimentation rates (in cm/1000 yrs) for Shackleton S8-79 cores.