

Planktonic foraminifera from the Pliocene Coralline Crag of Suffolk, Eastern England

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ABSTRACT – Nine species of planktonic foraminifera have recently been identified from the Coralline Crag of Suffolk, Eastern England. Stratigraphically important species include *Globorotalia puncticulata* (Deshayes) and *Neogloboquadrina atlantica* (Berggren) whose joint ranges, based on evidence from the North Atlantic, indicate an age for the deposit of between c. 4.2 and 2.3 Ma; other published evidence suggests that it may not be younger than c. 3.4 Ma. The low planktonic foraminiferal species diversity is interpreted as being due to a combination of factors, including the shallow water nature of the Coralline Crag, which would preclude deeper water species of planktonic foraminifera, and the possibility that the source of the fauna was from relatively high latitudes of the North Atlantic via the northern entrance to the North Sea. The planktonic foraminifera recorded indicate that the water temperature of the sea was within the range 10–18°C.

The Coralline Crag contains very rich Lusitanian faunas of gastropod and bivalve molluscs, bryozoans, ostracods and benthic foraminifera.

INTRODUCTION

Foraminifera from the Coralline Crag, a richly fossiliferous shallow marine deposit, which adjoins and underlies part of the southern North Sea (Fig. 1), were first recorded and systematically illustrated by Jones *et al.* (1866). At that time the only indigenous planktonic specimens were recorded as *Globigerina bulloides* d'Orbigny.

A number of slides in the foraminiferal collections of the British Museum (Natural History) contain planktonic foraminifera from the Coralline Crag: H. B. Brady (P 38449; Sutton Knoll), H. B. Brady (P 38436; Sudbourne Park), C. D. Ovey (ex P 38547; Sudbourne Park), F. Möckler (P 16385, P 16387, P 16388; Gedgrave Cliff), W. K. Parker & T. R. Jones (P 48315, P 48356; Sutton Knoll) (for localities, see Fig. 1; for occurrences, see Table 1). All these slides are labelled “*Globigerina bulloides* d'Orbigny”, but in fact contain exclusively *Neogloboquadrina atlantica* (Berggren), which is now found to be the commonest species in the Coralline Crag. The actual specimen illustrated by Jones *et al.* (1866, pl. 2, figs. 1, 2) cannot be located with certainty, but it is probably one of a suite of specimens from Sutton Knoll in the Parker & Jones Collection; it is undoubtedly referable to *N. atlantica*, and in possessing a high spire, is similar to that illustrated by us in Pl. 2, figs. 5–7.

Subsequent work by Carter (1951; 1957), Wilkinson (1980) and Doppert (1985) have concentrated almost solely on the benthic foraminifera. The most recent work is by Hodgson & Funnell (1986) who have

re-interpreted the benthic foraminifera, particularly from a palaeoecological viewpoint, and some reference is made in their paper to the quantitative occurrence of planktonic species formally described herein.

King (1983) recorded and illustrated the following species of planktonic foraminifera from the Pliocene of the North Sea: *Globorotalia inflata* (d'Orbigny), *G. puncticulata* (Deshayes), *Neogloboquadrina atlantica* (Berggren) and *N. pachyderma* (Ehrenberg); also *N. atlantica* from the Coralline Crag. From the evidence of the benthic foraminifera King (1983, 14) suggested that the Coralline Crag was coeval with his (benthic) Early Pliocene Zone NSB 14 and from the presence of sinistrally coiled *N. atlantica* he indicated a correlation with his (planktonic) Late Miocene-Early Pliocene Zone NSP 15 (see Table 2).

This paper describes and illustrates the planktonic foraminifera obtained from samples collected by D. Curry at Sutton Knoll and Gedgrave Cliff and by N. J. Morris at Ramsholt Cliff. See Fig. 1 for localities.

The samples from Sutton Knoll (grid ref. TM 305 441), Ramsholt Cliff (TM 298 428) and Gedgrave Cliff (TM 398 486) are all thought to be from the Silty Sand Facies (Facies A) of the Coralline Crag (Mathers *et al.*, 1984). This represents a lower energy environment than much of the Coralline Crag, and molluscs and bryozoans from it are well preserved. This facies probably corresponds to the Lower Division (15m) (Prestwich, 1871) of the total (25m) thickness of the Coralline Crag (see Mathers *et al.*, 1984). Doppert

(1985) has suggested that the benthic foraminifera from these localities may indicate slightly older deposits than the remainder of the Coralline Crag, corresponding to the lower part, rather than the main part of the Netherlands FB Zone. This is consistent with the correlation of the Coralline Crag with the Early Pliocene NSB 14 Zone of King (1983). Andrew & West (1977) equated the samples from the Orford Borehole (depth 33–38 feet), on palynological evidence to the Brunsumian (Early Pliocene) Stage of the Netherlands succession.

Planktonic foraminiferal species are rare in the Coralline Crag when compared with the benthic foraminifera. The dominant species, *N. atlantica*, has a strong robust test and is also found in the higher energy Facies B (Mathers *et al.*, 1984) at localities near Sudbourne, including Crag Farm (see Fig. 1); planktonic foraminifera of Facies C are too badly preserved, however, to be specifically identifiable (G. E. Hodgson, pers. comm.). All other species, with the exception of *G. puncticulata*, are very rare, with only a few specimens of most and with single specimens only of *Orbulina universa* d'Orbigny and *Turborotalia* cf. *quinqueloba* (Natland). The SEM photographs in Plates 1 and 2 show that the tests are well preserved.

TAXONOMIC NOTES

Synonymies are confined to the original citation, redescription of type material, important name changes, and King's (1983) records from the North Sea. All figured specimens are housed in the Protozoa Section, Department of Palaeontology, British

Museum (Natural History), London, registration nos. P 51974–P 51983.

Globigerina brayi Wiesner (Pl. 1, figs. 12, 13)

- 1884 *Globigerina* sp. Brady: 603, pl. 82, figs. 8, 9.
1931 *Globigerina bradyi* Wiesner: 133.
1960 *Globigerina bradyi* Wiesner; Banner & Blow: 5 pl. 3, figs. 1, 2 (lectotype).

Remarks. As already discussed by Jenkins *et al.* (1986), we consider this species to be distinct from *G. uvula* (Ehrenberg). *G. bradyi* ranges from the Early Oligocene to the Pleistocene (Bolli, 1957; Jenkins, 1966, 1967) and is also recorded in the Recent (Brady, 1884; Wiesner, 1931). In the Coralline Crag deposits this small, high spired species is very rare and has only been found at Ramsholt Cliff.

Globigerina bulloides d'Orbigny (Pl. 1, figs. 1–3)

- 1791 "*Polym. Tuberosa et Globulifera*" Soldani (*pars*): 117, pl. 123, fig. 0 only (vas 251).
1826 *Globigerina bulloides* d'Orbigny: 227, list no. 1, modèle no. 76 only.
1960 *Globigerina bulloides* d'Orbigny; Banner & Blow: 3, pl. 1, figs. 1a–c (lectotype).

Remarks. This is the only species recorded by Jones *et al.* (1866) but all their specimens (Brit. Mus. (Nat. Hist.) Collections) are referable to *Neogloboquadrina atlantica* (Berggren) (see p. 1 herein). The true *G. bulloides* does occur in the present material (Sutton Knoll and Gedgrave Cliff), but it is very rare. *G. bulloides s.l.* is a long ranging species (see Jenkins *et al.*, 1986).

Globigerinita glutinata Egger (Pl. 1, figs. 7, 8)

- 1893 *Globigerina glutinata* Egger: 371, pl. 13, figs. 19–21.
1962 *Globigerinita glutinata* (Egger); Parker: 246, pl. 9, figs. 1–16.

Remarks. The illustrated specimen has a broken-off bulla. The species has only been found at Ramsholt Cliff. A few small specimens, however, were also found at Sutton Knoll and Gedgrave Cliff with no trace of a bulla, and may belong to the possibly related species *C. juvenilis* Bolli (see comments in Jenkins *et al.*, 1986); they are not illustrated.

Globorotalia puncticulata (Deshayes) (Pl. 1, figs. 14–16)

- 1826 *Globigerina punctulata* d'Orbigny: 277 (*nomen nudum*).
1832 *Globigerina puncticulata* Deshayes: 170.
1960 *Globigerina puncticulata* Deshayes; Banner & Blow: 15, pl. 5, figs. 7a–c (lectotype).

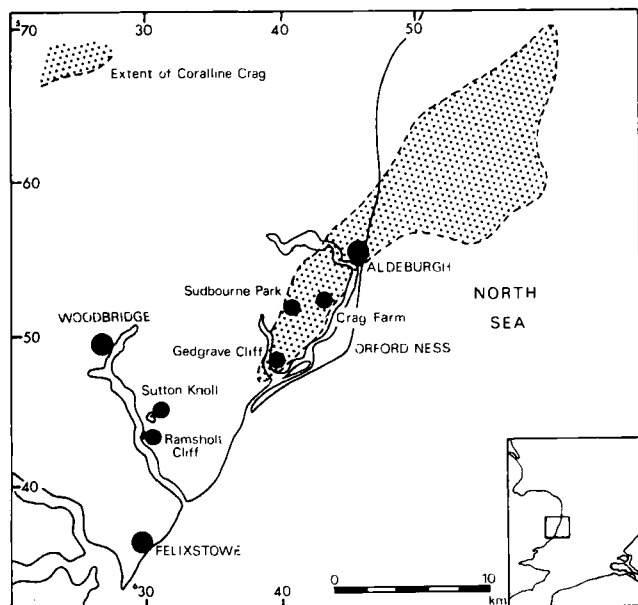


Fig. 1. Distribution of the Coralline Crag, showing localities mentioned in the text.

Table 1. Occurrence of planktonic foraminifera in the Coralline Crag.

		<i>Globigerina bradyi</i>	<i>Globigerina bulloides</i>	<i>Globigerinita glutinata</i>	<i>Globorotalia puncticulata</i>	<i>Neogloboquadrina atlantica</i>	<i>Neogloboquadrina humerosa</i>	<i>Neogloboquadrina pachyderma</i>	<i>Orbulina universa</i>	<i>Turborotalita cf. quinqueloba</i>
	P = present R = rare VR = very rare ? = uncertain identification									
Facies C (Skeletal sand)	Crag Pit Nursery, Aldeburgh									
		(planktonics poorly preserved and unidentifiable)								
Facies B (Sandwave)	Crag Farm									P
	Sudbourne Park									P
	Gedgrave Cliff		VR	?		P	R	R		VR
Facies A (Silty sand)	Sutton Knoll		VR	?	P	P		R		
	Ramsholt Cliff	VR		R		P		R		?
	Orford Borehole					P				

1983 *Globorotalia puncticulata* (Deshayes); King: 36, pl. 6, figs. 14, 15.

Remarks. There is good evidence that *G. puncticulata* evolved from *G. sphericomiozea* Walters in the Early Pliocene (Jenkins, 1975; Scott, 1980; Kennett & Srinivasan, 1983) but Malmgren & Kennett (1981) regard its ancestor as *G. conomiozea* Kennett. This evolution took place in the mid-high latitudes of the oceans of the Southern Hemisphere, but the evolutionary event has not been recorded either in the North Atlantic, where *G. puncticulata* made a late entry in the Early Pliocene (Poore, 1978), or in the tropical-subtropical belt such as the eastern equatorial Pacific (Jenkins & Orr, 1972).

At around the Early/Late Pliocene boundary, in the mid-latitudes of the S.W. Pacific, *G. puncticulata* evolved into *G. inflata* (d'Orbigny), and in the North Atlantic Poore (1978) reports that there is an overlap in their stratigraphic ranges in the lower part of the Late Pliocene of DSDP Site 410 (Fig. 2). Weaver (1986), on the other hand, states that there is no overlap in the ranges of the two species in the upper part of the Late Pliocene of the DSDP Sites drilled on Legs 80 (Site

548), 81 (Site 552A) and 94 (Sites 606–611)(Fig. 2). In the North Sea, King (1983) also recorded the extinction of *G. puncticulata* just before the first appearance of *G. inflata* near the Early/Late Pliocene boundary. In the Coralline Crag, *G. puncticulata* is present but is unaccompanied by its descendent species, *G. inflata*.

One of the main morphological differences between *G. puncticulata* and *G. inflata* is the number of chambers in the final whorl. From counts made on S. W. Pacific populations, Malmgren & Kennett (1981) showed that this varies from a mean of 4.0 to 3.6 in *G. puncticulata*, in contrast to figures of 3.6 to 3.25 for *G. inflata*, the mean in each case decreasing with time from the earliest occurrence (first number) to the latest (second number). Of the 35 specimens of *G. puncticulata* obtained from the Sutton Knoll sample the following range of chamber counts in the final whorl was made: one specimen (4.5 chambers), 24 (4.0), eight (3.75) and two (3.5), giving a mean of 3.9 chambers in the final whorl.

In order to assess whether Malmgren & Kennett's (1981) figures hold true for populations in the North Atlantic, and are thus applicable to the Coralline Crag,

an analysis was made of the chamber numbers in the final whorl of *G. puncticulata* at DSDP Site 609B (Fig. 2); 100 specimens were examined from each of four samples, one at the base of its stratigraphic range, one in the middle and two at the top. In the lowermost sample (Core Catcher 29; Early Pliocene), the mean number of chambers in the final whorl was 4.05, in the middle sample (Core Catcher 24) it was 3.99 and in the two top samples (Core Catcher 20 and 19; Late Pliocene) the figures were 3.97 and 3.93, respectively. Thus the results from both Site 609B and from the Coralline Crag would place these populations within the lowermost part of the stratigraphic range of *G. puncticulata* as given by Malmgren & Kennett (1981) for the S. W. Pacific. It therefore appears that in the North Atlantic this species was either undergoing a much slower rate of morphological change or it may not have been connected with the evolutionary lineage which led to *G. inflata* as reported from the Southern Hemisphere. Some evidence is provided for this latter hypothesis by Weaver (1986) who has reported a cryptogenic appearance of *G. inflata* at a number of DSDP Sites in the North Atlantic after the extinction of *G. puncticulata*.

Neogloboquadrina atlantica (Berggren)
(Pl. 2, figs. 5–10)

- 1972 *Globigerina atlantica* Berggren: 972, pl. 1, figs. 1–7, pl. 2, figs. 5–8.
1974 *Neogloboquadrina atlantica* (Berggren); Poore & Berggren: 108, pl. 3, figs. 11, 12.
1983 *Neogloboquadrina atlantica* (Berggren); King: 36, pl. 6, figs. 26, 27.

Remarks. Poore (1978) recorded dextrally coiled *N. atlantica* in the Late Miocene in the DSDP Sites 407 and 408, with a change to sinistral coiling at the base of the Pliocene and its extinction more or less at the Pliocene/Quaternary boundary. Weaver (1986) has a similar range but shows its extinction within the Late Pliocene (Table 2).

Specimens of *N. atlantica* were first recorded in the Coralline Crag by King (1983) but in the historical

collections in the British Museum (Natural History) from Sutton, Gedgrave and localities around Sudbourne, it was previously identified as *Globigerina bulloides* d'Orbigny (see p. 2, herein). In the present study it was found at Ramsholt Cliff, Gedgrave Cliff and Sutton Knoll; it also occurs in the Coralline Crag samples from the Orford borehole in which Andrews & West (1977) identified pollen which they equated with the Brunsumian (Early Pliocene) pollen stage of the Dutch succession. In all the material so far examined by us the coiling direction is sinistral.

A proportion of specimens of *N. atlantica* in the Coralline Crag are high spired (Pl. 2, figs. 5–7), a feature which does not appear to have been previously recorded; similar specimens, however, occur in a topotype sample from DSDP Site 116 and have been seen by one of us (D. G. J.).

Neogloboquadrina humerosa (Takayanagi & Saito)
(Pl. 1, figs. 4–6)

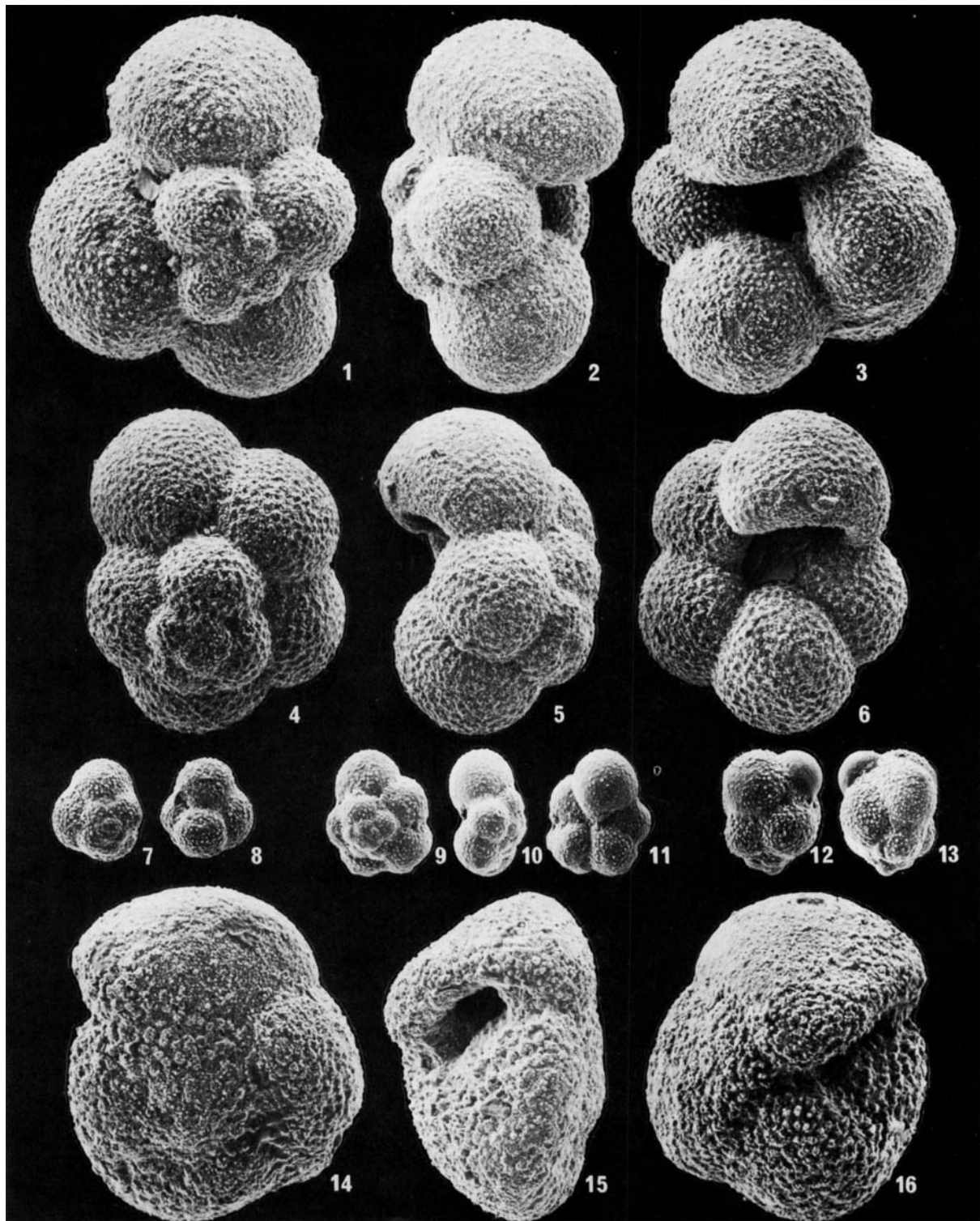
- 1962 *Globorotalia humerosa* Takayanagi & Saito: 78, pl. 28, figs. 1, 2.
1976 *Neogloboquadrina humerosa* (Takayanagi & Saito); Srinivasan & Kennett: 335, pl. 6, figs. 1–13.
1983 *Neogloboquadrina* ex gr. *acostaensis* (Blow)/*humerosa* (Takayanagi & Saito); King: 36, pl. 6, figs. 24, 25.

Remarks. *N. humerosa* was originally described from a warm-water area and had 6–7 chambers in the final whorl, but in the cooler mid-latitudes there is a reduction to 5–6 chambers. Kennett & Srinivasan (1980) recognised this as phenotypic variation and Kennett & Srinivasan (1983: 196) suggested a latitudinal cline with end members *N. humerosa* (warm) and *N. subcretacea* (Lomnicki) (temperate). Unfortunately, there is a taxonomic problem associated with the latter name and the types of the replacement taxon, *N. dutertrei* (d'Orbigny) *blowi* Rögl & Bolli, as re-illustrated in Bolli & Saunders (1985, 211, figs. 27, 28), appear to be morphologically different from *N. humerosa*. If a name is required for the 5–6 chambered form,

Explanation of Plate 1

All specimens are $\times 125$

- Figs. 1–3. *Globigerina bulloides* d'Orbigny. Spiral, edge and umbilical views, P 51974. From Sutton Knoll.
Figs. 4–6. *Neogloboquadrina humerosa* (Takayanagi & Saito). Spiral, edge and umbilical views, P 51975. From Gedgrave Cliff.
Figs. 7, 8. *Globigerinita glutinata* (Egger). Spiral and umbilical view; the bulla has broken off. P 51976. From Ramsholt Cliff.
Figs. 9–11. *Turborotalita* cf. *quinqueloba* (Natland). Spiral, edge and umbilical views, P 51977. From Ramsholt Cliff.
Figs. 12, 13. *Globigerina bradyi* Wiesner. Two side views, P 51978. From Ramsholt Cliff.
Figs. 14–16. *Globorotalia puncticulata* (Deshayes). Spiral, edge and umbilical views, P 51979. From Sutton Knoll.



EPOCH	PLANKTONIC FORAMINIFERAL ZONES (Blow, 1969)	POLARITY AND AGE (after Berggren <i>et al.</i> , 1985)	KEY SPECIES OF PLANKTONIC FORAMINIFERA (after Weaver 1986)	THIS PAPER	CURRY <i>et al.</i> (1978)	HUGHES AND JENKINS (1981)	KING (1983)		
							BENTHONIC FORAM. ZONES		
PLEISTOCENE	N23	0.5	<i>G. inflata</i>				NSB17		
	N22	1.0							
PLIOCENE	L	N21	<i>G. puncticulata</i>	Coralline Crag	Coralline Crag	Coralline Crag	NSB15		
		N19							3.0
	E	N18	4.0	<i>N. atlantica</i>				NSB14	Coralline Crag
		N17	5.0						
MIOCENE	N17	5.5	<i>N. atlantica</i>						

Table 2. Ranges of several key species of planktonic foraminifera (after Weaver, 1986) plotted against Berggren *et al.*'s (1985) time scale, and showing the stratigraphic position of the Coralline Crag according to various authors.

then *N. praehumerosa* (Natori) is available, but here we take the view that it is not necessary.

The cooler water variant of *N. humerosa* is distinguished from *N. atlantica* (Berggren) in having 5–6, rather than 4 chambers in the final whorl; *N. acostaensis* has a lipped aperture and *N. dutertrei* (d'Orbigny) has an umbilical tooth, neither features being in *N. humerosa*. In the North Atlantic *N. humerosa* has a range of Late Miocene to Late Pliocene (Poore, 1978). It was only found in the Coralline Crag at the Gedgrave Cliff locality, where it is rare.

Neogloboquadrina pachyderma (Ehrenberg)
(Pl. 2, figs. 1–3)

- 1861 *Aristerospira pachyderma* Ehrenberg: 303.
1873 *Aristerospira pachyderma* Ehrenberg; Ehrenberg: pl. 1, fig. 4.
1962 *Globigerina pachyderma* (Ehrenberg); Parker: 224, pl. 1, figs. 26–35; pl. 2, figs. 1–6.
1983 *Neogloboquadrina pachyderma* (Ehrenberg); King: 36, pl. 6, figs. 23, 29.

Remarks. Specimens of *N. pachyderma* are much smaller and rarer than *N. atlantica* (Berggren) in the Coralline Crag; the populations are mixed sinistrally and dextrally coiled specimens, compared with exclusively sinistrally coiled *N. atlantica*. Specimens were found at Ramsholt Cliff, Gedgrave Cliff and Sutton Knoll.

Orbulina universa d'Orbigny
(Pl. 2, fig. 4)

- 1839 *Orbulina universa* d'Orbigny: 3, pl. 1, fig. 1.
Remarks. Only one specimen was found in the Coralline Crag samples, from Gedgrave Cliff.

Turborotalita cf. quinqueloba (Natland)
(Pl. 1, figs. 9–11)

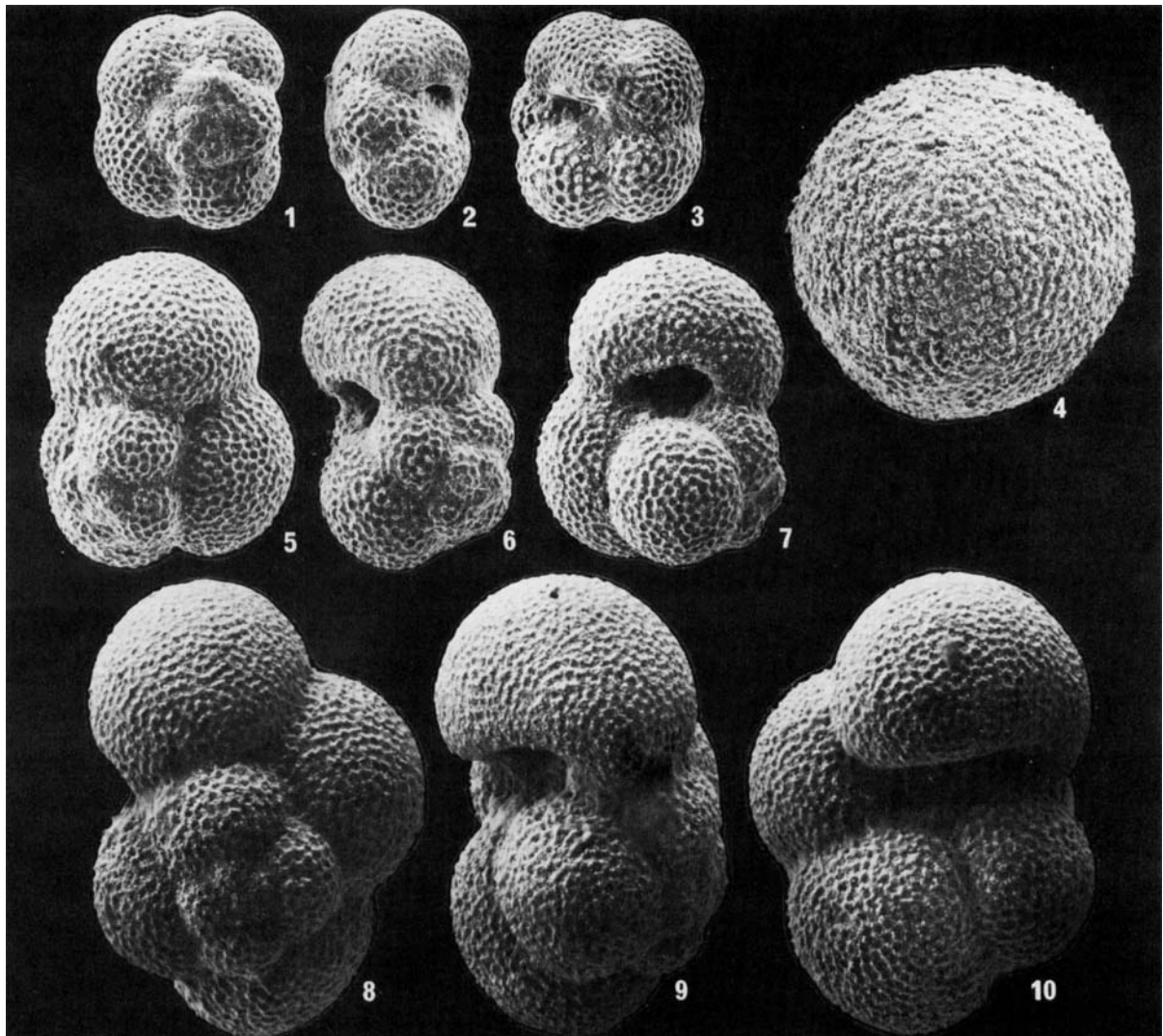
- cf. 1938 *Globigerina quinqueloba* Natland: 149, pl. 6, fig. 7.
cf. 1984 *Turborotalita quinqueloba* (Natland); Holmes: 101 *et seq.*, pl. 3, figs. 9–11.

Remarks. One possible specimen was found at Ramsholt Cliff.

PALAEOECOLOGY

The duration of the Early Pliocene has been estimated at 1.8 Ma, from 5.2 to 3.4 Ma (Berggren *et al.*, 1985) (Table 2). It was a time of high planktonic foraminiferal diversity in the North Atlantic. At DSDP Sites 407 and 408 (lat. 63° N) (see Fig. 2) Poore (1978) recorded 25 and 22 species respectively and at the warmer Site 410 (lat. 45° N) there were no less than 45 species present. The low species diversity in the Early Pliocene sediments of the North Sea area, with five species listed by King (1983) and nine species found by us in the Coralline Crag (lat. 52° 30'–53° 00' N), is therefore relatively anomalous.

It is possible that the English Channel was not open in the Early Pliocene (Pomeroy, 1982) and the low diversity fauna of the North Sea area was only connected to the North Atlantic via the northern passage (at about lat. 60° N). Comparison would therefore be expected with the fauna obtained from DSDP Sites 407 and 408 (Table 2; Fig. 2). Indeed, examination of the faunas from within the stratigraphic range of *Globorotalia puncticulata* (Deshayes) at these sites reveals a diversity of only 16 and 19 species, respectively, in the upper part of the Early Pliocene. On the other hand, the southern North Sea is sufficiently remote from open oceanic waters to account for the



Explanation of Plate 2

All specimens are $\times 125$

Figs. 1-3. *Neogloboquadrina pachyderma* (Ehrenberg). Spiral, edge and umbilical views, P 51980. From Ramsholt Cliff.

Fig. 4. *Orbulina universa* d'Orbigny. P 51981. From Gedgrave Cliff.

Figs. 5-10. *Neogloboquadrina atlantica* (Berggren): figs. 5-7, spiral, edge and umbilical view of a high-spired individual, P 51982; figs. 8-10, spiral, edge and umbilical views, P 51983. Both from Sutton Knoll.

lower diversity, even with a southern connection. The absence of some of the deeper water species, such as *Globorotalia scitula* (Brady) in the Coralline Crag can be explained by its shallow water origin.

Of the nine species found in the Coralline Crag, three of them, namely *Globorotalia puncticulata* (Deshayes), *Neogloboquadrina atlantica* (Berggren) and *N. humerosa* (Takayanagi & Saito), are extinct. According to Bé (1977), the remaining six species live today within the Transitional Faunas Provinces, with the surface water temperature range of 10–18° C.

AGE AND CORRELATION

At DSDP Site 410 (Fig. 2), *Globorotalia puncticulata* (Deshayes) first appeared in the lower part of the Early Pliocene (Poore, 1978) where its range overlaps that of *G. conomiozea* Kennett, its immediate ancestor in the S. W. Pacific, according to Malmgren & Kennett (1981). Further north at DSDP Sites 407 and 408 (Fig. 2), *G. puncticulata* made a later entry in the Early Pliocene and is unaccompanied by its immediate ancestor (Poore, 1978). Since it makes a cryptogenic appearance, it is therefore reasonable to infer that its entry into the North Sea may have been at a similar time to, or even later than at Sites 407 and 408 (assuming the connection to the North Atlantic was via the northern entrance to the North Sea). If this is accepted the placing of the entry of *G. puncticulata* into the North Sea at the Miocene/Pliocene boundary by King (1983) is probably too early.

Weaver (1986), having examined the planktonic foraminifera of DSDP Sites 606 and 611 (Leg 94), considers that *G. puncticulata* appeared for the first time in the North Atlantic in the Early Pliocene at c. 4.2 Ma and that it became extinct just before the first appearance of its descendent species, *G. inflata* (d'Orbigny) (Table 2). Poore (1978) showed a long overlap in the ranges of these two species at Site 410 and a possible short overlap at the more northern Site 408 and no overlap at Site 407.

Hooper & Funnell (1986) also recorded . . . "an apparent and very rapid transition between these two species, at around 2.3 Ma" at DSDP Site 552A (Fig. 2) which is at lat. 56° N in the North Atlantic, but later concluded that the first appearance of *G. inflata* was caused by its migration and not by its direct evolution from *G. puncticulata*. Further south at DSDP Site 548 (Fig. 2) at lat. 48° N, Loubere & Jakiel (1985) concluded that there was an evolutionary transition between the two species, although their stratigraphic range chart for the site shows the overlap only occurring in one sample. Whereas Poore (1978) recorded the first appearance of *G. inflata* with the first ice-rafted material in the North Atlantic, dated by Shackleton *et al.* (1984) at 2.4 Ma, Weaver & Clement (1986) are of the opinion that *G. inflata* appeared in the Late Pliocene at about 2.0–2.2 Ma, with the extinctions

of *G. puncticulata* and *N. atlantica* occurring at 2.2–2.4 Ma and 2.3–2.4 Ma, respectively; we used the first figure in each case in Table 2.

Hodgson & Funnell (1986) have recently reported the occurrence of the (?) planktonic algal cyst, *Bolboforma costata* Murray, in a sample of Coralline Crag taken from an excavation near Ramsholt Cliff. This fossil is so far only recorded in the nannofossil Zone NN15 (i.e. between c. 3.5 and 3.4 Ma) (Murray, 1984) and it seems probable that the Coralline Crag itself represents only the early part of the joint range of *G. puncticulata* and *N. atlantica*.

CONCLUSIONS

The Coralline Crag deposits were laid down during the Pliocene within the joint ranges of *G. puncticulata* and *N. atlantica* (c. 4.2 to 2.3 Ma); other evidence (Hodgson & Funnell, 1986) suggests that the deposits are mostly Early Pliocene in age, probably no younger than c. 3.4 Ma.

As far as we can judge, all our samples containing planktonic foraminifera, including the Gedgrave Cliff samples taken from an excavation at the base of the section, are referable to Facies A – relatively low energy deposits underlying the higher energy, more generally exposed, sand-wave facies (Hodgson & Funnell, 1986) of the Coralline Crag. Tidal currents in the southern North Sea Basin may have been less strong and a southwestern connection with the North Atlantic may have been less well developed than during later Coralline and Red Crag times. In any case the low planktonic foraminiferal species diversity indicates a rather remote connection with the open ocean waters of the North Atlantic. The planktonic foraminifera

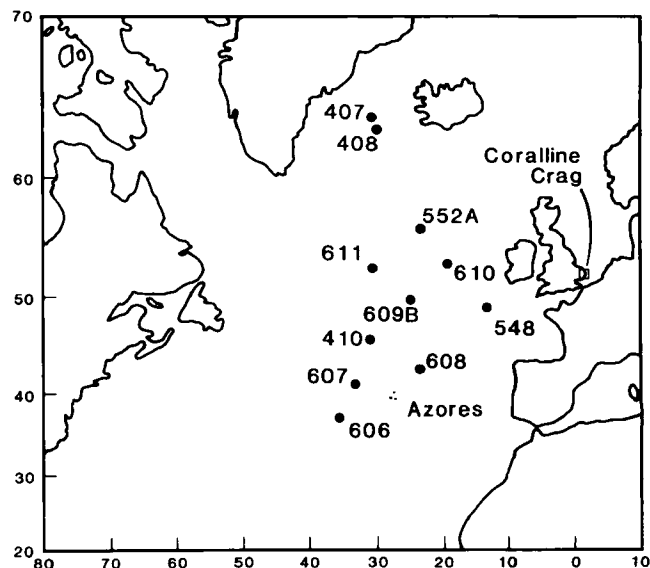


Fig. 2 Map of the North Atlantic showing location of DSDP Sites mentioned in the text and the Coralline Crag.

suggest surface water temperatures in the range 10–18° C.

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