

# Tubular agglutinated foraminifera as indicators of organic carbon flux

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## ABSTRACT

The dimensions of tubular agglutinated foraminifera such as *Rhizammina* and *Rhabdammina* respond in a predictable manner to changes in the flux of organic carbon to the sea floor. In both the modern western North Atlantic and in an ancient example (the K/T boundary in Gubbio), the slender, finely-grained tubes (<100  $\mu\text{m}$  diameter) dominate in oligotrophic regimes, whereas in eutrophic regimes the abundance of tubes is higher, and the mean and standard deviation of the tube diameter increases. Large tubes (> 500  $\mu\text{m}$ ) are present only when organic flux is comparatively high. Although our observations are at present not directly calibrated to primary productivity levels, we maintain that the potential for using tubular agglutinated foraminifera does exist.

## INTRODUCTION

The amount of secondary production at the sea floor is directly proportional to the flux of food particles available to the benthos. Studies of calcareous benthic foraminifera from the equatorial Pacific have demonstrated beyond any doubt that the accumulation rate of benthic foraminifera in pelagic sediments can be directly linked to the amount of primary productivity in surface waters (Berger *et al.*, 1994), and constitutes one of the best trophic proxies for organic carbon flux to the sea floor. Studies of Pleistocene cores from the equatorial Pacific have shown that not only were larger populations of benthic foraminifera sustained during glacial stages when primary productivity was higher than today, but the mean dimensions of taxa such as *Uvigerina* also increased (Pederson *et al.*, 1988). If this size increase in benthic foraminifera is a regular feature of high productivity regimes, then a simple count of benthic foraminifera may underestimate the benthic foraminiferal biomass. Perhaps a more robust proxy for organic carbon flux would be some measure of benthic foraminiferal volume.

The Benthic Foraminiferal Accumulate Rate (BFAR) can only be used faithfully under the best of circumstances. If there is increased dissolution (which is sometimes the case in areas with high productivity), or dilution by terrigenous sediments the index must be used with caution. Unfortunately, in the case of the deep sea or in clastic basins where only agglutinated foraminifera are preserved, we are still at a loss to use the BFAR to adequately predict productivity from benthic foraminiferal assemblages.

As a first step towards defining a trophic proxy for organic carbon flux from deep water agglutinated foraminiferal assemblages, we examined the dimensions of the tubular agglutinated foraminifera

*Rhizammina* and *Rhabdammina* from two environmental settings (one modern, the other ancient) where significant gradients or rapid changes in primary productivity are well documented. We selected the tubular forms because they are abundant in a variety of environmental settings, are reported to be epifaunal detritivores or deposit feeders (Jones & Charnock, 1985), often forming branching networks on the sediment surface or in the fluffy surface layer (Geroch & Kaminski, 1993). Other tubular forms have been observed to be suspension feeders that capture organic detritus using a spiderweb-like net of pseudopodia (Altenbach *et al.*, 1988). They are often abundantly preserved in the fossil flysch-type assemblages. By comparing our fossil record from Gubbio with the modern analogue of the western North Atlantic, we can gain a rough appreciation of the magnitude of change in organic productivity across the K/T boundary.

## Material and Methods

Surficial sediment was sampled from four box cores collected in February-March, 1990 on board the CSS Hudson Cruise 89038 (Table 1). These four sites constitute a transect from highly productive slope waters to the oligotrophic Sargasso Sea, and are described in detail by Kuhn & Collins (this volume). Station 027 on the continental slope of the Baltimore Canyon area (off New Jersey) has a high terrigenous influx, and the dark greenish-grey colour of the sediment indicates depleted oxygen conditions below the sediment surface. Stations 020 and 016 are within areas influenced by the Gulf Stream and its rings, while Station 007 on the Hatteras Abyssal Plain is situated within the Sargasso Sea, seaward of any influence from Gulf Stream rings. In this boxcore, the

**Table 1:** Location of HUD-89038 boxcore stations

Station	Latitude	Longitude	Depth	Remarks
BC 007	33° 41.2' N	57° 38.3' W	4437 m	northwest Sargasso Sea
BC 016	36° 00.40' N	66° 05.40' W	4654 m	Sargasso Sea, beneath cold core rings
BC 020	37° 31.23' N	72° 00.97' W	3098 m	Gulf Stream area
BC 027	38° 44.58' N	72° 29.67' W	2330 m	Baltimore Canyon

whole sediment column was well oxygenated, indicating low organic carbon flux.

Primary productivity across the transect varies by at least a factor of four. The Sargasso Sea has primary productivity values on the order of 25-40  $\text{gC}_{\text{org}}/\text{m}^2\text{y}$ , while the inshore waters overlying the Baltimore Canyon continental slope has production values of 90-180  $\text{gC}_{\text{org}}/\text{m}^2\text{y}$  (Berger *et al.*, 1987). Because Station 027 is 2000 m shallower than the stations in the Sargasso Sea, a greater proportion of the export production reaches the sea floor. The sea floor organic carbon flux may be 14-15 times higher than in the Sargasso Sea, if the flux equations of Berger (1989) can be confidently applied to this area.

Foraminiferal samples were collected from the top centimetre of a 7 cm diameter push core that was inserted into the box core. The samples were immediately fixed in a formaldehyde/sea water solution buffered with borax and stained with Rose Bengal. Samples were then sieved, dried, and specimens were mounted onto cardboard slides.

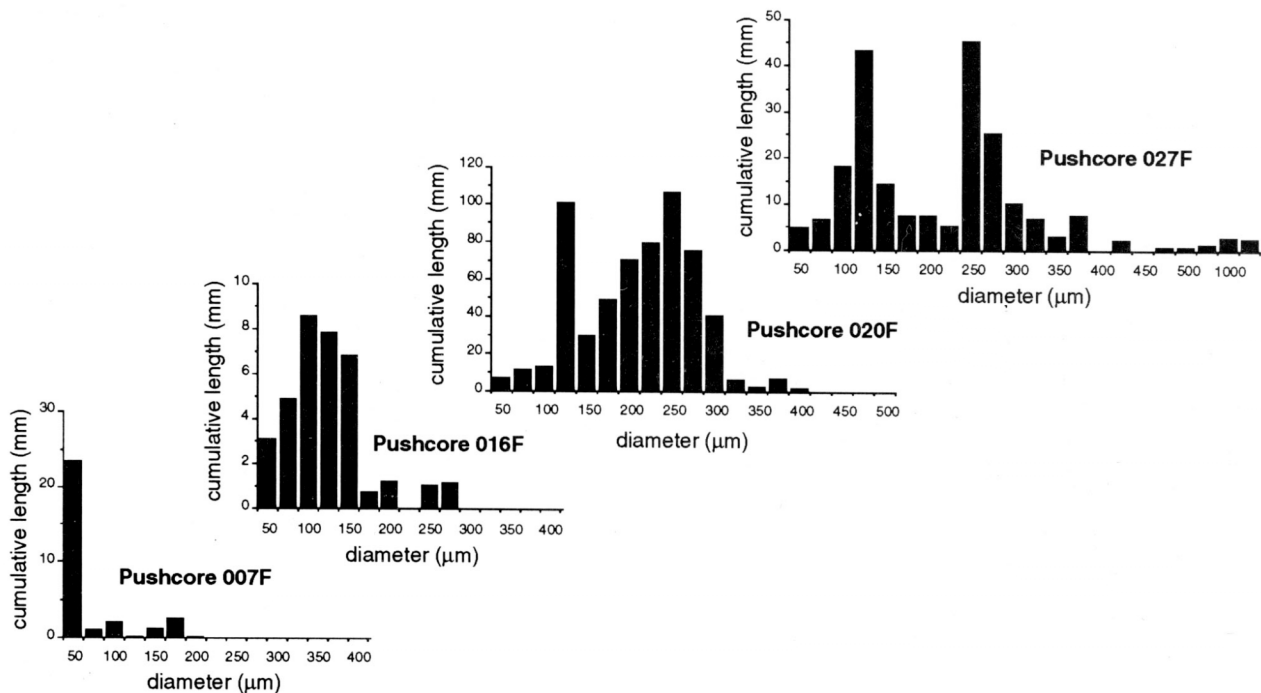
The K/T boundary samples analysed in this study were collected from the Contessa Highway section, near Gubbio, Italy. Samples weighing exactly 100g

were dissolved in HCl to release the agglutinated foraminifera, sieved over a 63  $\mu\text{m}$  screen, then dried. The residue was then boiled in Calgon and sieved again. This process was repeated until no limestone or clay remained. Agglutinated foraminifera were picked from the >125  $\mu\text{m}$  fraction of the dried residues. The length and maximum width of every tubular fragment was measured with an optical micrometer.

## RESULTS

### New Jersey - Sargasso Sea Transect

The distribution of size classes of tubular agglutinated foraminifera shows clear differences along the transect (Fig. 1). *Rhabdammina* spp. and large fragments of *Astrorhiza* spp. with test diameters above 400  $\mu\text{m}$  characterise Station 027 on the New Jersey slope. *Rhabdammina* spp. with a bimodal maximum in test diameter at 125  $\mu\text{m}$  and 250-300  $\mu\text{m}$  dominate at the Station 020 beneath the Gulf Stream. At the deeper Station 016, the dominant mode is at 100-150  $\mu\text{m}$ , but there is still evidence of a much smaller



**Figure 1.** Diameter of tubular agglutinated foraminifera in surface sediment samples from the New Jersey continental slope (Station 027); the Western Boundary Undercurrent/Gulf Stream (Station 020), cold core rings zone of the Sargasso Sea (Station 016), and in the oligotrophic Sargasso Sea (Station 007). Based on measurements of 72 (Station 007); 51 (Station 016); 321 (Station 020); and 205 (Station 020) individuals and fragments. Note that Y-axes are not to the same scale.

population of tubes with test diameters between 250 and 300  $\mu\text{m}$ . There were no tubes larger than 300  $\mu\text{m}$ . Station 016 is not directly affected by Gulf Stream, but the occasional cold core ring may bring enhanced productivity to the area. At Station 007, which is well within the Sargasso Sea, the size distribution is distinctly unimodal, and tiny rhizamminids with a diameter of ca. 50  $\mu\text{m}$  dominate the sample. The largest tubes at this station have a width of only 200  $\mu\text{m}$ .

**Cretaceous/Tertiary Boundary at Gubbio**

Carbon isotopes provide evidence of a world-wide reduction in oceanic primary productivity coincident with the deposition of the K/T boundary clay and during the first few hundred thousand years of the Paleocene (Zachos & Arthur, 1986; Kaminski & Malmgren, 1989). The Scaglia Rossa near Gubbio in Central Italy was deposited under tranquil conditions at a paleodepth of about 2500-3000m (Labude, 1984), and deep-water agglutinated foraminifera are abundant throughout the formation (Kuhnt, 1990). Because all the samples were collected from a single location, we can eliminate any bias in our tube diameter data owing to changes in water depth, oceanic currents, or geographical position. We can be reasonably certain that variability in our faunal data reflects changes in trophic structure related to productivity.

The tubular foraminifera present in the Contessa Section mostly belong to the genera *Rhizammina*,

*Nothia*, *Rhabdammina*, and *Bathysiphon*. In the sample collected from the uppermost Maastrichtian (3-8 cm below the K/T boundary), the 100-150  $\mu\text{m}$  size class dominates. However, the distribution is skewed, with a sizeable proportion of the population between 200 and 400  $\mu\text{m}$ . The odd larger specimen is also present (to 560  $\mu\text{m}$ ). The cumulative length of the tubes is high (123.29 mm/ 100g).

The basal Paleocene samples from Contessa display dramatically reduced numbers of tubes (the cumulative length is only 6.84 mm/ 100g). In this study we sampled every limestone bed individually, and the data presented in Figure 2 represents the combined numbers from four 100g samples (2-10 cm above the boundary clay). The size classes show a broad peak between 120 and 240  $\mu\text{m}$ , but the size distribution appears to be truncated at 250  $\mu\text{m}$ . Only a single larger (300  $\mu\text{m}$ ) specimen was found. Significantly, the taxonomic composition of this sample differs from that of the Maastrichtian, with most of the assemblage comprised of *Rhabdammina*, rather than small *Rhizammina*.

Higher in the Paleocene, a sample collected from 30-37 cm above the K/T boundary already shows the beginning of the recovery of tubular forms. The cumulative length of tubes in this sample is 30.53 mm/ 100g). The size classes again show a broad peak between 100 and 160  $\mu\text{m}$ , and the larger tubes (>250  $\mu\text{m}$ ) are beginning to make their reappearance. The maximum diameter encountered was 440  $\mu\text{m}$ .

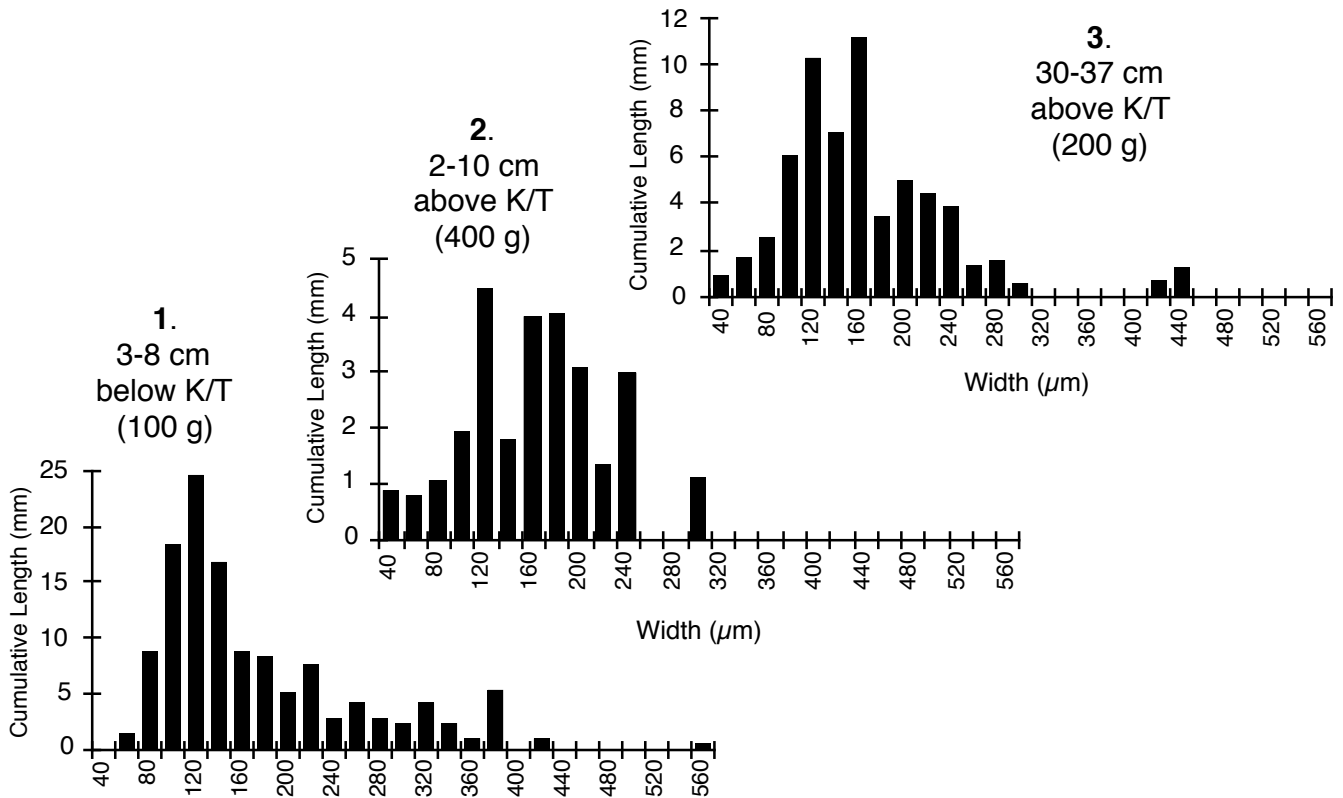


Figure 2. Diameter of tubular agglutinated foraminifera in samples from the K/T boundary in the Contessa Highway Section. Based on measurements of 218 (3-8 cm below the boundary); 56 (basal Paleocene); and 116 (30-37 cm above the boundary) individuals and fragments. Note that Y-axes are not to the same scale.

## DISCUSSION

This reconnaissance study of both the modern North Atlantic and a fossil analogue reveals that both the relative size and total abundance of tubular agglutinated foraminifera varies with respect to productivity. The highly productive area of the Baltimore Canyon sustains high tube populations, with a bimodal distribution. In this area, a small proportion of the assemblage reaches a diameter of  $>400 \mu\text{m}$ . In deeper water beneath the Gulf Stream, the tail of the size distribution becomes truncated at  $400 \mu\text{m}$ . In the oligotrophic waters of the Sargasso Sea, the tube population is sparse and the size distribution is unimodal, consisting entirely of very small forms.

The distribution of size classes in the uppermost Maastrichtian of the Contessa Valley section is unimodal with a broad tail extending to  $450 \mu\text{m}$ . The tube population in this sample has a size distribution that is intermediate between those recovered from Station 016 in the northern Sargasso Sea and Station 020 beneath the Gulf Stream. Not surprisingly, the "Strangelove Ocean" of the earliest Paleocene is manifested by an abrupt crash in the tube population. Numbers of tubes in the basal Paleocene of Contessa are one-sixth of Maastrichtian values. As expected, the large tubes ( $>250 \mu\text{m}$ ) have disappeared, but surprisingly, the smallest "*Dendrophrya*-type" tubes also declined drastically. As a result, the mean width of those tubes that remain actually shows an increase compared with the Maastrichtian population.

The meaning of this size change is not intuitive, because one would expect to observe a decrease in the mean width associated with the "Strangelove Ocean". However, the basal Paleocene benthic foraminiferal assemblages are dominated by infaunal morphotypes, which are normally present in areas of high organic carbon accumulation. The tubes present are of the *Rhabdammina* type, and these may have been surficial detritivores that lived on the sediment surface rather than living as suspension feeders (Geroch & Kaminski, 1993). It appears that the small, delicate specimens of *Rhizammina*, a form that is known to live in the surficial fluff, were present in much reduced numbers in the earliest Paleocene. Recovery of the tubular foraminifera is evident 30 cm above the K/T boundary, with a return to larger specimens and a population dominated by 120-160  $\mu\text{m}$  size class.

Although our observations are at present strictly qualitative, we maintain that the potential for using tubular agglutinated foraminifera as a proxy for organic flux does exist. Our initial survey indicates that major differences are observed in the tube population from oligotrophic to eutrophic areas. Surprisingly, the magnitude of change in tube diameters at the K/T boundary was low in comparison to the range of variability observed among modern populations of tubular forms. The key to developing a "paleoproductivity index" will be to directly calibrate tube diameter to primary productivity by the use of other proxy information. This may lead to a valuable new

tool for using flysch-type assemblages as indicators of past environmental conditions.

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