VOLUME CALCULATION OF CRETACEOUS CALCAREOUS NANNOFOSSILS

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Abstract: Volume estimates are calculated for common mid-Cretaceous nannofossils, using a methodology previously developed from studies of extant nannoplankton. The range of volume variation within this group is highlighted, and the potential of such estimates for giving new insights into palaeoecological and palaeoceanographic studies is outlined.

Introduction

Nannofossils vary in linear size by about an order of magnitude, consequently they vary in volume by about three orders of magnitude, *i.e.* 1000-fold. In traditional palaeoecological analyses, this variation is ignored, however, there is obviously potential for investigating whether volume-calibrated census-data may yield more meaningful data, especially for studies of carbonate formation.

Several estimates of the volume of extant coccoliths have been published, primarily to allow conversion of coccolith fluxes into carbonate fluxes (Paasche, 1962; Honjo, 1976; Samtleben & Bickert, 1990; Faggerbakke *et al.*, 1994; Beaufort & Heussner, 1999; Young & Ziveri, 2000). These estimates are being widely used in sediment-trap studies (*e.g.* Broerse, 2000; Sprengel, 2000). The purpose of this paper is to produce estimates of the volume and mass of the most abundant calcareous nannofossils of the mid-Cretaceous (Barremian-Albian). From these estimates, the amount of $CaCO_3$ produced by coccoliths during interpreted eutrophic and oligotrophic conditions will, subsequently, be estimated (Tremolada & Erba, in prep.). It is hoped that this will provide a new approach to the study of a key time-interval which was affected by some of the strongest perturbations of Earth's history: in particular, the widespread deposition of black shales, and the associated Oceanic Anoxic Events, are characteristic of this age.

There have previously been only a few estimates of the volume of Mesozoic nannofossils. Williams & Bralower (1995) proposed an 'averaged Cretaceous nannofossil' with a volume of 14µm³. In the study of Mattioli & Pittet (2002), analyses were mostly performed on the Jurassic nannolith, *Schizosphaerella punctulata*. The present work represents the first attempt to investigate the significance of volume variation within Cretaceous nannofloras.

Material and methods

The best-preserved samples available were investigated in order to determine the average dimensions of the most abundant mid-Cretaceous nannofossils. Samples from ODP Legs 185 (Marianne-Bonin Trench) and 171 (Blake Nose), and DSDP Leg 62 (Mid-Pacific Mountains) were studied, along with some outcrop samples from the Tethyan area. The interpreted oligotrophic assemblages are dominated by *Watznaueria barnesiae*, *Nannoconus* spp., *Zeugrhabdotus embergeri* and *Rhagodiscus asper*, whereas interpreted eutrophic assemblages are characterised by high abundances of *Zeugrhabdotus erectus*, *Discorhabdus rotatorius*, *Biscutum constans* and *Zeugrhabdotus* spp. (interpreted after, *e.g.*, Erba, 1992; Erba *et al.*, 1992; Erba, 1994).

As noted by Young & Ziveri (2000), the volume function for any given shape is of the form $V=K_s*l^3$, where K_s is a constant depending on the shape, and l is a characteristic dimension. Thus, there are essentially two steps to determining nannofossil volume, first size analysis, to determine average size, second shape analysis, to determine K_s. Since volume is proportional to length cubed, accurate size determination is critical. For size determination, images of coccoliths and nannoliths were collected using a digital image-capture system (Young *et al.*, 1996) at 1600x and 1250x magnification, then the dimensions were measured using the software NIH-Image, adapted for nannoplankton analyses. For each taxon, at least 250 specimens were measured to provide accurate size estimates.

For shape analysis, two approaches were used. For coccoliths and nannoconids, the NIH-Image macro program, described by Young & Ziveri (2000), was used to calculate volumes of rotation from cross-sections. Given a digitised cross-section and an axial ratio as inputs, the program measures and displays thickness as a function of distance from the axis of symmetry, calculates the implied volume, and displays the result. To produce cross-sections, mobile mounts were used in order to tilt individual specimens; images of these were captured. Outlines of the cross-sections were then traced in a graphics program and exported to NIH-Image for quantification.

For geometric-shaped nannoliths (pentaliths, *Assipetra infracretacea, etc.*), volumes were calculated using appropriate mathematical formulae for average-sized specimens. K_s values were then calculated. These K_s values can be used to calculate volumes for populations of different average size.

Results

The results of the volume calculations are presented in Table 1. The following notes give details of the basis for the calculations.

species	volume (microns^3)	mass (pg)	major dimension (microns)	dimension used	Ks adopted	Ks - range		
COCCOLITHS								
Watznaueria barnesiae	21	57	6,1	length	0,09	0.067-0.098		
Zeugrhabdotus embergeri	87	234	9,0	length	0,12	0.104-0.127		
Rhagodiscus asper	14	39	5,23	length	0,10	0.093-0.106		
Z. diplogrammus	9,3	25	5,01	length	0,07	0.052-0.068		
Z. elegans	5,4	15	4,43	length	0,06	0.036-0.049		
Z. erectus	0,8	2	2,64	length	0,04	0.024-0.038		
Discorhabdus rotatorius	4,0	11	3,08	length	0,14	0.124-0.144		
Biscutum constans	3,2	9	3,43	length	0,08	0.063-0.089		
NANNOLITHS								
Nannoconus steinmannii	1246	3364	18,40	height	0,20	0.10-0.34		
N. truittii	341	920	8,80	height	0,50	0.37-0.58		
N. bucheri	664	1794	11,56	height	0,43	0.33-0.52		
						geometric solid	thickness	minor dimension
Rucinolithus terebrodentarius (small)	24,3	66	4,01	width	0,38	cylinder	1.93	
R. terebrodentarius (large)	270	729	9,76	width	0,29	cylinder	3.61	
Assipetra infracretacea (small)	35,4	96	4,61	width	0,36	parallelepiped	2.12	3,61
A. infracretacea (large)	323	872	9,90	width	0,33	parallelepiped	4.41	7,41
Micrantholithus hoschulzii	38	103	3,00	side length	1,41	pentagonal prism	1.4	3,60
M. obtusus	157	424	5,70	side length	0,85	pentagonal prism	1.9	5.81

Table 1: Volume calculations, also showing K_s values

Nannoconids: volumes of the nannoconid group were calculated using three approaches: (1) the volumes of rotation approach was applied to several captured cross-sections of each species; (2) the volume of rotation was also applied to the cross-section drawing of Perch-Nielsen (1985: see Figure 1); and (3) a simple geometrical estimation of the volume of the total nannolith and central canal was also performed. *Nannoconus steinmannii steinmannii* is shaped like the frustum of a cone. The major and minor diameters, and the height, were measured and the total volume was calculated. In this species, the canal is cylinder-shaped and the diameter is about 1µm. *Nannoconus bucheri* and *Nannoconus truittii* are cylinder-shaped nannoconids. They belong to the wide-canal group, and the thickness of the wall was measured on both cross- and axial-sections.

The results from these different calculations are compared in Table 2. There is significant range in the shape-constants for each species but the results of the different methods are comparable, hence we have calculated a mean of the estimates for each species.

For coccoliths, the volume of rotation approach was used for all species. Cross-sections (Figure 1) were produced using, primarily, captured images from mobile mounts, and the K_s constant was calculated from these using the volume of rotation macro of Young & Ziveri (2000). The major axis (length) of elliptical coccoliths was adopted as the characteristic dimension.

Watznaueria barnesiae displays a wide size-range. From these analyses, a mean major-axis value of 6.1µm and an ellipticity value (major/minor-axis ratio) of 1.14 was determined. The calculated volume of 21µm^3 should not, however, be used in other studies. Instead, the mean size in the population should be determined, and an appropriate volume calculated using the K_s value. This is good practice for all species, but is essential for species which vary greatly in size.

The central process of *Zeugrhabdotus embergeri* was measured, and its volume geometrically calculated. Unfortunately, no specimens of *Rhagodiscus asper* showed a well-preserved central process, so we increased the coccolith volume by 15%.

In the genus *Zeugrhabdotus*, the bridge represents *c.*20% of the total volume. The volume of the calcified skeleton was calculated as follows:

$$V CaCO_3 = V tot - V area + V bridge$$

where V*area* represents the volume of the inner area delimited by the rim, and V*bridge* the volume of the bridge. The parallelepiped volume formula was used to determine the bridge volume, where possible. The calculated volume of *Zeugrhabdotus erectus*, one of the smallest common Cretaceous coccoliths, is 0.76µm^3. This result is in agreement with 0.9µm^3, the estimated volume of a 'typical small coccolith' of the living nannoplankton (Young & Ziveri, 2000).

For *Assipetra infracretacea* (normal- and large-

species		number of estimates	min	max	mean
N. steinmannii	our sections	18	0,1	0,49	0,21
	PN85 sections	2	0,3	0,27	0,27
	simple volume	1			0,12
	average all estimates				**0,21**
N. truittii	our sections	6	0,3	0,8	0,50
	PN85 sections	4	0,4	0,68	0,51
	simple volume	1			0,47
	average all estimates				**0,50**
N. bucheri	our sections	5	0,3	0,52	0,47
	PN85 sections	2	0,4	0,47	0,44
	simple volume				0,35
	average all estimates				**0,42**

Table 2: Volume estimates for the *Nannoconus* species studied, comparing results of different approaches
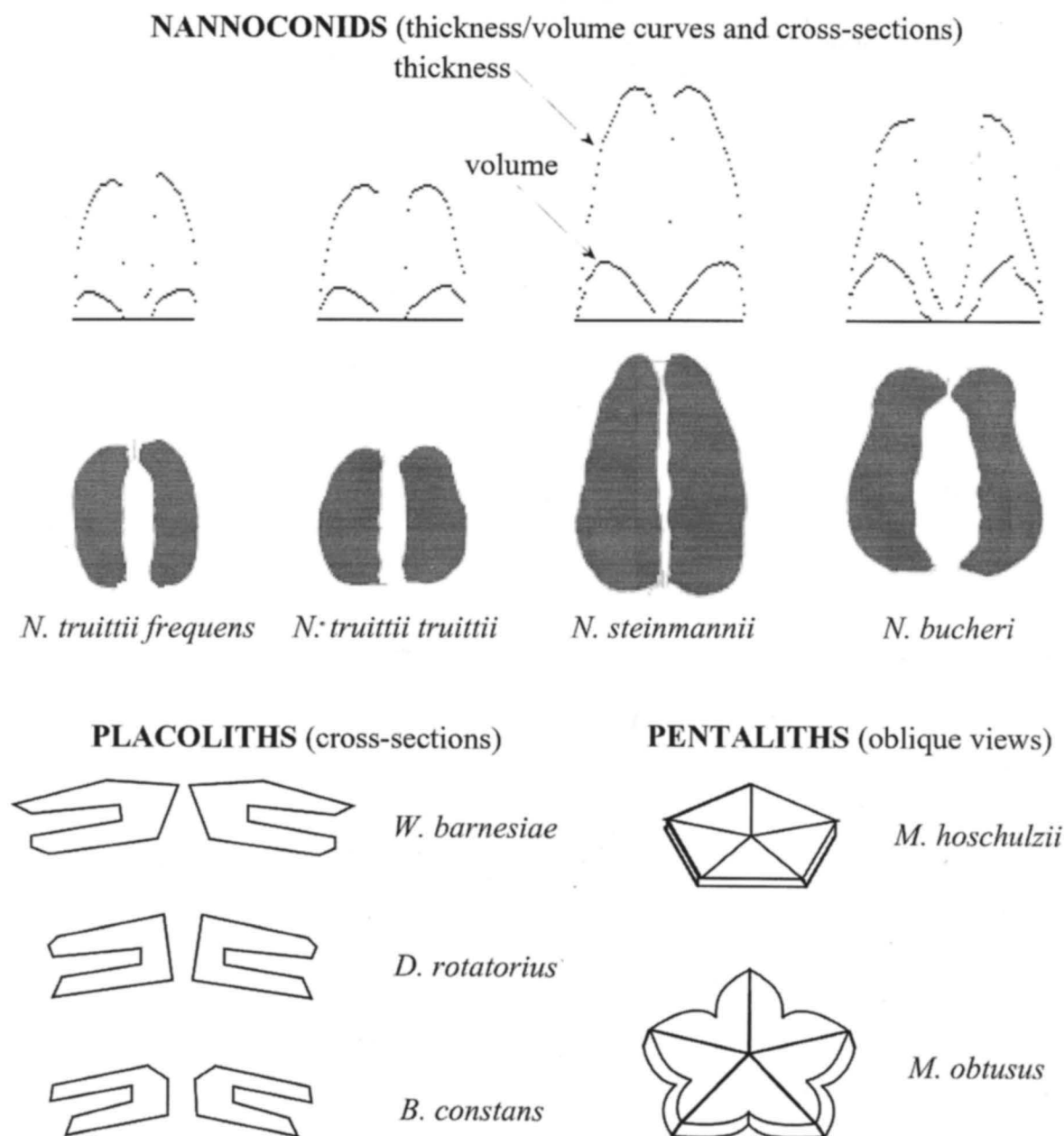
Figure 1: *Top* - representative nannoconid cross-sections of the studied species, derived from SEM illustrations from Perch-Nielsen (1985). Other cross-sections were traced from photomicrographs. Plots above the profiles show program output: thickness of specimen through a sequence of increments from the centre of the specimen, and volume of each increment. The program sums the volume increments to produce a total volume estimate. Note that the left and right profiles are separately analysed to give two estimates of volume. *Bottom* - reconstructions of placolith cross-sections and oblique views of the most common pentaliths of the mid-Cretaceous

sized morphotypes), a subrectangular-shaped nannolith, the geometric function for calculating the volume of a parallelepiped was used. *Rucinolithus terebrodentarius* (normal- and large-sized morphotypes) is composed of a double whorl of eight imbricate elements. Its shape can be approximated as cylindrical.

Discussion

Young & Ziveri (2000) estimated the errors in volume determination as *c.*50%. The error percentage for Cretaceous nannofloras is inevitably higher due to diagenesis. A comparison of SEMs of even well-preserved Cretaceous nannofossils with those of extant nannoplankton suggests that volume increase is pervasive during diagenesis, and for nannoconids there is the real possibility that the original nannoliths may have been highly porous rather than solid. Consequently, results should be interpreted with caution, and only broad-scale patterns interpreted, however, given the very large variations in volume between species (from $<1\mu m^3$ to $>1000\mu m^3$), even estimates with such high uncertainty can provide a valuable perspective for palaeoecological and biogeochemical interpretations of raw count data.

The results (Table 1) quantify a previously-observed contrast between interpreted oligotrophic and eutrophic indicators. The oligotrophic indicator-species (according

to previous interpretations) have the largest volumes and masses, whereas the higher fertility indicators (according to previous interpretations) are smaller, and so have much lower volumes. Based on such estimates of coccolith mass, it may be possible to investigate biogenic fluxes, characterising lower- and higher-fertility conditions, recorded in different lithologies (Tremolada & Erba, in prep.). In addition, these estimates may be used to help investigate the response of phytoplankton to nutrification events and to calibrate the real contribution of nannoplankton to pelagic carbonates.

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