

A minute new species of *Saccammina* (monothalamous Foraminifera; Protista) from the abyssal PacificN. OHKAWARA^{1,2,*}, H. KITAZATO¹, K. UEMATSU³ & A. J. GOODAY⁴¹Institute for Research on Earth Evolution, Japan Agency for Marine-Earth Science and Technology (JAMSTEC) 2-15 Natsushima-cho, Yokosuka 237-0061, Japan²Graduate School of Environment and Information Sciences, Yokohama National University 79-7 Tokiwadai, Hodogaya-ku, Yokohama 240-0067, Japan³Marine Technology Center, Japan Agency for Marine-Earth Science and Technology (JAMSTEC) 2-15 Natsushima-cho, Yokosuka 237-0061, Japan⁴National Oceanography Centre Southampton, Empress Dock, European Way, Southampton SO14 3ZH, UK

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ABSTRACT – *Saccammina minimus* sp. nov., a spherical agglutinated organism presumed to be a foraminiferan, is described from the Kaplan Central site in the abyssal eastern Equatorial Pacific (5042 m water depth). The new species is minute in size (<100 µm diameter) with a test wall composed of a jumble of small mineral grains and a few relatively larger diatom fragments. Occasional specimens, often droplet-shaped rather than spherical, have a simple aperture. The new species is by far the most abundant organism in sieve fractions >32 µm of samples collected at the KC site. In six subcores (6.6 cm² surface area, 0–1 cm layer) from two cores obtained during a single deployment of a multiple corer, it represented 59% of all stained foraminifera in the samples. However, it had an extremely patchy small-scale distribution on a scale of centimetres; for example, 3, 285 and 1090 specimens were extracted from three subcores. A separate study has reported similar patterns among other minute indeterminate monothalamous foraminifera at the Kaplan East site (4032–4089 m water depth) located to the east, c. 1200 km from our study site. The reason for these very patchy distributions is not clear. *J. Micropalaeontol.* 28(2): 143–151, November 2009.

KEYWORDS: *agglutinated foraminifera, single-chambered, saccamminid, psammosphaerid, meiofauna*

INTRODUCTION

Deep-sea benthic foraminifera are well known from geological studies that have documented the distribution and diversity of species living on the ocean floor (Douglas & Woodruff, 1981; Murray, 1991, 2006). Most of our knowledge of these faunas concerns the hard-shelled, predominantly calcareous species that are well represented in the deep-sea fossil record. However, deep-sea sediments abound in a variety of other foraminifera and foraminifera-like protists with agglutinated or organic-walled shells, which are much more delicate and have little fossilization potential (Gooday *et al.*, 2004, 2008). Many of these belong to poorly known, single-chambered (monothalamous) taxa.

A recent study based on fine sediment residues (>32 µm) revealed very diverse assemblages of these monothalamous organisms at the Kaplan East (KE) site in the eastern equatorial Pacific (Nozawa *et al.*, 2006). A dominant component in some samples were simple agglutinated spheres without apertures, <100 µm in diameter, termed ‘indeterminate psammosphaerids’. Similar foraminiferal assemblages are present at the Kaplan Central (KC) site, located c. 1200 km west of the KE site. An important component of these assemblages are minute agglutinated spheres, resembling those found by Nozawa *et al.* (2006) but clearly belonging to a different species. We presume that these abundant organisms are foraminifera. Because some specimens have a single aperture, we describe them as a new species of the genus *Saccammina*.

MATERIALS AND METHOD**Sampling**

Samples were collected in the KC area during a cruise of the R/V *L'Atalante* (17 May–28 June 2004) using a Barnett-type multiple corer (Barnett *et al.*, 1984) fitted with core tubes having an

internal diameter of 96 mm. Two cores were taken from one deployment of the corer at Stn CRS 866 (14°02'N, 130°04'W, 5042 m water depth). The distance between two cores, situated on opposite sides of the coring head, was 75 cm. Each core was sub-sampled using three 50 ml cut-off syringes. The subcores were sliced into 0.5 cm thick layers to 1 cm depth and, thereafter, into 1 cm thick layers to 5 cm depth. Each slice was fixed in 4% formalin buffered with borax.

In the laboratory, the 0–0.5 cm and 0.5–1.0 cm layers of sediment were sieved on a 32 µm screen and stained using a 0.1% rose Bengal solution in sea water for one day. Sieved residues were placed in 20% ethylene glycol solution. All stained foraminifera were then sorted under the binocular stereomicroscope and mounted in glycerol in cavity slides.

Photography

Light photographs were taken either using a Nikon D50 digital camera attached to a Nikon Eclipse TE300 inverted microscope or a CoolPix 4500 digital camera attached to an Olympus BH-2 microscope. Scanning Electron Microscope (SEM) photographs were obtained at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) using a JEOL JSM-6700F SEM.

SYSTEMATIC DESCRIPTION

The higher-level classification of eukaryotes proposed by Adl *et al.* (2005) is followed, which recognizes a series of supergroups within the Protista. The new species is placed in the subclass Textulariina in the belief that it is an agglutinated foraminiferan. However, given the current uncertainty regarding the systematics of monothalamous foraminifera (e.g. Pawlowski *et al.*, 2003), we avoid assigning it to any lower taxon.

Protista

Supergroup **Rhizaria** Cavalier-Smith, 2002
 Class **Foraminifera** d'Orbigny, 1826
 Subclass **Textulariina** Mikhalevich, 1980
 Genus **Saccammina** Carpenter, 1869

Saccammina minimus sp. nov.
 (Pls 1–5)

Type species. The type specimens from Stn CRS 866 (14°02' N, 130°04' W, 5042 m water depth) are deposited in Micropaleontology Collection, National Museum of Nature and Science, Tokyo, under reg. nos MPC-03009 (holotype; Pl. 1, fig. 1), MPC-030010-030016 (7 paratypes; Pl. 1, figs 2–8). Six additional paratypes are stored in the Palaeontology Department, Natural History Museum, London, registration number ZF5204-5209 (Pl. 2, figs 1–6).

Derivation of name. Latin *minimus*, meaning smallest.

Diagnosis. Minute (<100 µm in diameter), spherical, delicately constructed test composed of jumble of loosely agglutinated particles, mostly <10 µm in size, but also often incorporating several larger shard-like diatom fragments. Simple aperture, sometimes associated with short neck, sometimes present. Cell body incorporates relatively large stercomata; peduncular sheath absent.

Other material. Some 455 specimens were examined from the type locality.

Description. This encompasses a description of the test morphology, interior and wall structure.

Test morphology: The test is minute, ranging from 54 µm to 91 µm in diameter (mean 69.1 ± 5.6 µm SD, *n*=200) (Fig. 1). Seven specimens observed by SEM were measured prior to drying and mounting on an SEM stub. They underwent a reduction in mean diameter from 70.7 µm to 62.5 µm, suggesting that the test had shrunk by an average of 11.6%. However, the degree of shrinkage varied considerably between specimens (Table 1).

Although most specimens are more or less spherical and lack an aperture (Pl. 1), a small, simple aperture is developed in a minority of individuals (Pl. 2). In these specimens, the test is often droplet-shaped, with the round aperture located at the pointed end, which may be produced into a short neck.

Wall structure: The wall is *c.* 4 µm thick. When observed by light microscopy, the outer surface appears well defined but rather uneven, comprising a mixture of tiny mineral grains of different sizes and shapes (Pl. 1). Some particles seem to be flat lying while others project from the surface to varying extents. These projecting particles include a variable number of larger grains. In the SEM, the wall appears as a loose jumble of particles of different sizes and compositions and arranged in a haphazard fashion, resulting in a very uneven exterior surface (Pls 3–5). The particles often project at high angles from the surface, an arrangement that may be partly due to shrinkage of the test. Shrinkage probably also accounts for the depression

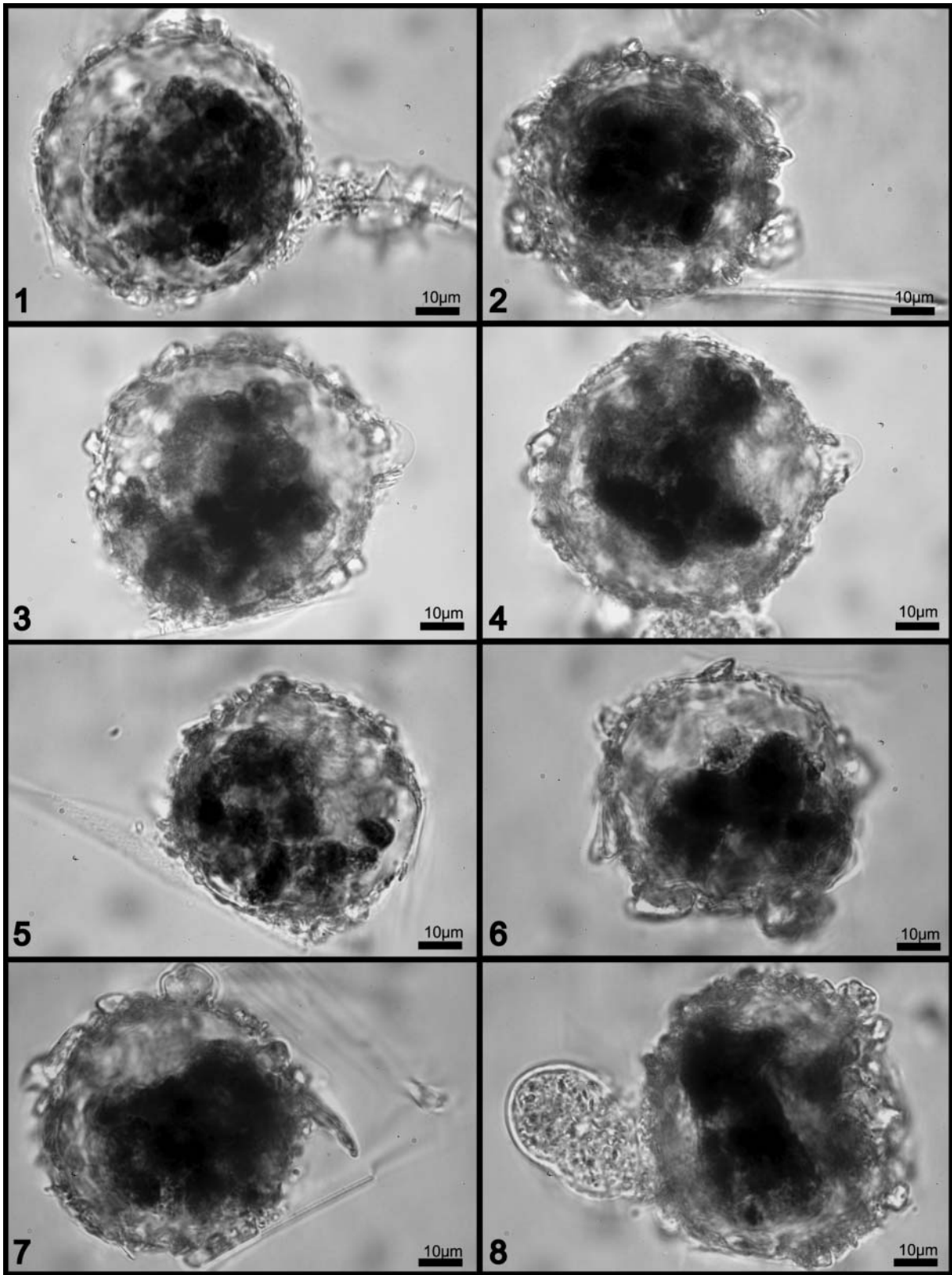
seen on parts of the test surface in some specimens. Many of the agglutinated grains are mineral particles, often plate-like and ranging from *c.* 10 µm to <1 µm in size. These grains sometimes display flat cleavage planes (Pl. 3, fig. 8). Others have a more rounded, equi-dimensional shape. The smaller particles occupy the spaces between the larger particles (Pl. 4, fig. 6). Most specimens also incorporate a few siliceous, biogenic particles, usually angular, plate-like fragments of diatom frustules but also occasional radiolarian fragments or sponge spicules (Pl. 4, figs 4, 8). The diatom fragments may be a relatively large and visually dominant feature of the test in SEM images (Pl. 3, fig. 2).

Because the agglutinated particles vary in size and composition, the appearance of the wall is rather variable in the seven specimens examined by SEM. Specimen A (Pl. 3, figs 1–4), 47 µm diameter, is composed of a mass of plate-like mineral grains, often <5 µm. Smaller grains of a similar shape, typically <1 µm in size and <0.2 µm thick, are visible between these relatively large particles. At least one diatom fragment, measuring 16 µm, is present. This specimen is attached to a large, flat, angular diatom shard, 130 µm long. Specimen B (Pl. 3, figs 5–8) is 65 µm diameter and includes some more rounded mineral particles, a mixture of larger and smaller grains, in addition to plate-like grains *c.* 0.5 µm thick, some of which have a well-developed cleavage. At least one diatom fragment, *c.* 20 µm in size, is present. Specimen C (Pl. 4, figs 1, 2) is 64 µm diameter and includes three large diatom shards (30–50 µm) and at least two sponge spicules. Specimen D (Pl. 4, figs 3–6) is 69 µm diameter with a prominent depression. Several diatom fragments, up to 45 µm in size, and a radiolarian fragment 25 µm in size, are attached to the surface. Specimen E (Pl. 4, figs 7, 8) is 72 µm diameter. The test particles are a heterogeneous mixture of mineral grains, most of them plate-like (in some cases >10 µm in size) but others more rounded. Five relatively small diatom fragments and two radiolarian fragments are also present. Specimen F (Pl. 5, figs 1, 2) is 64 µm diameter. One large and several smaller diatom fragments (17–52 µm in size) are a prominent feature. Specimen G (Pl. 5, figs 3, 4) is 73 µm diameter with a deep depression. There are several diatom fragments 20–30 µm in size, a large plate-like particle *c.* 18 µm and the usual mix of plate-like and more rounded particles.

Although an inner organic lining is not usually evident, an organic partition, possibly a detached lining, subdivides the test interior of one individual (Pl. 2, fig. 5). There is some evidence for the presence of an organic cement in SEM images. This appears as amorphous material coating grain surfaces (Pl. 3, fig. 4).

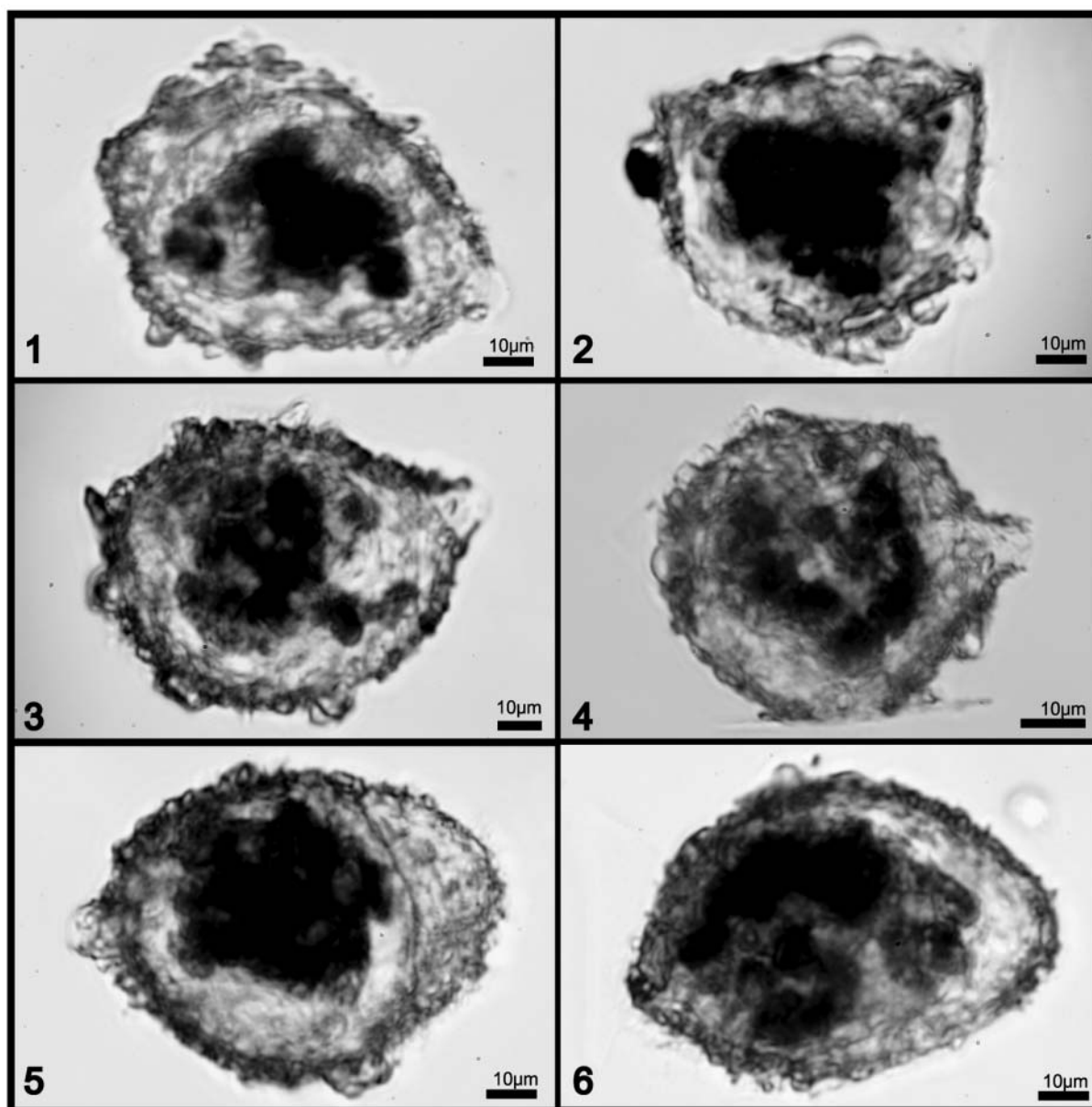
Test interior: The test lumen occupies 75% of the test diameter and is a simple, undivided space. It contains a more or less spherical cytoplasmic body, 65–75 µm diameter, which incorporates dark oval structures, presumably stercomata. There is no evidence for a peduncular sheath. Obviously dead specimens, devoid of cytoplasm, were not observed.

Remarks. The generic placement of the new species is problematic. It has a more or less spherical test, which in some specimens is interrupted by an aperture at the end of a short neck (Pl. 2). Although the general morphology therefore resembles that of *Saccammina* (aperture present) and *Psammospaera* (no aperture), the test is much smaller than typical members of either of



Explanation of Plate 1.

figs 1–8. *Saccammina minimus* sp. nov.; transmitted light micrograph of specimens in glycerol: **1**, holotype registration number MPC-03009; **2**, paratype MPC-030010; **3**, paratype MPC-030011; **4**, Paratype MPC-030012; **5**, paratype MPC-030013; **6**, paratype MPC-030014; **7**, paratype MPC-030015; **8**, paratype MPC-030016.

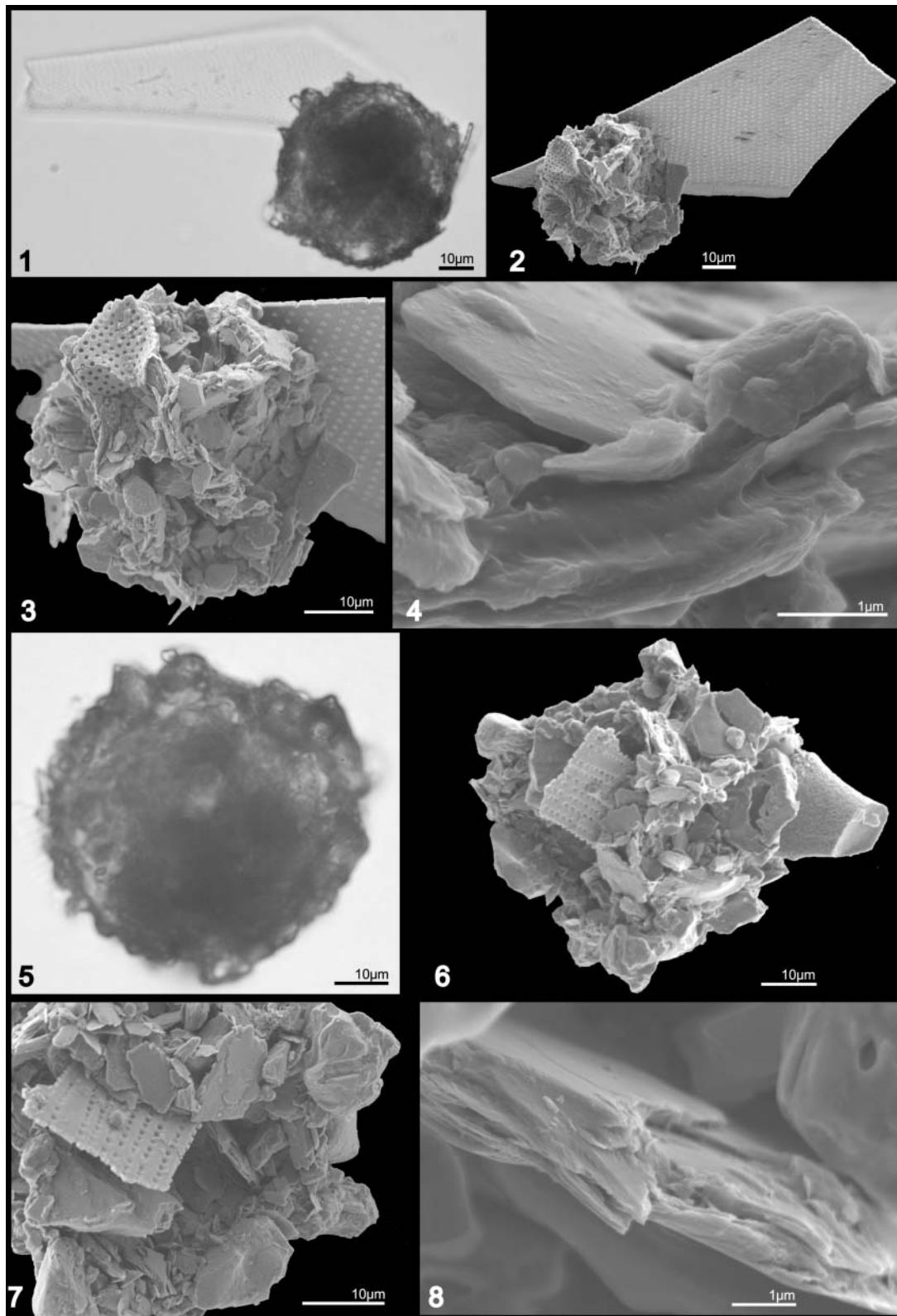


Explanation of Plate 2.

figs 1–6. *Saccamina minimus* sp. nov.; transmitted light micrograph of specimens in glycerol, note the presence of an aperture in figs 1–4; **1**, paratype registration number ZF-5204; **2**, paratype ZF-5205; **3**, paratype ZF-5206; **4**, paratype ZF-5207, **5**, paratype ZF-5208, note the apparent inner organic layer detached from the agglutinated wall; **6**, paratype ZF-5209.

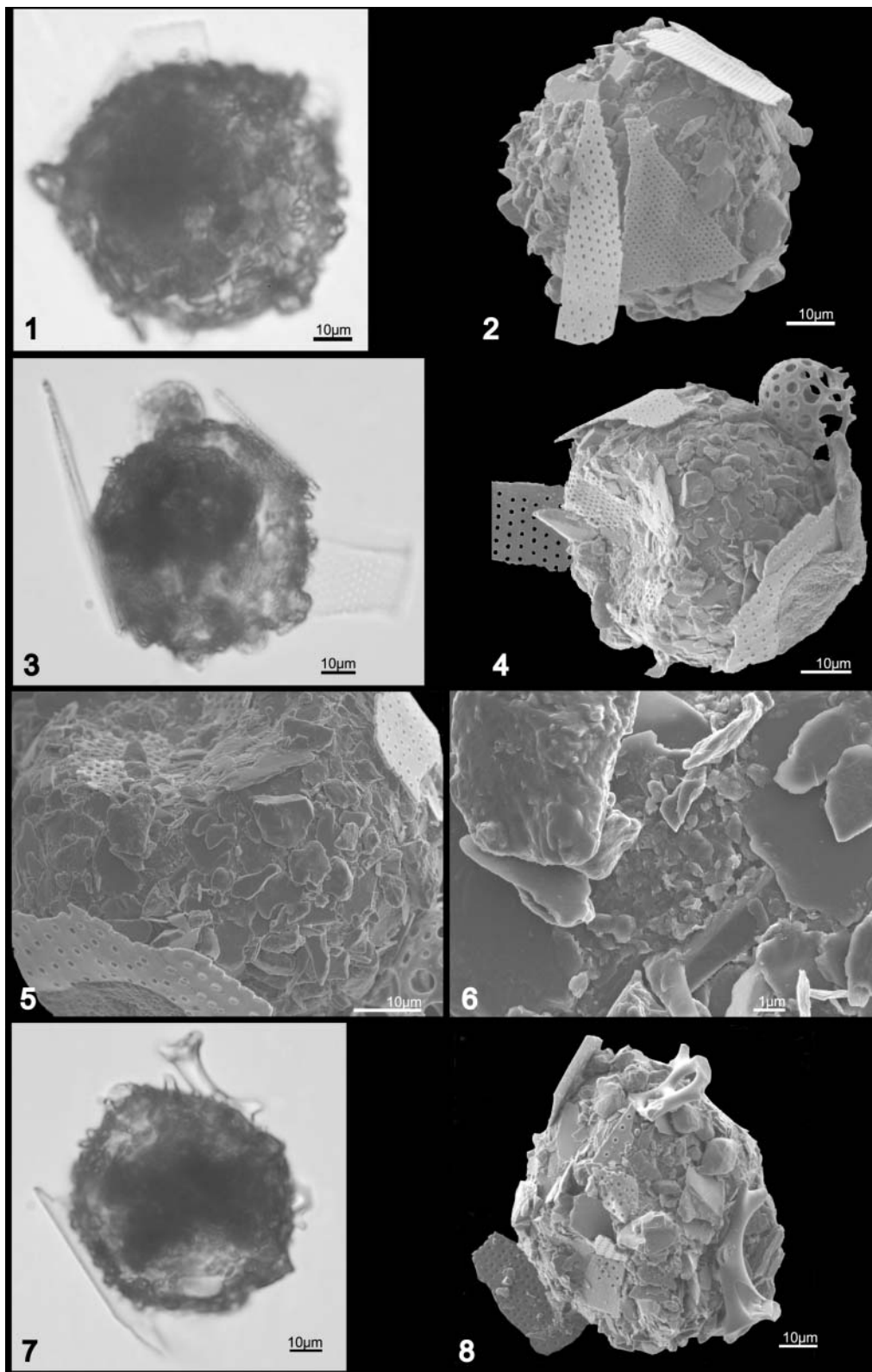
these genera, both of which often reach a diameter of several millimetres (Loeblich & Tappan, 1987). Also, the wall is more loosely constructed and much less well organized; in *Psammospaera* it typically comprises a single layer of quartz particles with the interstices filled by finer grains. Nevertheless, it is difficult to justify the establishment of a new genus on purely morphological grounds. Therefore, we provisionally place the new species in *Saccamina*, based mainly on the presence of an aperture at the end of a short neck in some specimens. However, we suspect that molecular data, which are currently unavailable, will reveal that our tiny abyssal species is not closely related to either of these larger and essentially bathyal taxa.

Nozawa *et al.* (2006) report large numbers of minute ‘psammospaerids’ from the KE site in the eastern part of the Equatorial Pacific nodule field (*c.* 15°N, 119°W, *c.* 4100 m water depth). Although these more or less spherical agglutinated chambers could be divided into different types based mainly on the wall structure and composition, it was impossible to recognize morphospecies consistently and they were therefore regarded as ‘indeterminate psammospaerids’ by Nozawa *et al.* (2006). The new species from the KC site, on the other hand, has a fairly consistent appearance in the light microscope, despite some variation in the test wall composition, notably in the number and size of the diatom fragments that it incorpor-



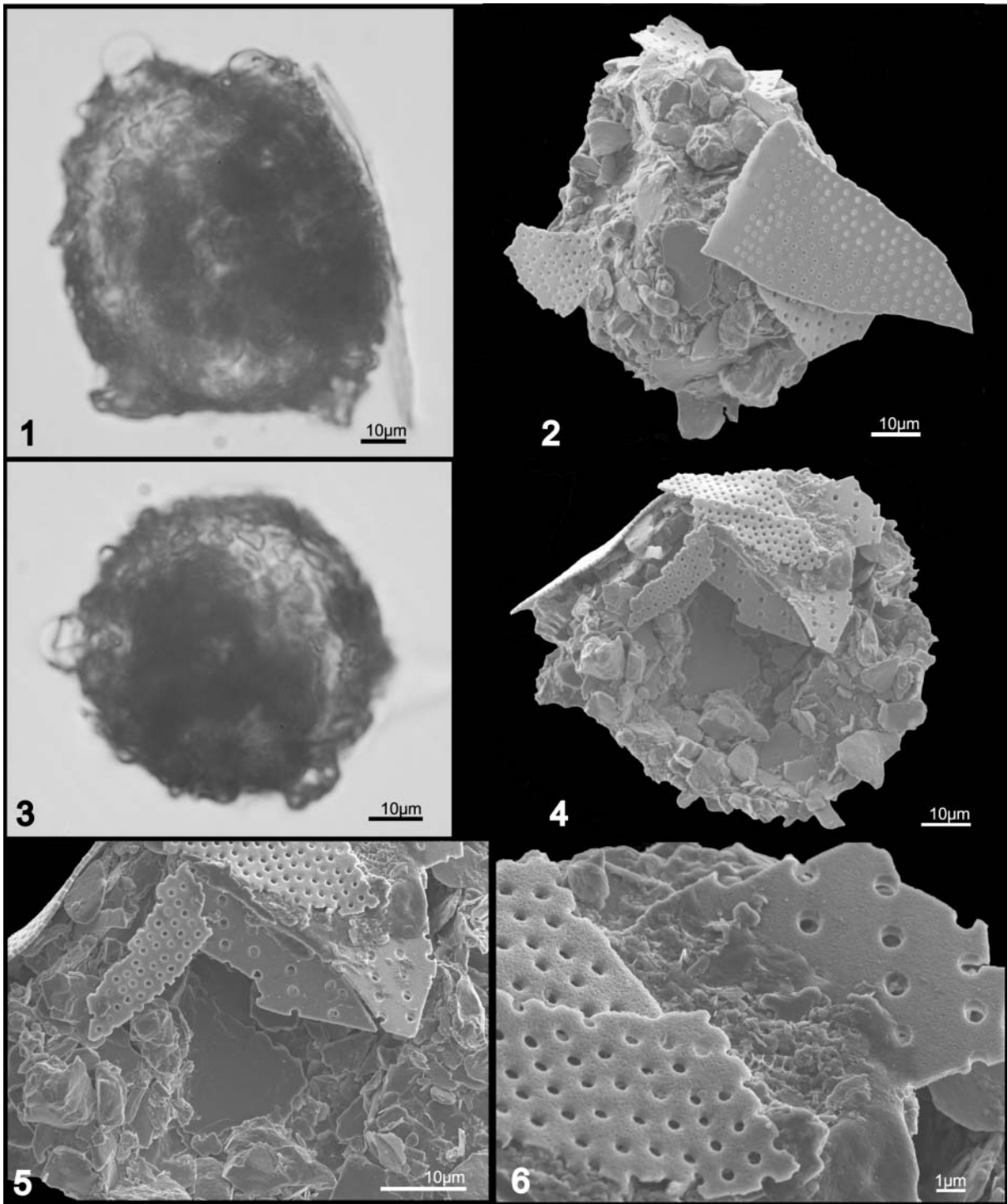
Explanation of Plate 3.

figs 1–8. *Saccammina minimus* sp. nov.: **1**, transmitted light micrograph of specimen in glycerol, incorporating large, plate-like diatom shard; **2**, same specimen photographed by SEM showing large diatom fragment; **3**, closer view of agglutinated sphere; **4**, detail showing agglutinated grains and probable organic cement; **5**, transmitted light micrograph of second specimen in glycerol; **6**, same specimen photographed by SEM; **7**, **8**, progressively closer views of test surface; note cleavage of plate-like grains.



Explanation of Plate 4.

figs 1–8. *Saccammina minimus* sp. nov.: **1**, transmitted light micrograph of specimen in glycerol, incorporating several plate-like diatom shards; **2**, same specimen photographed by SEM; **3**, transmitted light micrograph of second specimen in glycerol, incorporating several plate-like diatom shards and a radiolarian test; **4**, same specimen photographed by SEM; **5, 6**, progressively closer views of test surface; **7**, transmitted light micrograph of third specimen in glycerol; **8**, same specimen photographed by SEM, incorporating several radiolarian fragments.



Explanation of Plate 5.

figs 1–6. *Saccammina minimus* sp. nov.: **1**, transmitted light micrograph of specimen in glycerol, incorporating several plate-like diatom shards; **2**, same specimen photographed by SEM; **3**, transmitted light micrograph of second specimen in glycerol; **4**, same specimen photographed by SEM; **5**, **6**, progressively closer views showing diatom fragments.

ates. Moreover, the test wall in the KC species differs from that of the KE psammosphaerids. It is thinner and more uniform in thickness and includes a much higher proportion of larger particles,

some of which project from the test surface. In contrast, the test surface in the KE psammosphaerids has a ‘fluffy’, fine-grained appearance.

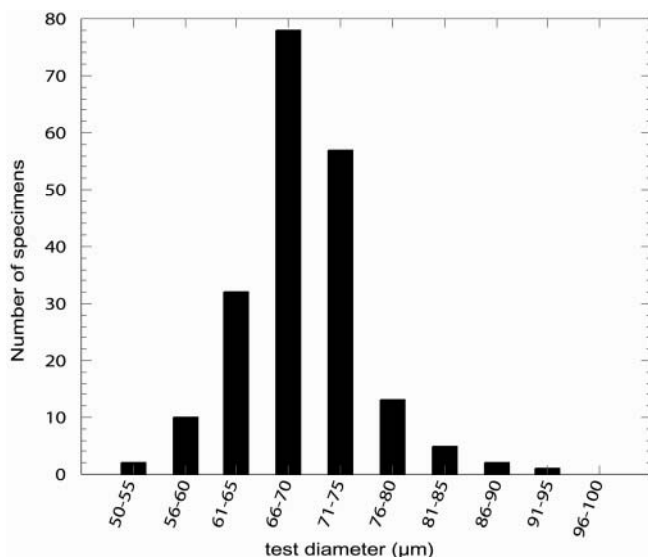


Fig. 1. Size distribution of *Saccammina minimus* (n=200). Measurements disregard large diatom and other biogenic fragments.

ABUNDANCE AND SMALL-SCALE DISTRIBUTION

The distribution of the new species is extremely patchy, with numbers ranging from 7 to 988 (core A) and 3 to 1090 (core B) in individual subsamples from the two cores (Table 2). These numbers represent 6–95% (core A) and 2–94% (core B) of all psammosphaerids and 3–86% (core A) and 0.8–84% (core B) of all stained foraminifera in the samples. The cores had a surface area of 72.4 cm² (diameter 9.6 cm) and the subcores of 6.6 cm² (diameter 2.9 cm), suggesting that the patch size was on the order of centimetres. The mean abundances in the two cores represented 47% and 38%, respectively, of the mean abundance of psammosphaerids and total foraminifera.

Deeper sediment layers (1–2, 2–3, 3–4, 4–5 cm) of subcore A2 from site CRS866 yielded only two specimens of *Saccammina minimus*, both from the 1–2 cm layer, compared to 988 present in the 0–1 cm layer. Moreover, within the top 1 cm, the vast majority of specimens (98.3% in Core A, 96.7% in Core B) were found in the upper 0.5 cm layer (Table 2). The new species, therefore, is confined more or less entirely to the surficial layer of the sediment.

DISCUSSION

A notable feature of *Saccammina minimus* is the extreme variation in numbers of individuals between samples (Table 2). A

Specimen	Test diameter (µm)		% difference
	Light microscope	SEM	
A	69.7	47.3	31.9
B	74.9	65.3	12.8
C	67.9	63.9	5.8
D	69.0	64.7	8.3
E	71.4	66.1	7.5
F	73.4	63.9	13.0
G	68.9	66.0	4.3

Table 1. Test diameters of seven specimens measured in glycerol by light microscopy and following drying and mounting on SEM stub

similar phenomenon was observed in the case of the indeterminate psammosphaerids reported by Nozawa *et al.* (2006). This raises the possibility that the agglutinated spheres represent the fragmented remains of a larger organism, for example a komokiacean, a group of foraminiferan-like organisms that are common in the abyssal Pacific (Tendal & Hessler, 1977) and frequently occur as fragments (Bernstein *et al.*, 1978; Snider *et al.*, 1984). Nozawa *et al.* (2006) noted the presence of numerous isolated chambers with organic walls overlain by agglutinated particles and frequently drawn out into an open-ended, tubular extension. The occurrence of occasional clusters of similar chambers joined by delicate tubules led Nozawa *et al.* (2006) to suspect that these structures were derived from very delicate komokiaceans. Similar chambers are present in our KC samples, although they are much less common than at KE. However, the species described here is consistently devoid of a tubular extension or any structure that would suggest it represented fragments of a larger organism. We therefore consider our specimens to be individuals of a tiny saccamminid species. *Saccammina minimus* is presently known only known from the Kaplan Central site. As noted above, agglutinated spheres described by Nozawa *et al.* (2006) from the Kaplan East site clearly represent a different species or series of species. Other foraminiferal studies in the Pacific Ocean have not included the 32–63-µm fraction in which almost all specimens of the new species are concentrated.

If the spheres at the KE and KC sites are not fragments, then it is unclear why their distribution is so patchy. Possibly, they represent the products of a reproductive event. In this case, they may be juveniles that develop into larger monothalamous

	Core A				Core B			
	A1	A2	A3	Mean	B4	B5	B6	Mean
<i>S. minimus</i>	7	988	12	336	3	1090	285	459
Total spherical monothalamous	119	1037	134	430	144	1165	388	566
Total foraminifera	257	1147	368	591	382	1297	569	749
% abundance of <i>S. minimus</i> :								
total spherical monothalamous	5.9	95.3	9.0	36.7	2.1	93.6	73.5	56.4
total foraminifera	2.7	86.1	3.3	30.7	0.8	84.0	50.1	45.0
in 0–0.5 cm layer	28.6	99.6	8.3	98.0	100	96.2	99.3	96.9

Table 2. Numbers of individuals of *Saccammina minimus* sp. nov. in single syringe subsamples from cores A and B of the same multiple corer deployment, compared to total abundance of spherical monothalamous and other foraminifera.

foraminifera. However, the size distribution of the spheres is very uniform and we have not observed any larger spheres that could represent fully grown specimens of this species. We are therefore inclined to believe that they not juveniles.

Saccammina minimus is by far the most abundant foraminiferan-like species at the Kaplan Central site. The abundance of agglutinated spheres and similar monothalamous foraminifera at this and other Pacific abyssal sites (Snider *et al.*, 1984; Nozawa *et al.*, 2006) suggests that they play an important role in benthic ecosystems in central areas of this ocean. Elsewhere, we have argued that because of their sheer abundance, such organisms may be important in carbon cycling at abyssal depths (Gooday *et al.*, 2008). However, their delicate construction, the fact that specimens are more or less confined to the top 0.5 cm layer of the sediment, and the absence of any obviously dead tests, suggests that they have almost no fossilization potential.

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