

Extinct foraminifera figured in Brady's *Challenger* Report

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ABSTRACT – Brady's (1884) widely available monograph on foraminifera from the *Challenger* Expedition is generally assumed to illustrate hundreds of living species from modern seafloor sediment from around the world. This assumption may have contributed to the delay in recognizing the youngest extinction 'episode' in the deep sea, which occurred during the mid-Pleistocene Climate Transition. At least 18 of the species illustrated by Brady are part of the group of *c.* 70 elongate, benthic foraminifera now known to have died out globally between 1.2 and 0.6 million years ago. The figured specimens were sampled from just seven stations that presumably contain relict or reworked sediment, possibly mixed in with Holocene. The majority (14 species) come from two stations (191A, 192) off Kei Islands, Banda Sea, Indonesia. Station 192, from *c.* 250 m depth, is considerably shallower than the established fossil bathymetric ranges of the extinct species and therefore tectonic uplift is inferred. Additional pre-Holocene or even extinct species may also be among those illustrated by Brady, especially from the seven stations so far identified. *J. Micropalaeontol.* 24(2): 171–175, October 2005.

KEYWORDS: *Deep-sea benthic foraminifera, mid-Pleistocene extinctions, Challenger Expedition, Brady*

BRADY'S CHALLENGER FORAMINIFERA

For more than a century Brady's beautifully illustrated plates of foraminifera dredged by HMS *Challenger* (Brady, 1884) have been the first reference book consulted by those starting to identify Recent foraminiferal faunas, particularly those from deeper water. This is because of the detail in the clear figures, the large number of species illustrated and the ready availability of updated identifications provided by two major 'revisions' by Barker (1960) and Jones (1994).

Since they were all dredged from surficial sediment, most readers who have consulted Brady's colossus many times over the years have assumed that all species illustrated are part of the Recent global foraminiferal fauna. Such an assumption is reinforced by the stratigraphic ranges assembled by Jones (1994, Appendix 4) which extend up to the Recent for all of Brady's figured species and modern depth ranges are cited for most (Jones, 1994, Appendices 2–3).

MID-PLEISTOCENE EXTINCTION OF DEEP-SEA FORAMINIFERA

Studies on Deep Sea Drilling Project (DSDP) and Ocean Drilling Project (ODP) cores in the last two decades now suggest that a number of the species so well figured in Brady (1884) became extinct globally during the mid-Pleistocene Climatic Transition (e.g. Weinholz & Lutze, 1989; Schönfeld, 1996; Hayward, 2001, 2002; Kawagata *et al.*, 2005). These include many of the species selected by Jones (1994) for more detailed additional illustration using optical and scanning electron micrographs (Jones, 1994, Suppl. pls 1–2). These studies indicate that many elongate, cylindrical bathyal and upper abyssal benthic foraminifera, often with small, restricted apertures, became extinct over an extended period of several hundred thousand years (Schönfeld, 1996; Hayward, 2002). Two families – Pleurostomellidae and Stilostomellidae – and one subfamily – Plectofrondiculariinae – became extinct globally or virtually so, together with a number of additional species in other families, especially the Nodosariidae (Hayward, 2002). Rare Rose-

Bengal-stained (live?) specimens of *Pleurostomella* have been recorded from the South Atlantic and may come from a small surviving population (Timm, 1992).

REWORKED OR RELICT SEAFLOOR SPECIMENS

Strong bottom currents at any depth in the ocean can result in erosion or long periods of non-deposition on the ocean floor producing a hiatus. Many such hiatuses have been recognized in deep-sea sequences cored by DSDP and ODP, as well as in on-land exposures. Thus, it is to be expected that some areas of modern seafloor are sites of non-deposition in the Holocene and are underlain by older sediment, or that older sediment has been reworked and mixed in with Holocene sediment. Anyone who undertakes extended studies on Recent foraminifera will, at various times, encounter seafloor samples containing recognizably reworked fossil foraminifera, or recognizable older, often iron-stained relict foraminifera. At other times, the preservational state of the foraminifera provides little hint that some specimens are much older, unless distinctive extinct species are recognized. It is not surprising, therefore, that among the samples dredged by the *Challenger* in the 1870s, there were some that contained older, even extinct foraminifera.

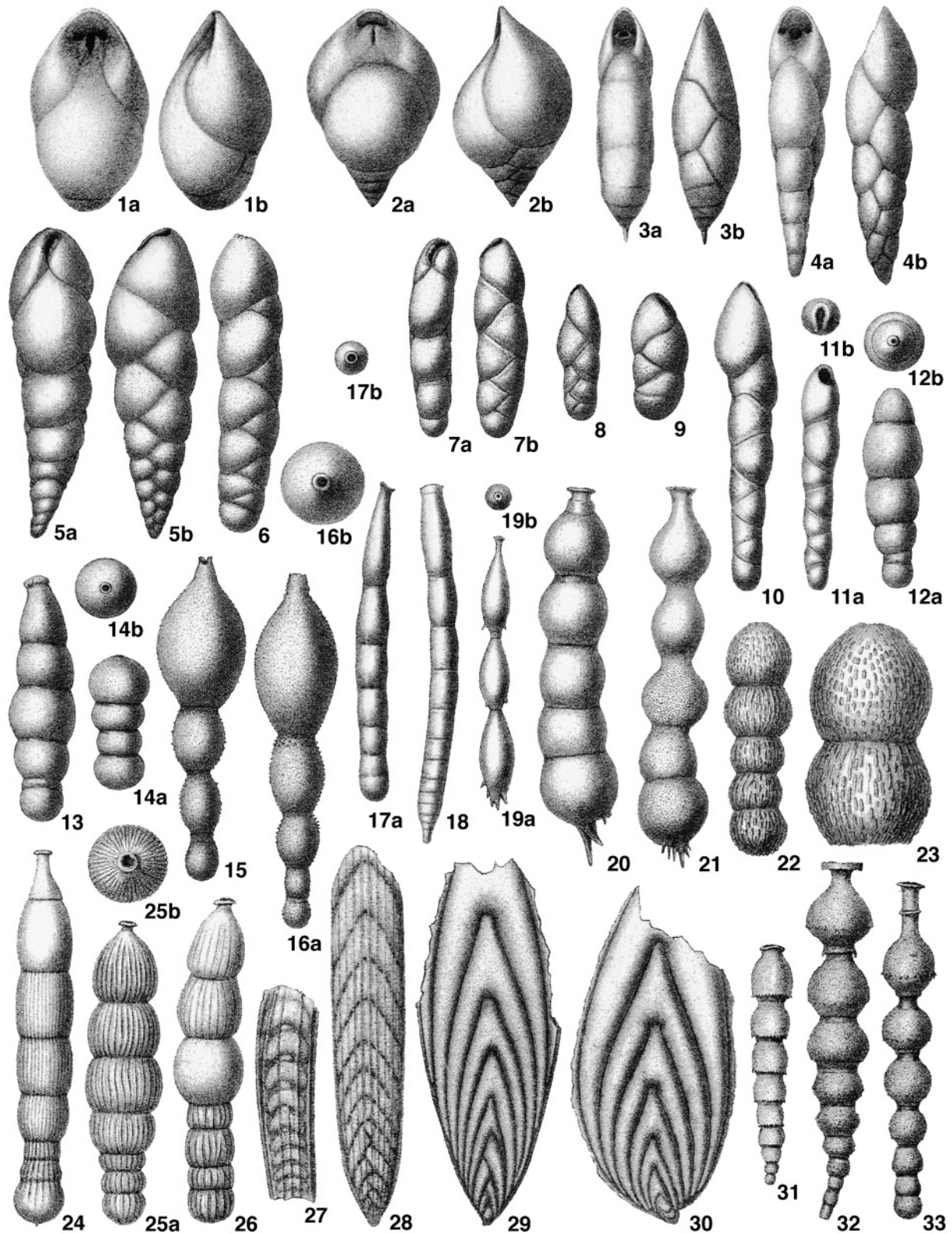
EXTINCT SPECIES ILLUSTRATED IN BRADY'S CHALLENGER FORAMINIFERA

At least 18 species (Table 1) illustrated in Brady (1884) are among the *c.* 70 bathyal Pleistocene foraminiferal species now believed to have become extinct by 600 000 years ago (Hayward, 2002; Kawagata *et al.*, 2005). These extinct *Challenger* taxa (Pl. 1) include four species of *Pleurostomella*, four species of *Orthomorphina*, three species of *Siphonodosaria*, two species of *Stilostomella* and one each of *Fursenkoina*, *Myllostomella*, *Parafondicularia*, *Plectofrondicularia* and *Proxifrons*. The figured specimens of these species come from just seven of the *Challenger* dredge stations (Stns 120, 191A, 192, 296, 300, 332, 346, Table 1, Fig. 1). The majority of them (14 species) come from only two stations (191A, 192) from off the Kei Islands,

Identification from this study	Plate, fig	Jones (1994) name	Brady (1884) name	Station
Extinct				
<i>Pleurostomella brevis</i> Schwager, 1866	Pl. 51, fig. 20	<i>Pleurostomella brevis</i>	<i>Pleurostomella brevis</i>	192
<i>Pleurostomella brevis</i> Schwager, 1866	Pl. 51, fig. 21	<i>Pleurostomella recens</i>	<i>Pleurostomella rapa</i>	192
<i>Pleurostomella acuminata</i> Cushman, 1922	Pl. 51, fig. 22	<i>Pleurostomella acuminata</i>	<i>Pleurostomella alternans</i>	192
<i>Pleurostomella alternans</i> Schwager, 1866	Pl. 51, fig. 23	<i>Pleurostomella</i> sp. nov.	<i>Pleurostomella alternans</i>	192
<i>Fursenkoina texturata</i> (Brady, 1884)	Pl. 52, figs 6, 14–17	<i>Fursenkoina texturata</i>	<i>Virgulina texturata</i> & <i>V. subdepressa</i>	296
<i>Pleurostomella obtusa</i> Berthelin, 1880	Pl. 52, fig. 12	<i>Pleurostomella</i> sp. nov.	<i>Pleurostomella subnodosa</i>	346
<i>Pleurostomella obtusa</i> Berthelin, 1880	Pl. 52, fig. 13	<i>Pleurostomella</i> sp. nov.	<i>Pleurostomella subnodosa</i>	332
<i>Orthomorphina jedlitschikai</i> (Thalmann, 1937)	Pl. 62, figs 1–2	<i>Orthomorphina jedlitschikai</i>	<i>Nodosaria radicata</i> var. <i>annulata</i>	192
<i>Orthomorphina ambigua</i> (Neugeboren, 1856)	Pl. 62, fig. 3	<i>Glandulodosaria ambigua</i>	<i>Nodosaria radicata</i> var. <i>ambigua</i>	192
<i>Stilosomella fistuca</i> (Schwager, 1866)	Pl. 62, figs 7–8	<i>Stilosomella fistuca</i>	<i>Nodosaria subterremata</i>	192
<i>Mytilostomella costai</i> (Schwager, 1866)	Pl. 62, fig. 23	<i>Stilosomella consobrina</i>	<i>Nodosaria (Dentalina) consobrina</i>	191A
<i>Mytilostomella costai</i> (Schwager, 1866)	Pl. 62, fig. 24	<i>Stilosomella consobrina</i>	<i>Nodosaria (Dentalina) consobrina</i>	300
? <i>Stilosomella retrorsa</i> (Reuss, 1863)	Pl. 63, fig. 7	<i>Stilosomella retrorsa</i>	<i>Nodosaria (Dentalina) retrorsa</i>	191A
<i>Siphonodosaria insecta</i> (Schwager, 1866)	Pl. 63, figs 8–9	<i>Stilosomella abyssorum</i>	<i>Nodosaria (?) abyssorum</i>	296
<i>Orthomorphina trincherasensis</i> (Bermudez, 1949)	Pl. 63, figs 17–18	<i>Glandulodosaria</i> sp. nov.	<i>Nodosaria verruculosa</i>	192
<i>Orthomorphina perversa</i> (Schwager, 1866)	Pl. 64, figs 25–27	<i>Orthomorphina challengeriana</i>	<i>Nodosaria perversa</i>	192
<i>Plectofrondicularia californica</i> Cushman & Stewart, 1926	Pl. 66, fig. 6	<i>Plectofrondicularia helenae</i>	<i>Fronidularia interrupta</i>	192
<i>Parafondicularia antonina</i> (Karrer, 1878)	Pl. 66, fig. 7	<i>Plectofrondicularia helenae</i>	<i>Fronidularia interrupta</i>	192
<i>Proxifrons inaequalis</i> (Costa, 1855)	Pl. 66, figs 11–12	<i>Plectofrondicularia advena</i>	<i>Fronidularia inaequalis</i>	191A
<i>Siphonodosaria bradyi</i> (Cushman, 1927)	Pl. 76, fig. 8	<i>Nodogenerina virgula</i>	<i>Sagrina virgula</i>	120
<i>Siphonodosaria sagrinensis</i> (Bagg, 1912)	Pl. 76, fig. 9–10	<i>Nodogenerina antillea</i>	<i>Sagrina virgula</i>	192
Possibly extinct				
<i>Uvigerina hispida</i> Schwager, 1866	Pl. 75, figs 6–7, 9	<i>Uvigerina auberiana</i>	<i>Uvigerina asperula</i> & <i>U. asperula</i> var. <i>auberiana</i>	191A
<i>Rectobolvinia</i> cf. <i>curta</i> (Cushman, 1926)	Pl. 75, fig. 25	<i>Siphogenerina striata</i> var. <i>curta</i>	<i>Sagrina striata</i>	192
<i>Trifarina reussi</i> (Cushman, 1913)	Pl. 67, figs 4–6	<i>Trifarina reussi</i>	<i>Rhabdognomium minuta</i>	192

The identifications in this study generally follow the taxonomy outlined by Hayward (2002).

Table 1. Species figured by Brady (1884) and now considered extinct or possibly extinct.



Explanation of Plate 1.

Reproductions of Brady's (1884) figures of species that became extinct during the middle Pleistocene. **figs 1-2.** *Pleurostomella brevis* Schwager, 1866. **figs 3a, b.** *Pleurostomella acuminata* Cushman, 1922. **figs 4a, b.** *Pleurostomella alternans* Schwager, 1866. **figs 5-9.** *Fursenkoina texturata* (Brady, 1884). **figs 10-11.** *Pleurostomella obtusa* Berthelin, 1880. **figs 12-13.** *Orthomorphina jedlitschkai* (Thalmann, 1937). **figs 14a, b.** *Orthomorphina ambigua* (Neugeboren, 1856). **figs 15-16.** *Stilostomella fistuca* (Schwager, 1866). **figs 17-18.** *Myllostomella costai* (Schwager, 1866). **figs 19a, b.** ?*Stilostomella retrorsa* (Reuss, 1863). **figs 20-21.** *Siphonodosaria insecta* (Schwager, 1866). **figs 22-23.** *Orthomorphina trincherasensis* (Bermudez, 1949). **figs 24-26.** *Orthomorphina perversa* (Schwager, 1866). **fig. 27.** *Plectofrondicularia californica* Cushman & Stewart, 1926. **fig. 28.** *Parafondicularia antonina* (Karrer, 1878). **figs 29-30.** *Proxifrons inaequalis* (Costa, 1855). **fig. 31.** *Siphonodosaria bradyi* (Cushman, 1927). **figs 32-33.** *Siphonodosaria sagrinensis* (Bagg, 1912).

Station	Depth fm. (m)	Latitude and Longitude	Location
120	675 (1235)	8° 37' S; 34° 28' W	Red mud, Pemambuco, Atlantic Ocean
191A	580 (1061)	5° 26' S; 133° 19' E	Green mud, Kei Islands, Banda Sea, Pacific Ocean
192	129 (237)	5° 49' S; 132° 14' E	Blue mud, Kei Islands, Banda Sea, Pacific Ocean
296	1825 (3340)	38° 06' S; 88° 02' W	<i>Globigerina</i> ooze, South Pacific
300	1375 (2590)	33° 42' S; 78° 18' W	<i>Globigerina</i> ooze, Juan Fernandez, Pacific Ocean
332	2200 (4026)	37° 29' S; 27° 31' W	<i>Globigerina</i> ooze, South Atlantic
346	2350 (4300)	2° 42' S; 14° 41' W	<i>Globigerina</i> ooze, South Atlantic

Table 2. *Challenger* Stations from which the 18 extinct species were obtained (Fig. 1).

Indonesia (Fig. 1). This co-occurrence of many of the apparently extinct species provides further strong support for this developing hypothesis. Brady (1884) illustrates a further 33 species obtained from these two stations, some or many of which are also likely to be reworked or relict. Of these, many are clearly still extant (e.g. *Bulimina aculeata*, *Globobulimina pacifica*, *Osangularia bengalensis*, *Sigmoidella elegantissima*, *Trifarina bradyi*) while the status (extinct, extant) of several others is indeterminate and deserves more study (e.g. *Rectobolivina cf. curta*, *Trifarina reussi*, *Uvigerina hispida*, Table 1).

Studies (e.g. Hayward, 2002) indicate that all of the extinct *Challenger* species, except perhaps *Proxifrons inaequalis*, lived at mid bathyal or greater depths (>500 m) during the Neogene. The depths at which six of the seven stations were obtained (Table 2) are consistent with these depths. The only species of this group that occurs in the two deepest stations (>4000 m, Stns 332, 346) is *Pleuostomella obtusa*, a species that studies (Hayward, 2002) suggest was restricted to abyssal depths (>2000 m). The only station that is shallower than mid-bathyal is Stn 192, taken from c. 250 m depth off Kei Islands, East Indonesia. This station contains the majority (11) of the extinct species (Table 1) and to be at this elevation they must have been uplifted tectonically since deposition. This explanation is consistent with the location of the station within a major collisional plate boundary zone.

DISCUSSION

It is suggested that the illustration of so many of these extinct species in Brady's (1884) *Challenger* volume may be one of the main reasons why this early-mid-Pleistocene extinction period in the deep sea was not recognized until relatively recently. Admittedly, other workers have sometimes recorded these taxa from seafloor sediment samples and assumed they were part of the extant fauna, even highlighting their value as indicators of abyssal environments (e.g. Bandy & Rodolfo, 1964).

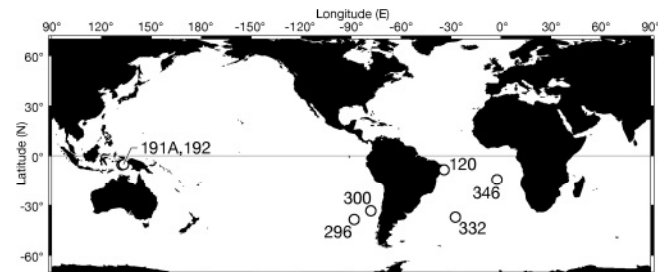


Fig. 1. Location of the seven *Challenger* stations from which the figured specimens of 18 extinct species were obtained.

Other reasons that have contributed to the non-recognition of this extinction period until recently include:

1. Middle and Late Pleistocene deep-sea sediments (younger than 800 ka) are too young to have been uplifted and exposed on land for stratigraphic study, except perhaps in eastern Sicily (A. di Stefano, pers. comm.);
2. piston cores mostly penetrated a maximum c. 10 m into the seafloor and usually did not sample the extinction period;
3. prior to the 1980s, deep-sea drilling techniques used a rotary bit and thus young, less compacted sediment was often disturbed and unsuitable for high-resolution studies through the Pleistocene;
4. prior to the 1980s, isotope labs were fewer and less automated than today, thus, high resolution studies of the Pleistocene were seldom undertaken.

Hydraulic piston coring of multiple holes at a single site was introduced by the DSDP in the early 1980s and, together with increased modern capability to take longer piston cores, has facilitated the studies on Early and Middle Pleistocene deep-sea benthic foraminifera that have now documented this significant extinction event globally (e.g. Schönfeld, 1996; Hayward, 2002).

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REFERENCES

- Bandy, O.L. & Rodolfo, K.S. 1964. Distribution of foraminifera and sediments, Peru–Chile Trench area. *Deep-Sea Research*, **11**: 817–837.
- Barker, R.W. 1960. *Taxonomic notes on the species figured by H.B. Brady in his report on the foraminifera dredged by HMS Challenger during the years 1873–1876*. Society of Economic Paleontologists and Mineralogists Special Publication, **9**: 238pp.
- Brady, H.B. 1884. Report on the foraminifera dredged by HMS Challenger, during the years 1873–1876. *Report of Scientific Results of the Exploration Voyage of HMS Challenger, Zoology*, **9**: 1–814.
- Hayward, B.W. 2001. Global deep-sea extinctions during the Pleistocene ice-ages. *Geology*, **29**: 599–602.

Extinct *Challenger* foraminifera

- Hayward, B.W. 2002. Late Pliocene to middle Pleistocene extinctions of deep-sea benthic foraminifera ('*Stilostomella* extinction') in the Southwest Pacific. *Journal of Foraminiferal Research*, **32**: 274–306.
- Jones, R.W. 1994. *The Challenger Foraminifera*. Oxford University Press, Oxford, 149pp.
- Kawagata, S., Hayward, B.W., Grenfell, H.R. & Sabaa, A.T. 2005. Mid-Pleistocene extinction of deep-sea foraminifera in the North Atlantic Gateway (ODP sites 980 and 982). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **221**: 267–291.
- Schönfeld, J. 1996. The 'Stilostomella Extinction'; structure and dynamics of the last turn-over in deep-sea benthic foraminiferal assemblages. In: Moguilevsky, E.A. & Whatley, R. (Eds), *Microfossils and Oceanic Environments*. University of Wales, Aberystwyth Press, 27–37.
- Timm, S. 1992. Rezente Tiefsee-Benthosforaminiferen aus Oberflächensedimenten des Golfes von Guinea (Westafrika) –Taxonomie, Verbreitung, Ökologie und Korngrößenfraktionen. *Reports Geologische-Paläontologisches Institut und Museum Universität Kiel*, **59**: 1–192.
- Weinholz, P. & Lutze, G.F. 1989. The *Stilostomella* extinction. In: Ruddiman, W.F. & Sarnthein, M. (Eds), *Proceedings of the Ocean Drilling Program, Scientific Results*, **108**: 113–117.