

FORAMINIFERA FROM THE *PECTEN* CONGLOMERATE (PLIOCENE) OF COCKBURN ISLAND, ANTARCTIC PENINSULA

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The *Pecten* Conglomerate was first proposed and described by Andersson (1906) at a type locality on Cockburn Island, a small island situated between James Ross and Seymour Islands, Antarctic Peninsula. The name of the formation is taken from the bivalve *Chlamys anderssoni* (Hennig, 1910) which occurs in abundance at the type locality. In the first publication on the foraminifera recovered from this unit, Holland (1910) described and illustrated a fauna of 8 genera and 11 species. Early investigators employed macropaleontological and paleoclimatic data in assigning either a Pliocene or Pleistocene age to the formation and paleontologists agreed that the *Pecten* Conglomerate represented an interglacial or pre-glacial environment. In the present investigation of the foraminifera, the diversity has been augmented to 19 genera and 24 species. The assemblage contains only calcareous benthic taxa. Agglutinated and planktic taxa are not present. Rich assemblages of macrofauna and microfauna/flora in the *Pecten* Conglomerate provide a biotope of more than 100 species. High energy, coastal marine environments with water depths not exceeding 50 meters are deduced from foraminiferal and other paleontological data. There is no evidence for the presence of thick grounded ice sheets or ice shelves over this area during deposition, although the occurrence of seasonal sea-ice cannot be discounted. The foraminiferal assemblage is correlated with almost identical Pliocene assemblages from the Wright and Taylor Valleys, and southern and western McMurdo Sound, and Larsemann Hills near Prydz Bay, East Antarctica. Diatoms which co-occur with the Cockburn Island foraminifera indicate an age of 2.8–2.0 Ma (late Pliocene) and K/Ar radiometric ages of 3.65 and 2.8 Ma (late Pliocene) were obtained from basalts which respectively underlie and possibly overlie the *Pecten* Conglomerate. Paleontological data indicate deglacial/interglacial conditions at latitude 64°S in the Antarctic Peninsula, and support arguments favoring relatively mild polar climate in many parts of Antarctica during the Pliocene.

Key words: Foraminifera, paleoecology, Pliocene, glacial-deglacial history, Antarctica.

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INTRODUCTION

The *Pecten* Conglomerate of Cockburn Island has been one of the more cited stratigraphic units in Antarctic literature over the past 90 years. This is a tribute to excellence of the original field work and paleontological collecting undertaken by Otto NORDENSKJÖLD's Swedish South Polar Expedition (1901–1903) to the Snow Hill Island–Seymour Island–James Ross Island–Cockburn Island region of the northern Antarctic Peninsula (NORDENSKJÖLD 1905, 1920; NORDENSKJÖLD *et al.* 1905). To many early geologists, and particularly to paleobiogeographers, the *Pecten* Conglomerate represented the repository of the last high latitude period of relative warmth (Pliocene) before the advent of the Ice Age (Pleistocene). While some elements of this traditional scenario are basically correct, we now understand that the *Pecten* Conglomerate and its diverse biota likely represent one deglacial (interglacial) interval in a long cryospheric record which extends back to at least the late Eocene and maybe earlier. The *Pecten* Conglomerate has been mentioned in many reviews of Antarctic geology (*e.g.* FAIRBRIDGE 1952; HARRINGTON 1965), but little new information has been added to the original research of the 1901–1903 Swedish South Polar Expedition.

The *Pecten* Conglomerate was first discovered by Dr. J. Gunnar ANDERSSON and Gösta BODMAN during their visit to Cockburn Island in October 1903. The first published description was by ANDERSSON (1906) in his paper *On the geology of Graham Land*. Samples taken during this visit were distributed to paleontologists in Europe for monographic treatment. A paper on the foraminifera extracted from a single sample (collector J. G. ANDERSSON, Swedish South Polar Expedition SPE-Locality No. 12) was published by HOLLAND (1910). ANDERSSON (1906) assigned a Pliocene age to the *Pecten* Conglomerate on the basis of its supposed non-glacial origin, and therefore its pre-Pleistocene age; and correlation with pectinid-bearing sediments in South America, regarded as Pliocene in age. The results of the present study confirm the Pliocene age of the formation, but not entirely for the reasons adopted by J. Gunnar ANDERSSON (1906).

More than three-quarters of a century have elapsed since HOLLAND's (1910) pioneering work on the foraminifera of the *Pecten* Conglomerate. A re-examination of the fauna and an updating of the original systematic descriptions and generic and species assignments seems overdue.

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during field collection activities in 1982; and S.A. MARENSSI, S.J. POREBSKI and S.N. SANTILLANA assisted Andrzej GAŹDZICKI on Cockburn Island during 1988. Professor Valdar JAANUSSON kindly made the collections of the 1901–1903 Swedish South Polar Expedition available for study and hosted Andrzej GAŹDZICKI's visit to the Naturhistoriska Riksmuseet, Stockholm in 1987. Dr. Christian HJORT, Department of Quaternary Geology, University of Lund provided valuable background information of the activities and scientific personnel associated with the 1901–1903 Expedition. We acknowledge the assistance of Ewa HARA, Institute of Paleobiology, Warszawa, in preparation of samples. Marianne HEYN, Ute BOCK and Gerhard SCHMIEDL of the Alfred Wegener Institute, Bremerhaven, assisted us in scanning electron microscope procedures. We would particularly like to acknowledge assistance, use of facilities and warm hospitality provided the authors by Professor Dr. Dieter FÜTTERER, Dr. Andreas MACKENSEN, and Dr. Werner EHRMANN, all of the Alfred Wegener Institute, Bremerhaven. The Alexander von Humboldt Foundation, Bonn (Bad Godesberg) awarded generous support to both authors during the completion of this investigation. Drafts of manuscript were reviewed by David M. HARWOOD, Gary S. WILSON and John H. WRENN. Peter-N. WEBB undertook this work with support from the National Science Foundation (Office of Polar Programs) grants DPP/NSF 79-07043 and 89-19910A.

GEOLOGY OF COCKBURN ISLAND

GEOGRAPHY

Cockburn Island lies 5 km north of Cape Bodman, Seymour Island, at latitude 64°13'S and longitude 56°50'E (Text-figs 1–2). The geographic position of the island is unlikely to have changed from these coordinates during and since the Pliocene. The island is elongate in map view and is about 2.5 km across at its widest point (Text-fig. 2). The lower part of the island rises from sea level as steep slopes, whereas the upper part assumes the form of a level meseta-like surface located approximately 250 meters above sea level (Text-fig. 3; ANDERSSON 1906, p. 41, fig. 3; see also ZINSMEISTER and WEBB 1982, fig. 1; DOKTOR *et al.* 1988, pl. 11: 1; GAŹDZICKI 1993, figs 1–2). A cone-shaped promontory rising approximately 450 meters above sea level dominates the northwestern edge of the meseta. The island's distinctive physiography results from a protective cap of basalt overlying loosely consolidated Upper Cretaceous and Eocene sediments. Elevations cited here are the same as first estimated by ANDERSSON and BODMAN in 1903. These have been widely accepted by subsequent workers, but may require adjustment.

STRATIGRAPHY

The stratigraphy of Cockburn Island consists of four major rock subdivisions and four hiatus intervals, recognized here as unconformities (or erosion surfaces) and given the notation U₁ to U₄ (Text-fig. 4).

MARAMBIO GROUP (LÓPEZ DE BERTODANO FORMATION) AND THE LA MESETA FORMATION: UPPER CRETACEOUS AND EOCENE

Fossil-bearing sediments of the Cretaceous Marambio (López de Bertodano Formation) Group and the Eocene La Meseta Formation are exposed in the lower slopes of the island. Early discussions of these rocks and their fossils on Cockburn Island and adjacent islands were provided by ANDERSSON (1906), ANDERSSON in BUCKMAN (1910), HENNIG (1910) and WILCKENS (1924); and more recently by FELDMANN and WOODBURNE (1988), ASKIN *et al.* (1991), CRAME *et al.* (1991), PIRRIE *et al.* (1992), and BARNES and RIDING (1994).

COCKBURN UNCONFORMITY U₄: FAULTING OR UNCONFORMITY BETWEEN CRETACEOUS AND TERTIARY SEDIMENTS

The relationship between the Cretaceous and Tertiary sediments on Cockburn Island is important in considering late Pliocene-Pleistocene uplift history of the *Pecten* Conglomerate. Both fault and unconformable relationships have been proposed. CROFT (1947) proposed that Cretaceous and Tertiary sediments on Cockburn Island are separated by faulting. BIBBY (1966, fig. 1) portrays this fault as cutting both the sedimentary and volcanic rocks, although he also comments (p. 34), "No faulting of post-James Ross Island

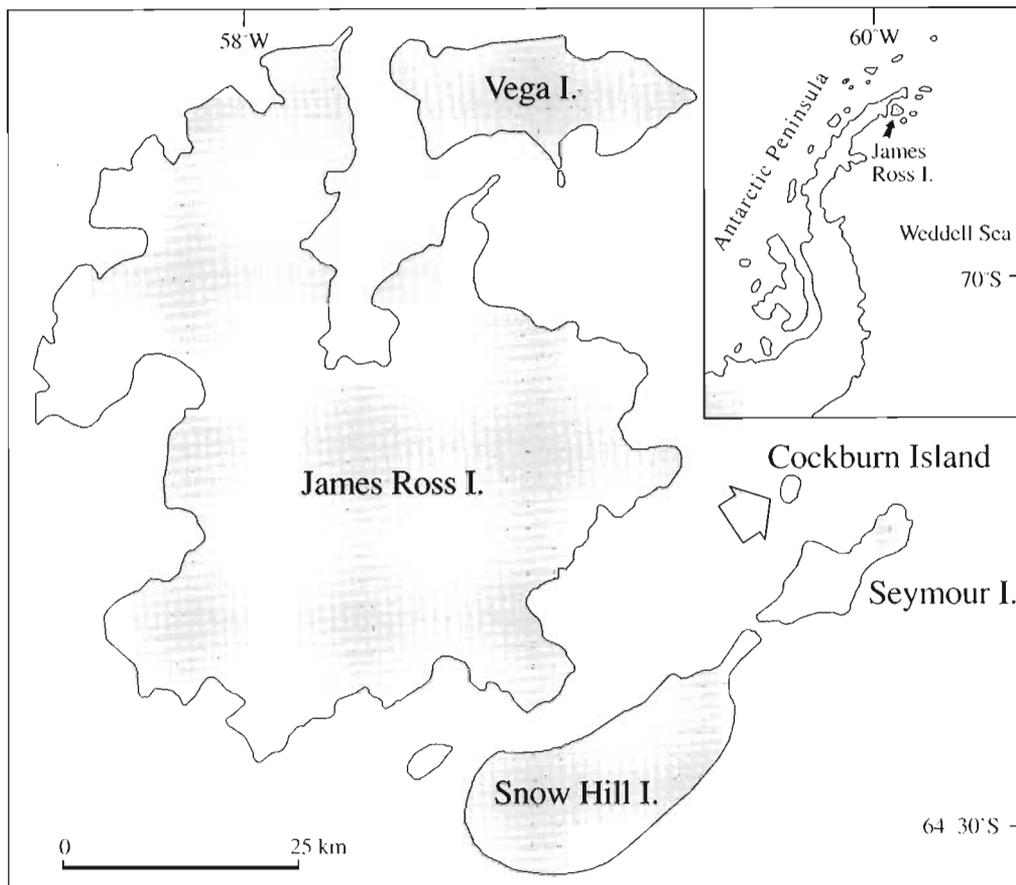


Fig. 1

Map of the Antarctic Peninsula, and the Cockburn–Seymour–James Ross Islands region.

Volcanic age, except that observed in relation to Prince Gustav Channel, was observed by the writer". NELSON (1975, map 1) confines a major fault on Cockburn Island to the Cretaceous and Tertiary sedimentary succession and does not involve the Pliocene James Ross Island Volcanic Group. ANDERSSON (1906) and ANDERSSON in BUCKMAN (1910) may also have recognized this feature (fault or unconformity) on the eastern face of Cockburn Island. ANDERSSON in BUCKMAN (1910, p. 42; see also HENNIG 1910, p. 3), illustrated Cretaceous and Tertiary sediments separated by a basalt dyke in his now well-known cross section of Cockburn Island. ANDERSSON'S (1910) re-interpretation of structural relationships at this site followed BUCKMAN'S recognition of Tertiary brachiopods in what ANDERSSON considered were Cretaceous sediments. ANDERSSON writes in BUCKMAN (1910, p. 42), "This remarkable discovery proves that the beds of Cockburn Island must have undergone dislocations, which brought Tertiary strata to the same level as those of Cretaceous age. In fact Mr NORDENSKJÖLD on our joint visit to Cockburn Island, some days after my discovery of the different fossiliferous beds in this island, pointed out that the sandy beds in the slope above the glauconite bank were disturbed and contorted". ELLIOT and RIESKE (1987) followed earlier workers in accepting fault separation of contiguous Cretaceous and Tertiary strata on Cockburn Island. ASKIN *et al.* (1991, p. 101) note, however, "The steep contact between the Cretaceous and Tertiary strata on the east side of Cockburn Island is not exposed, although in a gully just above the shore to the north of the basalt spine, the Tertiary beds lie unconformably on the older beds.", and (p. 102), "The anomalously high dips of the Tertiary beds on Cockburn Island are here regarded as largely primary and the unexposed steep contact on the east side of the island as a possible unconformity, probably a buttress unconformity against a paleocanyon wall". BARNES and RIDING (1994, figs 2 and 5) provide the most detailed description and mapping of the unconformable and fault relationships between Cretaceous and Cenozoic successions on Cockburn Island. We accept the unconformity argument and show it as U_1 in Text-fig. 4. Rejection of the argument for high angle faulting of Cretaceous, Eocene, and Pliocene rocks removes the requirement to explain the latest Pliocene–Pleistocene uplift of the *Pecten* Conglomerate by local fault displacement.

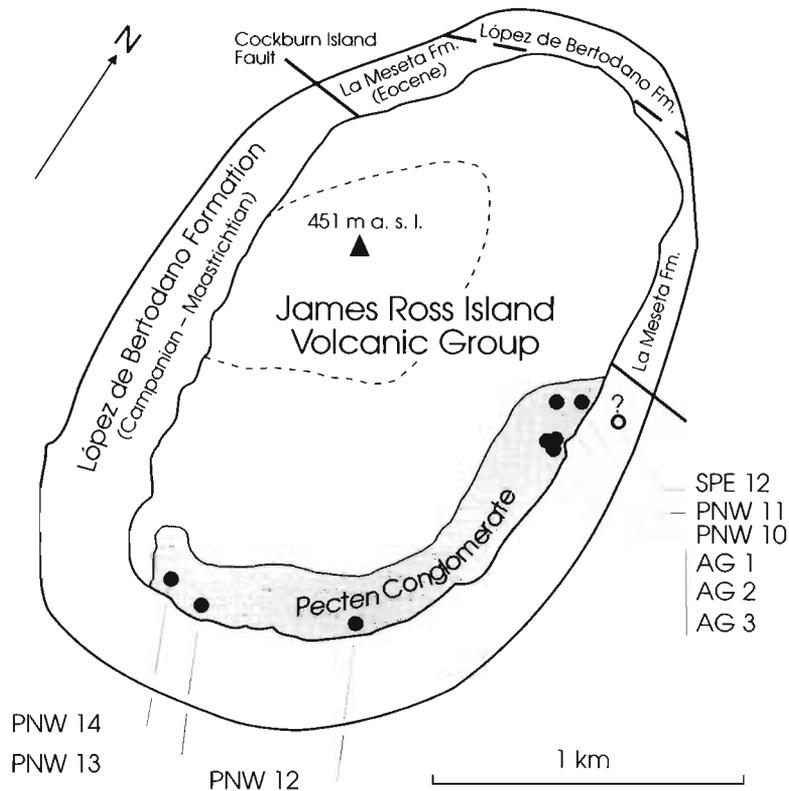


Fig. 2

Geologic map of Cockburn Island, showing collection sites of *Pecten* Conglomerate samples used in this investigation. The original 1901–1903 Swedish South Polar Expedition sample SPE 12 (ANDERSSON 1906) was collected as float blocks on the lower slopes of the island. The K/Ar date of 3.65 Ma was obtained from a sample of James Ross Island Volcanic Group basalt collected stratigraphically below samples PNW10 and 11. Pre-*Pecten* Conglomerate geology is taken from aerial photographs, ASKIN *et al.* (1991), and BARNES and RIDING (1994).

COCKBURN UNCONFORMITY U_3 : OLIGOCENE–MIOCENE OR LOWER PLIOCENE EROSION SURFACE

A high-relief erosion surface (Unconformity U_3) (Text-fig. 4) cuts across the Upper Cretaceous and Eocene sediments (ZINSMEISTER and WEBB 1982, figs 1–3). The origin of this surface is unexplained. It may have resulted from glacial erosion and may have developed below sea level. Its precise age is poorly established, but must be somewhere between the age of the youngest La Meseta Formation sediments (Eocene) and the oldest age for the James Ross Island Volcanic Group on Cockburn Island (currently 3.65 Ma or mid Pliocene, see below). BIBBY (1966, fig. 26) discussed an unconformity at a similar stratigraphic position in the successions of western James Ross Island and alluded to its formation below sea level.

JAMES ROSS ISLAND VOLCANIC GROUP: PLIOCENE

Basalt flows of the James Ross Island Volcanic Group cap the upper part of the island and display an irregular lower profile where they fill depressions above Cockburn Unconformity U_3 (Text-fig. 4). Marine sedimentary facies (which contain ophiuroids and an echinoid) of the James Ross Island Volcanic Group (PIRRIE and SYKES 1987), and an undated marine tillite with *Chlamys anderssoni* between the James Ross Island Volcanic Group and the underlying Cretaceous sediments (SMELLIE *et al.* 1988), occur on James Ross Island, but as yet have no equivalent in Cockburn Island stratigraphy (Text-fig. 4).

The oldest age reported for the basalt from James Ross Island is 6.5 Ma (latest Miocene) see SMELLIE *et al.* (1988). The lowermost basalt flows on Cockburn Island have not been dated radiometrically. A date at this stratigraphic level would allow the determination of the youngest age of Cockburn Unconformity U_3 (Text-fig. 4). The age of the basalt dyke which cuts close to the Cretaceous–Tertiary contact (Cockburn Unconformity U_4) on the eastern side of Cockburn Island, mentioned above and discussed by ANDERSSON

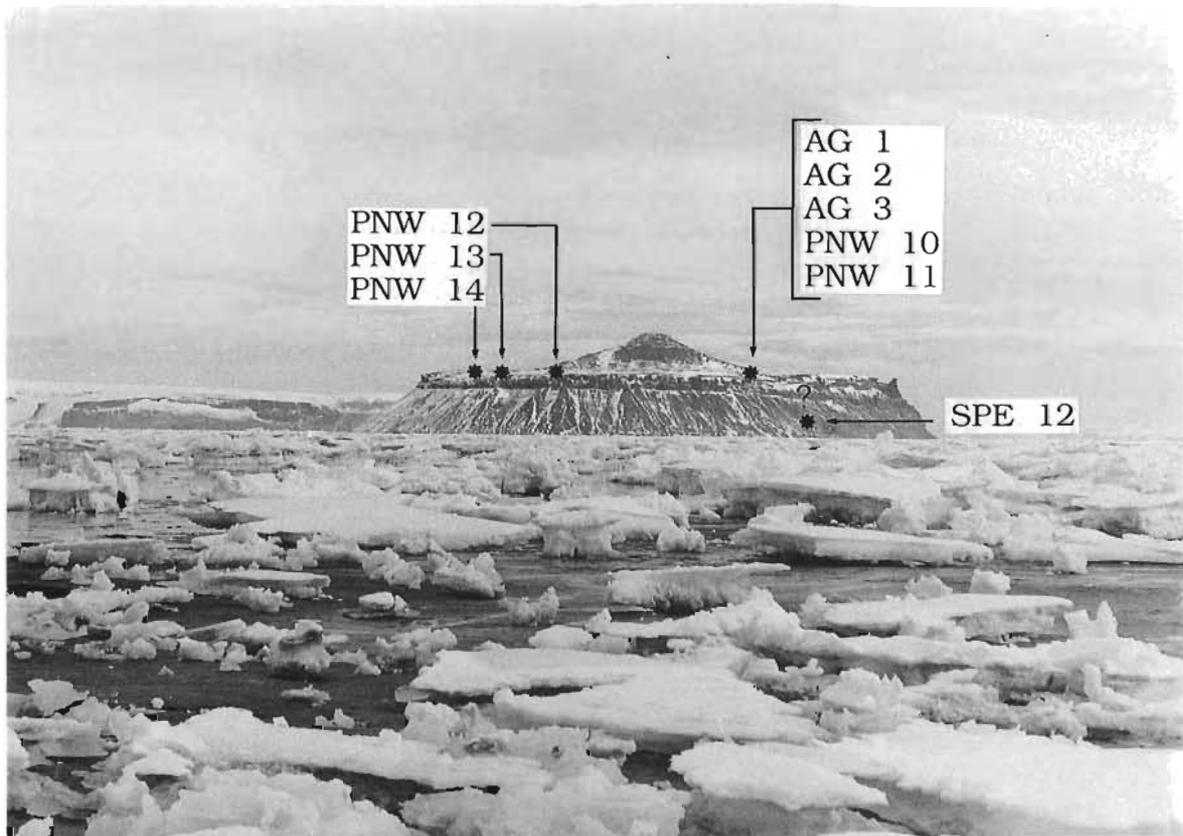


Fig. 3

Photograph of the southern and eastern sides of Cockburn Island, showing Upper Cretaceous and Tertiary sediments on the lower slopes, and near-horizontal James Ross Island Volcanic Group rocks. Arrowed are collection sites of the *Pecten* Conglomerate. Samples prefixed by PNW collected by P.-N. WEBB (in 1982), AG by A. GAZDZICKI (in 1988), SPE by Swedish South Polar Expedition (in 1903), see also Text-fig. 2. Photograph taken from Cross Valley, Seymour Island (February 1994).

(1910), ASKIN *et al.* (1991), BARNES and RIDING (1994) and others as part of the fault and unconformity discussions is not yet determined. Is this dyke Pliocene in age and does it follow an old fault plane that was reactivated during the Pliocene; or does it follow a zone of weakness associated with the unconformity discussed by ASKIN *et al.* (1991) and others?

A sample of the uppermost basalt exposed immediately below the *Pecten* Conglomerate yielded a K/Ar radiometric age of 3.65 Ma (WEBB and ANDREASEN 1986). A sample collected topographically higher than the sedimentary outcrops, and possibly stratigraphically younger, yielded a date of 2.8 Ma (Randall A. KELLER, Oregon State University, personal communication). The multiple event volcanism implied by these two dates is possible in terms of what we know of the James Ross Island Volcanic Group (SMELLIE *et al.* 1988).

COCKBURN UNCONFORMITY U_2 : UPPER PLIOCENE

A prominent near-horizontal bench (Cockburn Unconformity U_2) is cut into the basalt, approximately 250 meters above sea level on the southern and eastern sides of the mesa top (ZINSMEISTER and WEBB 1982, fig. 3) see Text-fig. 2. It is on this bench that remnants of the *Pecten* Conglomerate crop out (Text-fig. 3). We deduce from the radiometric dates cited above, that Cockburn Unconformity U_2 (or erosion surface) and the *Pecten* Conglomerate are younger than 3.65 Ma and possibly older than 2.8 Ma (*i.e.* upper Pliocene). It is unclear whether the development of this erosion surface is contemporaneous with the deposition of the *Pecten* Conglomerate or whether the two events are separated by a short span of late Pliocene time, *i.e.* tens of thousands to several hundred thousand years (see ZINSMEISTER and WEBB 1982, fig. 1; DOKTOR *et al.* 1988, pl. 11: 1).

PECTEN CONGLOMERATE: UPPER PLIOCENE

See below, and Text-figs 2–4.

COCKBURN UNCONFORMITY U₁: UPPERMOST PLIOCENE–PLEISTOCENE

This surface probably resulted from multiple glacial erosional events. The erosion of the *Pecten* Conglomerate and the upper surface of the James Ross Island Volcanic Group are among the features produced by late glacial dissection.

***PECTEN* CONGLOMERATE (ANDERSSON, 1906)**

ORIGINAL DESCRIPTION

At the time of his visit to Cockburn Island, ANDERSSON noted blocks of fossiliferous conglomerate scattered on the talus slopes up to 160 meters above sea level on the eastern side of the island (Text-fig. 2). Gösta BODMAN, his companion during the visit, climbed to the top of the meseta from the western side of the island and found fragments of pectinid on the meseta, but none of the host sediment *in situ*. ANDERSSON commented (1906, p. 51), "Evidently it covers only a small part of the plateau, as the blocks of the conglomerate are met with nowhere in the slopes of the island, except at Locality 12" (*i.e.*, SPE 12 herein). ANDERSSON (1906) derived the name of the formation from the well preserved and abundant pectinid *Myochlamys anderssoni* HENNIG, 1910 which occurred in the float blocks recovered from the talus slopes (Text-figs 2–3). HENNIG (1910) also provided information on local geology and petrography, some of it original, some apparently gleaned from conversations with J. Gunnar ANDERSSON, and information taken directly from ANDERSSON (1906).

TYPE AREA AND STRATOTYPE SECTION

The type area is well-constrained, but a formal type section for the formation has yet to be measured. The best exposures occur near the extreme southern and eastern limits of the bench. We believe the formation covers the entire length of the bench and is obscured by basaltic debris. The exposure at the northeast corner of the bench provides a partial section through the sedimentary succession and the contact with the underlying basalt (ZINSMEISTER and WEBB 1982, fig. 3) (Cockburn Unconformity U₂, Text-fig. 4). We estimate the remnant succession of *Pecten* Conglomerate to be somewhere between 5 and 10 meters in thickness, but suggest, that because surviving outcrops may have been protected from glacial erosion within the bench depression and much of the exposed succession later eroded, the original total thickness may have been greater.

Other than a possible occurrence at Fiordo Belén (DEL VALLE *et al.* 1987), no other outcrops of the *Pecten* Conglomerate are known in the James Ross and Seymour Islands region. ANDERSSON (1906, p. 63) and also ANDERSSON in BUCKMAN (1910, p. 43) was probably correct in considering the formation to have had a wider distribution before destruction by subsequent glacial dissection. BARTON (1965) applied the formation name to pectinid-bearing sediments in the Lions Rump Group of King George Island (South Shetland Islands). GAŹDZICKA and GAŹDZICKI (1985), BIRKENMAJER and GAŹDZICKI (1986) showed these sediments to be Oligocene and not Pliocene in age. The Cockburn Island and King George Island pectinid-bearing successions appear to be unrelated (BIRKENMAJER *et al.* 1991).

LITHOLOGY

At the northeast corner of the bench on Cockburn Island, the basal sediments consist of coarse-grained, poorly sorted, and finely-bedded conglomeratic sandstone (Text-figs 5–6). The clasts in the conglomerate are poorly rounded pebbles and boulders of basaltic composition. Nearby, the coarser conglomeratic facies is replaced by finer-grained, orange-brown gravelly sandstone in which well-preserved *Chlamys anderssoni* (HENNIG) shells are present (Text-fig. 5). Scallop shells occur only rarely in the conglomeratic facies. We did not observe exotic crystalline clasts in outcrops, or other evidence for ice rafting. STEWART (1937) examined a sample of the *Pecten* Conglomerate and noted the presence of common basaltic material and

Age	Paleontological and radiometric data	Lithostratigraphy	Remarks
Pleistocene		Scattered igneous and metamorphic erratics	Glacial dissection Uplift of <i>Pecten</i> Conglomerate to 220-250 meters above sea level from a paleodepth of < 50 meters
Pliocene	2.8 to 2.0 Ma (Diatoms)	U ₁ <i>Pecten</i> Conglomerate	Glacially dissected erosion surface Shallow marine (?littoral), conglomerate, sandstone and siltstone; richly fossiliferous, including, <i>Chlamys anderssoni</i> (HENNIG), diatoms, foraminifera, radiolarians, silicoflagellates, sponges, echinoids, bryozoans, ostracods, barnacles, molluscs, and brachiopods.
Pliocene	3.65 and 2.8 Ma (K/Ar dates on basalts)	U ₂ James Ross Island Volcanic Group	Ice and/or water dissected erosion surface ?Submarine basalt flow and intercalated tuffaceous sediments. Pyroclastic tuffs and marine tillite with <i>Chlamys anderssoni</i> (HENNIG), in basal James Ross Island Volcanic Group at James Ross Island not yet recognized at Cockburn Island
Eocene	Paleontology	U ₃ La Meseta Formation	Ice and/or water dissected erosion surface No evidence for Eocene fossils reworked into <i>Pecten</i> Conglomerate
Cretaceous	Paleontology	U ₄ López de Bertodano Formation	Cretaceous foraminifera and calcareous nannoplankton reworked into suprajacent <i>Pecten</i> Conglomerate

Fig. 4

Mesozoic (Cretaceous)–Cenozoic stratigraphic nomenclature for Cockburn Island.

a few crystalline fragments. Microfossil preparations contain recycled Upper Cretaceous agglutinated and planktic foraminifera, and calcareous nannoplankton (GAŹDZICKA and GAŹDZICKI 1994). It is apparent then, that the provenance for the formation includes the rocks of the Upper Cretaceous Marambio Group and the upper Miocene–lower Pliocene James Ross Island Volcanic Group. No sediments and microfossils appear to have been recycled into the *Pecten* Conglomerate from Paleogene sediments such as the Eocene La Meseta Formation. The presence of James Ross Island Volcanic Group rocks and Marambio Group microfossils implies that these rocks were above sea level, eroded, and transported to the coastline at which the *Pecten* Conglomerate was being deposited.

AGE ASSIGNMENTS IN EARLY LITERATURE

Definitions of the Miocene, Pliocene and Pleistocene epochs and their temporal values have evolved over the past ninety years. The ages assigned by the pioneer geologists in the area must be interpreted with early 20th century stratigraphic nomenclature in mind. In the first decade of the century the Pleistocene and Pliocene were thought to have represented glacial and pre-glacial climatic conditions respectively. ANDERSSON (1906) interpreted the *Pecten* Conglomerate macrofauna as indicative of non-glacial conditions and, must, therefore, have been Pliocene in age. His age determination was also based on correlation of the macrofossil fauna with the Paraná–Cape Fairweather Beds in Patagonia (South America). Slightly later, BUCKMAN (1910) proposed a Pleistocene age for the *Pecten* Conglomerate based on his interpretation of three species of brachiopods. So firm was ANDERSSON's belief that the *Pecten* Conglomerate was a non-glacial deposit that he wrote in BUCKMAN (1910, p. 43), "that even the beginning of the glaciation of these tracts falls into (*i.e.* within) the Quaternary period." Despite BUCKMAN's suggested age revision and ANDERSSON's apparent acceptance, WILCKENS (1924), SOOT-RYEN (1952), and more recent authors continued to adopt a Pliocene age for the deposit. In contrast, HENNIG (1910) and FAIRBRIDGE (1952) opted for a Pleistocene age, and HARRINGTON (1965) diplomatically referred to the age as early Pleistocene or late Pliocene. The non-glacial/pre-glacial argument no longer applies as it is now realized that the cryospheric history of West and East Antarctica extends to at least the late Eocene and the *Pecten*

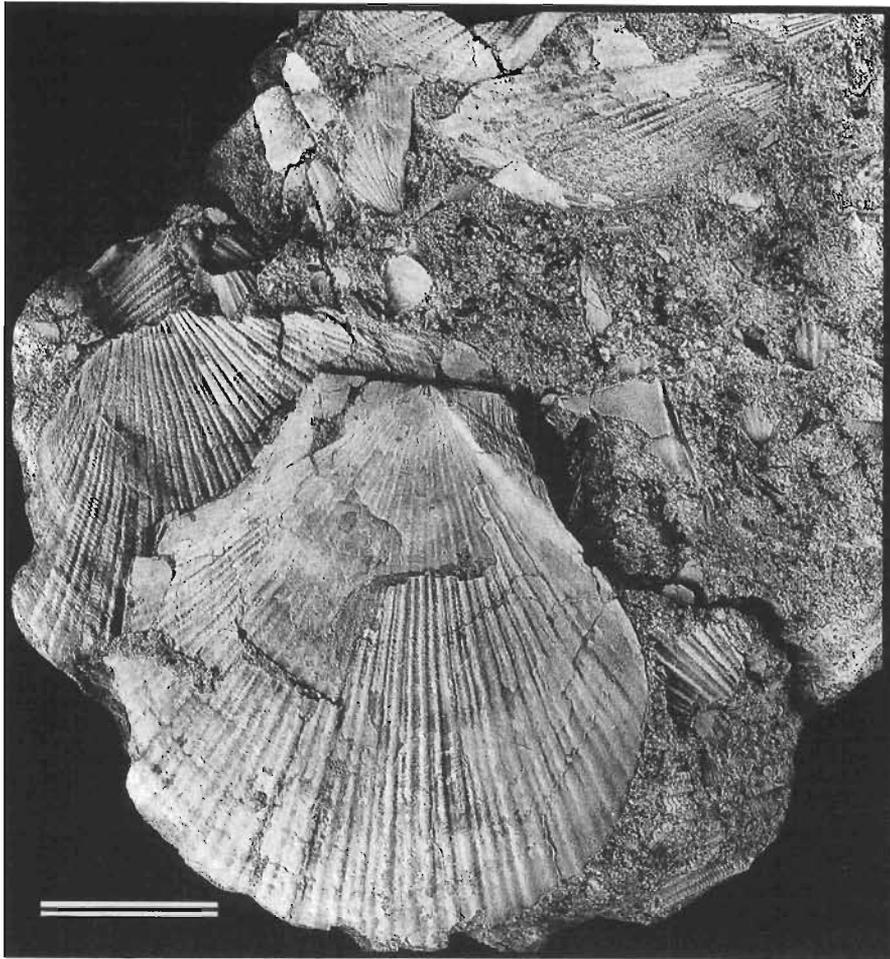


Fig. 5

A sample from the *Pecten* Conglomerate (AG 1 site) with well preserved specimens of *Chlamys anderssoni* (HENNIG, 1910). Scale bar is 3 cm long.

Conglomerate represents but one of a number of deglacial or interglacial events. Thus, the Pliocene age assumed by many for almost a century was, to a degree, a fortuitous choice, particularly as the lower and upper limits of the Pliocene Epoch have changed markedly in the course of this century. In similar vein, the middle-upper Miocene age given by ANDERSSON (1906) to the Ross Island Formation (James Ross Island Volcanic Group of ADIE 1953) because they were interposed between Lower Miocene (now regarded as Eocene) sediments and the Pliocene *Pecten* Conglomerate was also in part correct.

AGE ADOPTED HERE

Radiometric dates documented above allow the assignment of an oldest age for the *Pecten* Conglomerate of 3.65 Ma. HARWOOD (1986) assigned the marine diatom flora to 2.8–2.0 Ma. The foraminiferid *Ammoelphidiella antarctica* CONATO *et* SEGRE (= *Trochoelphidiella onyx* WEBB) occurs in both the *Pecten* Conglomerate and at a number of other sites in the McMurdo Sound area (ISHMAN and WEBB 1988). In DVDP drillhole 10, Taylor Valley, ISHMAN and RIECK (1992) employed magnetostratigraphic and biostratigraphic data to constrain the age of the *Ammoelphidiella antarctica* Zone to between 3.4 and 3.7 Ma. *Ammoelphidiella antarctica* and *Chlamys anderssoni* also occur in the Scallop Hill Formation of northern Brown Peninsula, southern McMurdo Sound, between volcanic rocks dated at other localities on Brown Peninsula as 2.25 and 2.2 Ma (SPEDEN 1962; EGGERS 1979; LECKIE and WEBB 1979). Volcanic boulders collected within the formation provided dates of 2.58 and 2.62 Ma (WEBB and ANDREASEN 1986). The latter authors interpreted the Scallop Hill Formation as being younger than the age of the youngest dated basalt boulder, *i.e.* 2.58 Ma or late Pliocene. Earlier, WEBB (1972, 1974) suggested an age between 2.5

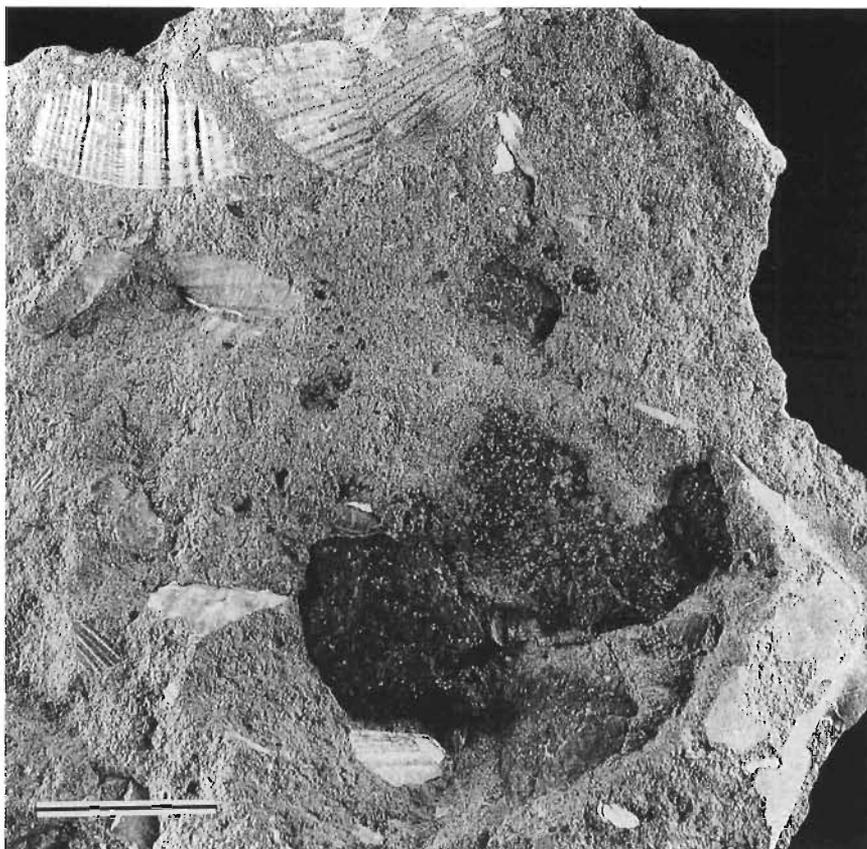


Fig. 6

A sample from the *Pecten* Conglomerate (AG 1 site) with fragments of *Chlamys anderssoni* (HENNIG) and basaltic clasts from the James Ross Island Volcanic Group. Scale bar is 3 cm long.

and 3.7 Ma, for the *Pecten* Gravels of Wright Valley based on a surmised relationship to dated volcanics in Wright Valley. In a more recent estimation for the age of the *Pecten* Gravels, PRENTICE *et al.* (1993) calculated a $^{87}\text{Sr}/^{86}\text{Sr}$ ratio-based age of 5 ± 1 Ma from *Chlamys tuftsensis*, a species which co-occurs with *Ammoelphidiella antarctica* CONATO *et* SEGRE, 1974 (= *Trochoelphidiella onyx* WEBB, 1974) in the Prospect Mesa Gravels (= *Pecten* Gravels) of central Wright Valley.

In summary, radiometric and paleontologic evidence from Cockburn Island indicates that the *Pecten* Conglomerate was deposited during the late Pliocene and possibly during a late Pliocene high stand of sea level. The formation may be associated with one of two sea level highstand cycles between 2.4 and 3.6 Ma (HAQ *et al.* 1987). It may be coeval with either the Scallop Hill Formation (< 2.58 Ma) of Brown Peninsula or the *Ammoelphidiella antarctica* Zone of DVDP 10 in Taylor Valley (3.4 to 3.7 Ma). *Ammoelphidiella antarctica* appears to be confined to the Pliocene (WEBB 1988), but, as a shallow water benthic organism it may have made up to three or four appearances during Pliocene transgressions in Antarctica, thereby providing an intermittent biostratigraphic record.

FORAMINIFERA

INTRODUCTORY REMARKS

We would like to have incorporated Richard HOLLAND's primary collection in the present study, but were unsuccessful in attempts to locate it. Professor Valdar JAANUSSON reported that it does not appear to be in the collections of the Naturhistoriska Riksmuseet, Stockholm. Dr. J.E. WHITTAKER, Head of Micropaleontology, British Museum of Natural History, London, was unable to locate the collection in either the BMNH

or British Geological Survey, Nottingham. Dr. Whittaker noted that Richard HOLLAND lived for a time in London and that some of his micropaleontological library was donated to the BMNH in 1946. HOLLAND worked extensively with H.W. BURROWS, an architect, who devoted his leisure time to studying fossils, including foraminifera. We have been unable to establish how and why the collection of Cockburn Island foraminifera made its way from Stockholm to Richard HOLLAND. It is possible that H.W. BURROWS was somehow involved in arranging for HOLLAND to carry out this study. Frederick CHAPMAN investigated the Quaternary foraminifera from Cape Barne–Cape Royds, Ross Island, Antarctica about this time and it is also possible that he was in some way involved (CHAPMAN 1916a; WARD and WEBB 1986).

HOLLAND (1910) based his study of *Pecten* Conglomerate foraminifera on a single sample (Swedish South Polar Expedition Locality No. 12). HOLLAND received a collection of foraminifers and apparently did not work with the original sediment. He records that the number of tests submitted to him totaled 304. We do not know who prepared the collection, but given the state of microscopy at the time and the results we have obtained, the unknown curator provided a reasonably representative collection to HOLLAND. HOLLAND (1910) identified, described and illustrated 8 genera and 11 species. He noted that preservation varied from excellent to very poor and observed (p. 4), "the specimens are rather poorly grown and seem to indicate starved or brackish water conditions". Only calcareous benthic taxa were recognized. HOLLAND (1910) observed that five-sixths (or 83 percent) of the fauna was made up of *Cassidulina crassa* D'ORBIGNY. As his standard references, he used the then fashionable papers by BRADY, D'ORBIGNY, JONES, PARKER and BRADY, LAMARCK, LINNÉ, DE MONTAGU, PARKER and JONES, TERQUEM, WALKER, and WALKER and BOYS. This literature emphasized Recent deep and shallow water faunas, as well as faunas from the younger sediments of the Paris Basin. Much of the information provided in HOLLAND (1910) is repeated by HENNIG (1910) who added additional information on ecological distribution for some species. Most of HENNIG's comments emphasized brackish and estuarine environments as the likely environment under which the *Pecten* Conglomerate was deposited.

SAMPLE MATERIAL USED IN THE PRESENT STUDY

Our review of the foraminifera is based on collections made at the type locality on Cockburn Island in March 1982 (Peter-N. WEBB) and January 1988 (Andrzej GAŹDZICKI). A piece of J. Gunnar ANDERSSON's original sample from Locality No. 12 was obtained from the Naturhistoriska Riksmuseet, Stockholm in 1987 and the fauna extracted from this sample is incorporated in the results presented here. We refer to this sample and its assemblage as SPE 12. Six of the samples collected by the authors at Cockburn Island are also used here and are referred to as AG 1–AG 3, and PNW 12–PNW 14 (Text-figs 2–3). Our samples were collected at available outcrops (see Text-figs 2–3) and no stratigraphic order is implied. Original sample size of AG and PNW samples is approximately two kilograms. More than 1600 tests extracted from these seven samples were used in the present study.

SYSTEMATIC NOTES

The classification of Order Foraminiferida used here is that of LOEBLICH and TAPPAN (1988). Family, subfamily and generic nomenclature and authors and dates of publication are provided below, but not cited in the references. This information is readily available in LOEBLICH and TAPPAN (1988). Systematic notes provided below are accompanied by a listing of our revisions to HOLLAND's generic and species determinations (Table 1). In Table 2, we show taxa recorded in the seven samples examined. Information includes the numbers of tests recovered, a total count of all tests in each sample, and for the more common taxa, the percentage contribution to the assemblage. Representative collections are lodged in the Institute of Paleobiology, Polish Academy of Sciences, Warszawa under the catalogue number ZPAL F.XXXVIII; and the U.S. National Museum (Smithsonian), Washington, D.C.

Family *Spirillinidae* REUSS *et* FRITSCH, 1861
 Genus *Patellina* WILLIAMSON, 1858
Patellina corrugata WILLIAMSON, 1858

1858. *Patellina corrugata* WILLIAMSON, p. 46, pl. 3: 86–89.

1986. *Patellina corrugata* WILLIAMSON; WARD and WEBB, p. 194, pl. 5: 13–14.

Remarks. — A single robust specimen in PNW 13.

Table 1
Systematic revision of foraminiferal taxa from the 1901–1903 Swedish South Polar Expedition sample SPE 12 described and illustrated by HOLLAND (1910).

This Investigation	HOLLAND (1910)
<i>Patellina corrugata</i> WILLIAMSON	—
<i>Pyrgo fornasinii</i> CHAPMAN <i>et</i> PARR	<i>Biloculina ringens</i> (LAMARCK)
<i>Pyrgo elongata</i> (D'ORBIGNY)	<i>Biloculina elongata</i> D'ORBIGNY
<i>Triloculina</i> sp.	<i>Miliolina grata</i> (TERQUEM)
<i>Lenticulina gibba</i> (D'ORBIGNY)	<i>Cristellaria gibba</i> D'ORBIGNY
<i>Pseudonodosaria</i> sp.	<i>Polymorphina gutta</i> (D'ORBIGNY)
<i>Fissurina</i> cf. <i>semimarginata</i> (REUSS)	—
<i>Fissurina</i> cf. <i>laevigata</i> REUSS	—
<i>Fissurina</i> cf. <i>quadrata</i> (WILLIAMSON)	—
<i>Oolina globosa</i> (MONTAGU)	<i>Lagena globosa</i> (MONTAGU)
<i>Cassidulina crassa</i> D'ORBIGNY	<i>Cassidulina crassa</i> D'ORBIGNY
<i>Cassidulinoides parkerianus</i> (BRADY)	—
<i>Globocassidulina subglobosa</i> (BRADY)	—
<i>Angulogerina angulosa</i> (WILLIAMSON)	—
<i>Fursenkoina</i> cf. <i>earlandi</i> (PARR)	—
<i>Epistominella vitrea</i> PARKER	—
<i>Discorbinella</i> sp.	—
<i>Cibicides refulgens</i> DE MONTFORT	<i>Truncatulina refulgens</i> (DE MONTFORT)
<i>Cibicides lobatulus</i> (WALKER <i>et</i> JACOB)	<i>Truncatulina lobatula</i> (WALKER)
(not recognised)	<i>Truncatulina ungariana</i> (D'ORBIGNY)
<i>Nonionella bradii</i> (CHAPMAN)	—
<i>Nonionella</i> cf. <i>turgida</i> (WILLIAMSON)	—
<i>Melonis</i> sp.	—
<i>Cribrononion</i> sp.	—
<i>Ammoelphidiella antarctica</i> CONATO <i>et</i> SEGRE	<i>Rotalia beccarii</i> (LINNÉ)

Family **Hauerinidae** SCHWAGER, 1876

Subfamily **Miliolinellinae** VELLA, 1957

Genus *Pyrgo* DEFRANCE, 1824

Pyrgo fornasinii CHAPMAN *et* PARR, 1935

(Pl. 34: 1–3)

1884. *Biloculina ringens* (LAMARCK); BRADY, pl. 2: 7.

1910. *Biloculina ringens* (LAMARCK); HOLLAND, p. 5, pl. 1: 5–8.

1935. *Pyrgo fornasinii* CHAPMAN *et* PARR, p. 5.

1960. *Pyrgo fornasinii* CHAPMAN *et* PARR; BARKER, p. 4, pl. 2: 7.

Remarks. — Large circular shaped tests. HOLLAND (1910) gives a test diameter range of 0.75 to 2.9 mm. He also indicates that this species is common in SPE 12 although we did not record it in the re-processed split of the same sample. Six tests in AG 3, where it makes up 3 percent of the assemblage. HOLLAND comments on the test shape variability in his material. Some forms assume an oval shape with a well-rounded periphery, while others exhibit a more circular form and sharp edge around the final chamber, as in *P. depressa* (D'ORBIGNY).

Pyrgo elongata (D'ORBIGNY, 1826)

1826. *Biloculina elongata* D'ORBIGNY, p. 298, no. 4.

1884. *Biloculina elongata* D'ORBIGNY; BRADY, p. 144, pl. 2: 9.

1910. *Biloculina elongata* D'ORBIGNY; HOLLAND, p. 6, pl. 1: 9–10.

1960. *Pyrgo elongata* (D'ORBIGNY); BARKER, p. 4, pl. 2: 9.

Remarks. — No specimens were recovered from our samples. HOLLAND (1910) noted that in his material the variability of shape included a trend towards the more circular *Pyrgo fornasinii* CHAPMAN *et* PARR [= *Biloculina ringens* (LAMARCK)].

Genus *Triloculina* D'ORBIGNY, 1826

Triloculina sp.

1910. *Miliolina grata* (TERQUEM); HOLLAND, p. 6, pl. 1: 3–4.

Remarks. — HOLLAND (1910) described and illustrated a single un-ornamented sub-triangular miliolinellid with a diameter of 1.75 mm. The aperture is shown as a short crescentic slit, without a bifid tooth, but perhaps with a small apertural flap. We did not encounter this form during our study. From HOLLAND's description and illustrations the specimen is probably best placed in the genus *Triloculina* until comparable material is recovered.

Family **Nodosariidae** EHRENBERG, 1838

Genus *Lenticulina* LAMARCK, 1804

Lenticulina gibba (D'ORBIGNY, 1839)

(Pl. 34: 6)

1839. *Cristellaria gibba* D'ORBIGNY, p. 63, pl. 7: 20–21.

1884. *Cristellaria gibba* D'ORBIGNY; BRADY, pl. 69: 8–9.

1910. *Cristellaria gibba* D'ORBIGNY; HOLLAND, p. 8, pl. 2: 3.

1960. *Lenticulina gibba* (D'ORBIGNY); BARKER, p. 144, pl. 69: 8–9.

Remarks. — Specimens show a tendency to uncoil and resemble *Astacolus*. Rare. In addition to the specimen illustrated by HOLLAND (1910) from SPE 12 we recovered one specimen in AG 2 and one in PNW 13.

Genus *Pseudonodosaria* BOOMGART, 1949

Pseudonodosaria sp.

(Pl. 34: 4–5)

1910. *Polymorphina gutta* (D'ORBIGNY); HOLLAND, p. 9, pl. 1: 11–12.

Remarks. — HOLLAND (1910) illustrated the single specimen he had available. This was globular, with a slight spine-like protuberance at the initial end, and a distinctly radiate aperture. He placed this with the polymorphines but admitted being unable to discern internal chambering. We have similar single large specimens in AG 1 and PNW 13, with distinctive overlapping nodosarid chambers and radiate apertures. We suggest this form be placed with *Pseudonodosaria* sp.

Family **Ellipsolageninidae** A. SILVESTRI, 1923

Genus *Fissurina* REUSS, 1850

Fissurina cf. *semimarginata* (REUSS, 1871)

(Pl. 34: 7)

1871. *Lagena marginata* MONTAGU var. *semimarginata* REUSS, p. 468, pl. 4: 4–6.

1953. *Fissurina semimarginata* (REUSS); LOEBLICH and TAPPAN, p. 78, pl. 14: 3.

1960. *Fissurina semimarginata* (REUSS); BARKER, p. 122, pl. 59: 19.

Remarks. — Very small, slightly compressed, characterized by a single un-ornamented keel on the lower half of the test. A single test in PNW 13.

Fissurina cf. *laevigata* REUSS, 1850

1884. *Lagena laevigata* REUSS; BRADY, pl. 114: 8.

1960. *Fissurina laevigata* REUSS; BARKER, p. 236, pl. 114: 8.

Remarks. — Test very small, almost spherical in outline, slightly compressed with a smooth exterior. A single specimen in PNW 13.

Fissurina cf. *quadrata* (WILLIAMSON, 1858)

1884. *Lagena quadrata* (WILLIAMSON); BRADY, pl. 59: 16.

1960. *Fissurina quadrata* (WILLIAMSON) var. *carinata* CHAPMAN; BARKER, p. 122, pl. 59: 16.

Remarks. — Test very small, subspherical in axial view, characterized by two short and un-ornamented keels near the base of the test. Rare, three specimens in PNW 13.

Genus *Oolina* D'ORBIGNY, 1839*Oolina globosa* (MONTAGU, 1803)

1884. *Lagena globosa* (MONTAGU); BRADY, pl. 56: 1–3.

1910. *Lagena globosa* (MONTAGU); HOLLAND, p. 8, pl. 2: 8–9.

1960. *Oolina globosa* (MONTAGU); BARKER, p. 114, pl. 56: 1–3.

Remarks. — Spherical in axial view. Slightly elongate, aperture on short neck. Smooth exterior. Rare, but the more common of the ellipsolagenids in PNW 13.

Family **Cassidulinidae** D'ORBIGNY, 1839Genus *Cassidulina* D'ORBIGNY, 1826*Cassidulina crassa* D'ORBIGNY, 1839

(Pl. 35: 1–3)

1839. *Cassidulina crassa* D'ORBIGNY; BRADY, pl. 54: 4–5.

1910. *Cassidulina crassa* D'ORBIGNY; HOLLAND, p. 7, pl. 2: 2, 5.

1960. *Cassidulina crassa* D'ORBIGNY; BARKER, p. 110, pl. 54: 4–5.

Remarks. — HOLLAND (1910) recognized this species as the dominant form (83 percent) in the material supplied to him from sample SPE 12. In our split of SPE 12 it constitutes 84 percent of the fauna and is also a dominant form in AG 1, AG 2, AG 3 and PNW 12. It is a relatively minor (5 percent) contributor to PNW 13, an assemblage we regard as the least modified (see below) of our collections. Where *Cassidulina crassa* is dominant, the tests are large and preservation ranges from good to decorticated. It is probable that tests survived repeated transport, thus enhancing the final high percentage occurrence. *C. crassa* is also the dominant species (46 to 67 percent) in the Larsemann Hills Pliocene assemblages (QUILTY *et al.* 1991). As illustrated by BRADY (1884), the test shape ranges from subglobular (usually the smaller forms) to slightly compressed (larger forms). This may be an expression of ontogeny and generation. This is a common species in many polar and deep water assemblages. As noted by BARKER (1960), some authors have favored the placement of the more compressed and elongate tests in *C. oblonga* REUSS, whereas others favored retention of these in *C. crassa*. MARKS (1951) confirmed this by placing *C. oblonga* in synonymy with *C. crassa*.

Genus *Cassidulinoides* CUSHMAN, 1927*Cassidulinoides parkerianus* (BRADY, 1884)

(Pl. 35: 4–6)

1884. *Cassidulina parkeriana* BRADY, pl. 52: 11–16.

1960. *Cassidulinoides parkerianus* (BRADY); BARKER, p. 110, pl. 52: 11–16.

Remarks. — HOLLAND (1910) did not report this species and we found only five specimens in the split of SPE 12. A few specimens are present in all our samples and it constitutes 5.5 percent of the assemblage in PNW 12. QUILTY *et al.* (1991) reports *C. cf. parkerianus* as the second most common species after *Cassidulina crassa* D'ORBIGNY in the Larsemann Hills Pliocene. At this latter locality it makes up to between 18 and 33 percent of the assemblage.

Genus *Globocassidulina* VOLOSHINOVA, 1960*Globocassidulina subglobosa* (BRADY, 1881)

(Pl. 35: 7)

1884. *Cassidulina subglobosa* BRADY; BRADY, pl. 54: 17.

1960. *Cassidulina subglobosa* BRADY; BARKER, p. 112, pl. 54: 17.

1988. *Globocassidulina subglobosa* (BRADY); LOEBLICH and TAPPAN, p. 505, pl. 557: 18–23.

Remarks. — Tests much smaller than the accompanying compressed and at times slightly uncoiled *Cassidulina crassa* D'ORBIGNY and the elongate and uncoiled *Cassidulinoides parkerianus* (BRADY). Tests of *C. subglobosa* are tightly enrolled. Most common in AG 2 (11 percent of assemblage) and best preserved in PNW 13.

Family **Buliminidae** HOFKER, 1951
 Genus *Angulogerina* CUSHMAN, 1927
Angulogerina angulosa (WILLIAMSON, 1858)
 (Pl. 34: 8–10)

1858. *Uvigerina angulosa* WILLIAMSON, p. 67.

1884. *Uvigerina angulosa* WILLIAMSON; BRADY, pl. 74: 15–16.

1960. *Angulogerina angulosa* (WILLIAMSON); BARKER, p. 154, pl. 74: 15–16.

1988. *Angulogerina angulosa* (WILLIAMSON); LOEBLICH and TAPPAN, p. 528, pl. 574: 5–9.

Remarks. — Test triserial and triangular throughout. Ornamentation consists of distinct longitudinal costae. Not reported by HOLLAND (1910) in SPE 12. Rare. Samples SPE 12, AG 2 and PNW 13 contain two, three and one specimens respectively.

Family **Fursenkoinidae** LOEBLICH *et* TAPPAN, 1961
 Genus *Fursenkoina* LOEBLICH *et* TAPPAN, 1961
Fursenkoina cf. *earlandi* (PARR, 1950)
 (Pl. 35: 8–9)

1950. *Bolivina earlandi* PARR, p. 339, pl. 12: 16.

1986. *Fursenkoina earlandi* (PARR); WARD and WEBB, p. 194, pl. 6: 8.

Remarks. — Test very small, hyaline and well preserved. Moderately common in PNW 13 (3 percent).

Family **Pseudoparrellinidae** VOLOSHINOVA, 1952
 Genus *Epistominella* HUSEZIMA *et* MARUHASI, 1944
Epistominella vitrea PARKER, 1953
 (Pl. 35: 10–11)

1953. *Epistominella vitrea* PARKER *et al.*, p. 9, pl. 4: 34–36, 40–41.

1984. *Epistominella vitrea* PARKER *et al.*; WARD and WEBB, p. 190, pl. 4: 15–16.

1991. *Epistominella vitrea* PARKER *et al.*; QUILTY *et al.*, p. 3, pl. 1: 12–13.

Remarks. — Tiny, hyaline, well preserved tests. QUILTY *et al.* (1991) reports *E. vitrea* as making up between 2 and 18 percent of the Larsemann Hills assemblage. Relatively common in the split of SPE 12 (3 percent) and in PNW 13 (6 percent).

Family **Discorbinellidae** SIGAL, 1952
 Genus *Discorbinella* CUSHMAN *et* MARTIN, 1935
Discorbinella sp.

Remarks. — Plano-convex, trochospiral side almost flat, umbilical side slightly convex, periphery rounded, seven chambers in the last whorl, sutures strongly recurved on both trochospiral and umbilical side of test. Rare. Two specimens in PNW 13 and a single specimen in SPE 12.

Family **Cibicididae** CUSHMAN, 1927
 Genus *Cibicides* DE MONTFORT, 1808
Cibicides refulgens DE MONTFORT, 1808
 (Pl. 36: 4–6)

1884. *Truncatulina refulgens* (DE MONTFORT); BRADY, pl. 92: 7–9.

1910. *Truncatulina refulgens* (DE MONTFORT); HOLLAND, p. 10, pl. 2: 1, 7.

1960. *Cibicides refulgens* DE MONTFORT; BARKER, p. 190, pl. 92: 7–9.

1988. *Cibicides refulgens* DE MONTFORT; LOEBLICH and TAPPAN, p. 582, pl. 634: 1–3.

Remarks. — Much confusion exists in the literature as to the distinction between *Cibicides refulgens* (DE MONTFORT, 1808) and *Cibicides lobatulus* (WALKER *et* JACOB, 1798). HOLLAND (1910) recognized both species but illustrated only a test identified as *Truncatulina refulgens*. HOLLAND writes of *C. refulgens* (p. 10), "This is but a variety of the common *Truncatulina lobatula* in which the convexity of the oral surface is more pronounced and the sutures and peripheral margins of the chambers on the aboral surface are more distinctly emphasized". HOLLAND's figures agree reasonably well with LOEBLICH and TAPPAN's (1988) illustration of *C. refulgens*. We recognize *C. refulgens* tests that are strongly plano-convex, but note there is considerable variation in concavity and convexity on the spiral side. In some tests, longitudinal grooves across the spiral side indicate attachment to sponge spicules or other linear objects. *C. refulgens* is present in all samples, and the dominant species in PNW 13 (33 percent).

Cibicides lobatulus (WALKER *et* JACOB, 1798)
(Pl. 36: 1–3)

1798. *Nautilus lobatulus* WALKER *et* JACOB, p. 642, pl. 14: 36.

1884. *Truncatulina lobatula* (WALKER *et* JACOB); BRADY, pl. 92: 10, pl. 93: 1, 4–5.

1910. *Truncatulina lobatula* (WALKER *et* JACOB); HOLLAND, p. 10.

1960. *Cibicides lobatulus* (WALKER *et* JACOB); BARKER, pp. 190 and 192, pl. 92: 10, pl. 93: 1, 4–5.

Remarks. — Following the discussion of *C. refulgens*, above, we apply the name *C. lobatulus* to tests that are plano-to concavo-convex, and in which the convexity of the umbilical side is much lower than for *C. refulgens*. *C. lobatulus* tends to spread laterally and may assume irregular shapes, this being attributed to attachment strategies. The sutures, chambering and porosity on the spiral side may not be as well developed as in *C. refulgens*, again this probably resulting from the effects of attachment. We stress though, that the differences between of *C. lobatulus* and *C. refulgens* are probably induced ecophenotypically.

Family **Nonionidae** SCHULTZE, 1854
Genus *Nonionella* CUSHMAN, 1926
Nonionella bradii (CHAPMAN, 1916)
(Pl. 36: 7–8)

1884. *Nonionina scapha* (FICHTELI *et* MOLL.); BRADY, pl. 109: 16.

1916b. *Nonionina scapha* var. *bradii* CHAPMAN, p. 71, pl. 5: 42.

1960. *Nonionella bradii* (CHAPMAN); BARKER, p. 224, pl. 109: 16.

Remarks. — Common only in PNW 13 (12 percent).

Nonionella cf. *turgida* (WILLIAMSON, 1858)

1884. *Nonionina turgida* WILLIAMSON; BRADY, pl. 109: 17–19.

1960. *Nonionella turgida* (WILLIAMSON); BARKER, p. 224, pl. 109: 17–19.

Remarks. — Single specimen in PNW 13.

Genus *Melonis* DE MONTFORT, 1808
Melonis sp.
(Pl. 37: 1–2)

Remarks. — Eight moderately inflated chambers in final whorl, broadly rounded periphery, bi-umbilicate, umbilical depression, shallow, test wall hyaline and perforate. Three specimens in PNW 13 and one in SPE 12.

Genus *Cribrononion* THALMANN, 1947
Cribrononion sp.
(Pl. 37: 3–4)

Remarks. — Test moderately inflated in apertural view, six chambers in final whorl, sutures slightly depressed. Rows of sutural pores extend from the umbilicus on both sides and around periphery. Umbilical areas pustulose. Single specimens in PNW 13 and SPE 12.

Family **Elphidiidae** GALLOWAY, 1933
 Genus *Ammoelphidiella* CONATO et SEGRE, 1974
Ammoelphidiella antarctica CONATO et SEGRE, 1974
 (Pl. 37: 5–7; Pl. 38: 1–10; Text-fig. 7a–d)

1910. *Rotalia beccarii* (LINNÉ); HOLLAND, p. 11, pl. 2: 11–12.

1974. *Ammoelphidiella antarctica* CONATO et SEGRE, p. 12.

1974. *Trochoelphidiella onyxi* WEBB, p. 196, text-figs 4–6, pls 1–5.

1988. *Ammoelphidiella antarctica* CONATO et SEGRE; LOEBLICH and TAPPAN, p. 678, pl. 794: 8–17.

1991. *Ammoelphidiella antarctica* CONATO et SEGRE; QUILTY *et al.*, p. 5, pl. 1: 21.

Remarks. — HOLLAND (1910) noted that this species was quite common in his split of SPE 12. This taxon constitutes about 19 percent of the total specimens extracted from the *Pecten* Conglomerate. Tests in PNW 13 are well preserved and include a wide range of test sizes. Both generations are present but the smaller megalospheric tests dominate. The few-chambered juvenile forms noted by WEBB (1974) in the Pliocene *Pecten* Gravels of Wright Valley are not present in the *Pecten* Conglomerate. Tests present

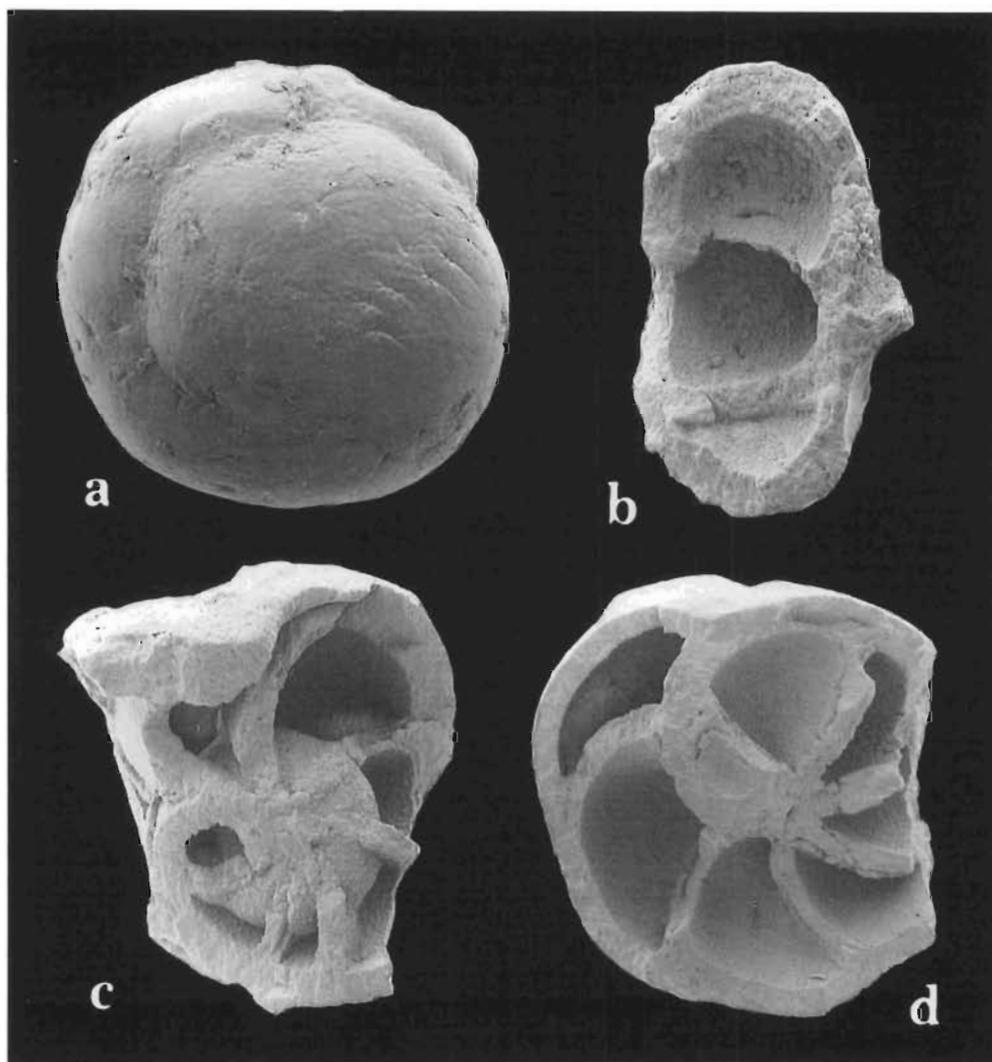


Fig. 7

Ammoelphidiella antarctica CONATO et SEGRE, 1974

- a — highly convex spiral side, trochospiral-streptospiral coiling well developed, sample AG 1, ZPAL F.XXXVIII/19, $\times 110$;
 b — broken test, side view, very thick wall, sample AG 1, ZPAL F.XXXVIII/20, $\times 80$; c — broken test viewed from umbilical side, circular whorl of initial chambers at center, very thick test wall and sutures, sample AG 1, ZPAL F.XXXVIII/21, $\times 75$;
 d — broken test from umbilical side, sample AG 3, ZPAL F.XXXVIII/22, $\times 75$.

in AG 1–3, PNW 12 and SPE 12 are mostly the larger, more inflated and subspherical microspheric generation. We suggest that the large, rugged, matrix-filled and often poorly preserved tests which make a major contribution to samples AG 1–3, PNW 12 and SPE 12, have been size-sorted and selectively concentrated. This species appears to be an excellent Pliocene index. Apart from its occurrence in the *Pecten* Conglomerate, it is also found in the Pliocene Larsemann Hills assemblages (QUILTY *et al.* 1991), and in a number of outcrops and drillholes in the Wright and Taylor Valleys and southern McMurdo Sound region (WEBB 1974, 1988; EGGERS 1979; ISHMAN and WEBB 1988; and ISHMAN and RIECK 1992).

COMMENTS ON THE FORAMINIFERAL ASSEMBLAGES

Nineteen genera and twenty-four species are documented, a two-fold increase over the diversity documented by HOLLAND (1910) see Table 1 and Pls 34–38. The most common taxa are members of the families Cassidulinidae, Cibicididae, and Elphidiidae (Table 2). In most instances, five species constitute ninety per cent of each assemblage in terms of test abundance. These taxa are: *Cassidulina crassa*, *Globocassidulina subglobosa*, *Cassidulinoides parkerianus*, *Cibicides lobatulus*, and *Ammoelphidiella antarctica* (Table 2).

Sample PNW 13 provides the highest diversity at twenty one species (Table 2). Eighteen species are present in SPE 12. Diversity totals in the other five samples ranges between 2 and 9 species. Although only three of the assemblage counts attained the ideal figure of 300 tests, we believe we have established an approximate accounting for each assemblage and have probably isolated 90 percent or more of the total *Pecten* Conglomerate foraminifer fauna.

We have utilized WALTON's (1964) percentage dominance/species number scheme to compare, contrast and explain assemblages (Text-fig. 8). These factors were originally used as a method for distinguishing bathymetric distribution of shallow water foraminiferal assemblages in the Gulf of Mexico. This is also a useful method for showing clustering (similarity) and scatter (dissimilarity) among related assemblages. Our experience has been that inner shelf-shallow water biofacies are most prone to reorganization. According to WALTON's (1964) plot, natural assemblages obtained along a shallow water to deeper water outer shelf transect should cluster along a high percentage dominance-low species to low percentage dominance-high species number curve or field. Departure from this curve or field might be taken to indicate restructuring of the death assemblage by physical recycling, size sorting, removal of taxa to deeper water, and selective destruction of species.

In the case of the *Pecten* Conglomerate microfaunas, we were able to plot only six assemblages, but even from this small number a wide degree of scatter is apparent (Text-fig. 8). Although natural local biotope differentiation in littoral-sublittoral environmental settings might explain the scatter, we believe that physical restructuring under conditions of high energy water turbation is a more likely mechanism. PNW 13 is the richest assemblage species-wise, contains a wide range of test sizes, and preservation is generally good. Taxa such as the trochospiral *Ammoelphidiella antarctica* exhibit a more equally balanced proportion of generations, ontogenetic stages, and test sizes. PNW 13 is interpreted as a relatively complete death assemblage or "population". All other assemblages are of lower diversity, display a higher percentage dominance value for the most common species and display poor preservation overall. In assemblage PNW 12, for example, tests are very large, are highly worn or fractured, and are commonly infilled with red-stained sediment or secondary calcite. Fragile final chambers are often missing. Clearly, these are remnant assemblages that have been subject to multiple recycling in high energy conditions. For this reason the dominant or obvious genera such as *Pyrgo*, *Cassidulina*, *Cassidulinoides*, *Cibicides* and *Ammoelphidiella* are relatively large. Although historic sample SPE 12, part of which was studied by HOLLAND (1910), has a relatively high diversity of 18 species, it also exhibits a very high percentage for the most dominant species (84 percent for *Cassidulina crassa*) and plots well outside the general cluster for all other samples (Text-fig. 8). Most tests in this sample are severely abraded and broken, tests are in-filled with sediment, and are iron-stained. Tests are mostly large and have probably been subjected to repeated reworking and size sorting. It is probable, then, that the high species diversity in this sample resulted from the physical aggregation of a few large and robust tests of such taxa as *Pyrgo fornasinii*, *Pyrgo elongata*, *Triloculina* sp., *Lenticulina gibba*, and *Pseudonodosaria* sp. Dominance/species number data from WEBB (1974) and QUILTY *et al.* (1991) are also plotted in Text-fig. 8. These show the well-preserved Prospect Mesa (= *Pecten* Gravels) assemblage (WEBB 1974) from Wright Valley to lie closest to PNW 13. The Larsemann Hills assemblages cluster reasonably well but may also have been subject to some post-mortem re-organization. The contribution of foraminiferal assemblages to paleoecology and paleoclimate is discussed below.

Table 2

Foraminiferal content of seven samples from the *Pecten* Conglomerate, Cockburn Island. Occurrences noted in SPE 12, a sample collected by J.G. ANDERSSON at Swedish South Polar Expedition Locality 12 (see Text-figs 2–3) are based mostly on our processing of additional materials from the original sample. Occurrences represented under SPE 12 as 1* indicates that a taxon was noted by HOLLAND (1910), usually one or only a few tests, but was not recovered in re-processing of a split of SPE 12 in the course of the present investigation. Figures represent test counts, and figures placed in parentheses indicate percentage contribution of a specific taxon to an assemblage. Samples prefixed by AG collected by A. GAŹDZICKI; PNW by P.-N. WEBB. Fossil material other than foraminifera encountered in microfossil preparations is also summarized.

Genus / Species	SPE 12	AG 1	AG 2	AG 3	PNW 12	PNW 13	PNW 14
<i>Patellina corrugata</i> WILLIAMSON						1	
<i>Pyrgo fornasinii</i> CHAPMAN et PARR	1*	5 (3%)	1	6 (3%)	1		
<i>Pyrgo elongata</i> D'ORBIGNY	1*						
<i>Triloculina</i> sp.	1*						
<i>Lenticulina gibba</i> (D'ORBIGNY)	1*		1			1	
<i>Pseudonodosaria</i> sp.	1*	1				2	
<i>Fissurina</i> cf. <i>semimarginata</i> (REUSS)						1	
<i>Fissurina</i> cf. <i>laevigata</i> REUSS						1	
<i>Fissurina</i> cf. <i>quadrata</i> (WILLIAMSON)						3	
<i>Oolina globosa</i> (MONTAGU)	1*			1	1	5	
<i>Cassidulina crassa</i> D'ORBIGNY	334 (84%)	62 (39%)	270 (75%)	120 (57%)	159 (72%)	15 (5%)	
<i>Cassidulinoides parkerianus</i> (BRADY)	5 (1.3%)	6 (4%)	13 (4%)	3 (1.5%)	12 (5.5%)	9 (3%)	
<i>Globocassidulina subglobosa</i> (BRADY)	7 (1.8%)	7 (4%)	39 (11%)			13 (4.5%)	
<i>Angulogerina angulosa</i> (WILLIAMSON)	2		3 (1%)			1	
<i>Fursenkoina</i> cf. <i>earlandi</i> (PARR)						10 (3%)	
<i>Epistominella vitrea</i> PARKER	11 (2.8%)					18 (6%)	
<i>Discorbinella</i> sp.	1					2	
<i>Cibicides refulgens</i> DE MONTFORT	6 (1.5%)	12 (7%)	9 (2.5%)	25 (12%)	7 (3%)	99 (33%)	
<i>Cibicides lobatulus</i> (WALKER et JACOB)	1*				6 (3%)	12 (4%)	1
<i>Nonionella bradii</i> (CHAPMAN)	1		1		1	37 (12%)	
<i>Nonionella</i> cf. <i>turgida</i> (WILLIAMSON)						1	
<i>Melonis</i> sp.	1					3	
<i>Cribrononion</i> sp.	1					1	
<i>Ammonelphidiella antarctica</i> CONATO et SEGRE	19 (5%)	64 (41%)	22 (6%)	54 (26%)	34 (15%)	84 (28%)	1
Total specimens	396	157	359	209	221	303	2
Species/assemblage	18	7	9	6	8	21	2
Other fossil material:							
Recycled Cretaceous calcareous nannoplankton		×	×	×			
Recycled Cretaceous foraminifera		×	×	×			×
Silicoflagellates					×		
Diatoms		×				×	
Radiolaria							×
Sponge spicules	×	×			×	×	
Molluscan debris	×	×	×	×	×	×	×
Ostracods	×	×	×	×		×	
Bryozoans	×	×				×	
Echinoid spines and plates	×	×		×	×	×	

COMPARISON OF THE *PECTEN* CONGLOMERATE FORAMINIFERAL ASSEMBLAGES WITH OTHER ANTARCTIC PLIOCENE ASSEMBLAGES

The Cockburn Island and Larsemann Hills successions probably existed on bay-indented coastlines, whereas Wright Valley was the site of a fjord. Sediments at the three localities include fine to coarse-grained sands (sandstones), pebble to boulder conglomerates, and diamictites. Each succession is only a few meters thick and probably represents erosional remnants. The foraminifera are interpreted as indicative of shallow water marine interglacial or deglacial conditions associated with periods of high stands of sea level. Species number per assemblage at these three widely separated localities is less than 21 (Text-fig. 8) and in each instance the four most dominant taxa make up 90 percent of the assemblage. All taxa present are members of calcareous benthic families. Neither agglutinated nor planktic taxa were recovered at any of the sites.

Ammonoelphidiella antarctica CONATO *et* SEGRE, 1974 (= *Trochoelphidiella onxyi* WEBB, 1974) is common to all three regions mentioned above. This large and distinctive species appears to be a widespread and useful Pliocene inshore benthic index in Antarctic basins. *Ammonoelphidiella antarctica* is the dominant species (58 percent) in the well preserved Wright Valley Prospect Mesa Formation (= *Pecten* Gravel) fjordal assemblage (WEBB 1974), but comprises only 4 percent of the Larsemann Hill assemblage (QUILTY *et al.* 1991). At Cockburn Island it constitutes between 6 and 41 percent in six of the assemblages (Table 2). This degree of variability, its poor preservation and often large size, suggests it is prone to survival through multiple phases of recycling within the Pliocene. Its spherical-sub spherical form probably facilitates bottom transport where pronounced wave action and currents are dominant.

Members of the Cassidulinidae are a dominant component at Larsemann Hills (81 percent) but less significant in the Wright Valley assemblage. In PNW 13 at Cockburn Island, this family contributes 12.5 percent to the assemblage, while in samples interpreted as recycled (*e.g.* AG 2) the figure is elevated to 90 percent, in which case, preservation is often very poor.

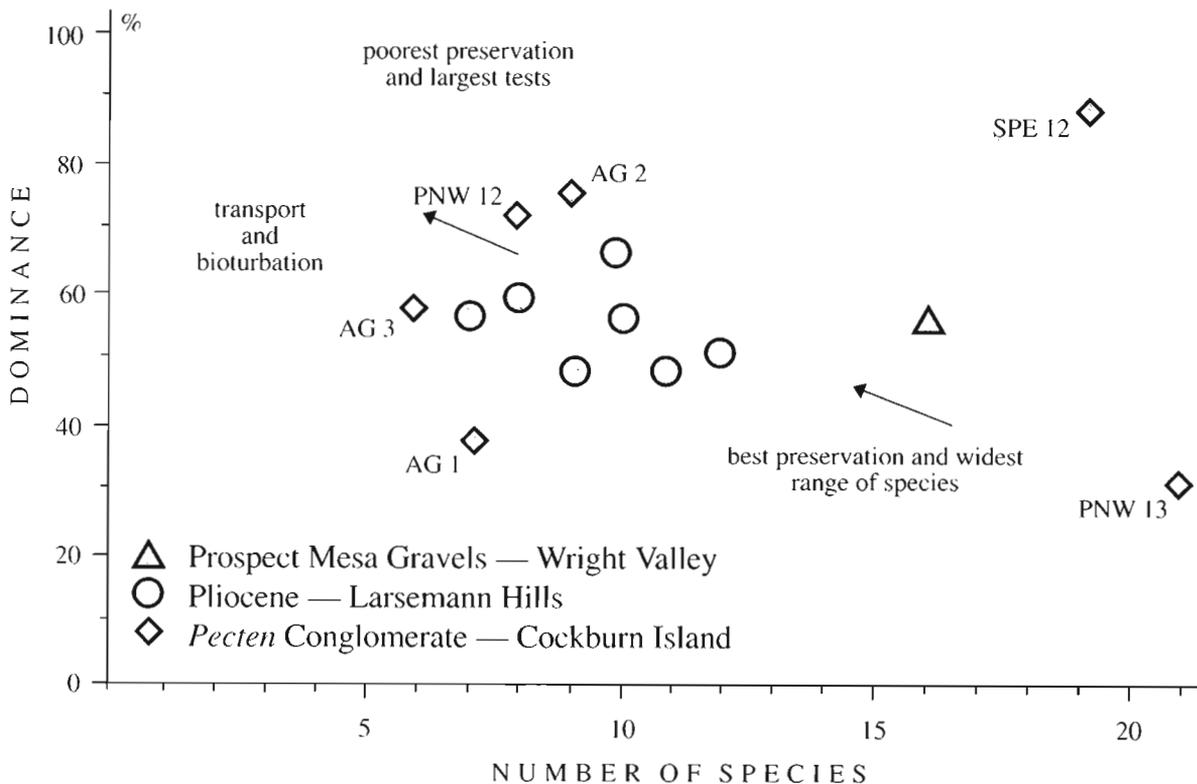


Fig. 8

Percentage dominance for the most common species in each of six *Pecten* Conglomerate assemblages plotted against total species diversity. Similar assemblage data derived from Pliocene assemblages in Wright Valley (WEBB 1974) and Larsemann Hills (QUILTY *et al.* 1991) are also plotted. Assemblage PNW 13 is considered to be closest to an original biocoenosis. All other Cockburn Island assemblages, including SPE 12 used in HOLLAND'S (1910) study, reflect varying degrees of restructuring in high energy littoral environments. Arrows indicate progressive alteration of assemblages.

Cibicididae make up 1 to 5 percent of the Larsemann Hills and Wright Valley assemblages, but may be considerably more abundant at Cockburn Island. In sample PNW 13 this family contributes 37 percent to the assemblage, a figure thought to be a reasonably accurate tally for the original biocoenosis. Here, preservation is excellent and there is a wide range in test sizes. These large but sometimes fragile tests break down on transport and in the re-transported samples such as AG 1, 2 and 3, and PNW 12, the family contribution drops 12 percent or less.

It is noteworthy that *Ehrenbergina glabra* HERON-ALLEN *et* EARLAND, a form very common in present-day polar faunas, is present in moderate and consistent numbers at Larsemann Hills but is not present in either Wright Valley or Cockburn Island assemblages.

Molluscs are common at all three sites, and at Cockburn Island and Wright Valley scallops are the dominant macrofossil. Echinoids are reported in both the Larsemann Hills and Cockburn Island assemblages. Large and robust echinoid spines are extremely common at Cockburn Island. The presence of this group points to sediment bioturbation as a potential agent in test recycling. Sponges are present at all three sites and probably contributed to the benthic microenvironments in which the foraminifera lived. Many of the large foraminifera in the *Pecten* Conglomerate assemblages have been densely drilled by predators and this is an additional agent in test disintegration. Drillholes are particularly apparent in *Cassidulina crassa*, *Cibicides refulgens*, and *Ammoelphidiella antarctica*. WEBB (1972, 1974) also noted a high incidence of predation in *Ammoelphidiella antarctica* from the *Pecten* Gravels assemblage of Wright Valley.

MODERN-DAY POLAR FORAMINIFERAL BIOTOPE ANALOGS

We will attempt to identify a modern polar latitude analog of the *Pecten* Conglomerate foraminiferal biofacies. Here, we must exercise caution in drawing too close a parallel since there may have been significant marine paleoclimate contrasts between the late Pliocene and present-day coastal environments. Most present-day coastal areas are covered by seasonal and in some instances multi-year sea-ice and the presence of coastal ice has not been demonstrated in the case of the *Pecten* Conglomerate. Nevertheless, we believe that a reasonably close modern analog to the *Pecten* Conglomerate foraminiferal assemblages is provided at Explorers Cove, western McMurdo Sound (BERNHARD 1987).

The Explorers Cove study site entailed consideration of a variety of subtle seasonal to daily physical and chemical perturbations, including sea-ice build-up and break out, and wave, current and tidal action. Other important factors taken into consideration in BERNHARD'S (1987) study included sediment and biotope transport into slightly deeper water and the introduction of organic rich terrestrial meltwater from nearby land. Water depths chosen for the study ranged between 2.5 and 27 meters, and sampling sites extended no more than 55 meters offshore. BERNHARD (1987) distinguished seven foraminiferal biotopes; shallow, boulder, open deep-water (maximum water depth 27 m), sponge mat, sediments underlying sponge mats, seasonally anoxic (micro) basin, and anchor ice. The number of species per biotope was found to be on the order of 5 to 7. Genera that were widespread and common to most biotopes included; *Patellina*, *Pyrgo*, *Globocassidulina*, *Cassidulinoides*, *Fursenkoina*, *Epistominella*, *Cibicides*, and *Astrononion*. These genera, or very close relatives, are also members of the *Pecten* Conglomerate assemblage. The megafauna at Explorers Cove consists of the scallop *Adamussium colbecki*, rosselid sponges, ophiuroids, asteroids, and gastropods. BERNHARD (1987) reported highest live-dead abundance adjacent to boulders and beneath sponge mats. The boulder biotope possessed the highest foraminifera standing stock and total abundance figures. Many aspects of BERNHARD'S results match the admittedly much more imperfect data provided for the Cockburn Island assemblages. One major difference is that 19 of the 60 species investigated by BERNHARD (1987) were agglutinated forms. Agglutinated tests may have been present in the Cockburn Island *Pecten* Conglomerate biofaces but disintegrated *post-mortem*. Wave action, tidal activity, and/or bottom currents, appear to have played a much greater role in the development of the *Pecten* Conglomerate than with the Explorers Cove environment. It is possible that physical perturbation and destruction of the biota, especially in near-littoral microenvironments, was suppressed by seasonal ice at Explorers Cove, whereas there may have been little or no protection afforded by sea-ice ice cover at Cockburn Island. The Explorer Cove analogy satisfies one aspect in interpreting the *Pecten* Conglomerate biotope. At the latter site we are dealing with a coastal setting, very shallow water, and high energy water conditions.

PALEOECOLOGICAL INTERPRETATIONS OF MACROFOSSILS AND MICROFOSSILS FROM THE *PECTEN* CONGLOMERATE

TOTAL FOSSIL ASSEMBLAGE

The following fossil groups have been documented in the *Pecten* Conglomerate: calcareous nannoplankton-recycled (GAŹDZICKA and GAŹDZICKI 1994), freshwater and marine diatoms (HARWOOD 1986), radiolarians (HARWOOD 1986; this investigation), silicoflagellates (HARWOOD 1986), foraminifera-*in situ* (HOLLAND 1910; HENNIG 1910; this investigation), foraminifera-recycled (GAŹDZICKA and GAŹDZICKI 1994; this investigation), sponges (HARWOOD 1986), echinoids (this investigation), ostracods (HENNIG 1910; SZCZĘCHURA and BŁASZYK 1996 this volume), bryozoans (HENNIG 1910), barnacles (HENNIG 1910), molluscs (HENNIG 1910; WILCKENS 1924; SOOT-RYEN 1952), and brachiopods (HENNIG 1910; BUCKMAN 1910). No terrestrial macrofossil material, such as wood or leaves has been recovered.

The most diverse fossil groups are diatoms (21 genera and 57 species), foraminifera (19 genera and 24 species), bryozoans (10 genera and 12 species), brachiopods (3 genera and species), and molluscs (3 genera and species). The macro- and microfauna is obviously marine but HARWOOD (1986) noted the presence of rare freshwater diatoms among marine the diatom taxa. Debris of all macrofossil groups is encountered in microfossil preparations (Table 2). No intact echinoids have been reported but we find rare echinoid plates and very common echinoid spines in microfossil preparations (Table 2). Although the pioneer paleontological work by the 1901–1903 Swedish South Polar Expedition, in all fossil groups, is in need of systematic revision, the total *Pecten* Conglomerate biotope contains more than 50 genera and 100 species. Future field collection and laboratory data reduction is likely to increase the diversity and abundance within the *Pecten* Conglomerate biotope.

BATHYMETRY AND TERRESTRIAL INFLUENCES

The bathymetry of the deposit can be estimated from several of the groups present. HARWOOD (1986) reports that 7 genera and 14 species of diatoms are associated with water depths less than 50 meters. Among the foraminifera, the very large miliolinellid *Pyrgo* (Pl. 34: 1–3) and large elphidid *Ammoelphidiella* (Pl. 37: 5–7; Pl. 38: 1–10; Text-fig. 7a–d) are forms which are also expected to have favored environments in the photic zone. In general, the tests of foraminifera are both large and heavily calcified and again this points to a shallow coastal environment. Both the foraminifera and the macrofossil groups have been subjected to a high degree of abrasion and fragmentation (Text-fig. 7b–d). We take this to indicate high energy conditions close to a shoreline within the reach of wave base, current agitation and frequent sorting. Both HOLLAND (1910) and HENNIG (1910) believed that the foraminifera might be associated with brackish estuarine conditions, and HENNIG (1910, p. 59) suggested the possible affect of icebergs as a source of reduced salinity. We have no information on degree of runoff of terrestrial water at the coastline and no record of ice-berg presence. However, both suggestions should be kept under consideration. One intriguing observation is that the tests of foraminifera, particularly in the assemblages that are considered to have experienced repeated transport, are iron-stained to a deep red-brown color. It is probable that the mobile iron was derived from the deeply weathered volcanic terrain of flows and tuffaceous sediments from which part of the *Pecten* Conglomerate was derived. If iron-rich waters were percolating through the *Pecten* Conglomerate at a littoral site, then considerable penecontemporaneous and/or post depositional drainage from terrestrial sites is implied.

MARINE PALEOCLIMATE AT LITTORAL-INNER SHELF SITES DURING THE LATE PLIOCENE

HENNIG (1910) interpreted the biogeographic and thermal aspects of the *Pecten* Conglomerate macrofossil assemblage through comparison with environmental tolerances of the same extant taxa in the Southern Ocean, Patagonia, Falkland Islands and Chatham Islands (off New Zealand). He noted that half the species in the Cockburn Island assemblage live in water temperatures between 2 and more than 10°C. For this reason the *Pecten* Conglomerate fauna has been cited in most literature as indicating pre- or interglacial conditions. HENNIG's (1910) assessment of paleotemperature based on macrofaunas, should be reviewed to ascertain its validity.

IMPLICATIONS FOR TERRESTRIAL PALEOGEOGRAPHY AND PALEOTOPOGRAPHY

Since the *Pecten* Conglomerate developed at a coastline, its lithological and pre-Pliocene paleontological content might reveal something about late Pliocene terrestrial paleogeography and paleotopography. Large clasts of James Ross Island Volcanic Group rocks in the formation (Text-fig. 6) indicate a local terrestrial source. The presence of recycled foraminifera and calcareous nannoplankton from the Marambio Group (Upper Cretaceous) suggest either deep dissection of the volcanic cover so as to release Cretaceous rocks to erosion, or the existence of a highland of Cretaceous rocks, or both. Surprisingly, we have recovered no recycled microfossils from the Paleocene Sobral or Eocene La Meseta Formations, indicating that they were not within the catchment area of the Pliocene *Pecten* Conglomerate or not exposed above sea level in the Pliocene. It will be recalled from Text-fig. 4 that the La Meseta Formation rocks almost directly underlie the *Pecten* Conglomerate. No evidence for an Oligocene-Miocene succession, represented by Cockburn Unconformity U₃ (in Text-fig. 4), has been recovered and we deduce that no rocks of this age span were above sea level in the latest Pliocene.

IMPLICATIONS FOR TECTONIC HISTORY

Late Cenozoic tectonic events in the James Ross Island area (including Cockburn Island) are considered by several authors. BIBBY (1966) wrote of faulting and subsidence (submarine) associated with the eruption of Miocene James Ross Island Volcanic Group rocks. Furthermore, he wrote (p. 36), "When this volcanic episode ended a resumption of shallow-water sedimentation resulted in the formation of the Pliocene *Pecten* Conglomerate". BIBBY (1965, 1966) proposed post-Pliocene uplift of the entire area and cited the existence of young (?Pleistocene) raised beaches as the most obvious evidence.

NELSON (1975, pp. 6, and 59) emphasized emergence of topography since the end of the Miocene, and used the present elevation (220–250 m) and assumed age (Pliocene) of the *Pecten* Conglomerate on Cockburn Island as a datum, to suggest (p. 60), "it is feasible that at least 4000 ft. (1219 m) of re-emergence of the area (*i.e.* James Ross Island area) had taken place before the close of the Pliocene". As noted earlier, we must take into consideration what was actually meant by Miocene and Pliocene, even twenty years ago. In some older time scales the Miocene-Pliocene boundary was placed at 12 Ma rather than the present 5.2 Ma.

ADIE (1964) included the Cockburn Island *Pecten* Conglomerate locality in his Scotia Arc and Graham Land survey of past sea-levels. He attributed the present elevation of the deposit (220–250 m) to a Pliocene high stand of interglacial sea level. This was also a view emphasized by FAIRBRIDGE (1952). No estimation of the role of tectonic uplift was incorporated in these views.

Given our conclusions on paleobathymetry, that the *Pecten* Conglomerate represents a shoreline biofacies deposited and developed in water depths of no more than 50 meters, and that deposit is approximately 250 meters above present sea level, there is then the potential for approximately 300 meters of uplift since time of deposition. Accepting an age span for the deposit to be 2.8–2.0 Ma (HARWOOD 1986), the rate of uplift for the Cockburn Island region lies somewhere in the range of 100–150 m/m.y. The present elevation of the *Pecten* Conglomerate on Cockburn Island is among the highest for any exposed marine Pliocene sediments in Antarctica (WEBB 1972, 1974; EGGERS 1979; QUILTY *et al.* 1991). Uplift may be due to regional emergence, local faulting or some combination of the two. Our earlier discussion of possible faulting on Cockburn Island tends to rule out this factor as a dominant influence. The *Pecten* Conglomerate provides a useful late Pliocene tectonic datum in this region of the Antarctic Peninsula. Should paleobathymetric data become available from well calibrated marine intercalations within the lower part of the James Ross Island Volcanic Group, documentation of the uplift history could, be extended earlier, to the latest Miocene (*c.* 6–7 Ma).

CONCLUDING REMARKS

The *Pecten* Conglomerate was deposited during the late Pliocene, possibly during one of two high-stands of sea level reported by HAQ *et al.* (1987) between 2.4 and 3.5 Ma. The stratotype on Cockburn Island is an erosional remnant and may represent a relatively short span of late Pliocene time. Its elevation

of 220–250 meters above sea level is attributed to a post-depositional uplift rate of between 100 and 150 meters/million years.

A diverse macro- and microfauna/flora of more than 100 species existed close to a coastline, in water no deeper than 50 meters. The formation contains the most paleontologically diverse Pliocene succession known in Antarctica. The *Pecten* Conglomerate and its fossil assemblages are situated at latitude 64°S, the northernmost of the known Antarctic Pliocene localities. This setting provides a potentially important biogeographic link between the shallow marine assemblages of South America and other parts of Antarctica, and an understanding of coastal conditions in the extreme southwest Atlantic Ocean during the Pliocene. Early investigators were correct in interpreting these fossil assemblages as representative of interglacial conditions.

The foraminiferal fauna shares many features in common with Pliocene assemblages in the southwestern Ross Sea–Transantarctic Mountains, and Larsemann Hills, near Prydz Bay, East Antarctica. Similarity among such widely separated coastal foraminiferal biotopes makes it likely that communication occurred around the coastal periphery of the continent or *via* interior seaways. Foraminiferal and other paleontological evidence suggests there is little likelihood that this region of West Antarctica was submerged beneath either ice sheets, ice streams or ice shelves, although the presence of seasonal sea-ice cannot be ruled out.

The paleoclimate at the coastline in the Cockburn Island region and in other coastal regions of Pliocene Antarctica appears to have been polar but mild and the term deglacial seems appropriate. Our data support arguments which call for quite widespread deglacial coastal marine and coastal terrestrial environments during significant intervals of Pliocene time (SPEDEN *et al.* 1962; WEBB 1972, 1974, 1988, 1990, 1991; WEBB *et al.* 1984; HARWOOD 1986, 1991; WEBB and ANDREASEN 1986; ISHMAN and WEBB 1988; PICKARD *et al.* 1988; QUILTY *et al.* 1991; WEBB and HARWOOD 1991; BARRWETT *et al.* 1992; and ISHMAN and RIECK 1992). Late Pliocene terrestrial climate in the Transantarctic Mountains at 85°S latitude was polar and involved glacial conditions (MCKELVEY *et al.* 1991), but annual climate allowed for the existence and propagation of low diversity shrub forests (WEBB and HARWOOD 1987, 1993). According to the Pliocene “Transantarctic Landbridge” hypothesis of WEBB and HARWOOD (1993) possibilities existed for both marine and terrestrial linkages through West Antarctica between the Antarctic Peninsula, the Transantarctic Mountains, and perhaps other parts of East Antarctica.

The Pliocene deglacial conditions which we have interpreted for coastal marine and coastal terrestrial environments might be expected to be reflected in the offshore deep marine record. Unfortunately, no marine Pliocene records exist for the southern Weddell Sea region. Two distant data points are available for consideration. These are, the Maud Rise–Agulhas Transect (ABELMANN *et al.* 1990) and the Ocean Drilling Program Site 697–Jane Basin (BURCKLE *et al.* 1990). These sites are 2500 and 900 kilometers distant respectively from Cockburn Island. Using abundance patterns and species compositions, ABELMANN *et al.* (1990) recognized a period between 4.8 and 3.5 Ma when surface waters were between 5 and 10°C warmer than present. During the Pliocene climatic optimum (4.8 to 4.4 Ma) several low and middle latitude siliceous species invaded the Southern Ocean. Major changes had occurred in deep sea siliceous groups by 2.6 to 2.4 Ma and there was evidence for sea-ice in the Weddell Sea. To accommodate these observations, one hypothesis we might pursue, is that a *Pecten* Conglomerate-like macro- and microfauna-microflora, which also had subantarctic-cold temperate affinities, entered Antarctica during the early Pliocene (Pliocene Climatic Optimum) and survived as the late Pliocene *Pecten* Conglomerate assemblage. In the second study cited above, BURCKLE *et al.* (1990) used diatom data to deduce that during the Gauss and early Matuyama Chrons (3.5 to 2.0 Ma), the interval of time during which the *Pecten* Conglomerate was deposited along the shorelines of West Antarctica, there was sea-ice cover on the waters over the Jane Basin and ice growth on Antarctica. While this may have been possible somewhere in Antarctica, the Cockburn Island data indicate that there was no ice sheet developed at the coastline.

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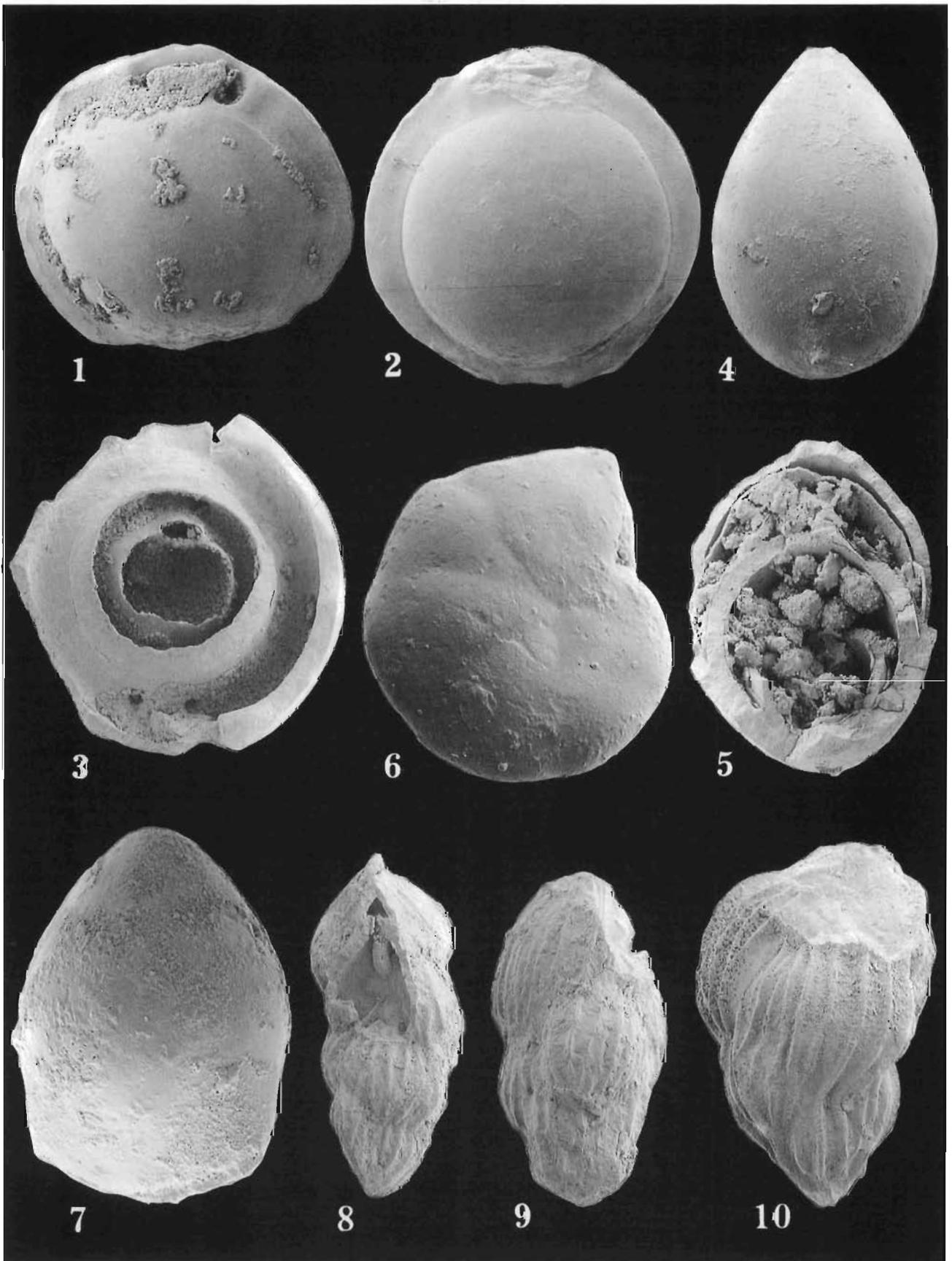
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A. GAŹDZICKI and P.-N. WEBB: FORAMINIFERA FROM THE *PECTEN* CONGLOMERATE (PLIOCENE)
OF COCKBURN ISLAND, ANTARCTIC PENINSULA

PLATE 34

<i>Pyrgo fornasinii</i> CHAPMAN et PARR, 1935	159
Fig. 1. Sample AG 1, ZPAL F.XXXVIII/1, × 50.	
Fig. 2. Sample AG 2, ZPAL F.XXXVIII/2, × 45.	
Fig. 3. Sample AG 1, ZPAL F.XXXVIII/3, × 40.	
<i>Pseudonodosaria</i> sp.	160
Fig. 4. Sample PNW 13, × 100.	
Fig. 5. Sample AG 1, ZPAL F.XXXVIII/4, × 40.	
<i>Lenticulina gibba</i> (D'ORBIGNY, 1839)	160
Fig. 6. Sample PNW 13, × 210.	
<i>Fissurina</i> cf. <i>semimarginata</i> (REUSS, 1871)	160
Fig. 7. Sample PNW 13, × 225.	
<i>Angulogerina angulosa</i> (WILLIAMSON, 1858)	162
Fig. 8. Sample SPE 12, × 77.	
Fig. 9. Sample AG 2, ZPAL F.XXXVIII/5, × 87.	
Fig. 10. Sample AG 2, ZPAL F.XXXVIII/6, × 135.	

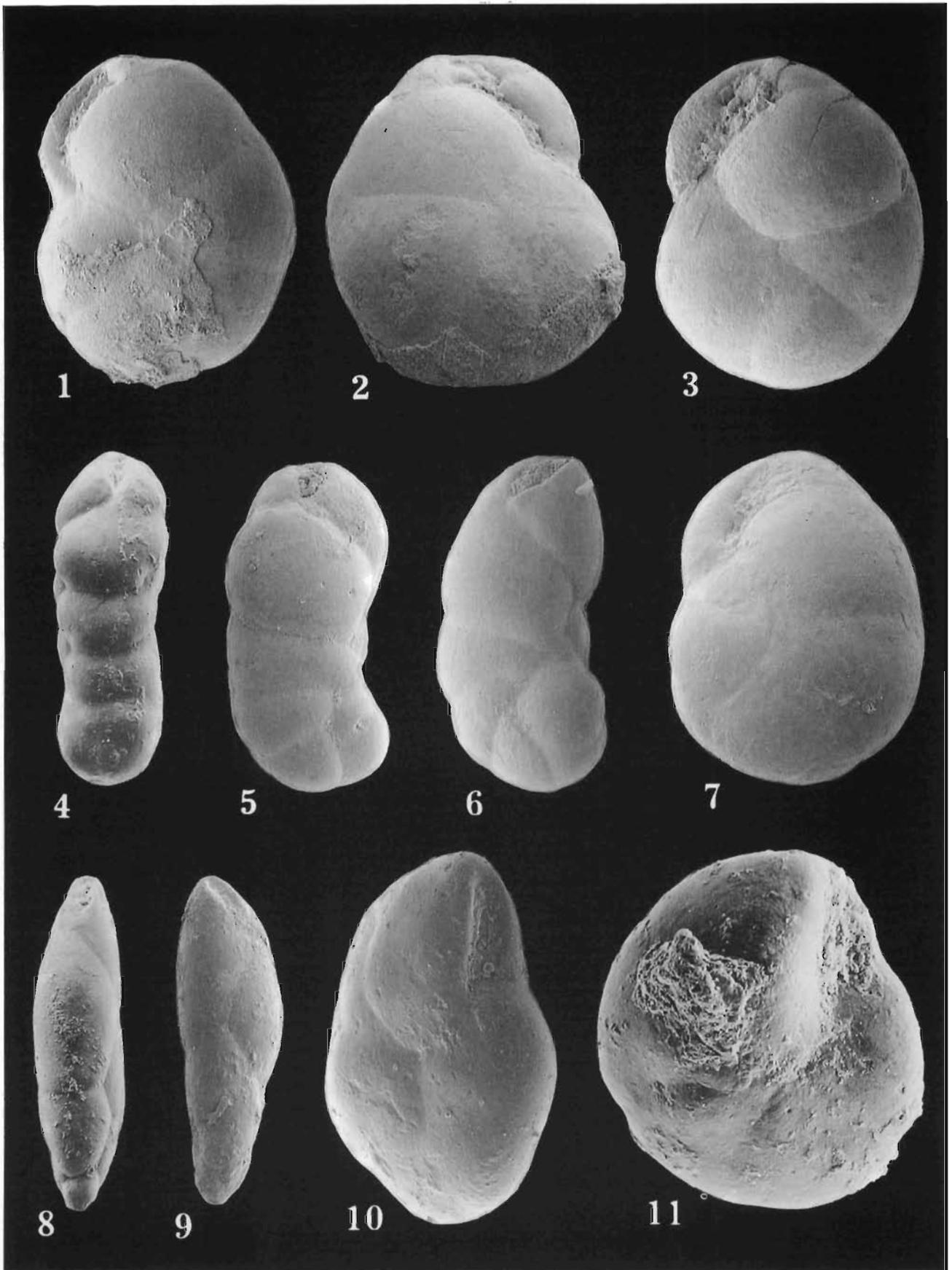


A. GAŹDZICKI and P.-N. WEBB: FORAMINIFERA FROM THE *PECTEN* CONGLOMERATE (PLIOCENE) OF COCKBURN ISLAND, ANTARCTIC PENINSULA

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OF COCKBURN ISLAND, ANTARCTIC PENINSULA

PLATE 35

<i>Cassidulina crassa</i> D'ORBIGNY, 1839	161
Fig. 1. Sample SPE 12, × 80.	
Fig. 2. Sample SPE 12, × 100.	
Fig. 3. Sample SPE 12, × 100.	
<i>Cassidulinoides parkerianus</i> (BRADY, 1884)	161
Fig. 4. Sample PNW 12, × 75.	
Fig. 5. Sample SPE 12, × 120.	
Fig. 6. Sample AG 3, ZPAL F.XXXVIII/7, × 150.	
<i>Globocassidulina subglobosa</i> (BRADY, 1881)	161
Fig. 7. Sample AG 2, ZPAL F.XXXVIII/8, × 105.	
<i>Fursenkoina</i> cf. <i>earlandi</i> (PARR, 1950)	162
Fig. 8. Sample PNW 13, × 135.	
Fig. 9. Sample PNW 13, × 150.	
<i>Epistominella vitrea</i> PARKER, 1953	162
Fig. 10. Sample PNW 13, × 250.	
Fig. 11. Sample PNW 13, × 215.	

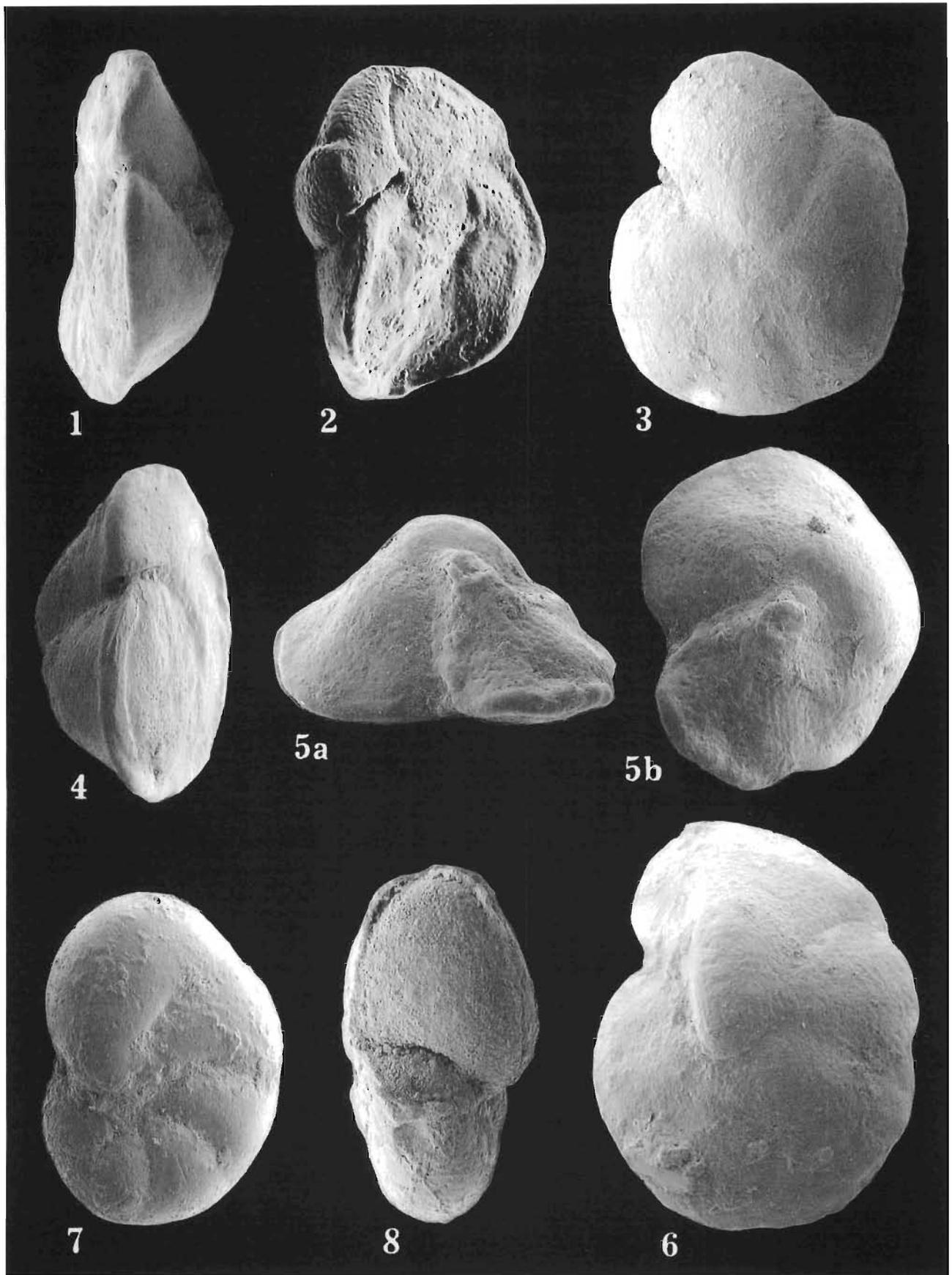


A. GAŹDZICKI and P.-N. WEBB: FORAMINIFERA FROM THE *PECTEN* CONGLOMERATE (PLIOCENE) OF COCKBURN ISLAND, ANTARCTIC PENINSULA

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OF COCKBURN ISLAND, ANTARCTIC PENINSULA

PLATE 36

<i>Cibicides lobatulus</i> (WALKER <i>et</i> JACOB, 1798)	163
Fig. 1. Sample PNW 13, × 485.	
Fig. 2. Sample PNW 13, × 110.	
Fig. 3. Sample PNW 13, × 435.	
<i>Cibicides refulgens</i> DE MONTFORT, 1808	162
Fig. 4. Sample PNW 13, × 80.	
Fig. 5a–b. Sample PNW 13, × 125.	
Fig. 6. Sample PNW 13, × 105.	
<i>Nonionella bradii</i> (CHAPMAN, 1916)	163
Fig. 7. Sample PNW 13, × 240.	
Fig. 8. Sample PNW 13, × 260.	

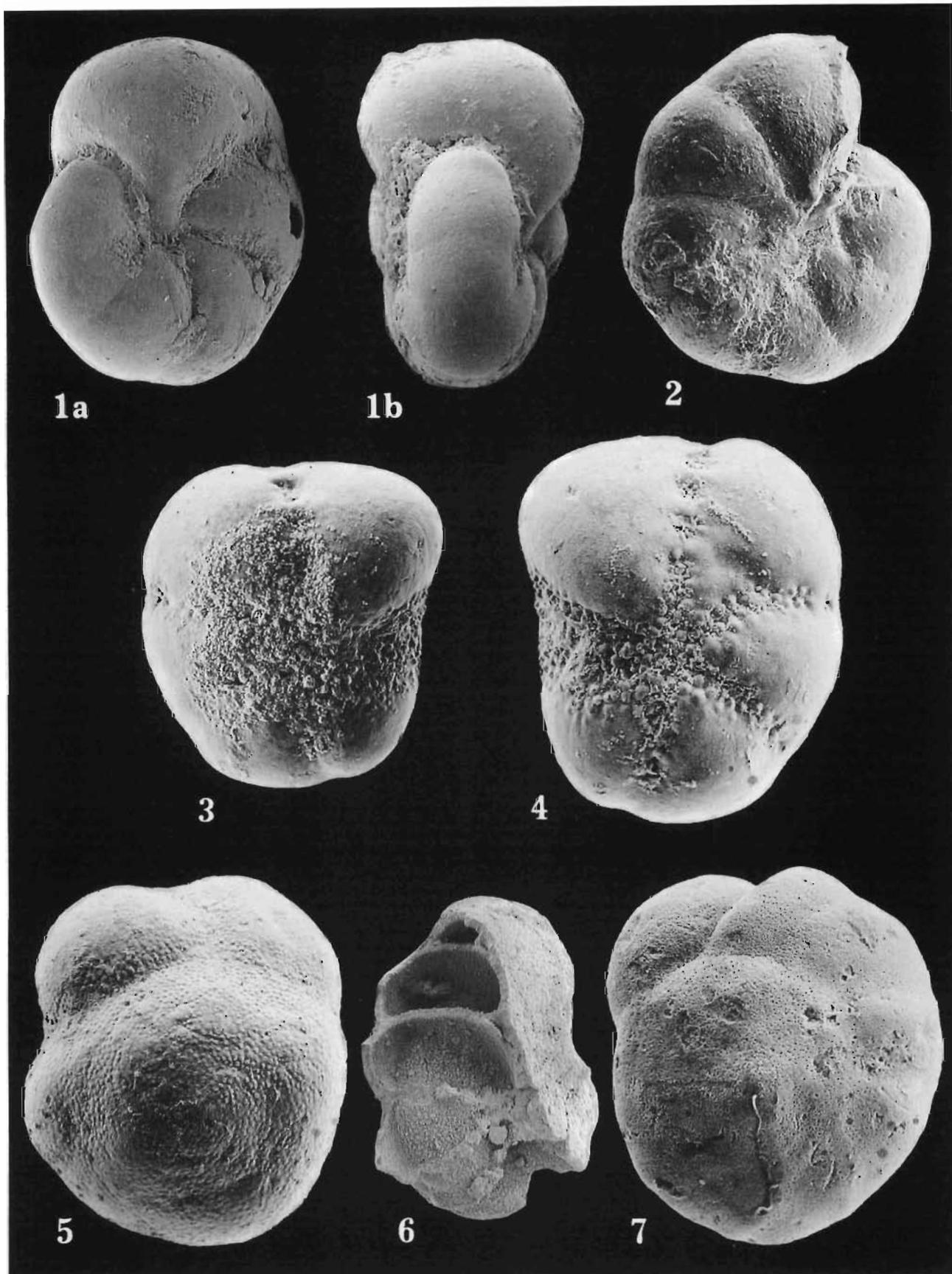


A. GAŹDZICKI and P.-N. WEBB: FORAMINIFERA FROM THE *PECTEN* CONGLOMERATE (PLIOCENE) OF COCKBURN ISLAND, ANTARCTIC PENINSULA

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OF COCKBURN ISLAND, ANTARCTIC PENINSULA

PLATE 37

<i>Melonis</i> sp.	163
Fig. 1a-b. Sample PNW 13, × 525.	
Fig. 2. Sample PNW 13, × 255.	
<i>Cribrononion</i> sp.	163
Fig. 3. Sample PNW 13, × 205.	
Fig. 4. Sample PNW 13, × 235.	
<i>Ammoelphidiella antarctica</i> CONATO <i>et</i> SEGRE, 1974	164
Fig. 5. Spiral side view, paired septal foramina infilled by matrix or ornament, sample PNW 12, × 70.	
Fig. 6. Broken test, spiral side with chambers at left, umbilical side right, note triangular shaped septal canal between septa towards umbilical side of test, sample PNW 13, × 105.	
Fig. 7. Spiral side view, last chamber strongly deflected to umbilical side of test, sample PNW 12, × 55.	



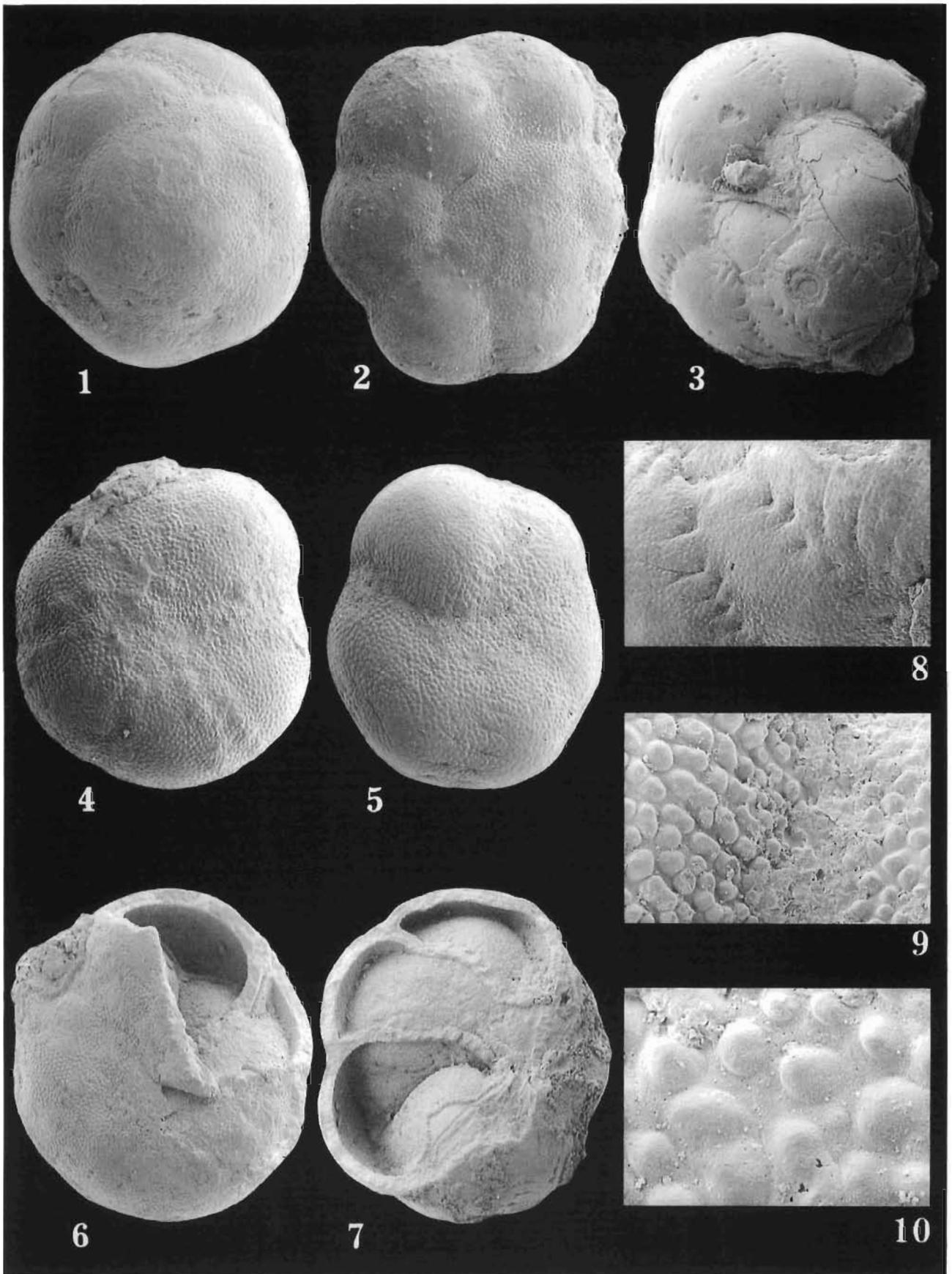
A. GAŹDZICKI and P.-N. WEBB: FORAMINIFERA FROM THE *PECTEN* CONGLOMERATE (PLIOCENE) OF COCKBURN ISLAND, ANTARCTIC PENINSULA

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PLATE 38

Ammoelphidiella antarctica CONATO *et* SEGRE, 1974 164

- Fig. 1. Spiral side view, highly convex, rows of paired septal foramina just visible, thick test wall, finely pustulose, sample AG 3, ZPAL F.XXXVIII/9, $\times 80$.
- Fig. 2. Spiral side view, test wall finely pustulose, spiral side is convex, sample AG 3, ZPAL F.XXXVIII/10, $\times 100$.
- Fig. 3. Spiral side view of a large probably microspheric test, last chamber missing, this test exhibits a tendency toward streptospiral coiling, about ten chambers in the final whorl, spiral side sutures are somewhat curved, paired septal foramina extend from spiral to umbilical sides, a few foramina in the spiral sutures, test has been battered and predated (bored in one place), pustulose ornament may have been worn off, sample AG 1, ZPAL F.XXXVIII/11, $\times 45$.
- Fig. 4. Umbilical side view, umbilical area is covered by plate covered with pustulose ornament, sutures are radial, septal canal beneath cover between two rows of foramina and raised ornament, sample AG 1, ZPAL F.XXXVIII/12, $\times 90$.
- Fig. 5. Umbilical side view, last chamber has poorly developed ornament, sample AG 1, ZPAL F.XXXVIII/13, $\times 105$.
- Fig. 6. Broken test from umbilical side, sample AG 3, ZPAL F.XXXVIII/14, $\times 80$.
- Fig. 7. Broken test viewed from umbilical side, attachment of final whorl of chambers to previous (?initial) whorl, slightly curved sutures (base) that pass to umbilical region exhibit traces of aerial septal foramina, pustulose ornament of previous chambers appears to have been resorbed, sample AG 1, ZPAL F. XXXVIII/15, $\times 50$.
- Fig. 8. Spiral side of test, rows of paired septal foramina separated by roof of septal canal wall, sample AG 1, ZPAL F.XXXVIII/16, $\times 100$.
- Fig. 9. Pustulose ornament, sample AG 3, ZPAL F.XXXVIII/17, $\times 500$.
- Fig. 10. Pustulose ornament, sample AG 1, ZPAL F.XXXVIII/18, $\times 1200$.



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