LATE MESOZOIC STRATIGRAPHY AND INVERTEBRATE PALAEONTOLOGY OF THE SOUTH ORKNEY ISLANDS

By M. R. A. Thomson

Abstract. Sparse, often poorly preserved marine fossils occur in localized sequences within Mesozoic alluvial-fan conglomerates in the South Orkney Islands, an area dominated by metamorphic rocks and a structurally deformed greywacke sequence. New collections of the faunas include a greater variety of species than was previously known, and they have enabled the following age limits to be set on the formations: Calcareous grit sequence, late Jurassic–earliest Cretaceous; Gibbon Bay Shale, late Jurassic or early Cretaceous; flaggy sandstones within the Spence Harbour Conglomerate, early Cretaceous (Neocomian). The Spence Harbour Conglomerate accumulated along the western margin of a trough, sited on present-day Lewthwaite Strait and is probably mainly early Cretaceous in age. Probably synchronous conglomerates (Powell Island Conglomerate) on the eastern margin of the same trough, have so far yielded only terrestrial plant debris.

The South Orkney Islands are situated on the southern limb of the Scotia Ridge and form part of the discontinuous island chain (Scotia arc) which joins southern South America to the Antarctic Peninsula (Fig. 1). The western part of the island group is formed mainly of low–medium grade regionally metamorphosed *para*schists (Matthews and Maling, 1967; Thomson, 1968, 1974), whereas the eastern part consists of pre-Jurassic cleaved greywackes and shales (Greywacke–Shale Formation) with a complex deformational history (Dalziel, 1971; Thomson, 1973). Slightly metamorphosed rocks on north-western Powell Island (Fig. 2), near the middle of the island group, suggest a tectonic gradation between these two major rock groups (Dalziel and others, 1977).

On lithological grounds the Greywacke–Shale Formation has been equated with the Trinity Peninsula Formation (? Carboniferous–Triassic) of northern Graham Land (Adie, 1957). Radiolaria, recently separated from a chert on Scapa Rock believed to be interbedded with the Greywacke–Shale Formation in the Weddell and Saddle Islands group, are probably late Triassic in age (Dalziel and others, 1981). The metamorphic complex of Signy Island has yielded K-Ar mineral ages (Miller, 1960; Grikurov and others, 1967; Rex, 1976) indicative of an important tectonic/metamorphic event in earliest Jurassic times. An Rb-Sr date of about 280 Ma (earliest Permian) from Signy Island (Rex, 1976) awaits confirmation.

In strong contrast with these highly deformed rocks there is an assemblage of younger, undeformed, and locally fossiliferous sedimentary rocks (mainly conglomerates or breccias with

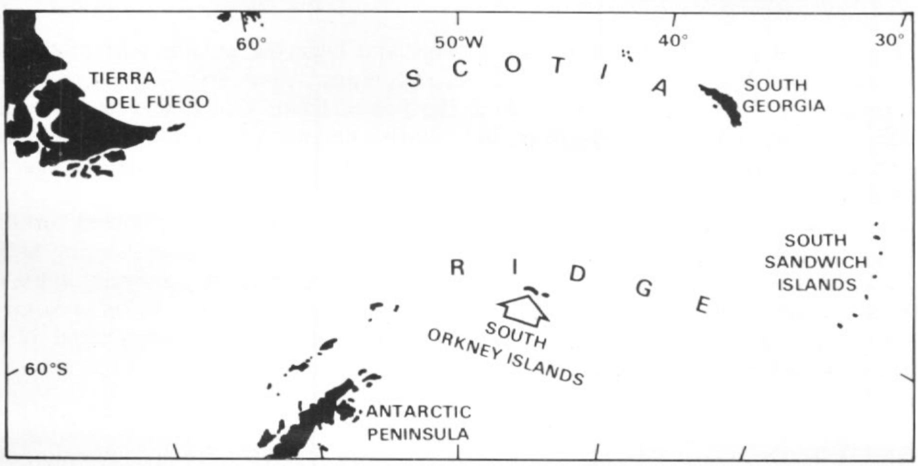


Fig. 1. Sketch map of the Scotia Ridge showing the location of the South Orkney Islands.

TABLE I. STRATIGRAPHY OF THE YOUNGER SEDIMENTARY FORMATIONS OF THE SOUTH ORKNEY ISLANDS

Gibbon Bay	*Robertson Islands*	*Powell Island*
	Dolerite dyke	
Spence Harbour Conglomerate (Marine fossils in calcareous boulders at Rayner Point)	Spence Harbour Conglomerate (Marine fossils in flaggy sandstones on Matthews Island) ←?→	Powell Island Conglomerate (Fossil floras in sandy interbeds)
Gibbon Bay Shale (Marine fossils)	~~~~~~~~	—— Fault —— ~~~~
~~	Metamorphic complex (Quartz-mica-schists)	Greywacke–Shale Formation
Brecciated schists		
- - - - - - - -		
Metamorphic complex (Quartz-mica-schists)		

minor shales and sandstones) which crop out patchily on eastern Coronation Island, the Robertson Islands and Powell Island (Fig. 2). These are the Gibbon Bay Shale, Spence Harbour Conglomerate and Powell Island Conglomerate (Table I: see also Matthews, 1959; Thomson, 1971, 1973, 1974). Calcareous grit clasts in the Spence Harbour Conglomerate represent the eroded remnants of a fourth sedimentary formation that has not yet been located *in situ* and which is perhaps no longer exposed.

Invertebrate marine fossils occur sparsely in the Gibbon Bay Shale, in sandstones within the Spence Harbour Conglomerate on Matthews Island, and in the derived calcareous grit boulders in the same conglomeratic formation at Rayner Point (Fig. 3). Only plant fossils have been recovered from the Powell Island Conglomerate. Previous collections of invertebrate fossils were described by Thomson and Willey (1975) and Thomson (1975), and this enabled the following tentative stratigraphical scheme to be proposed:

Spence Harbour Conglomerate	Middle to Upper Cretaceous
Gibbon Bay Shale	(?) Lower Cretaceous
Calcareous grit sequence (not exposed *in situ*)	Upper Jurassic to lowest Cretaceous

With the exception of moulds of carbonized twigs and logs, the greater part of the Spence Harbour and Powell Island Conglomerates is unfossiliferous. A moderately well-preserved flora from siltstones and fine sandstone interbeds in the Powell Island Conglomerate north of J[illegible] Peaks (Fig. 2) has yet to be described, but provisional identifications by H. A. Orlando (Thomson, 1973, p. 161) suggested a lower Jurassic age. A second, but less well-preserved, flora from southernmost Powell Island awaits study.

The new fossil collections, which form the basis of this paper, were obtained through the courtesy of Dr I. W. D. Dalziel (Lamont Doherty Geological Observatory) during U.S. R/V *Hero* Cruise 77/1 (Dalziel and others, 1977). They demonstrate a greater diversity in the faunas than was previously known and enable slightly more confident age limits to be set on some of the formations. The previous suggestion that the Spence Harbour Conglomerate ranged as high as mid-Cretaceous (see above) is now considered unlikely.

DEPOSITIONAL ENVIRONMENT

The Spence Harbour and Powell Island Conglomerates represent the accumulation of rock debris as alluvial fans, locally derived from the west and east respectively (Elliot and Wells, in

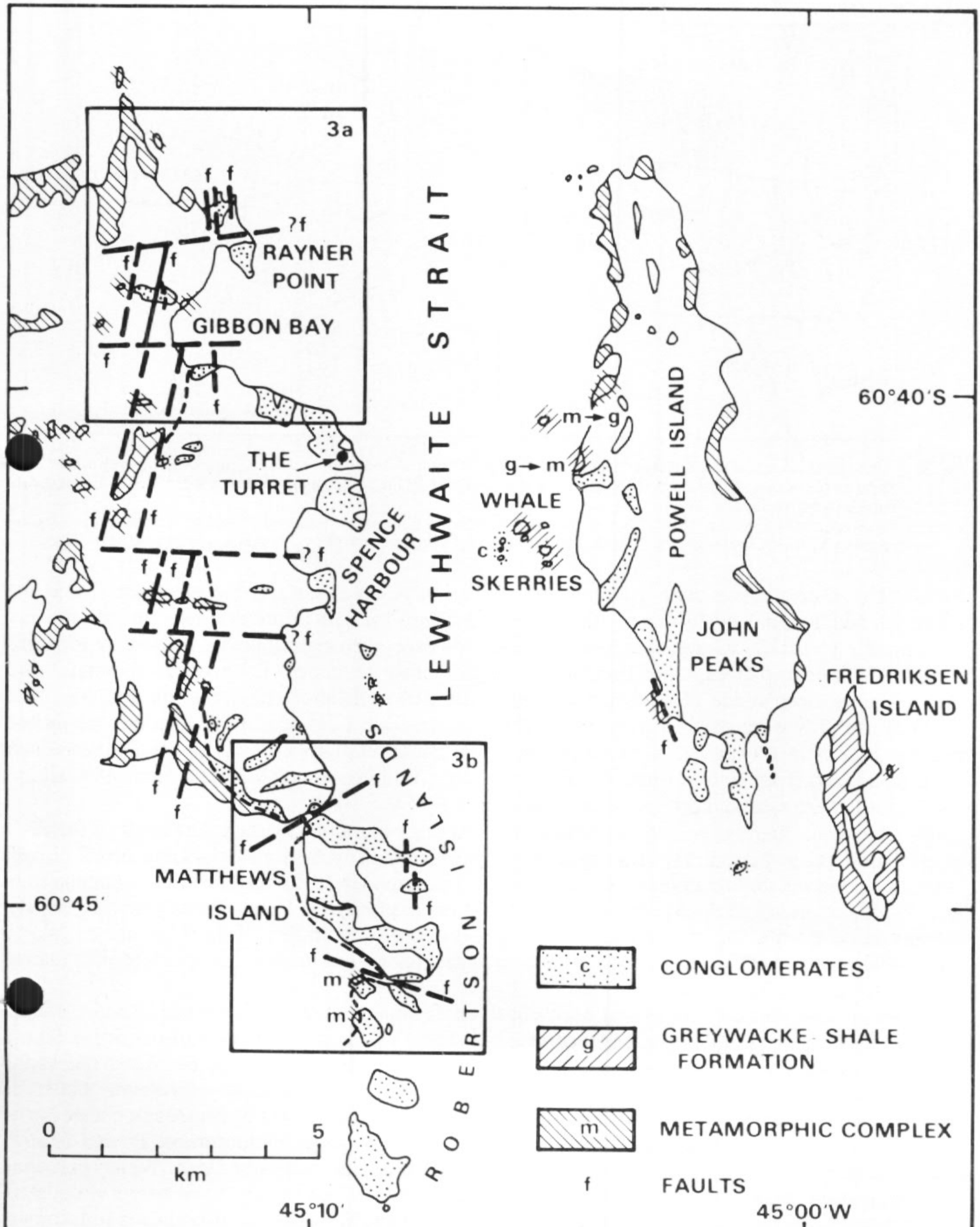


Fig. 2. Geological sketch map of eastern Coronation Island (left), Lewthwaite Strait and Powell Island (after Dalziel and others, 1977 with modifications by J. W. Thomson). The coastline has been modified from Landsat imagery (January 1979). The pecked line indicates the basal unconformity of the Spence Harbour Conglomerate on the metamorphic complex.

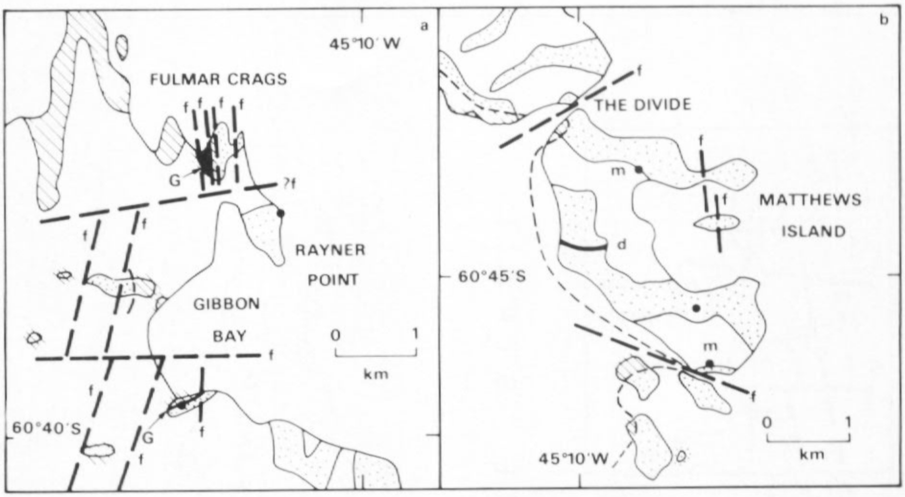


Fig. 3a. Geological sketch map of Gibbon Bay and Fulmar Crags, showing the extent of the Gibbon Bay Shale (
Solid circles denote fossiliferous localities; that at Rayner Point corresponds to the occurrence of derived calcareous grit boulders.

b. Geological sketch map of Matthews Island area, showing the occurrence of fossiliferous sandstones (solid circles). Moraine localities, m; dolerite dyke, d. Geological ornament for both maps is the same as in Fig. 2.

press). The source areas were uplifted fault blocks of *para*schists and metasediments, and the resultant depositional basin was a north–south graben, located approximately on present-day Lewthwaite Strait and its adjacent land masses. However, the original north–south extent of this trough is unknown. The greater part of the conglomerate sequences is terrestrial in origin, and the abundant occurrence of carbonized logs in the Powell Island Conglomerate indicates that some of the fans were derived from wooded mountainsides. Leaf-bearing sandstones within the conglomerates on Powell Island probably represent accumulations in pools or small lakes which were developed from time to time. Marine incursions (Gibbon Bay Shale and Matthews Island sandstones) were rare and probably short lived.

The thickness, angularity and immaturity of the conglomerates suggests that uplift of the fault blocks took place periodically throughout the depositional cycle, thus providing more or less constantly rejuvenated source areas. This situation is emphasized by the fossiliferous calcareous grit boulders within the Spence Harbour Conglomerate at Rayner Point. These grits are largely composed of angular debris derived from the metamorphic complex of the Coronation Island area, which were themselves uplifted after their initial formation and re-incorporated into a later stage of the alluvial fan cycle.

Although rare volcanic clasts had been observed in thin sections of the Powell Island Conglomerate (Thomson, 1973), it was believed that Mesozoic volcanism had been absent in the South Orkney Islands area (Thomson, in press). However, petrological studies by Wells (personal communication) have now revealed the presence of substantial quantities of volcanic clasts in parts of the same conglomerate formation. These constitute 50–70% of the rocks on westernmost Whale Skerries and approximately 25% of a debris flow on southernmost Powell Island. Although primary volcanic deposits of Mesozoic age have not been identified, Wells (personal communication) believes that the volcanic clasts may be derived locally from as yet unlocated representatives of the Antarctic Peninsula Volcanic Group (Thomson, in press). It is not known whether these pre-dated or were penecontemporaneous with the Powell Island Conglomerate.

The Gibbon Bay Shale is interpreted as representing a period of quiet-water deposition in an area receiving little coarse debris. The small physical size of the enclosed faunal constituents suggests that the conditions under which the deposit accumulated were somewhat adverse for normal growth. Although some species, such as the nuculanids, may have lived under them, it is possible that more open-marine forms, such as the ammonites and belemnites, may have been washed in and were unable to survive for very long. Thus, a shallow-water area, well inside the main fault graben and with restricted access to the open sea, is envisaged for the Gibbon Bay Shale.

Elliot and Wells (in press) have already deduced from sedimentological criteria that the marine sandstones of Matthews Island were deposited in shallow, quiet-water conditions, perhaps in a lagoon. Intercalated occurrences of debris-flow units emphasize proximity to the shore line. Evidence confirming such an interpretation is provided by some of the fossils, notably a large limpet, and the way in which most of the ammonites are preserved. The latter generally show evidence of strong dorso-ventral compression during fossilization, suggesting that they came to rest in more or less vertical positions and were buried in such orientations. For this to happen, Raup (1973) deduced experimentally from modern *Nautilus*, and by calculation for *coiled* fossil cephalopods, that the water depth was probably less than 10 m.

Stratigraphy

1. *Calcareous grit sequence*

The calcareous grit sequence has not been seen *in situ* and is only known as cobbles and boulders in the Spence Harbour Conglomerate at Rayner Point (Fig. 3a) (Matthews, 1959; Thomson, 1974) and perhaps as rare clasts in the Gibbon Bay Shale (see below). The distribution of the grit clasts in the Spence Harbour Conglomerate is further restricted in that they only seem to occur on the eastern side of the point, and are only present in appreciable quantities from the high-water mark to about 20 m up the cliff. Because of their high calcareous content they weather much more rapidly than the surrounding siliceous matrix with its quartz-mica-schist clasts. Many are therefore partly or completely weathered out and are difficult to collect.

"Grit" is a term familiar to British geologists, particularly from its usage in the term Millstone Grit of the Carboniferous. Rarely used now, it is nevertheless descriptive of often poorly sorted, coarse angular sands and granule conglomerates. It was used by Matthews (1959) who first discovered the boulders at Rayner Point, and repeated by Thomson (1974) in her study based on Matthews' field work. Although the term has fallen into disrepute because of misuse, it is retained here as a useful description and to avoid overcomplicating the stratigraphical terminology.

The grit boulders consist of poorly sorted grey-coloured sandstones and fine conglomerates. Individual clasts are angular to subangular, with the largest of the sand-sized fraction in the coarse to very coarse ranges (0.5–4.0 mm). Angular granules and pebbles up to 1.5 cm are present in some samples. Clasts consist of metamorphic quartz, lithic fragments of quartz-mica-schist, and rarer mica flakes. They are loosely packed and often matrix-supported in finely and coarsely crystalline calcite. Shell fragments (mainly bivalves and echinoderms) sometimes reach coquina-like concentrations. A finer-grained dark brown variant of the above lithology occurs less commonly, sometimes as rounded pebbles within the more typical quartzose grey grits.

2. *Gibbon Bay Shale*

The type locality of the Gibbon Bay Shale (and previously the only known occurrence) is in the south-western corner of Gibbon Bay (Fig. 3a). During the present re-investigation, a second outcrop, suspected to exist at Fulmar Crags, 3 km to the north, was also investigated.

Although the type locality has already been described in some detail (Thomson, 1974) subsequent observations warrant a redescription. The outcrop of the shale trends roughly east–west over a distance of about 350 m. Its eastern end is terminated by a fault contact against downthrown massive conglomerates of the overlying Spence Harbour Conglomerate. Its western extremity is lost under snow and ice cover, but may also be faulted. The sequence is approximately 2 m thick at its eastern end where it is exposed at the top of a steep boulder-covered bank and in an eroded cleft beneath the conglomerates. At its western end, it is nearer 5 m thick and is intermittently exposed on a more open, scree-covered bench. The shale rests on badly weathered and "brecciated" mica-schist which appears to represent an ancient weathered land surface; similar brecciated schists elsewhere on eastern Coronation Island (Thomson, 1974, fig. 7) probably represent a continuation of the same surface.

The dark-coloured shale is locally iron-stained and badly sheared. It crumbles readily into small chips, but there are localized (?) rotated nodule-like pods up to 20 cm in diameter in which the deformation is much less marked. Locally, there are ferruginous and calcareous concretions and, near the middle of the outcrop in the cleft, the top of the shale is marked by large irregularly-shaped concretions (cf. Thomson, 1974, pl. IVa). Schist boulders are scattered throughout the sequence but the calcareous grit boulders observed by Matthews (Thomson, 1974, fig. 8) were not found again. Towards the western, and topographically highest, part of the outcrop there is a 3-m-long lens of indurated yellowish, well-sorted, quartz-rich sandstone in the top of the shale. Blocks of similar lithology occur in the upper part of the shale in the cleft. The base of the overlying conglomerate is strongly load-casted as is also the upper surface of the sandstone. This suggests that the shale, sandstone and conglomerates all form part of one continuous sedimentary cycle.

On the northern face of Fulmar Crags (Fig. 3a) the shale is also present in a fault wedge between *in situ* schists to the west and a fault sliver of brecciated schists to the east. The shale is strongly sheared with a north–south cleavage oblique to the bedding; slip-strain cleavage is also locally developed. Thin sandstone interbeds, not seen at the type locality, are crumpled, but have internal laminations which suggest that the whole sequence faces westwards (I. W. D. Dalziel, personal communication), i.e. upwards towards the adjacent schists. In view of the height of the crags (about 300 m) and this anomalous field relationship, the faulting in this area probably resulted in a net vertical displacement of at least several hundred metres. Only one identifiable fossil was found after a lengthy search: a small *Nuculana*, apparently identical with those from the Gibbon Bay Shale at the type locality.

3. *Spence Harbour Conglomerate*

The Spence Harbour Conglomerate was first described in detail by Thomson (1971, 1974) from field observations by K. D. Holmes and D. H. Matthews. Its total thickness is unknown, but approximately 518 m are present in a single outcrop at The Turret on Coronation Island. This highly variable deposit rests unconformably on the schists of the metamorphic complex (Fig. 3b) and a sedimentological study by Elliot and Wells (in press) concluded that it represents an alluvial fan deposit, formed against an east-facing scarp close to the sea. Although debris flow units dominate the sequence, (?) talus, mudflow and fluvial deposits have also been recognized. The angular conglomerates are composed almost entirely of debris from the nearby schists, and are punctuated by beds of medium- to coarse-grained sandstone up to 0.75 m thick. However, on southern Matthews Island there is a thick (200 m) sequence of highly micaceous flaggy sandstones and thin debris flows containing rare marine fossils (Thomson, 1975).

Little solid rock is exposed and the greater part of the outcrop is covered with flaggy slabs spread over an area of approximately 0.25 km^2 on a north-facing slope. Careful searching here, and in a moraine on the northern part of the island, produced a total of only 14 invertebrate fossils. In view of the effective bedding plane exposure available for study, this poor return reflects the great rarity of these fossils.

The position of the fossiliferous sandstone within the conglomerate is difficult to assess because the beds below it and on the western side of the island are largely snow-covered. The basal unconformity is exposed on north-western Matthews Island and on three small islands immediately to the south (Fig. 3b), whereas the sandstones are exposed at an elevation of about 150 m approximately 500 m north of the nearest exposed part of the unconformity.

PALAEONTOLOGY

1. *Calcareous grit sequence*

In terms of species, the new collections add little to the known fauna (Thomson and Willey, 1975). A 58-mm-long belemnite guard, albeit fragmentary and corroded, represents the largest belemnite so far obtained from the boulders of this lithology. It is slightly hastate in outline and profile and has a gently tapering apex. Finer external morphological details are obscured by corrosion, but growth rings are visible in a polished section taken near the middle of the guard. These indicate a more or less circular cross-section with a centrally placed apical line. No indentation of the growth lines, which might indicate the presence of a ventral groove, is apparent. This suggests that a ventral groove was absent, very shallow, or very short (i.e. confined to either the apical or alveolar regions). With such poor material it is difficult to suggest even a tentative generic identification. However, it should be noted that the ventral groove, previously identified by Willey in another fragment (Thomson and Willey, 1975, fig. 2g) is poorly defined, being broad and shallow. It is thus possible that the present specimen may be identified with the earlier one, cautiously referred to *Belemnopsis*.

A bivalve fragment from a sandy, rather than a gritty boulder, has a radial ornament reminiscent of the Limidae.

The total fauna known from the Calcareous grit sequence is now as follows:

Oxytoma sp.
Entolium sp.
Neithea (?) sp.
Limid
Oyster fragments
Exogyra sp.
Trigonia (?) sp.
Protocardia (?) sp.
Belemnopsis (?) sp.
Echinoid spines
Bone fragments.

The new collections permit no refinement of the previous age estimate of Upper Jurassic to lowest Cretaceous. This was based on the identification of the belemnite *Belemnopsis (?)* sp. and is necessarily tentative.

2. *Gibbon Bay Shale*

The Gibbon Bay Shale at the type locality proved to be the most productive of the fossiliferous marine beds encountered in the South Orkney Islands. Intensive searching showed that the most common fossil is a small nuculanid bivalve, whereas the *Astarte*-like form, which figured so prominently in an earlier collection (Thomson and Willey, 1975), was not encountered again. Important new additions to the fauna include lytoceratid ammonites, a small belemnite, bivalves and small tusk-shaped shells, which may be scaphopods.

GASTROPODA

Three very small and indeterminate specimens are present in the new collection. The largest is less than 4 mm high and consists of two whorls and the protoconch.

BIVALVIA

Genus *Nucula* Lamarck 1799
Subgenus *Leionucula* Quenstedt 1930
Nucula (Leionucula?) sp.
Fig. 4a

Material

Two internal moulds (H.3009.52 and 53) and an external mould (H.3009.54), which may belong to the same species.

Description

Although the largest and best specimen (Fig. 4a) is only 14.5 mm long and 11.5 mm high, it

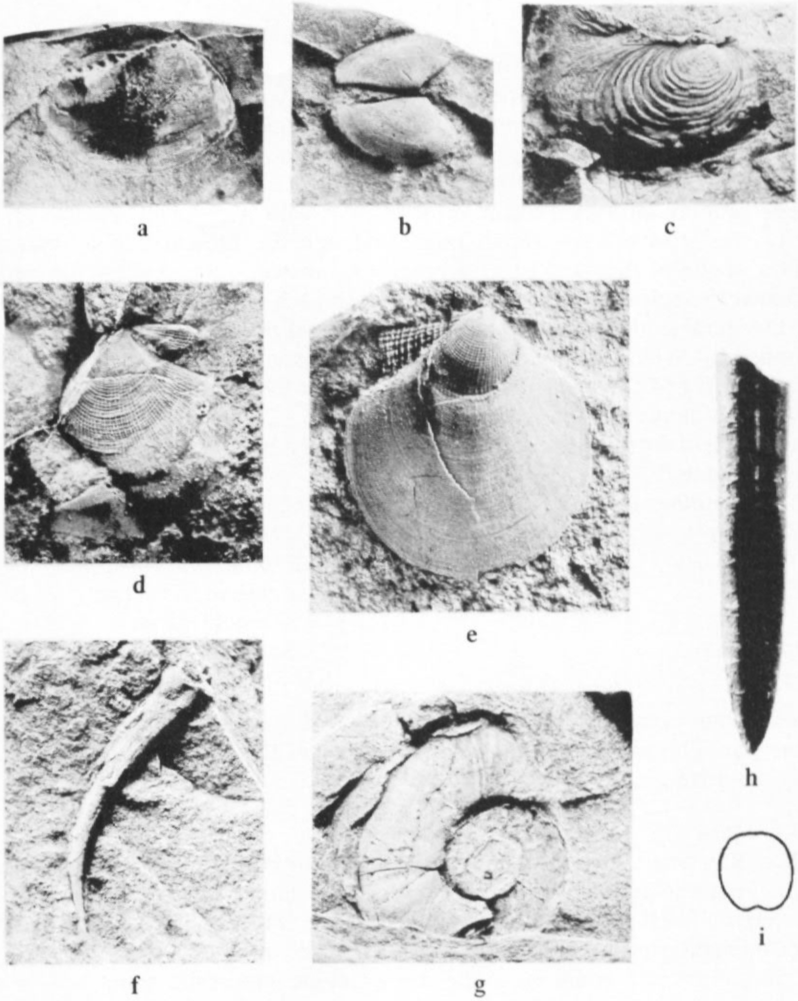


Fig. 4. Fossils from the Gibbon Bay Shale.
a. *Nucula (Leionucula ?)* sp.; latex cast from the internal mould of a right valve; ×2, (H.3009.52).
b. *Nuculana (?)* sp.; internal mould of paired valves; ×2, (H.3009.18).
c. *Steinmannia (?)* sp.; internal mould of a right valve; ×2, (H.3009.15).
d. *Camptonectes s.l.* sp. nov. *(?)*; latex cast from the external mould of a small right valve, showing the change from early-stage reticulate ornament to a later stage with fine curved radial striae only; ×3.5, (H.3009.7b).
e. *Camptonectes s.l.* sp. nov. *(?)*; latex cast from the external mould of a unique left valve from the southern side of Ablation Valley, Alexander Island; ×3.5, (KG. 712.111).
f. Scaphopod-like shell; ×3.5, (H.3009.47b).
g. *Lytoceras* sp.; part internal, part external mould; ×2, (H.3009.13).
h. *Belemnopsis* sp. juv. ex gr. *uhligi* Stevens; unique small guard; ×2, (H.3009.69).
i. *Belemnopsis* sp. juv. ex gr. *uhligi* Stevens; cross-section from the alveolar end of the specimen in Fig. 4h; ×2.

represents one of the largest fossils in the collection. The shell is triangular in outline with a rounded ventral margin, and is obliquely elongated towards one end (presumed anterior in view of the suggested affinities). Well impressed anterior and posterior adductor muscle scars are clearly visible; these both appear to be two-part structures with the dorsal half being more impressed than the ventral. The palial line is obscure, but a very fine lamellar ornament of unknown significance is present on and below the posterior adductor scar. The beak appears to have been slightly crushed into the umbonal cavity such that the more dorsal teeth now face inwards across the visceral cavity. These teeth are large, very prominent, feebly chevron-shaped and are borne on stout hinge plates. Between the anterior and posterior rows, beneath the beak there is a narrow triangular resilifer pit set at an oblique angle to the hinge.

The external morphology of this species is uncertain, although a small (3 mm) external mould, of comparable form to the large example described above, is smooth apart from very faint, fine dense growth lines.

Remarks

The presence of an oblique resilifer and lack of ventral crenulations on the internal surface of the shell combined with a probably smooth shell, support tentative assignment to the subgenus *Leionucula* Quenstedt. However, comparison with described nuculid species is not easy because most are based, at least in part, on external morphology and only the internal features of the present species are known with certainty. *Leionucula* sp. nov. *(?)* from the Valanginian of Livingston Island (Covacevich, 1976) is too poorly preserved for close comparison, but it appears to have a more oval outline. However, *"Nuculoma" livingstonensis* from the same beds is much closer. Although the largest of the present specimens (Fig. 4a) is a little over half the size of the holotype of *N. livingstonensis* it has a similar outline and proportions, except possibly for a more curved ventral margin. A smaller internal mould (H.3009.53, only 4 mm long) is similar to a small internal mould illustrated by Covacevich (1976, pl. 1, fig. 3f) except that it has a more triangular outline and a narrower umbonal region. Illustrations suggest that *"Nuculoma" livingstonensis* lacks the high prominent umbones seen on many described species of *Nuculoma*. However, the assignment of many fossil nuculids to particular genera is problematical and Covacevich did not discuss the reasons for his decision.

"Nucula" cf. *stationis* Wilckens from the Lower Cretaceous of Crabeater Point (Thomson, 1967) has finer and denser dentition than either the Gibbon Bay species or *Nuculoma livingstonensis*.

Genus *Nuculana* Link (1807)

Nuculana (?) sp.

Fig. 4b

Material

More than two dozen specimens from the type locality, and a single valve from Fulmar Crags. Most occur as single valves, but approximately 10% are paired.

Description and remarks

Although plentiful, the present specimens add little to previous knowledge of the species, other than giving a better idea of its shape (Fig. 4b). Like most fossils from the Gibbon Bay Shale, they are all very small, the largest being no more than 8 mm long. There is some variation in shell shape, but the valves are generally more elongate than the previously illustrated example (Thomson and Willey, 1975, fig. 3b); expressed as a percentage of the length, the height of the shell varies between 48 and 71, with an average of 58%. The valve outline is ovate with the umbo set in the anterior half, and an elongate posterior end. The species was thin-shelled and rarely preserved remains of the dentition consist of barely visible fine taxodont teeth. No details of the internal musculature or of the palial line are discernible on any of the specimens.

It has previously been remarked that assignment of this species to *Nuculana* can only be tentative without more precise information as to the presence or absence of a resilifer. However, the gross morphology of the specimens seems to match that of nuculanids rather than malletiids.

The rostrate posterior of *Nuculana s.s.* is not apparent in the Antarctic specimens, and their affinities could lie closer to related forms such as *Yoldia*.

(?) FAMILY INOCERAMIDAE GIEBEL 1852

Genus *Steinmannia* Fischer 1886

Steinmannia (?) sp.

Fig. 4c

Material

Two small internal moulds from Gibbon Bay (H.3009.14 and 15).

Description

This small distinctive species (Fig. 4c) has a weakly inflated shell with an elongate subquadrate outline and a long straight hinge line. The best specimen is 15 mm long with a 9 mm hinge line and the umbo placed only 4 mm from the anterior end. An ornament of coarse concentric growth corrugations, having angular cross sections, seems to be smoothing out towards the anterior and posterior ends of the shell.

Remarks

The lack of internal details, particularly of the hinge area, makes these bivalves very difficult to identify. They may be compared to a number of pterioids (inoceramids and posidoniids) with more or less equal degrees of uncertainty.

The ornament is inoceramid-like but preservation of the specimens is such that one might also expect to find traces of the stout hinge plate and multiple ligament pits, characteristic of that group: these are not present, however. There are a number of poorly known inoceramid genera and subgenera (*Mytiloceramus* Tollier, *Inoceramya* Ulrich, *Sergipia* Maury, and *Steinmannia* Fischer), which bear some external resemblance to the present species. However, of these *Mytiloceramus* has its umbo in an extreme anterior position, and *Inoceramya* has a posterior rib-like swelling beneath the hinge which is not present on the Antarctic specimens. The systematic positions of *Sergipia* and *Steinmannia* are uncertain. In the *Treatise,* Cox (*in* Moore, 1969, p. *N*320) included *Sergipia* in the Inoceramidae but remarked that "Like *Inoceramya*, this appears to constitute a link between *Steinmannia* of the Posidoniidae, and the Inoceramidae". However, *Steinmannia* was nevertheless included in the Inoceramidae. In the section on the Posidoniidae, Newell (*in* Moore, 1969, p. *N*342) reiterated the probable close links between the Inoceramidae and the Posidoniidae. The present specimens have a proportionally longer hinge line than species of the true *Posidonia* and perhaps lie nearer to the problematical *Steinmannia*. The type species, *S. bronni* (Voltz), has deep subcircular valves, but more variable forms with elongate variants have been described from the Middle Jurassic of East Africa as *"Posidonia" ornata* Quenstedt (Weir, 1930), and numerous forms of *"Posidonia"* and *"Posidonomya"* have been reported from southern South America. The latter were discussed and summarized by Weaver (1931, p. 216) who synonymized them all as "*Posidonomya* from the group of *P. alpina* Grass". Unfortunately, most of these, including a sample illustrated by Weaver (1931, pl. 18, fig. 80) were poorly illustrated. Nevertheless, it is probable that none of these achieves the quadrate shell form seen in the present specimens (Fig. 4c), which probably represent a distinct species. A superficially similar fragment from Patagonia, briefly described by Feruglio (1936, p. 31, pl. I, fig. 21) as *Inoceramus* sp., differs in being less elongate and apparently in having a terminal umbo. Specimens cautiously compared by him (Feruglio, 1936, p. 30, pl. I, figs 19 and 20) to Maury's *I. (Sergipia) posidonomyaeformis* are probably imperfectly preserved specimens of the pectinid *Entolium*.

Genus *Entolium* Meek 1865

Several fragments of *Entolium* occur in the present collection but all are poorly preserved and add nothing to the previous description (Thomson and Willey, 1975).

Genus *Camptonectes* Agassiz *in* Meek 1864

Camptonectes s.l. sp. nov. *(?)*

Fig. 4d

Material

Two small incomplete right valves (H.3009.70a,b and 73), the best showing both internal and external moulds.

Description

The right valve is feebly inflated and is orbicular in outline with a small but well-defined posterior auricle, and a large anterior one, separated from the disc by a deep byssal notch. The hinge line is straight. The antero-dorsal margin is feebly concave and is bordered by what appear to be the denticles of an early ctenolium, now largely overgrown by later additions to the anterior auricle. The early stage of the species has a fine ornament of radial riblets and raised concentric lines which produce a distinctive net-like pattern. A similar ornament is present on the anterior auricle, but that of the posterior one is less distinct and is dominated by faint growth lines. Above a shell height of about 5 mm there is a gradual transition to an almost smooth late stage with periodic growth steps. Faint curved radial striae, which are oblique to the last of the radial riblets, are visible on the antero-ventral part of the shell.

Remarks

The net-like or reticulate ornament on the early stage of this species is typical of *Camptochlamys* Arkell, a Middle to Upper Jurassic subgenus of *Camptonectes* (Hertlein *in* Moore, 1969, p. *N*352). However, the smoother late-stage is more typical of *Camptonectes s.s.*

A unique left valve (Fig. 4e) from the Tithonian of the Ablation Point area, Alexander Island, also shows a similar change in ornament. On that specimen the transition between the two styles of ornament occurs earlier and is a little more abrupt. Extremely fine curved radial striae are present towards the postero-ventral margin of the shell. Although the two specimens from the Gibbon Bay Shale and that from Ablation Point share an unusual change in ornament, specific identity of the two forms is left open until paired valves can be found at either locality. Even so, it is likely that the two are closely related, and they further demonstrate the close relationship between *Camptonectes s.s.* and *Camptochlamys*.

SCAPHOPODA

Fig. 4f

Internal and external moulds of three curved, tusk-shaped shells (H.3009.46–48) may represent scaphopod remains. The best example (Fig. 4f) is 12 mm long, 0.5 mm wide at its narrowest end, and 2.3 mm wide at its widest end (crushed). The shell is now replaced by a dark brown mineral, which is as yet unidentified but is similar to that seen by the author to have replaced some shells of other scaphopod-like remains, bivalves and cephalopods in the Lower Cretaceous rocks of Alexander Island. No external ornament is present on any of the specimens.

AMMONOIDEA

Genus *Lytoceras* Suess 1865

Lytoceras sp.

Fig. 4g

Material

Nine small, mostly fragmentary specimens from Gibbon Bay (H.3009.5–13).

Description and remarks

The best and largest specimen (Fig. 4g) has a maximum diameter of about 20 mm, although the aperture is now broken. Its shell is evolute with slowly expanding whorls which are barely in contact. Whorl cross-sections are strongly compressed but, as with all the other fossils from the Gibbon Bay Shale, they have been crushed. On all specimens, the ornament is feeble and consists of fine, slightly convex, crinkled riblets; on the best specimen periodic larger ribs seem to delineate the anterior margins of narrow, feebly impressed constrictions.

Apart from the strongly compressed whorl cross-sections, which are at least partly secondary, the specimens exhibit the general characteristics of *Lytoceras s.s.* However, the small size and poor preservation of the material do not warrant a specific identification.

Perhaps the morphologically closest species described from Antarctica is the finely ribbed *Lytoceras* sp. γ of (?) Tithonian age, from blocks in a moraine near Ablation Point, Alexander Island (Thomson, 1979, p. 9, pl. IIj and k). Nevertheless, the bimodal ribbing of that species cannot be demonstrated in the present specimens.

BELEMNOIDEA

Genus *Belemnopsis* Bayle 1878

Belemnopsis sp. juv. ex gr. *uhligi* Stevens 1963

Fig. 4h and i

Material

A single guard from Gibbon Bay (H.3009.69).

Description and remarks

This unique specimen (Fig. 4h and i) shows affinities with the *Belemnopsis uhligi* group or complex (Stevens, 1965, p. 206, table 20). Although the guard is only 26 mm long, it includes part of the alveolar region. It is cylindrical, non-hastate, and laterally compressed with a steadily tapering apex. In a cross-section approximately mid-way along the guard, the apical line is placed somewhat ventrally. The ventral groove is broad and moderately deep, shallowing adapically and terminating just before the apex is reached.

B. uhligi was erected by Stevens (1963) to accommodate a number of late Jurassic-early Cretaceous belemnites normally included with *B. gerardi* (Oppel), but which differ from the true *gerardi* in being non-hastate and in having a relatively broader ventral groove. Apart from its compressed cross-section (which may be at least partly due to crushing) the present specimen compares reasonably well with the holotype of *B. uhligi* itself (Stevens, 1963, pl. 99, figs 1–3 and 5). However, its ventral groove is relatively shallower than that of the type (a much larger specimen), and in this respect it is more like *B. aucklandica trechmanni* (Stevens, 1965, pls 9–12), except that it has a proportionally shorter guard and lacks the hastation of that species. The type of *B. uhligi* is one of Uhlig's (1910) examples of "*B. gerardi*" from the Spiti Shales. Two other examples of his (Uhlig, 1910, pl. 93, figs 5a and b, 7a and b) are substantially larger than the present specimens but they compare well on a proportional basis and also have slightly compressed cross-sections at least in the alveolar region.

Other comparable, although larger, specimens include Stolley's (1929, pl. 2, fig. 4) *B.* aff. *gerardi* from the Fajet limestone (Tithonian?) of Timor. In ventral aspect the resemblance is good, although Stolley omitted to show a cross-section of his example, which would have permitted closer comparison. An example from the Sula Islands, illustrated by Kruizinga (1921, pl. 1, fig. 1) as *B. gerardi* (Oppel) and included by Stevens (1963) in *B. uhligi*, also shows a good general resemblance but it is again a much larger specimen and has a more deeply incised ventral groove.

B. aff. *uhligi* from the Tithonian–Berriasian of Alexander Island (Willey, 1973, p. 39, fig. 4a and b) differs in having a groove which does not extend as close to the apex as it does in the present specimen.

In the absence of adult guards, it is not possible to identify the present juvenile with certainty. Nevertheless, it clearly belongs to the *uhligi* group and is perhaps more closely related to the type species than any other members of the group.

Age of the Gibbon Bay Shale

The known fauna of the Gibbon Bay Shale has been considerably extended by the present collection and now includes:

Rhynchonellid (?) indet.
Gastropoda spp. indet.
Nucula (Leionucula ?) sp.
Nuculana (?) sp.
Steinmannia (?) sp.
Entolium sp.
Camptonectes sp. nov. *(?)*
Exogyra (?) sp.
Astarte sp.
Belemnopsis ju. ex gr. *uhligi* Stevens
Lytoceras sp.
Scaphopods (?)

On the basis of circumstantial evidence it was previously suggested that the age of the Gibbon Bay Shale was Lower Cretaceous (Thomson and Willey, 1975, p. 20). However, some of the new fossil finds enable a more direct estimate to be made. Although the ammonites are species of the long-ranging genus *Lytoceras* and cannot be identified below the generic level, the belemnite and one of the bivalves are more diagnostic.

The belemnite is a *Belemnopsis* of the *uhligi* group. *B. uhligi* itself occurs in the Middle Kimmeridgian to Middle (or Upper?) Tithonian of India, Pakistan, Indonesia and New Guinea (Stevens, 1963, p. 695). In New Zealand, members of the complex *(B. aucklandica aucklandica* and *B. aucklandica trechmanni)* occur in the Ohauan and Puaroan stages (Kimmeridgian and Tithonian). Relatives also occur in the Uitenhage Formation of South Africa and the Valanginian of Malagasy (Stevens, 1965, p. 164–5). *B.* aff. *uhligi* has been reported from the Tithonian–Berriasian of Alexander Island (Willey, 1973).

The bivalve *Camptonectes* sp. nov. *(?)* compares well with a unique specimen from the Tithonian of Alexander Island. Thus, in view of the close affinities of the belemnite to *B. uhligi* proper, it is likely that the age of the Gibbon Bay Shale is late Jurassic (probably Tithonian) or earliest Cretaceous at the youngest.

3. *Spence Harbour Conglomerate*

In situ marine fossils occur only in the sandstones of Matthews Island (Fig. 3b) and even then are extremely rare. A few more were found in scree and moraine. The 14 new specimens obtained represent a substantial increase over the previous collection, and include the first recorded occurrences of gastropods and belemnites from the formation.

Gastropoda

Fig. 5

A large patelliform gastropod (H.3008.3; Fig. 5) is preserved as an incomplete external mould

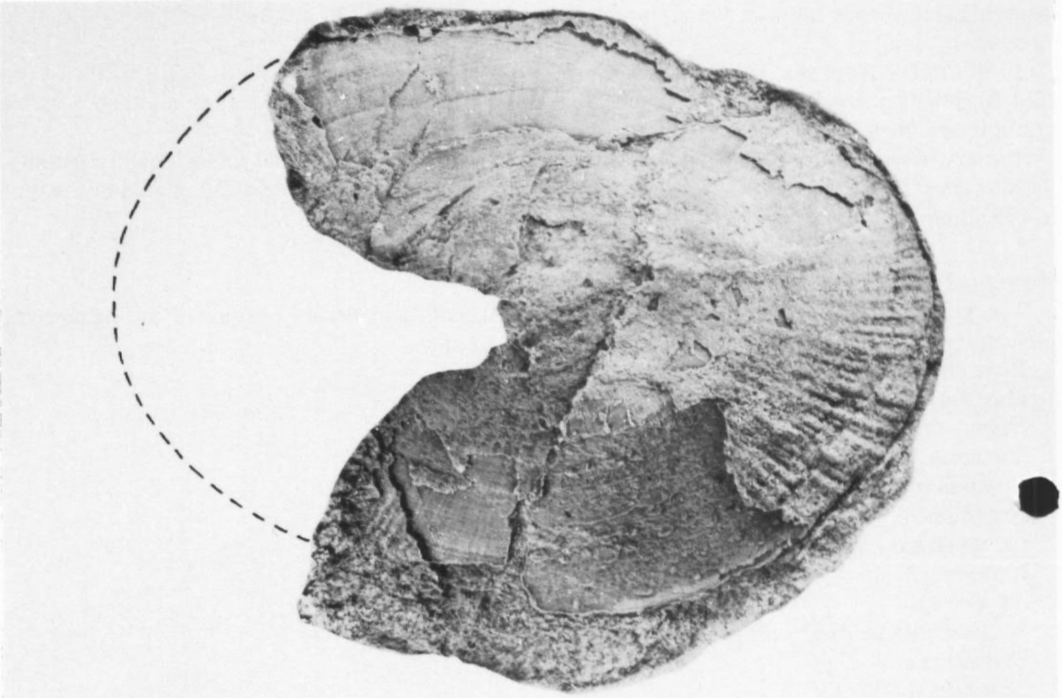


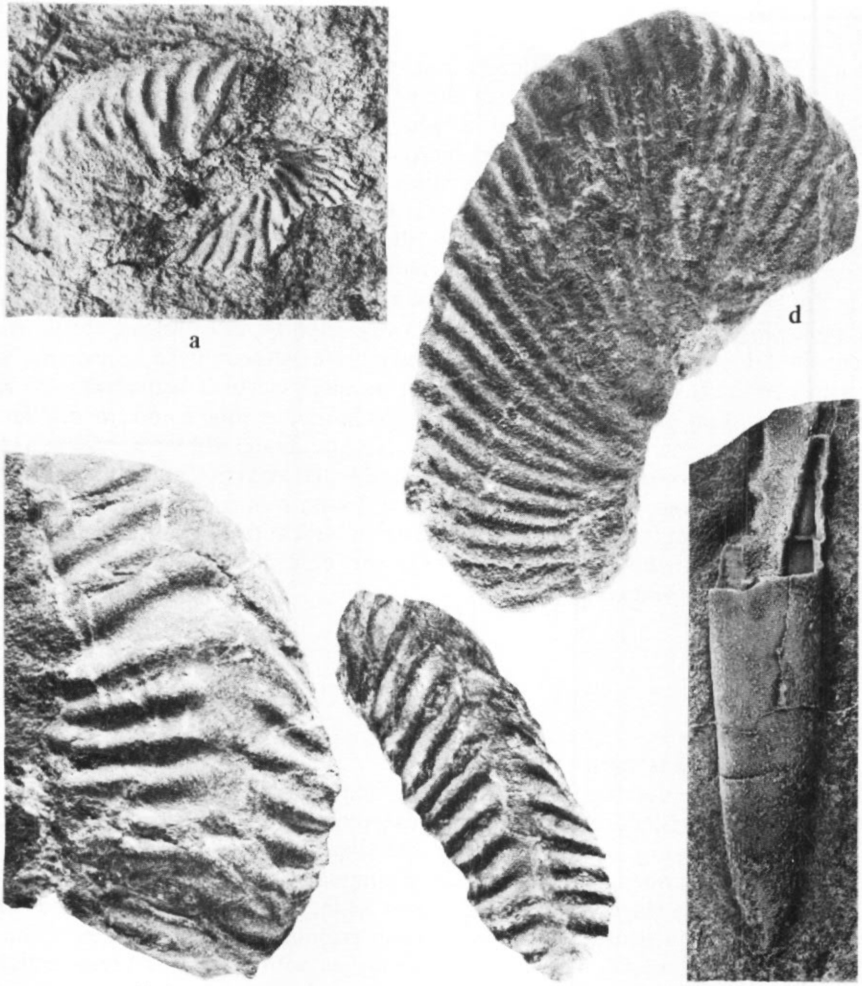
Fig. 5. Large patelliform gastropod from moraine debris derived from sandstones within the Spence Harbour Conglomerate; ×1, (H.3008.3).

in a sandstone slab from the northern moraine. The shell was originally about 11 cm long, 8 cm wide and is 3.5 cm high in its present, partly crushed state; shell material (about 2 mm thick) adhering to the mould shows no obvious traces of the muscle scars on its internal surface. External ornament consists of numerous rounded radial ribs that appear to be alternately coarser and finer on the small area over which they are preserved. Without details of the muscle scars, this specimen is unidentifiable at generic or higher levels. However, as fossil limpets are relatively rare, the specimen has an interest far outweighing its poor preservation. It shows little resemblance to the several known circum-Pacific Cretaceous species, generally referred to *Anisomyon* Meek and Hayden (Kanie, 1975, 1977). The ornament and regular shape of the present species are compatible with a tentative assignment to the Patellidae.

Ammonoidea

Fig. 6 a–d

At least two genera of ammonites are present in the new collection. The first (Fig. 6d) is represented by an obliquely crushed fragment which probably belongs to the same species as a previously illustrated indeterminate ventral mould (Thomson, 1975, fig. 1a). The present specimen is ornamented with relatively dense radial ribs, bundled in twos or threes as umbilical tubercles or bullae. Long intercalated ribs that stop a little short of the tubercles also occur. With such poor material it is pointless to speculate at length as to its specific identity. However, the two fragments together suggest an original strongly inflated shell with an ornament reminiscent of a variety of ammonites, including the early Cretaceous Olcostephanidae, some inflated late Cretaceous Kossmaticeratidae, and even some inflated middle to late Jurassic Stephanocerataceae. Similarities with olcostephanids are probably the most marked, and the associa-



a b c d e

Fig. 6. Cephalopoda from sandstones in the Spence Harbour Conglomerate of Matthews Island.
a. Indeterminate berriasellid ammonite; internal mould of a medium-sized individual; × 1, (H.3006.7a).
b. Indeterminate berriasellid ammonite; internal mould of a large dorso-ventrally crushed individual, showing a change from ribbing interrupted on the venter to ribbing which is continuous; × 1, (H.3006.5).
c. Indeterminate berriasellid ammonite; venter of a medium-sized dorso-ventrally crushed specimen, showing interrupted ribbing; × 1, (H.3006.4).
d. Olcostephanid (?) ammonite; internal mould of an obliquely crushed example; × 1, (H.3006.3).
e. Belemnite guard; latex cast from the external mould of a large robust form, showing the apical end of the alveolar cavity; × 1, (H.3009.1).

tion of the present fragments with those of a probable berriasellid (below) suggest that this is the most likely identification. Because of the lack of constrictions, probable strongly inflated whorl forms, and relatively low umbilical tubercles, an identification with the Olcostephaninae proper (and in particular *Olcostephanus*) rather than with the Spiticeratinae, seems the more likely. Occurrences of *Olcostephanus* in South America have been described in detail by Riccardi and others (1971). Their descriptions of considerable variation within some species, some of which may be sexual, render a more precise identification of the present material unwarranted.

The second (Fig. 6a–c) is represented by three crushed individuals in the present collection (H.3006.4, 5, 7a and b). Two obliquely crushed moulds of small individuals, previously compared to some Berriasellidae or Hoplitidae (Thomson, 1975), almost certainly represent juvenile examples of the same species. The form of the shell is unknown, although the juveniles and specimen H.3006.7a and b suggest that it was moderately evolute. In individuals up to 30–40 mm diameter the venter was flattened, but on large examples (H.3006.4 and 5) it appears to be more rounded. Ornament consists of prominent primary ribs which become almost bullate near mid-flank where they branch into two stout secondaries (Fig. 6). On the earliest stages preserved, there also appear to be a few simple ribs. The secondary ribs are straight to feebly concave and they are slightly projected at the ventral shoulder. On the smaller specimens, the secondaries are interrupted along the mid-ventral line by a smooth band (Fig. 6c), but on the largest example (Fig. 6b) they continue across, bowed slightly forward and a little reduced in prominence; the latter specimen also bears a constriction. Although the specimens cannot be identified with certainty, the style of the ornament probably accords better with the Berriasellidae than with that of any other ammonite group. The bifurcate ribbing and smooth band on the venter are seen on many members of the sub-family Neocomitinae; ribbing as coarse as that seen here and the presence of constrictions could suggest affinities with the genus *Kilianella* Uhlig. A possible *Kilianella* has been reported from Annenkov Island near South Georgia (Thomson and others, in press), but in that form the ribbing is less prominent and is not as persistently bifurcate.

No further examples of the "*Puzosia*"-like fragments described previously (Thomson, 1975) were obtained with the present collection.

BELEMNOIDEA

Fig. 6e

Four belemnite specimens were obtained from the Matthews Island sandstones: two from the debris associated with the outcrop (H.3006.1 and 2) and two (H.3007.1 and 2) from the moraine at the northern end of the island. All are poorly preserved and lack sufficient details to make even a generic assignment with any confidence. Their identification must await the collection of better material, but they are described here for the sake of completeness.

Specimen H.3006.2 is a fragmentary guard, about 38 mm long, embedded in sandstone. Some of the original calcite is present towards the alveolar region, although the apex of the guard is preserved as an external mould. The guard is cylindrical with a circular cross-section and an acutely tapered apex with an apical angle of 17°. A broad, relatively shallow ventral groove is present on the exposed upper face of the guard, but how far this might have extended towards the apex is unknown. The general shape of the guard and the clearly marked ventral groove suggest probable affinities with the genus *Belemnopsis* Bayle.

Specimen H.3008.2, a completely decalcified guard, preserved as an external mould in a sandstone slab from moraine, is devoid of surface ornament, but has a distinctive, slightly hastate needle-shaped outline. In its present state, the guard is separated into nine discrete sections, which show that the cross-section is more or less circular throughout its length. Reassembly of the fragments suggest a length of about 56 mm, with a maximum diameter of 3.7 mm about 30 mm from the apex. If any surface grooves were originally present, they were either too fine to be preserved in the coarse matrix, or were present in the "upper" surface of the guard, now represented by the open face of the mould. The marked acicular form of the guard is somewhat reminiscent of *Cylindroteuthis* Bayle. However, in that genus the guard outline is typically cylindrical rather than hastate, a condition more typical of the Belemnopseidae. Without further diagnostic characters (e.g. grooves) this specimen is unidentifiable. *Cylindroteuthis* is mainly known from the Northern Hemisphere, although a few specimens are known from the Middle Jurassic of New Zealand and perhaps also South America (Stevens, 1965). A second decalcified specimen (H.3006.1) is from the apical end of another small slim guard and may belong to the same species as the above described specimen.

The fourth specimen (H.3008.1, Fig. 6e) is a largely external mould of a short robust cylindro-conical guard with its alveolus now filled with coarse sandstone. The only (?) original calcite is confined to an incomplete ring around the alveolar cavity. The alveolus has an angle of 20° and extends well down into the guard. It appears that the protoconch was central or displaced slighty to one side (? ventrally). In cross-section the guard is more or less circular, perhaps slightly compressed. Surface grooves are absent from the guard as it is preserved, and if originally present must have been on the face now on the open side of the mould. The total length of the guard is about 75 mm, and the maximum diameter is 14 mm. Like the previous specimen, this one has a distinctive form, but lacks sufficient features to make an identification. The stocky guard and deeply embedded alveolus are reminiscent of *Pachyteuthis* Bayle, but the genus is only known with certainty from the Northern Hemisphere.

Age of the Spence Harbour Conglomerate

The total known fauna from the sandstones of Matthews Island is now as follows:

Patelliform gastropod
Entolium (?) sp.
Olcostephanid ammonite
Berriasellid ammonite
"Puzosia"-like ammonite
Belemnopsis (?) sp.
Belemnites (genera uncertain).

On the basis of ammonite fragments, thought to be from a "*Puzosia*"-like species, it was first suggested (Thomson, 1975) that the age of the Spence Harbour Conglomerate was "Middle to Upper Cretaceous". Although a more likely systematic identification cannot be offered for these fragments at present, the presence of marginally better preserved ammonite remains in the new collection places this original age estimate in doubt. Taken as a pair, the olcostephanid and berriasellid ammonites are suggestive of a Neocomian (pre-Aptian Cretaceous) age, whereas the possible presence of *Olcostephanus* itself would more precisely imply a Middle Valanginian to Middle Hauterivian age.

None of the belemnites has enough diagnostic features preserved to be of much stratigraphical value, although it is significant that the three species present seem to be most closely related to pre-late Cretaceous forms.

A pre-late Cretaceous age for the Spence Harbour Conglomerate is also indicated by unpublished K-Ar whole rock dating of a unique basic dyke, which cuts the conglomerate on Matthews Island (Figs 2 and 3b). Three samples, collected by P. F. Barker (University of Birmingham) and processed by Dr R. J. Pankhurst, gave an age close to 90 Ma.

Since there is nothing in the preservation of any of the fossils in the sandstones of Matthews Island to suggest that some might be derived and that faunas of different ages may be mixed, the identification of "*Puzosia*"-like fragments is enigmatic. All the new evidence presented here favours a pre-late Cretaceous age for the Spence Harbour Conglomerate and, on the basis of the olcostephanid and berriasellid ammonites, a Neocomian age seems the most probable.

Age Significance of the Fossils

These new collections, albeit sparse and often poorly preserved, significantly improve our biostratigraphical knowledge of the late Mesozoic successions of the South Orkney Islands (Table II). Of particular importance is recognition that the faunas of the Matthews Island sandstones are probably Neocomian rather than "Middle to Upper Cretaceous" in age, thus restricting the known period of sedimentation in western Lewthwaite Strait to the late Jurassic and early Creta-

TABLE II. STRATIGRAPHICAL AGE OF THE LATE MESOZOIC SEQUENCES OF WESTERN LEWTHWAITE STRAIT

Rock unit	*Stratigraphical age*	
	Thomson, 1975 Thomson and Willey, 1975	This paper
Spence Harbour Conglomerate (Matthews Island sandstones)	Middle to Upper Cretaceous	Neocomian
Gibbon Bay Shale	(?) Lower Cretaceous	Late Jurassic (Tithonian) or earliest Cretaceous
Calcareous grit sequence (not *in situ*)	Upper Jurassic to earliest Cretaceous	Late Jurassic to earliest Cretaceous

ceous. No marine fossils are known from the Powell Island Conglomerate, but the simplest geological interpretation of the area is that the Powell Island and Spence Harbour Conglomerates are coeval (Table I). The early Jurassic age, tentatively assigned to the Powell Island Conglomerate on the basis of a preliminary assessment of the flora (Orlando *in* Thomson, 1973), is in need of re-investigation. There appear to be close similarities between Jurassic and early Cretaceous "cycadophyte"/fern floras of the Antarctic Peninsula area, and there is considerable difficulty in distinguishing between the two. For example, the fossil flora of Hope Bay, northern Antarctic Peninsula has been widely reported as being Middle Jurassic, although its age has been disputed (cf. Taylor and others, 1979, p. 53). A very similar flora to that of Hope Bay has been collected from the Latady Formation of south-eastern Palmer Land and marine fossils from the same general area suggest a late Jurassic age (Rowley and Williams, in press). It is likely, therefore, that the fossil flora from the Powell Island Conglomerate is younger than presently supposed.

ACKNOWLEDGEMENTS

The author is indebted to Dr I. W. D. Dalziel (Columbia University, New York) for inviting him to join the US R/V *Hero* Cruise 77/1 to the South Orkney Islands, financed by the US National Science Foundation. Thanks are due to Captain P. Lennie and the crew of R/V *Hero* for their support and the many landings often made under extremely difficult conditions. Many of the fossils were collected by other geological members of the cruise; Dr D. H. Elliot, N. A. Wells and Dr W. J. Zinsmeister (Institute of Polar Studies, Ohio) and J. W. Thomson.

Dr G. R. Stevens (New Zealand Geological Survey) and Dr L. E. Willey gave considerable help in identifying the belemnites, and Dr P. F. Rawson (Queen Mary College, London) provided some useful advice on the ammonites.

MS received 4 November 1980; accepted in revised form 8 January 1981

REFERENCES

ADIE, R. J. 1957. The petrology of Graham Land: III. Metamorphic rocks of the Trinity Peninsula Series. *Falkland Islands Dependencies Survey Scientific Reports*, No. 20, 26 pp.

COVACEVICH, V. 1976. Fauna valanginiana de Península Byers, Isla Livingston, Antártica. *Revta. geol. Chile*, No. 3, 25–56.

DALZIEL, I. W. D. 1971. Structural studies in the Scotia Arc: the South Orkney Islands. *Antarct. Jnl U.S.*, **6,** No. 4, 124–26.

DALZIEL, I. W. D., ELLIOT, D. H., THOMSON, J. W., THOMSON, M. R. A., WELLS, N. A. *and* W. J. ZINSMEISTER. 1977. Geologic studies in the South Orkney Islands: R/V *Hero* Cruise 77/1, January 1977. *Antarct. Jnl U.S.*, **12,** No. 4, 98–101.

DALZIEL, I. W. D., ELLIOT, D. H., JONES, D. L., THOMSON, J. W., THOMSON, M. R. A., WELLS, N. A. *and* W. J. ZINSMEISTER. 1981. The geological significance of some Triassic microfossils from the South Orkney Islands, Scotia Ridge. *Geol. Mag.* **118,** No. 1, 15–25.

ELLIOT, D. H. *and* N. A. WELLS. In press. Mesozoic alluvial fans of the South Orkney Islands. (*In* CRADDOCK, C., *ed. Antarctic geoscience*. Madison, University of Wisconsin Press.)

FERUGLIO, E. 1936. Palaeontographia patagonica. Pt. 1. *Memorie Ist geol. miner. Univ. Padova,* **11,** 1–192.

GRIKUROV, G. E., KRYLOV, A. Ya. *and* Yu. I. SILIN. 1967. Absolyutnyy vozrast nekotorykh porod dugi Skotiya i Zemli Aleksandra I (Zapadnaya Antarktika) Absolute age of some rocks from the Scotia arc and Alexander I Land (Western Antarctica). *Dokl. Akad. Nauk SSSR*, Geology, **172,** No. 1, 168–71. English translation: *Dokl. (Proc.) Acad. Sci. USSR.*, Geological sciences sect., **172,** 19–22.

KANIE, Y. 1975. Some Cretaceous patelliform gastropods from the northern Pacific region. *Sci. Rep. Yokosuka Cy Mus.*, No. 21, 44 pp.

KANIE, Y. 1977. Succession of Cretaceous patelliform gastropods in the northern Pacific region. (*In* Mid-Cretaceous Events, Hokkaido Symposium, 1976. *Spec. pap. palaeont. Soc. Japan*, No. 21, 53–62.)

KRUIZINGA, P. 1921. De belemnieten uit de jurassische afzettingen van de Soela-eilanden. *Jaarb. Mijnw. Ned.-Oost-Indië*, **49** (for 1920), 158–89.

MATTHEWS, D. H. 1959. Aspects of the geology of the Scotia arc. *Geol. Mag.*, **96,** No. 6, 425–41.

MATTHEWS, D. H. *and* D. H. MALING. 1967. The geology of the South Orkney Islands: I. Signy Island. *Falkland Islands Dependencies Survey Scientific Reports*, No. 25, 32 pp.

MILLER, J. A. 1960. Potassium-argon ages of some rocks from the South Atlantic. *Nature, Lond.*, **187,** No. 4742, 1019–20.

MOORE, R. C. ed. 1969. *Treatise on invertebrate paleontology. Part N. Volume 1. Mollusca 6. Bivalvia.* Kansas, The Geological Society of America, Inc. and the University of Kansas.

RAUP, D. M. 1973. Depth inferences from vertically imbedded cephalopods. *Lethaia*, **6,** No. 3, 217–25.

REX, D. C. 1976. Geochronology in relation to the stratigraphy of the Antarctic Peninsula. *British Antarctic Survey Bulletin*, No. 43, 49–58.

RICCARDI, A. C., WESTERMANN, G. E. G. *and* R. LEVY. 1971. The Lower Cretaceous Ammonitina *Olcostephanus, Leopoldia* and *Favrella* from west-central Argentina. *Palaeontographica*, Abt. A. **136,** 83–121.

ROWLEY, P. D. *and* P. L. WILLIAMS. In press. Geology of the northern Lassiter Coast and southern Black Coast, Antarctic Peninsula. (*In* CRADDOCK, C., *ed. Antarctic geoscience*. Madison, University of Wisconsin Press.)

STEVENS, G. R. 1963. The systematic status of Oppel's specimens of *Belemnopsis gerardi*. *Palaeontology*, **6,** Pt. 4, 690–98.

STEVENS, G. R. 1965. The Jurassic and Cretaceous belemnites of New Zealand and a review of the Jurassic and Cretaceous belemnites of the Indo-Pacific region. *Palaeont. Bull., Wellington*, No. 36, 283 pp.

STOLLEY, E. 1929. Über ostindische Jura Belemnitiden. (*In* STOLLEY, E. *Palaeontologie von Timor*. Stuttgart, Sinsel & Co., Lief 16, Abh. 29, 91–213.)

TAYLOR, B. J., THOMSON, M. R. A. *and* L. E. WILLEY. 1979. The geology of the Ablation Point–Keystone Cliffs area, Alexander Island. *British Antarctic Survey Scientific Reports*, No. 82, 65 pp.

THOMSON, J. W. 1968. The geology of the South Orkney Islands: II. The petrology of Signy Island. *British Antarctic Survey Scientific Reports*, No. 62, 30 pp.

THOMSON, J. W. 1971. The geology of Matthews Island, South Orkney Islands. *British Antarctic Survey Bulletin*, No. 26, 51–57.

THOMSON, J. W. 1973. The geology of Powell, Christoffersen and Michelsen Islands, South Orkney Islands. *British Antarctic Survey Bulletin*, Nos. 33 and 34, 137–61.

THOMSON, J. W. 1974. The geology of the South Orkney Islands: III. Coronation Island. *British Antarctic Survey Scientific Reports*, No. 86, 39 pp.

THOMSON, M. R. A. 1967. A probable Cretaceous invertebrate fauna from Crabeater Point, Bowman Coast, Graham Land. *British Antarctic Survey Bulletin*, No. 14, 1–14.

THOMSON, M. R. A. 1975. Fossils from the South Orkney Islands: II. Matthews Island. *British Antarctic Survey Bulletin*, No. 40, 75–79.

THOMSON, M. R. A. 1979. Upper Jurassic and Lower Cretaceous ammonite faunas of the Ablation Point area, Alexander Island. *British Antarctic Survey Scientific Reports*, No. 97, 65 pp.

THOMSON, M. R. A. In press. Mesozoic Paleogeography of West Antarctica. (*In* CRADDOCK, C., *ed. Antarctic geoscience*. Madison, University of Wisconsin Press.)

THOMSON, M. R. A. *and* L. E. WILLEY. 1975. Fossils from the South Orkney Islands: I. Coronation Island. *British Antarctic Survey Bulletin*, No. 40, 15–21.

THOMSON, M. R. A., TANNER, P. W. G. *and* D. C. REX. In press. Fossil and radiometric evidence for ages of deposition and metamorphism of sedimentary sequences on South Georgia. (*In* CRADDOCK, C., *ed. Antarctic geoscience*. Madison, University of Wisconsin Press.)

UHLIG, V. 1910. The fauna of the Spiti Shales. *Mem. geol. Surv. India Palaeont. indica*, Ser. 15, **4,** Fasc. 3, 307–95.

WEAVER, C. E. 1931. Paleontology of the Jurassic and Cretaceous of west central Argentina. *Mem. Univ. Wash.*, **1,** 469 pp.

WEIR, J. 1930. Mesozoic Brachiopoda and Mollusca from Mombasa (*In* GREGORY, J. W. *and others*. Reports on geological collections from the coast lands of Kenya Colony made by Miss M. McKinnon Wood. *Monogr. geol. Dep. Hunter. Mus.*, No. 4, 77–102.)

WILLEY, L. E. 1973. Belemnites from south-eastern Alexander Island: II. The occurrence of the Family Belemnopseidae in the Upper Jurassic and Lower Cretaceous. *British Antarctic Survey Bulletin*, No. 36, 33–59.