

PALAEONTOLOGY AND ICHNOLOGY OF THE CUMBERLAND BAY FORMATION, SOUTH GEORGIA

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ABSTRACT. The Lower Cretaceous turbidites of the Cumberland Bay Formation (CBF), South Georgia, contain the bivalve *Aucellina* and the ichnogenera *Chondrites*, *Monocraterion*, *Palaeophycus*, *Planolites*, *Taenidium* and various forms *incertae sedis*. Despite the effects of metamorphism and tectonism, which appear to have destroyed microfossils in the CBF, the low faunal diversity is considered to be original. The CBF is thought to have been deposited in at least moderately deep water in a restricted basin, characterized by low oxygen levels and inhabited by a low-diversity ichnofauna and an opportunistic hard-bodied epifauna.

South Georgia comprises elements of an island-arc-back-arc basin system that was active from the Jurassic until the mid-Cretaceous (Dalziel and others, 1975). Most of the island is made up of the Cumberland Bay Formation (CBF: Fig. 1), a thick, deformed sequence of turbidites. Although fossils are rare, the formation seems to be mainly early Cretaceous in age (Thomson and others, 1982). The turbidites, mainly andesitic volcanoclastic greywackes (Winn, 1978; Tanner and others, 1981), are separated from their island-arc provenance and its basement by a major high-angle fault (Tanner, 1982). A second turbidite unit, the Sandebugten Formation, which is predominantly formed of silicic detritus, was probably derived from the continental side of the back-arc basin (Winn, 1978). The two turbidite formations are probably of equivalent age, but the Cumberland Bay Formation is thrust over the Sandebugten Formation (Tanner, 1982).

Whereas few macrofossils have been found in the Cumberland Bay Formation (Thomson and others, 1982), trace fossils are widespread and locally numerous. Fossil wood also occurs at several localities on the island (Jefferson and Macdonald, 1981).

All the fossils found *in situ* in the formation suggest an Aptian age (Thomson and others, 1982). However, belemnite fragments of possibly earlier age have been recovered from erratic blocks on the north-east coast (Stone and Willey, 1973). These have affinities with *Belemnopsis* (Upper Jurassic-lowest Cretaceous). Although their source is not known, the erratics have a CBF lithology (Stone and Willey, 1973) and were found in the region where the lowest structural levels of the formation crop out (Tanner, 1982).

The Annenkov Island Formation, which is thought to be laterally equivalent to the CBF (Suárez and Pettigrew, 1976) is assigned to the Lower Cretaceous, but much of the fauna is poorly preserved and difficult to compare with described forms (Thomson and others, 1982). Microfossils from the Larsen Harbour Formation, just below the conformable contact with the overlying Annenkov Island Formation, indicate an uppermost Jurassic or lowermost Cretaceous age (Tanner and others, 1981); this implies that the CBF may be at least Neocomian in part.

Literature on trace fossils in West Antarctica and the Scotia arc has been reviewed by Taylor (1967).

BODY FOSSILS

Three of the 12 fossil localities cited by Thomson and others (1982) (their localities A, N and O) were found during the course of this study (Fig. 1). These

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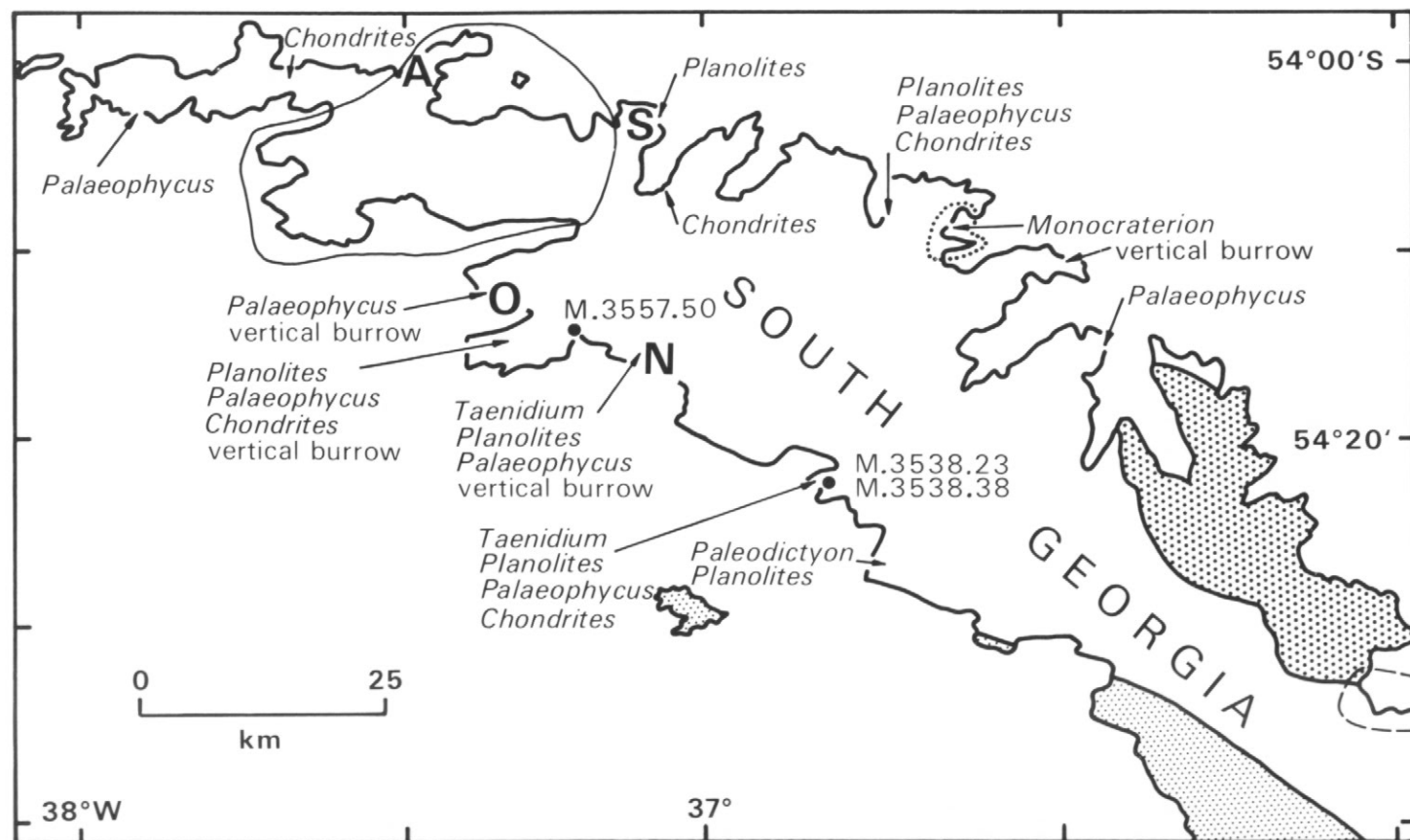


Fig. 1. Map of northern South Georgia showing the distribution of trace fossils found during this work (including the *Paleodictyon* of Tanner and others, 1981), the regions from which previous authors have described trace fossils and the location of samples used in microfossil analysis. Localities A, N and O correspond to those in Thomson and others (1982, fig. 1). S marks the area studied by Skidmore (1972). . . . , Limits of area studied by Wilkins (1947). ----, Limits of area studied by Stone (1975, 1980). —, Limits of area studied by Clayton (1976). ●, Location of samples for microfossil analysis. Cumberland Bay Formation: unshaded. Sandebugten Formation: heavy stipple. Other formations: light stipple.

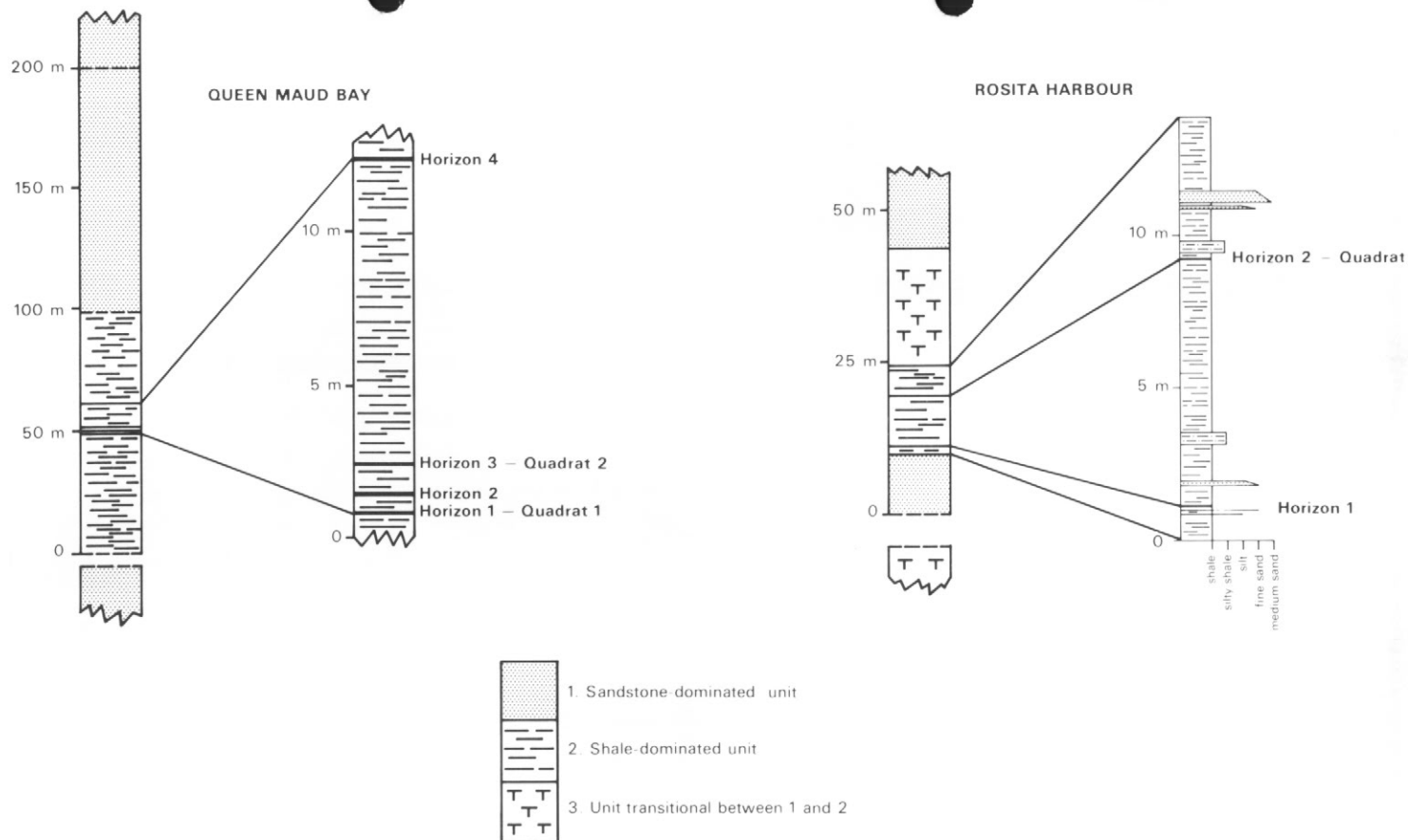


Fig. 2. Stratigraphical section showing succession of major units at fossil localities, with detailed sedimentological log of fossiliferous horizon at Rosita Harbour. In the section for Queen Maud Bay, the interval between 100 and 200 m is inaccessible but is probably dominated by the sandstone facies.

localities are described below in detail and possible reasons for the sparsity of the fauna are discussed.

Jossac Bight (locality N)

An indeterminate gastropod, found within a thick, coarse-grained turbidite bed at this locality, was not collected, but fine sediment seemed to infill an original shell. To date, the specimen is the only definite example of a macrofossil found within a CBF turbidite.

Queen Maud Bay (locality O)

At this, the most richly fossiliferous locality discovered, bivalves were found at four different levels in an 11-m-thick sequence (Fig. 2). The fossil beds occur towards the middle of nearly 100 m of shale-dominated succession, which is a rather thick development of shale for south-west coast (Tanner and Macdonald, in press). The only coarse-grained rocks are rare beds of flat-laminated fine sandstone (less than 2 cm thick) and occasional pale-weathering silty shale bands of similar thickness.

The fossils, poorly preserved as external moulds, casts of dissociated valves and (less frequently) as internal moulds are distorted by penetrative cleavage but they can all be assigned to the pteriomorph genus *Aucellina* Pompeckj, with forms similar to *A. andina* Fergulio and *A. radiatostriata* Bonarelli being recognized (Thomson and others, 1982).

At levels 1 and 3, which yielded the most specimens, left and right valves are present in roughly equal numbers, and the spacing of both complete valves and fragments was even across the bedding planes (Table I).

Rosita Harbour (locality A)

This locality yielded a monotypic bivalve fauna of *Aucellina* sp., preserved as external moulds and casts of dissociated valves. The shells were found at two horizons within 14-m-thick shale-dominated unit. Although the shale is much thinner here than at the previous locality, there are almost no coarse clastic incursions in this well-exposed section. The lower fossiliferous horizon had only two dissociated valves, whereas the upper one was even more densely covered than the two main horizons at Queen Maud Bay (Table I).

Discussion

The status of *Aucellina* has recently been reviewed by Macellari (1979). The shells have a gryphaeoid form, presumably as an adaptation to lift the plane of commissure

Table I. Density of bivalves on three bedding planes at Queen Maud Bay and Rosita Harbour.

Locality	Queen Maud Bay		Rosita Harbour
	Quadrat 1	Quadrat 2	
Quadrat area (cm ²)	1 350	276	100
No. complete valves	37	14	8
No. of fragments	6	11	15
No. of valves/m ²	274	507	800

clear of a muddy substrate. The genus is a rather variable one, the taxonomy is complicated and identification at the species level is best achieved by numerical methods.

MICROFOSSILS

Radiolaria have been reported within CBF mudstones (Clayton, 1976; Stone, 1980) but these are all poorly preserved and of little stratigraphical value (Thomson and others, 1982).

Three shale specimens (M.3538.23, M.3538.38 and M.3557.50) were selected for palynological analysis. These rocks were all from south-west coast localities (Fig. 1) and are the least tectonized shale samples collected anywhere within the formation. At the end of processing, each sample yielded a fine black organic residue which may have been spore material but was no longer identifiable (T. H. Jefferson, personal communication).

Evidently, metamorphic and tectonic effects have all but destroyed any microfossils that may have been present within the Cumberland Bay Formation.

TRACE FOSSILS

Trace fossils are the only common indicators of biological activity within the CBF. Various ichnogenera have been described by previous authors (Table II). In addition, Gregory (1915) identified various 'bryozoans', 'corals' and 'sponges' but these all proved to be trace fossils or inorganic pseudofossils (Wilckens, 1947; Thomson and others, 1982).

In the course of the present work the following ichnogenera were found: *Chondrites*, *Monocraterion*, *Palaeophycus*, *Planolites*, *Taenidium*, vertical burrows *incertae sedis* and horizontal burrows *incertae sedis*.

Table II. Summary of ichnogenera known from the Cumberland Bay Formation.

Author	Ichnogenus	Comments
Wilckens, 1947	<i>Chondrites</i>	Described <i>C. palaeozoicus</i>
	<i>Taenidium</i>	Described <i>T. lusitanicum</i>
	<i>Helminthopsis</i>	Described <i>H. labyrinthica</i>
	<i>Palaeophycus</i>	Described <i>P. arthropycoides</i>
	<i>Cylindrites</i>	Invalid name, could be equivalent to <i>Palaeophycus</i> (Häntzschel, 1975)
	<i>Gyrochorda</i>	<i>nom. null.</i> , perhaps equivalent to <i>Gyrochorte</i> (Häntzschel, 1975)
Trendall, 1959	<i>Chondrites</i>	
Skidmore, 1972	<i>Chondrites</i>	
	<i>Planolites</i>	
Stone, 1980	'Dumbbell-shape Dominichnia'	
	<i>Chondrites</i>	
	'Burrows'	Resemble <i>Taenidium</i>
Clayton, 1976	'Surface grazing trails'	<i>Helminthopsis</i>
	<i>Chondrites</i>	
	<i>Zoophycus</i>	
	'Tubular Burrows'	?
Tanner and others, 1981	'Vermicular structures'	?
	<i>Paleodictyon</i>	

There is no particular geographical zonation in the distribution of these and of the previously published examples (Fig. 1).

Burrow nomenclature

The naming of sub-horizontal burrow systems is rather confused, especially with regard to the ichnogenera *Planolites* Nicholson (1873) and *Palaeophycus* Hall (1847). There is no general agreement on the distinction of these forms, with statements contradictory to the original definition in both the *Treatise on Invertebrate Palaeontology* (Häntzschel, 1975) and in modern reviews of the subject (Osgood, 1970). The lack of general agreement among modern workers is evident from comparison of the many descriptions of *Planolites* from Crimes and Harper (1970, 1977) and Frey (1975) by various authors. These show diameter size variation from 1 to 20 mm, shape variation from straight to strongly curved; some authors restrict the name to unbranched forms while others say *Planolites* can be branched and few use the sediment-fill criterion mentioned by Häntzschel (1975, p. W89). The morphological descriptions overlap with those of the ichnogenera *Arthropycus*, *Fucusopsis*, *Helminthopsis*, *Palaeophycus* and *Scalarituba*.

In the absence of a major review of these 'simple' burrowing systems the descriptions here follow Häntzschel (1975), although the sediment fill criterion applied by Häntzschel to the distinction of *Palaeophycus* and *Planolites* has not been adopted in this paper.

Systematic descriptions

Ichnogenus *Chondrites* von Sternberg 1833

Fig. 3

Description. System of regularly branched, unornamented radial burrows of uniform diameter. Branching angle is constant and may reach third order, though second order is more common; branches never inter-penetrate. Burrows are usually

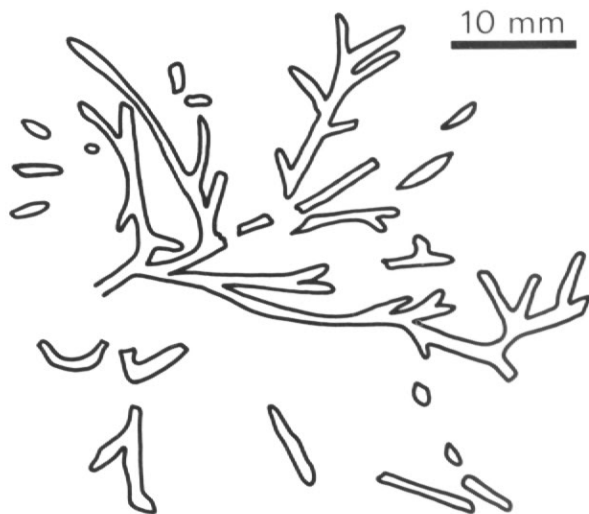
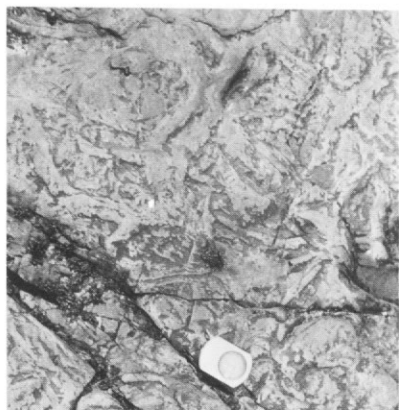


Fig. 3. *Chondrites*: camera lucida drawing from specimen M.3571.7. Scale bar is 10 m long.

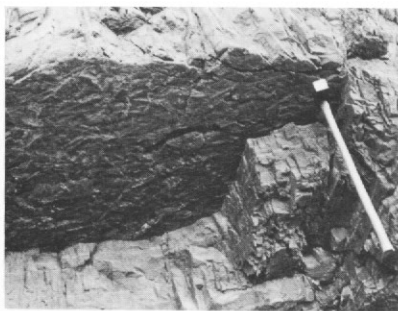
parallel or nearly parallel to stratification. On bedding planes this trace forms a dendritic network; on vertical sections it appears as a cluster of oval patches. *Chondrites* tends to be concentrated in the top of the interturbidite shales, infilled by sandstones. Whole burrow systems may reach 15 cm across and individual branches range from 0.5 to 2 mm in diameter.

Remarks. *Chondrites* is most commonly preserved as a sand infill in a mud matrix. The sandstone-filled burrows are usually preferentially prehnitized. Burrows infilled by mud-grade material occur in the laminated tops of turbidites that range in grain size from fine sand to silty shale.

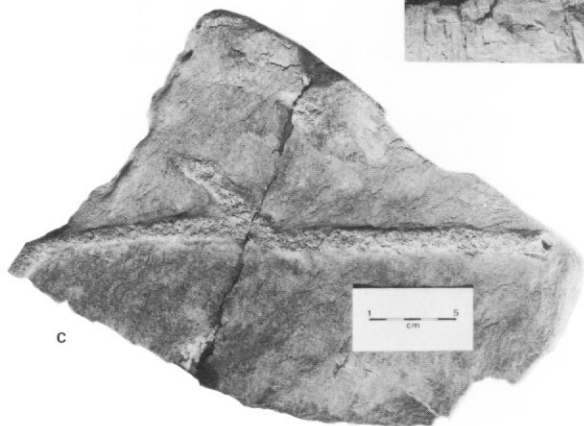
In general, the larger forms tend to be less regular and have a coarser infill than the small ones. However, much of this variation could be due to differential compaction and tectonism. Typical size variations within the specimens from South Georgia have been illustrated by Trendall (1959, fig. 14). Because of post-depositional effects, it is doubtful whether any divisions of the South Georgia *Chondrites* into ichnospecies would be meaningful. The stratigraphical range of *Chondrites* is Ordovician-Tertiary (Häntzschel, 1975). *Chondrites* has been interpreted as the feeding tunnels of a



a



b



c

Fig. 4. *Palaeophycus*: a, On a bedding plane. Compass is 74 mm long. b, On the base of a thick sandstone bed. Field of view is approximately 1 m. c, Isolate specimen in shale.

surface-dwelling organism, either a siphunculoid phobotactic worm (Simpson, 1957), or a multitentacled organism (Taylor, 1967).

Occurrence. *Chondrites* is widespread throughout the CBF.

Ichnogenus *Palaeophycus* Hall, 1847

Palaeophycus sp.

Fig. 4a, b, c

Description. Cylindrical or sub-cylindrical burrows, up to 15 mm in diameter. They are straight, unornamented, branching, subparallel to the bedding and usually occur within shale and silt units, sometimes adhering to the base of the overlying sandstone beds. Generally, many burrows occur together; they are frequently cross-cutting (Fig. 4a, b) but may be discrete (Fig. 4c).

Remarks. *Palaeophycus* traces are considered to be the 'pathways of various groups of errant animals' although 'no-one has studied the genus in detail' (Häntzschel, 1975, p. W89). Wilckens (1947) described *Palaeophycus* from the north-east coast of South Georgia, and established a new ichnospecies, *P. arthropycoides*. The stratigraphical range of the genus is Precambrian to Recent (Häntzschel, 1975).

Occurrence. *Palaeophycus* is widespread throughout the CBF.

Ichnogenus *Planolites* Nicholson 1873

Planolites sp.

Fig. 5a, b



a



b

Fig. 5. *Planolites*: a, Isolate example from north-eastern coast of South Georgia. b, Crossed burrows from same locality as (a).

Description. Straight to gently undulating, unbranched, unornamented cylindrical or subcylindrical burrows. They are parallel to the bedding and are usually 10–12 mm in diameter. They occur exclusively within the shale units, often with a sandy infill; they are usually isolate (Fig. 5a), but may cross-cut (Fig. 5b).

Remarks. The stratigraphical range is Precambrian to Recent (Häntzschel, 1975) and may date back as far as 1000 Ma (Crimes and others, 1977).

Occurrence. Planolites is widespread throughout the CBF.

Ichnogenus *Taenidium* Heer, 1877

Taenidium

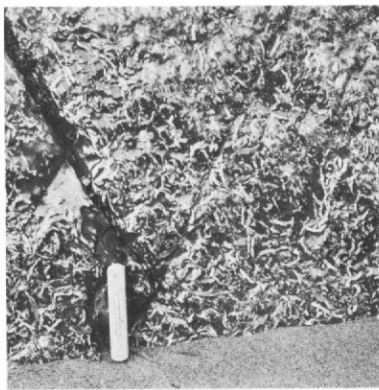
Fig. 6a, b, c

Description. Gently undulating burrows, usually flattened on the bedding plane, showing strong annular ornament and sometimes slight constriction. Branching is never more than first order, and burrows tend to be slightly expanded towards the end. They are 5 mm in diameter, filled with sand-grade material which is always preferentially prehnitized, and occur in interturbidite muds.

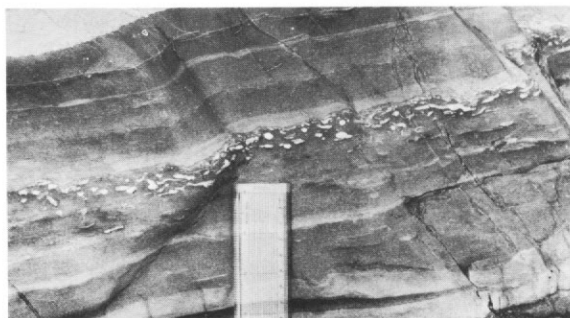
Remarks. All the *Taenidium* found resemble those figured by Häntzschel (1975,



a



b



c

Fig. 6. *Taenidium*: a, On bedding plane, south-western coast of South Georgia. b, On bedding plane, south-western coast of South Georgia. Spirit level is 140 mm long. c, Cross-section of a stratum rich in burrows.

fig. 70, 1 '*Taenidium* sp.')

 rather than the regularly-branching tree-like form *T. lusitanicum* described by Wilckens (1947, taf. 6, fig. 1-2; taf. 7, fig. 1) from South Georgia. It is distinguished from *Chondrites*, *Scalarituba* and *Arthropycus* by the style of branching and ornament, both of which are susceptible to tectonic alteration.

Taenidium ranges from the (?) Carboniferous to Tertiary (Häntzschel, 1975).

Occurrence. In great abundance at three widely-spaced localities (Fig. 1).

Vertical burrows *incertae sedis*

Isolated vertical burrows were found at five localities. At the three localities on the south-west coast the burrows are similar and consist of a discrete, vertical, cylindrical tube 3-5 mm in diameter that is infilled with coarser sediment. It is possible that these are the vertical component of *Chondrites* systems.

The best exposed of the five examples is smaller but otherwise similar morphologically to large 'escape burrows' figured by Bromley and others (1975, fig. 16.12). This form is not assigned to an ichnogenus, as the classification of such fugichnia is problematical (Simpson, 1975).

The fifth example is described below.

Ichnogenus *Monocraterion* Torell, 1870

Monocraterion sp.

Description. A single specimen from a vertical section, in a 4-cm-thick cross-laminated sandstone unit. The burrow, which was not collected, was picked out by shale-rich laminae, comprising a series of stacked, downward-pointing funnels; their apical angles varied upwards from 160° to 90°. The whole burrow was 10 mm in diameter.

Remarks. There was no indication of the axial tube which characterizes *Monocraterion* (Häntzschel, 1975). This, coupled with the change in funnel apical angle, suggests that the burrow's centre was out of the plane of section, and of the 'concordant' type (Crimes and others, 1977).

Hallam and Swett (1966) considered that *Monocraterion* was the response of a creature inhabiting a *Skolithos* burrow to rapid sedimentation. Since then, considerable debate has taken place concerning the ecological and sedimentological significance of *Monocraterion*, which is summarized by Crimes and others (1977). *Monocraterion* is not usually associated with flysch-facies rocks, but it would be unwise to attach much significance to this solitary example.

Horizontal burrows *incertae sedis*

The most common traces in the Cumberland Bay Formation are circular or oval patches of sandstones seen on vertical faces within shale units. They resemble structures seen in drill cores and assigned to *Planolites* by Ekdale (1977, pl. 2a and 3d).

PALAEOECOLOGY

Faunal diversity

The autochthonous elements of the CBF fauna comprise a single genus (perhaps even a single species) of bivalve (*Aucellina*) and nine ichnogenera, comprising no

more than 12 ichnospecies at an absolute maximum. Even with the addition of forms *incertae sedis*, there are no more than 14 ichnospecies present, of which five are represented by single examples.

Although there is insufficient detailed information to calculate any index of diversity (e.g. as discussed by Ager, 1963, chapter 14), the diversity seems to be low compared with other flysch assemblages of similar age. Attention has been drawn to the increasing diversity of the deep marine benthos through Phanerozoic time (Seilacher, 1974, 1977), which was thought to rise linearly from less than five ichnospecies in the Cambrian to roughly 40 in the Tertiary. This model has been modified by various authors; Seilacher (1978, quoted in Pickerill, 1980) suggested a Cretaceous diversity 'burst' and Pickerill (1980) has shown a similar radiation in the Ordovician. Nevertheless, there seems to be broad agreement that diversities have increased. Seilacher's (1974) model predicted 16–34 ichnospecies for Cretaceous flysch.

The low density and diversity of body fossils could be due to pre- or post-depositional factors. Calcium carbonate is known to dissolve in the CaCO_3 -depleted deep ocean waters; in the Atlantic at present, the dissolution depth is 2.5 km for aragonite and 5 km for calcite, compared with values of 0.5 and 3.5 km in the Pacific (Broecker, 1974). The diagenetic movement of calcite within the CBF (e.g. Macdonald, 1980; Stone, 1980) could destroy shells. Such effects detrimental to preservation could explain the low densities of body fossils, but not the low diversities of body fossil or trace fossil taxa. It is likely, therefore, that the overall low faunal diversity is original. Similarly, the low number of planktonic and nektonic elements in the CBF fauna is likely to represent an original biota.

By contrast, the Annenkov Island Formation, which has been interpreted as a shelf deposit marginal to the turbidite basin (Tanner and others, 1981), is much more fossiliferous both in bivalves and ammonites (Wilckens, 1947; Thomson and others, 1982).

An ecological model based on the relative abundance of trace and body fossils related to depth and dissolved oxygen levels was proposed by Rhoads (1975). Similarly, Seilacher (1977) indicated that the ratio of shell bearers to soft-bodied animals decreases with depth. Rhoads (1975) defined a zone of fluctuating oxygen levels (at variable depth) separating the fossiliferous oxygenated shelf areas from azoic anaerobic basins. He proposed eight biofacies related to this scheme, and the CBF is intermediate between Biofacies 5 (body fossils and trace fossils absent or rare) and Biofacies 8 (trace fossils common, body fossils absent or rare). These biofacies would be present in areas of high energy, high salinity or low oxygen.

The infrequent occurrences of *Aucellina* in the CBF fulfil most of the seven conditions proposed by Levinton (1970) for the recognition of opportunistic species. Opportunistic species are characteristic of physically controlled, high-stress environments, especially those which are verging on abiotic (Levinton, 1970). *Buchia*, which is a close relative of *Aucellina*, has an opportunistic strategy (Hallam, 1977) and it is frequently found monotypically in large numbers at other Antarctic Cretaceous localities (J. A. Crame, personal communication). The strongly inequivalve form of *Aucellina* shells suggests that they were adapted to a free-living, reclined mode of life on soft substrates (Macellari, 1979; Taylor and others, 1979). However, the possession of a byssal notch suggests attachment during at least part of their lives (Taylor and others, 1979).

It is interesting to note that *Aucellina* occurs in thick developments of mud-grade sediment, with no coarse clastic deposits. It could be that a temporary cessation of turbidity-current activity allowed the establishment of an opportunistic epifauna.

Depth of deposition

Seilacher (1967) suggested that trace fossils could be used as depth indicators and proposed a system of five depth-related facies defined on trace fossils. Although this scheme has been successfully applied to certain areas (Crimes, 1970a), other studies have shown that factors such as substrate, environmental energy and food availability might be equally important in controlling distribution (Crimes, 1970b, 1977; Książkiewicz, 1970; Selley, 1970; Rhoads, 1975; Corbo, 1979). The situation is particularly complex in turbidite-facies rocks, where high energy ('shallow') conditions extend into deep water (Crimes, 1977).

Within the CBF, the only common ichnogenera are *Planolites*, *Palaeophycus* and *Chondrites*, all of which have been shown to be facies-independent (Crimes, 1973; Kennedy, 1975; Pickerill, 1977, 1980; Corbo, 1979). The only forms found on South Georgia which seem to be generally accepted as facies-specific are *Helminthopsis* and *Paleodictyon*. *Helminthopsis* is referred to Seilacher's *Nereites* facies (deep water) (Crimes, 1970b) and seems to be restricted to it (Crimes, 1970b, 1975). *Paleodictyon* is similarly thought to be restricted to deep water (Crimes, 1970b; Corbo, 1979), or at least to regions below the mid-fan (Crimes, 1977), although in the Cretaceous succession of eastern Alexander Island, it occurs close to what is believed to have been the Mesozoic shore line (Taylor and others, 1979, p. 46).

Conclusions

The scant evidence suggests that the CBF was deposited in relatively deep water. Faunal diversity was low and physical stress was high, pointing to a partially anoxic environment, possibly within a restricted basin.

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