EARLY JURASSIC FOSSILS FROM CENTRAL ALEXANDER ISLAND AND THEIR GEOLOGICAL SETTING

M. R. A. Thomson *and* T. H. Tranter

British Antarctic Survey, Natural Environment Research Council,
High Cross, Madingley Road, Cambridge CB3 0ET, UK

ABSTRACT. Discoveries of fossils in the marine volcaniclastic rocks of the Lully Foothills of central Alexander Island shed new light on the age of part of the LeMay Group, a probable accretion complex. In particular, the presence of the ammonite *Epophioceras(?)* sp. demonstrates that rocks once thought to be Triassic in age must now be considered as Early Jurassic. This represents the first record of Early Jurassic marine strata in the Antarctic Peninsula and helps place new constraints on the timing of events in the subduction history of the region.

INTRODUCTION

A new collection of invertebrate faunal and floral remains from part of the LeMay Group of Alexander Island is described. The presence of an Early Jurassic (Sinemurian) ammonite conflicts with the Middle–Late Triassic (Ladinian–Carnian) age previously suggested for these rocks on the basis of an earlier fossil collection from the same area (Edwards, 1980a).

Fossils were collected from two localities: (1) station KG.2986, 70° 38′ S, 69° 42′ W*, and (2) station KG.2963, 70° 45′ S, 69° 39′ W approximately 13 km apart in the Lully Foothills of central Alexander Island (Fig. 1). The rocks of the Lully Foothills form part of the LeMay Group, a thick (several thousand metres) undivided sequence, composed chiefly of deformed turbiditic arkosic sandstones and siltstones, with minor lavas, tuffaceous sedimentary rocks and cherts (Edwards, 1980b; Burn, 1984) which crops out over large areas of Alexander Island. Somewhat atypically, the Lully Foothills are dominated by interbedded volcaniclastic sedimentary rocks, mafic lava flows and pillow lavas, and form a lithologically distinct unit of the group. The differences between the rocks of the Lully Foothills and those of the rest of the LeMay Group are so marked that it has been suggested that they warrant formation status within the group (Burn, 1984). Although the same general tectonic grain is apparent in the rocks of the Lully Foothills and the rest of the LeMay Group of central Alexander Island, their exact relationships are uncertain. The Lully Foothills may be separated from the LeMay Range by a fault zone and thus correlations of age and structural history cannot necessarily be drawn between the two areas.

Palaeontological and radiometric evidence for the age of the LeMay Group is rather sparse and was summarized by Edwards (1980a) and Burn (1984). Prior to the mid 1970s, the general consensus, based mainly on palynological data, a few radiometric dates and tentative correlations drawn between the LeMay Group and similar sequences of deformed sedimentary rocks elsewhere on the Antarctic Peninsula, was that the rocks were of late Palaeozoic–early Mesozoic age. The first macropalaeontological evidence for the age of any part of the LeMay Group was given by the discovery of a small fauna and flora from the Lully Foothills (Edwards, 1980a), of apparent Middle–Upper Triassic (Ladinian–Carnian) aspect. The present study is

---

* This position was previously quoted as 70° 38′ S., 69° 44′ W (Edwards, 1980a) but has been revised due to improved satellite image mapping.
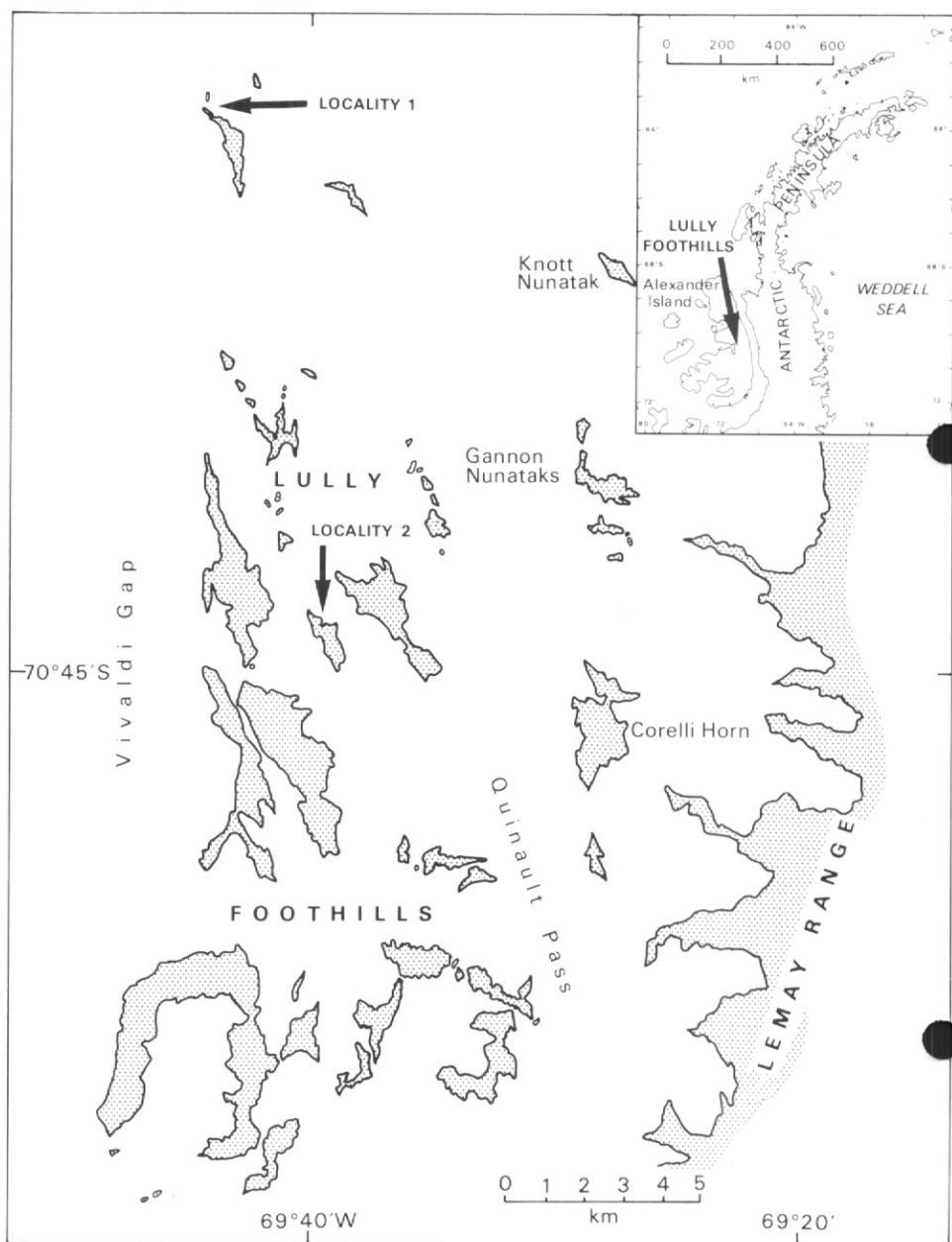
Fig. 1. Sketch maps to show the location of the Lully Foothills and of the fossil localities discussed. Locality 1 = KG.1944 (Edwards, 1980a) and KG.2986; Locality 2 = KG.2963. Stippled areas are exposures of LeMay Group rocks.

based on further collections from this locality (1) and from a nearby, previously undescribed locality (2). It demonstrates that the Triassic age inferred initially for the sedimentary rocks of the Lully Foothills is no longer tenable.

The original material collected by Edwards came from a thin tuff bed in the north-western Lully Foothills, that forms part of a sequence dipping steeply to the east and the right way up (Station KG.1944). That assemblage consisted largely of small gastropods, together with bivalves, some fragments of a colonial coral, echinoderm debris, and some indeterminate impressions of leaves (Edwards, 1980 a). Most of the specimens were too poorly preserved or insufficiently diagnostic to indicate anything more specific than a Mesozoic age, but some showed general similarities to Triassic species. The same outcrop was revisited by one of us (THT) during the 1983–84 field season (Locality 1, Station KG.2986) and a further collection was made from tuff beds in solid outcrop and in adjacent scree. The new collection includes an early Jurassic (Sinemurian) ammonite. Although it is possible that the actual bed within the sequence from which Edwards (1980 a) made his original collection was not relocated, it is significant that the new collection was made from the stratigraphically lowest part of the exposure. Therefore, Edwards' material could only have come from a similar or from a higher stratigraphical level.

In addition to the previously described locality, a new fossil locality (2, station KG.2963) was discovered. Again in largely tuffaceous sedimentary rocks, this one yielded a few, poorly-preserved fossils, which are consistent with, but not diagnostic of, an Early Jurassic age.

PALAEONTOLOGY

Locality 1

INVERTEBRATA
Phylum MOLLUSCA
Class GASTROPODA Cuvier 1797

In contrast to the fauna described by Edwards (1980 a; Table I) there are only a few gastropods in the present collection. Two small moulds (KG.2986.20 and 27) with smooth rounded whorls recall *Omphaloptycha* (?) sp. (Edwards, 1980 a, fig. 3 d) or possibly *Coelostylina* Kittl. However, the best specimen (below, Fig. 2a) is an external mould of a high-spired form, which represents the largest gastropod yet found at this locality and is probably a species of *Katosira* Koken.

Family ZYGOPLEURIDAE Wenz, 1938
Genus *Katosira* Koken, 1892
Katosira (?) sp.
Fig. 2a

Material. A single external mould (KG.2986.19).

Description and remarks. This shell is turriculate with a spire angle of 15°. In its present state it is 30 mm high but lacks both the apical whorls and the aperture. Whorls are a little broader than high, have flat to weakly convex sides and are separated by weakly impressed sutures. The dominant ornament consists of about 12 stout transverse ribs that are more or less opisthocline and at times faintly crescentic. Low-angle lighting reveals a series of weak concentric threads that have been reduced by corrosion. On the base of the spine there is a much stronger concentric rib around the periphery (beneath the suture on earlier whorls) and a second one inside this. The transverse ribs do not extend onto the base. The aperture is broken but its axial margin appears to have a collumelar-like form.

Table I. Fossil Gastropoda from Lully Foothills (after Edwards, 1980*a*).

Protofusus sp.	*Omphaloptycha* (*?*) sp.
Rhabdocolpus sp.	*Amberleya* (*Eucyclus*) (*?*) sp.
Procerithium (*Apicaria*) sp.	*Amphitrochus* sp.
(?) Procerithiid gen. et sp. indet.	turritelloid gastropods
Zygopleura (*Katosira*) sp.	*Scurriopsis* (*?*) *aranetexta** sp.nov.

* A spelling error was introduced after galley proof stage in Edwards' paper and the specific name was rendered incorrectly as *arahetexta* (cf. Edwards, 1980*a*, p. 44).
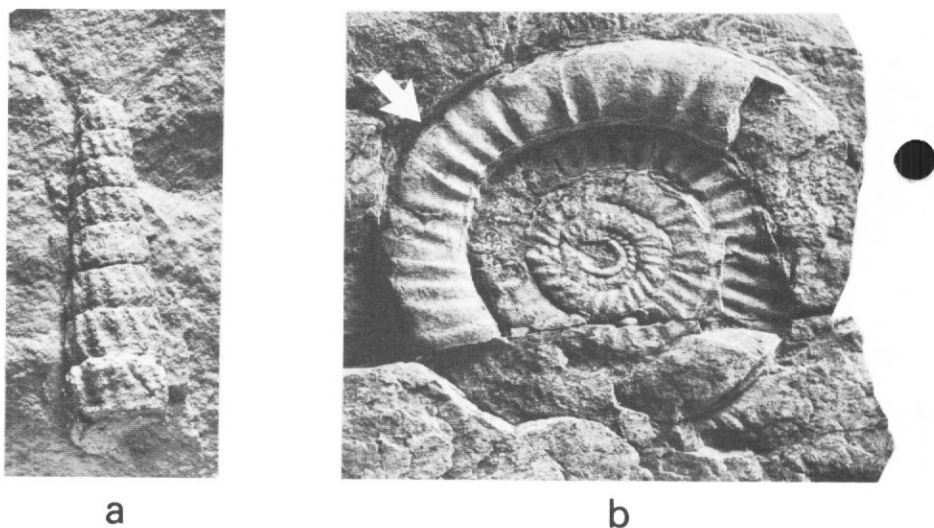

Fig. 2. a. *Katosira* (*?*) sp.: silicone cast from an external mould; × 1.5 (KG.2986.19). b. *Epophioceras* (*?*) sp.: a natural, part internal, part external mould; × 1 (KG.2986.13). The white arrow denotes the position of the suture shown in Fig. 3.

A small (7 mm) example referred to *Katosira* sp. was described from the same locality by Edwards (1980*a*). That specimen differs in having whorls with a weak angulation, and more obvious concentric threads, and ribs that are slightly opisthocline.

Order AMMONOIDEA Zittel, 1884

The original collection of fossils from the Lully Foothills (Edwards, 1980*a*) included an ammonite nucleus about 9 mm in diameter, which was not described. It has strongly depressed whorls and coarse, widely spaced ribs on the flank; ornament on the venter has been removed by corrosion. The new collection contains another nucleus (KG.2986.14) about 16 mm in diameter. It differs from the first in having whorls with an almost circular cross-section but, as it is preserved in cross-section only, nothing is known of the lateral aspect of the shell. Neither specimen is identifiable. However, a third (KG.2986.13), a part external/part internal mould of an individual about 60 mm in diameter, has features of a number of early Jurassic Arietitinae and Echioceratinae.

(?) Family ARIETITIDAE Hyatt, 1875
(?) Subfamily ARIETITINAE Hyatt, 1875
(?) Genus *Epophioceras* Spath, 1924
Epophioceras (?) sp.
Figs. 2b and 3

Description. The shell (Fig. 2b) is evolute (umbilical diameter = about 60% of total diameter) and multispiral with successive whorls barely overlapping. At least five whorls are visible on the specimen, although the nucleus is not preserved. The whorls

Fig. 3. *Epophioceras* (?) sp. Sketch of the suture showing the external (left) and first lateral (right) lobes; × 5 (KG.2986.13).

increase slowly in height and have a moderately compressed to oval cross-section. The venter is gently arched and has a low, rounded median keel, flanked by shallow grooves. On the last preserved part of the outer whorl, these grooves are particularly well marked but they have probably been accentuated by crushing. Lateral ornament consists of stout blunt ribs, which have maximum prominence near mid flank, and are separated by interspaces a little wider than themselves. It is estimated that there were about 20 ribs on the last half whorl. The precise attitude of the ribs is difficult to determine because of some tectonic distortion but many seem to be slightly prorsiradiate, rather than radial, particularly on the earlier whorls. Towards the ventral shoulder the ribs fade out and the venter itself is smooth. The suture (Fig. 3) is poorly preserved and difficult to decipher but two saddles, separated by a crudely trifid lateral lobe, are visible on the flank, about one quarter of a volution back from the last preserved part of the outer whorl. The first lateral saddle is broader than the second and appears to be irregularly trifid. The ventral lobe is deep.

The thin smooth part whorl at the centre of the ammonite (Fig. 2b) is proportionally too low to be part of the ammonite itself and is probably an encrusting serpulid.

Remarks. The general characteristics of this specimen recall a number of the Arietitidae and particularly the genus *Vermiceras* Hyatt. In the Treatise (Moore, 1957), it was noted that ventral grooves in *Vermiceras* were obsolete or obsolescent. However, in Hyatt's (1889, p. 155) original description, clear reference is made to the presence of ventral grooves [= 'channels'], which were only noted as obsolescent or obsolete on some very large specimens of questionable affinities. More recently, Donovan and others (1981, p. 136) synonymized *Metophioceras* Spath in *Vermiceras* s.s., thus implying that the presence of forms with marked ventral grooves is acceptable within *Vermiceras*. On the Antarctic specimen, grooves are present, although they do not appear to be as strongly marked as in *Metophioceras*.

There is good agreement, in the proportions of the shell and strength of the keel, between the Antarctic specimen and Tilmann's (1917, pl. XXIII, fig. 2) *Vermiceras*

stuebeli from northern Peru, except that the latter is more densely ribbed (27 ribs on the outer half whorl compared to about 20 on the present specimen). This observation was confirmed by reference to undescribed material in the British Museum (Natural History), labelled as *V. stuebeli* from the Bucklandi zone (basal Sinemurian) of Peru. Other specimens from the same level, but unidentified, all show a slightly denser pattern of ribbing. *V. spiratissimum* Quenstedt (1883, pl. 12, figs. 9 and 10), also from the same zone in France and Germany, has ribbing that appears to be less dense than on *V. stuebeli*, but it is still denser than that of the Antarctic species. *V. scylla* (Reynes) (1879, pl. XIV, figs. 13–16 and 19–25; Guerin-Franiatte, 1966, pl. 109 and 110) is also more densely ribbed and has a rather weak keel.

The genus *Vermiceras* occurs in Upper Hettangian–Lower Sinemurian strata, whereas homeomorphic forms in the Upper Sinemurian are referred to *Epophioceras* Spath. Hillebrandt (1970, p. 175; 1981, p. 506) twice commented on the difficulties of separating South American forms of *Vermiceras* and *Epophioceras* but pointed out that, in the suture, lobe U_1 is divided in *Vermiceras* whereas it is not in *Epophioceras*. Thus, because this part of the suture is not preserved in the Antarctic specimen (Fig. 3), it would seem that it is not possible to reach an unequivocal conclusion as to its precise affinities. Furthermore, despite the remarkably close homeomorphy of these two genera, on the basis of their suture development, they have been classified in two distinct subfamilies: *Vermiceras* in the Arietitinae (Donovan and others, 1981) and *Epophioceras* in the Echioceratinae (Schlatter, 1984).

There are several described species of *Epophioceras* that also closely resemble the Antarctic one. In particular, *E. longicella* Quenstedt from the Obtusum zone of France (Guerin-Franiatte, 1966, pl. 219) and Switzerland (Schlatter, 1984, figs 1 and 2) has a density of ribbing and a rate of coiling that match well with the present specimen, and also shows a tendency for the ribs to be weakly prorsiradiate. The only real differences are that the ribs on the Antarctic specimen appear to be weakening on the outer whorl and the European forms grew much larger. On the basis that it has been possible to match the Antarctic specimen a little more closely with a species of *Epophioceras* than of *Vermiceras*, a generic identification with the former is considered most likely. Like *Vermiceras*, *Epophioceras* has been described from South America (Hillebrandt, 1970, 1981) as well as from Europe.

<div style="text-align:center">

Phylum ECHINODERMATA
Subphylum ASTEROZOA

</div>

A superbly preserved external mould of an asteroid (Fig. 4a), showing parts of the oral and aboral surfaces has been described in detail by Smith and Tranter (1985) as a new species of a hitherto unknown genus, *Protremaster uniserialis*. Few Early Jurassic starfish are known and the Antarctic find represents an important contribution to the understanding of asteroid phylogeny. In addition, there are a number of arm fragments and part of a disc, representing a species of ophiuroid, which were examined by Dr A. B. Smith (British Museum (Nat. Hist.)). He noted the presence of the following features: broad ventral shields forming a continuous pavement, stout lateral arm shields with rudimentary spines on the ventral side only, large radial shields but no other disc plates, and short rapidly tapering arms. All these features suggest that the fragments are from a species of *Palaeocoma* d'Orbigny but preservation around the mouth region is too poor to make a specific identification (A. B. Smith, personal communication). *Palaeocoma* has previously been recorded from the Lower Jurassic (Hettangian–Pliensbachian) of Europe.
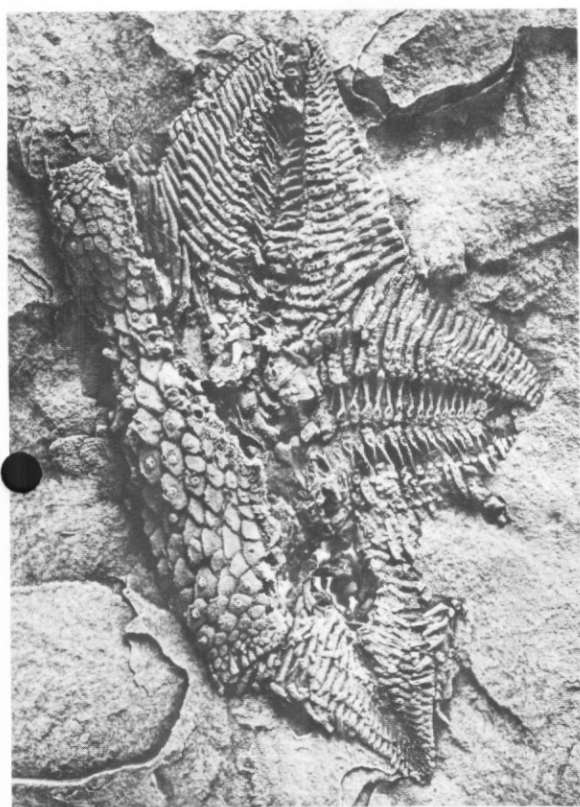
Fig. 4. a. *Protremaster uniserialis* Smith. Latex peel from a natural external mould in a fine grained tuffa-
ceous sandstone; × 2 (KG.2986.17). b. Gymnospermous shoot. Silicone cast from an external
mould; × 1.5 (KG.2986.4a).

PLANTAE
Gymnospermous shoot
Fig. 4b

Material. Part and counter part of a compressed mould of a small shoot
(KG.2986.4a, b), with part of the petrified axis enclosed.

Description. The external mould originally had a more or less complete cover of
limonitic material. Some of this was removed mechanically and by local application
of concentrated HCl. A latex cast of the cleaned mould (Fig. 4b) shows about 22 rows
of rhomboidal protuberances, which are arranged spirally with the rows angled at
about 50° to the shoot axis. The total length of the shoot is 46 mm and its width in
the compressed state is 14 mm; each protuberance is about 3 mm long, 2 mm wide,
less than 1 mm in height and has a rounded tip.

A thin section of the petrified axis shows that carbonized remains of original plant
tissue are preserved. A central pith is present, surrounded by patchily preserved cells
of the cortex. The leaf bases are arranged around the periphery.

Remarks. The poor preservation of this shoot makes a confident identification difficult. The rhomboidal shape of the leaves and their helical arrangement is typical of Mesozoic scale-leaved conifers, particularly *Brachyphyllum.*

OTHER FOSSILS

Numerous fragments of fossils were collected in addition to those just described. Most of these are unidentifiable but the following may be mentioned: a possible minute solitary coral, a crinoid ossicle, and a belemnite phragmocone measuring some 60 mm in length and about 25 mm wide at its broadest end. There are also a few poorly preserved fern-like leaf fragments.

Locality 2

The fossils from locality 2 are distinct from those of locality 1 and there is no reason to suppose that the two assemblages are necessarily of the same age, although they occur in the same general area. The most common fossils are fragments and isolated valves of thick-shelled bivalves. Among the fragments are some with a distinctly lamellar structure, reminiscent of the shell of oysters. The only other fossil is an indeterminate distorted gastropod with a trochiform shell form. The two best bivalves are described below.

<div align="center">

Class **BIVALVIA**
Family CARDINIIDAE Zittel, 1881
Genus *Cardinia* Agassiz, 1841
Cardinia sp. nov.
Fig. 5a–d

</div>

Material. A single internal mould of a right valve showing details of the dentition and musculature (KG.2963.3).

Description. The specimen was collected as a corroded shell in a tuffaceous sandstone matrix (Fig. 5a). The shell appeared to be sub circular to slightly oval in outline, and a little higher than long, with a prosogyrous umbo. The test was robust and ornamented with raised concentric growth rings. After casting the specimen, it was immersed in dilute HCl to see if any of the dentition was present and a wealth of detail was exposed (Fig. 5b–c).

The most striking features of the inside of the shell (Fig. 5c–d) is a stout hinge plate and adductor muscle scars recessed well into the shell. The prosogyrous umbo overhangs a triangular lunule, which extends posterior of the beak, and along the postero-dorsal margin there is a deeply incised nymph. On the hinge plate a relatively weak, rib-like cardinal tooth (3b) extends postero-ventrally from below the beak. A long, heavy anterior lateral tooth (A_1), with a tubercule-like termination, is separated from the dorsal margin by a narrow groove. Posteriorly there is a ridge-like structure beneath the nymph. It is shorter than the anterior lateral tooth and terminates squarely. At the postero-ventral extremity of the hinge plate is a large triangular

---

Fig. 5. *Cardinia* sp.nov. (KG.2963.3). a. The fossil in its original state, a right valve with a corroded shell and concentric ornament; × 1. b. The same specimen after cleaning with dilute HCl to reveal the internal mould; × 1. c. Silicone rubber cast from the internal mould; × 1. d. Cartoon drawn from Fig. 5c to illustrate the main internal details; × 1. aa = anterior adductor scar; c = cardinal tooth; l = lunule; L = lateral tooth with tuberculate termination; n = deeply incised nymph; pa = posterior adductor scar; s = socket.
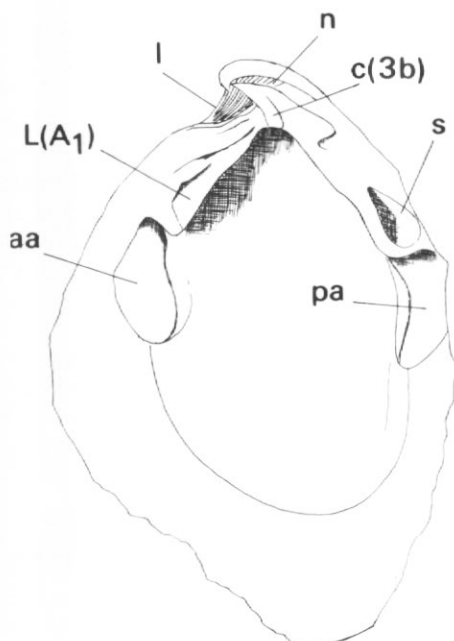
socket, which presumably received a large tooth from the left valve. Two elongate upright subequal adductor muscle scars are located off the ventral extremities of the hinge plate and are impressed into the thick shell; they are most deeply recessed towards their inner margins.

Remarks. The heavy shell, triangular lunule, deeply incised nymph and dentition of this bivalve are typical of the members of the Cardiniidae and particularly of the genus *Cardinia* Agassiz. The principal differences between the present specimen and described species is that they typically have elongate, frequently triangular shells (cf. Palmer, 1975), whereas the present one is upright and sub oval. More upright ovate shell forms are seen in such species as *Cardinia laevis* Young and Bird (cf. Palmer, 1975, pl. 3, figs. 4–6) from the Middle Lias of Yorkshire, but no described species is as upright as the Antarctic specimen. Although the rocks from which the bivalve was obtained are cleaved (p. 35), the shell was robust and there are no indications of distortion; the growth rings on the shell curved smoothly. If the shell had originally been more elongate and triangular, as in the well-known *C. hybrida* for example (cf. Palmer, 1975, pl. 1, figs. 5 and 6), the posterior angulation in the growth lines would have been preserved. It seems most probable that the specimen from Lully Foothills represents a new species of *Cardinia* but, because of its deficient state of preservation, formal naming will have to await the collection of better material.

Hayami (1958) recognized six morphological groups within the genus *Cardinia* and these were later reduced to four by Palmer (1975, p. 5). The Antarctic specimen shows characteristics of two groups: 'ovoids', which have an ovate outline, and 'rugoids', in which the growth lamellae are imbricated or even have upturned edges, as is apparently the case here (Fig. 5a).

<div align="center">
Family Uncertain
Genus Uncertain
Fig. 6a–c
</div>

Material. A single internal mould of a (?) left valve, showing the shell outline and details of the dentition (KG.2963.2). A second specimen (KG.2963.5) shows the umbones of an articulated specimen but no details of the dentition.

Description. The specimen was collected as a corroded subcircular shell (Fig. 6a), set in a coarse tuffaceous matrix. The external surface showed no features other than weak concentric ornament and the shell material was dissolved in dilute HCl to reveal the internal morphology (Fig. 6b and c). In outline it is trigonal to suboval ($l = 50$ mm, $h = 47$ mm) with a pointed upright umbo set slightly off centre. It has a well rounded (?) anterior margin and a slightly more angular posterior margin. No muscle scar (other than a faint indication of one at the blunter end of the valve) or pallial line are visible but it is assumed that the slightly blunter end is anterior. Beneath the umbo the hinge plate bears a stout triangular tooth with a shallow groove or fold in front and a deeper narrow socket behind. The anterior part of the hinge plate is apparently featureless but about mid way along the posterior part there is a poorly developed longitudinal slot, which seems to be delimited ventrally by a thin buttress beneath the hinge plate.

Remarks. This is an enigmatic species whose generic identification is uncertain. The most striking feature of its dentition is a prominent median triangular tooth in what is believed to be the left valve. This is reminiscent of tooth 2b in some Lucinacea, notably in the subfamily Myrteinae and particularly an unusual form from the Upper Oxfordian of England, *Perampliata ampliata* Arkell (1933, p. 284, text fig. 63; 1935, p. xx). That genus has a simple hinge similar to the present specimen's but lacks the
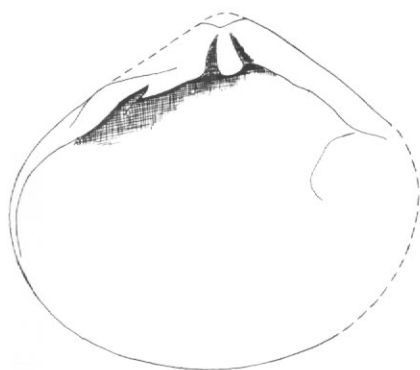
Fig. 6. Indeterminate bivalve (KG.2963.5). a. The fossil in its original state; ×1. b. Silicone rubber cast of the internal mould revealed by cleaning with dilute HCl; ×1. c. Cartoon drawn from Fig. 5b to illustrate the main internal details; ×1.

slot and buttress in the posterior part of the hinge plate. The function of the slot is unclear; it may have behaved either as a recess for an adductor muscle or alternatively as a socket for a tooth in the opposite valve.

AGE OF THE FAUNAS

Locality 1

An assessment of the first collection of fossils from the northern Lully Foothills led Edwards (1980a, p. 54) to conclude that they were consistent with an early Mesozoic, probably Middle–Late Triassic age. Species considered to be most important stratigraphically were bivalves, identified as *Waagenoperna* aff. *ozawai* (Kobayashi) and *Balantioselena* aff. *gairi* Speden, and a number of small gastropods with general similarities to those in Triassic faunas from Peru and Argentina. All of this material lacked critical features for confident identification (e.g. dentition in the bivalves, apertures on the gastropods) and identities had to be suggested on the basis of probability.

None of the bivalve species described by Edwards (1980a) has been recollected a a reassessment of these forms has to be made by reference to the original material only.

Although the Antarctic specimen Edwards (1980a, fig. 4d) referred to *W.* aff. *ozawai* (Middle–Upper Triassic of Japan) has general similarities to that species (cf. Kobayashi, 1935, pl. VII, figs. 3–6) it is much smaller than the Japanese specimens and shows no sign of the large postero-dorsal wing. In the Antarctic specimen the ligament area faces dorsally, at right angles to the plane of commissure. Although the attitude of the ligament area in *W. ozawai* is not clear, it appears to be much closer to the plane of commissure.

Similarly, whereas the specimen assigned to *B.* aff. *gairi* (Edwards, 1980a, fig. 4a) superficially has the general appearance of the Middle Triassic New Zealand species (cf. Speden, *in* Gair and others, 1962, figs. 4–11), its dentition is unknown and small simply-ornamented bivalves are extremely difficult to identify from external features only. Reference to the original illustrations and new collections from the same New Zealand locality (by courtesy of Dr H. J. Campbell, Geological Survey of New Zealand) show that the orientation of the shell in the New Zealand and Antarctic species is different. the direction of maximum growth in the Antarctic specimen is directed more strongly towards the posterior than in the true *Balantioselena* and its umbo is set more anteriorly. Perhaps even more striking is the external resemblance between the Antarctic '*B.* aff. *gairi*' and Terquem's (1855, p. 83, pl. XX, fig *Praeconia tetragona* from the Hettangian of France. However, the French specimen is approximately four times larger than the Antarctic one, and in the absence of hinge details, no identity between the two is implied in the present study.

Although it was not used as evidence for his age assessment, a specimen referred to as *Antiquilima?* sp. (Edwards, 1980a, fig. 4b) needs further comment. It lacks the marked differentiation between two or more orders of ribbing that characterize the genus. The secondary ribs on the Antarctic specimen arise by intercalation and eventually become as prominent as the rest of the ribs. The folding of the anterior ear against the disc of the shell is almost certainly the result of post-mortem distortion and raises the possibility that the shell outline as a whole and the now flexuous course of the ribbing may have been modified during fossilization also. The reticulate ornament is unusual in the Limidae and Edwards was unable to find a species with which to compare it closely. On balance it is doubtful whether this species can be referred satisfactorily to *Antiquilima* Cox. Nevertheless, it is worth pointing out that

there is a remarkable resemblance between it and another of Terquem's (1855, p. 104, pl. XIII, fig. 3) species from the Hettangian of France, *Lima nodulosa*. In particular the latter, as its name implies, has small nodes on the radial ribs where they intersect weaker concentric threads. Terquem noted that many of the nodes on *Lima nodulosa* had a small perforation suggestive of broken spinose extensions. The nodes are similar to those on the Antarctic specimen but its preservation is not good enough to determine if they were perforate or not.

The original collection from the Lully Foothills was dominated by external moulds of minute gastropods, none of which preserved details of the protoconch nor the aperture. Edwards (1980a) suggested generic identifications for these, although in several cases he expressed doubts even thus far. However, taken as a whole, they seemed to show general similarities to Triassic faunas described from Peru (Haas, 1953) and northern Argentina (Bonarelli, 1927), and therefore could be considered consistent with the probable Triassic age, deduced from the bivalves. All of the genera, with the exception of *Omphaloptycha* (?) also have Jurassic representatives and their absolute stratigraphic value is therefore suspect.

The present authors conclude that, in the light of new evidence, the tentative Middle–Late Triassic age, deduced by Edwards for the northern Lully Foothills fauna (locality 1: KG.2986) is no longer tenable. Whilst the generic status of the ammonite described here is questionable, it is not a Triassic form and its Early Jurassic affinities are open to little doubt. It shows features of a number of Sinemurian genera and the only argument is whether it indicates the lower or upper part of that stage. An Early Jurassic (Sinemurian) age is suggested for the fauna of locality 1.

Locality 2

Locality 2 is approximately 13 km south of the first and isolated from it (Fig. 1). The geological structure of the area is complicated and the stratigraphical relationships between the rocks of the two localities could not be discerned in the field. The only fossil of any stratigraphical value is the species of Cardinia, a genus which is known from the Carnian (Upper Triassic) to the Toarcian (Upper Lias). However, as a new species with no known representatives elsewhere, it is difficult to resolve the probable age of the fauna more precisely. The most likely possibility is that this fauna is not significantly different in age from that of locality 1.

SEDIMENTARY ENVIRONMENT

The rocks of both localities are mainly tuffs, varying from coarse to very fine sand grade, with minor quantities of silt and clay grade material and occasional thin beds of volcanic breccio-conglomerate. At locality 1, sedimentary structures, notably small scours and loading features are well preserved, and graded units up to a few centimetres in thickness are also common. In one case, fossil remains were found lying on top of a graded unit. The finer, ungraded parts of the sequence are bioturbated in places. However, the rocks of locality 2 have a strongly developed fracture cleavage parallel to the original sedimentary layering, and a weakly developed second fabric orientated obliquely to the first, and no sedimentary structures are preserved. The sedimentary sequence at locality 2 is interbedded with thin, discontinuous stringers and pods of basaltic lavas, ranging in thickness from a few centimetres to more than 2 m and generally lacking in chilled margins.

In thin section, much of the original mineralogy of the rocks from both localities

is obscured by alteration products, particularly chlorite, and by the development of secondary calcite. The rocks are mainly vitric and crystal tuffs (Fisher, 1961), dominated by volcanic glass shards, pumice and crystal fragments and lithic clasts. The glass is generally green or brown, a feature of glasses of mafic composition (Horn and others, 1969; Fisher and Schminke, 1984, p. 164). Most of the shards are moderately- to non-vesicular and are angular and blocky in outline, although some are more vesicular and show some bubble-wall glass texture (Fisher, 1963; Pettijohn and others, 1972, p. 262) and cuspate morphology (Fisher and Schminke, 1984, p. 101). Small laths of feldspar (An_{30-40}), chalcedonic growths of quartz and fine aggregates of secondary calcite occur within the glass shards, the rims of which are altered in places to a dark rim of fine isotropic material, probably palagonite. The pumice fragments are highly vesicular, and in some the vesicles are infilled with calcite and chlorite. Lithic clasts of basic igneous rocks are generally rounded and are altered to pale green chlorite, and little original mineralogy is visible. The large clasts in the volcanic breccio-conglomerate horizons contain large felted masses of chlorite, pseudomorphing original ? pyroxene phenocrysts.

Quartz, feldspar (An_{30-40}), and minor amounts of pyroxene (augite and ?pigeonite) occur as angular to subangular fragments of euhedral crystals. Embayed margins and inclusions of aphanitic material suggest that the quartz is volcanically derived (Pettijohn and others, 1972, p. 264). Sphene, epidote and pyrites also occur as accessory minerals.

The groundmass is of very fine grained, brown, isotropic material, probably composed of glass, breakdown products of ferromagnesian minerals and chlorite.

Environmental interpretation is based largely on the rocks of locality 1 as the strong cleavage development at locality 2 has destroyed most original sedimentary features.

Edwards (1980a) pointed to the rounded nature of the lithic clasts, the slight amount of rounding of some of the glass fragments, the presence of isolated, disarticulated bivalve shells and rapid lithological changes as evidence that the rocks of locality 1 result from the reworking of volcaniclastic material in a shallow water environment. The blocky morphology and the non- to moderately vesicular nature of the glass shards is characteristic of hydroclastic deposits produced from shallow-water submarine eruptions (Fisher and Schminke, 1984, p. 236). This interpretation for the origin of the volcaniclastic fragments is supported by observations elsewhere in the Lully Foothills where basaltic breccias and tuffs are interbedded with pillow lavas and lava flows (as at locality 1) indicating that contemporaneous volcanic activity was taking place nearby.

Sedimentary features such as load structures, intraclasts and scours, and normal graded beds all indicate that the hydroclastic debris has been reworked. The preservation of some fossils on the tops of small graded units also indicates that they may have been swept into the area of deposition along with the sediment. It has been suggested that the folded nature of the starfish fossil may be the result of its incorporation in and overwhelming by a slurry of moving sediment (Smith and Tranter, 1985).

Interpretation of water depth is rather equivocal. Edwards (1980a) used the presence of unidentifiable leaf fossils to suggest general proximity to a shoreline. If the assemblages are allochthonous, no conclusions can be drawn from the benthic components of the fauna. The remainder of the fauna is of little use in determining water depth as it consists of forms with a neritic habit or a wide depth distribution.

Conclusions

The Lully Foothills localities have yielded the first known Early Jurassic fauna from the Antarctic Peninsula region. Its recognition means that the Middle to Late Triassic age previously assigned to this part of the LeMay Group (Edwards 1980a) is no longer tenable.

Few radiometric dates are at present available for the rocks of the LeMay Group, but those published lie in the range 161–102 Ma (Late Jurassic–Early Cretaceous) (Grikurov and others, 1967), and these are thought to represent diagenetic or deformational events. Thus, the presence of an Early Jurassic fauna is important as it limits the period of uplift and deformation of this part of the LeMay Group to post Early Jurassic and pre-Late Jurassic–Early Cretaceous. Further evidence of the upper limit of this period is the existence of a supposed erosional unconformity in the eastern LeMay Range between the LeMay Group and the Upper Jurassic–Lower Cretaceous Fossil Bluff Formation (Edwards 1980c), restricting the date of uplift and deformation to pre-Late Jurassic.

The rocks of the LeMay Group have been tentatively correlated on lithological grounds and on their supposed similarities in terms of tectonic environment with other sequences of deformed upper Palaeozoic–lower Mesozoic sedimentary rocks along and to the north of the Antarctic Peninsula (see Burn, 1984, for review). These sequences resulted from active subduction and accretion processes occurring along the west of the Antarctic Peninsula at that time (Storey and Garrett, 1985), and include the Trinity Peninsula Group of northern Graham Land, the Miers Bluff Formation of the South Shetland Islands and the Greywacke-Shale Formation of the South Orkney Islands. They are all strongly deformed and predominantly unfossiliferous clastic sequences, and they all contain areas of outcrop in which evidence for shearing and mixing processes commonly associated with subduction and accretion can be seen. For example, a tectonic mélange from Fredriksen Island, South Orkney Islands has been described (Storey and Meneilly, 1983), and areas of broken formation have been recognized in the Trinity Peninsula Group (Hyden and Tanner, 1981). Broken formation and strongly sheared rocks occur on the eastern boundary of the Lully Foothills, suggesting that this area too could represent a tectonically emplaced slice, and other areas of broken formation and mélange have been noted from elsewhere in the LeMay Group of Alexander Island (Burn, 1984).

Although the ages of all these sequences are rather equivocal, the scant palaeontological information available suggests a Triassic age. Triassic radiolaria were recovered from a bedded chert associated with the Greywacke–Shale Formation (Dalziel and others, 1981) and a Triassic land flora has been described from Williams Point, Livingston Island, South Shetland Islands (Orlando, 1968), from beds that may be age equivalents of the Miers Bluff Formation (Smellie and others, 1984). A bivalve fauna has been collected from the Legoupil Formation, part of the Trinity Peninsula Group, and this also has strong Triassic affinities (Thomson, 1975). However, the presence of a Lower Jurassic fauna in the Lully Foothills does not in itself render the possible general correlations between these sequences unfeasible. In the long-term subduction-related accretionary environment envisaged for these sequences, similar sedimentary and structural events could easily occur in adjacent areas at different times, or complex tectonic movements could juxtapose rocks of differing ages. Thus strict lateral correlation may be largely impossible. The difficulties inherent in establishing correlations in these terranes are illustrated by the fact that a radiolarian assemblage recovered from a chert in the LeMay Group of northern Alexander Island, about 100 km to the north-north-west of the Lower Jurassic localities is of probable

mid-Cretaceous age (Burn, 1984), demonstrating that, in that area at least, sedimentation was still taking place much later in the Mesozoic. It must therefore be remembered that the Early Jurassic age is only strictly applicable to the volcaniclastic sediments of the northern and western Lully Foothills in the vicinity of the fossil localities and it cannot be extended with any confidence throughout the LeMay Group as a whole. The discovery of the fauna does, however, give useful further information on the extent and age of early Mesozoic sedimentation in western Antarctica and provides an aid for determining the timing of events in at least part of the LeMay Group and its relationship to its possible equivalents elsewhere on the Antarctic Peninsula and to the overall stratigraphic history of the area.

REFERENCES

ARKELL, W. J. 1933. A monograph of the British Corallian Lamellibranchia. Part 7. *Palaeontographical Society Monographs*, 274–324.
ARKELL, W. J. 1935. A monograph of the British Corallian Lamellibranchia. Part 9. *Palaeontographical Society Monographs*, 351–76, xvii–xxii.
BONARELLI, G. 1927. Fósiles de la formación petrolífera o sistema de Salts. *Boletín de la Academia Nacional de Ciencias en Cordoba*, **30**, 51–115.
BURN, R. W. 1984. The geology of the LeMay Group, Alexander Island. *British Antarctic Survey Scientific Reports* No. 109, 65 pp.
DALZIEL, I. W. D., ELLIOT, D. H., JONES, D. L., THOMSON, J. W., THOMSON, M. R. A., WELLS, N. A. *and* ZINSMEISTER, W. J. 1981. The geological significance of some Triassic microfossils from the South Orkney Islands, Scotia Ridge. *Geological Magazine*, **118**, No. 1, 15–25.
DONOVAN, D. T., CALLOMAN, J. H. *and* HOWARTH, M. K. 1981. Classification of the Jurassic Ammonitina. (*In* HOUSE, M. R. *and* SENIOR, J. R. eds. *The Ammonoidea*, London, Academic Press, 101–55. [The Systematics Association Special Volume No. 18.].)
EDWARDS, C. W. 1980a. Early Mesozoic marine fossils from central Alexander Island. *British Antarctic Survey Bulletin*, No. 49 (For 1979), 33–58.
EDWARDS, C. W. 1980b. *The geology of eastern and central Alexander Island*. PhD thesis, University of Birmingham 228 pp. [Unpublished].
EDWARDS, C. W. 1980c. New evidence of major faulting on Alexander Island. *British Antarctic Survey Bulletin*, No. 49 (For 1979), 15–20.
FISHER, R. V. 1961. Proposed classification of volcaniclastic sediments and rocks. *Bulletin of the Geological Society of America*, **72**, No. 9, 1409–14.
FISHER, R. V. 1963. Bubble wall texture and its significance. *Journal of Sedimentary Petrology*, **33**, 224–27.
FISHER, R. V. *and* SCHMINKE, H-U. 1984. *Pyroclastic Rocks*. Springer-Verlag, Berlin, 472 pp.
GAIR, H. S., GREGG, D. R. *and* SPEDEN, I. G. 1962. Triassic fossils from Corbies Creek, north Otago. *New Zealand Journal of Geology and Geophysics*, **5**, 92–113.
GRIKUROV, G. E., KRYLOV, A. YA *and* SILN, YU. I. 1967. Absolyutnyy vozrast nekotorykh porod dugi Skotia i Zemli Aleksandra I (Zapadnaya Antarktika). [Absolute age of some rocks from the Scotia arc and Alexander I Land (Western Antarctica)]. *Doklady Akademii Nauk. SSSR*, Geology, **172**, No. 1, 168–171. [English translation: *Doklady* (*Proceedings of the Academy of Sciences USSR.*, Geological sciences sect., **172**, 19–22].

GUERIN-FRANIATTE, S. 1966. *Ammonites du Lias inferieur de France. Psilocerataceae: Arietitidae.* 2 vols., Paris, Editions du Centre National de la Récherche Scientifique.

HAAS, O. 1953. Late Triassic gastropods from central Peru. Parts 1 and 2. (*In* Mesozoic invertebrate faunas of Peru. *Bulletin of the American Museum of Natural History*, **101**, 1–328.)

HAYAMI, I. 1958. Taxonomic notes on *Cardinia* with descriptions of a new species from the Lias of western Japan. *Journal of the Faculty of Science, Tokyo University*, Section 2 Geology, **11**, 115–30.

HILLEBRANDT, A. VON. 1970. Zur Biostratigraphie und Ammoniten-Fauna des sudamerikanischen Juras (insb. Chile). *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **136**, 166–221.

HILLEBRANDT, A. VON. 1981. Fauna de Ammonites del Liasico inferior y medio (Hettangiano hasta Pliensbachiano) de America del Sur (excluyendo Argentina). (*In Cuencas sedimentarias del Jurasico y Cretacico de America del Sur*, Buenos Aires, 499–537.)

HORN, D. R., DELACH, M. N. *and* HORN, B. M. 1969. Distribution of volcanic ash layers and turbidites in the north Pacific. *Bulletin of the Geological Society of America*, **80**, 1715–1724.

HYATT, A. 1889. Genesis of the Arietitidae. *Smithsonian Contributions to Knowledge. Washington*, No. 673, xi + 238 pp.

HYDEN, G. *and* TANNER, P. G. W. 1981. Late Palaeozoic–early Mesozoic fore-arc basin sedimentary rocks at the Pacific margin in western Antarctica. *Geolologische Rundschau*, **70**, 529–41.

KOBAYASHI, T. 1935. Einige neue triadische Bivalven aus der Innenzone Südwest-Japans. *Japanese Journal of Geology and Geography*, **12**, 27–32.

ⅯOORE, R. C. ed. 1957. *Treatise on invertebrate paleontology. Part L, Mollusca 4, Cephalopoda, Ammonoidea*, Lawrence, Kansas, Geological Society of America and University of Kansas Press.

ORLANDO, H. A. 1968. A new Triassic flora from Livingston Island, South Shetland Islands. *British Antarctic Survey Bulletin*, No. 16, 1–13.

PALMER, C. P. 1975. The British Lower Jurassic species of the bivalve genus *Cardinia*. *Bulletin of the British Museum (Natural History)*, Geology, **26**, No. 1, 1–44.

PETTIJOHN, F. J., POTTER, P. E. *and* SIEVER, R. 1972. *Sand and sandstone*. Springer-Verlag, Berlin, Heidelberg, New York. 618 pp.

QUENSTEDT, F. A. 1883–1885. *Die Ammoniten des schwabischen Jura. Bd 1. Der schwarze Jura (Lias).* Stuttgart, Schweizerbart'sche Verlagshandlung (E. Koch).

REYNES, P. 1879. *Monographie des ammonites 1er Partie: Lias.* Paris, Librarie J.-B. Bailliere & Fils.

SCHLATTER, R. 1984. Zur systematischen stellung der Gattung *Epophioceras* Spath (Ammonoidea). *Jahresbericht und Mitteilungen des Oberrheinischen Geologischen Vereins. Stuttgart.* N.F. **66**, 175–85.

SMELLIE, J. L., PANKHURST, R. J., THOMSON, M. R. A. *and* DAVIES, R. E. S. 1984. The geology of the South Shetland Islands. VI: Stratigraphy, geochemistry and evolution. *British Antarctic Survey Scientific Reports*, No. 87, 85 pp.

SMITH, A. B. *and* TRANTER, T. H. 1985. *Protremaster*, a new Lower Jurassic genus of asteroid from Antarctica. *Geological Magazine*, **122**, No. 4, 351–59.

STOREY, B. C. *and* MENEILLY, A. W. 1983. Mélange within subduction-accretion complex rocks of Fredriksen Island, South Orkney islands. *Geological Magazine*, **120**, No. 6, 555–66.

STOREY, B. C. *and* GARRETT, S. W. 1985. Crustal growth of the Antarctic Peninsula by accretion, magmatism and extension. *Geological Magazine*, **122**, No. 1, 5–14.

TERQUEM, M. O. 1855. Paléontologie de l'étage inférieur de la formation liasique de la Province de Luxembourg (Grand-Duché) et de Hettange, Départment de la Moselle. *Mémoires de la Société Géologique de la France, Ser. 2*, **5**, Pt. 2, 1–125.

THOMSON, M. R. A. 1975. New palaeontological and lithological observations on the Legoupil Formation, north-western Antarctic Peninsula. *British Antarctic Survey Bulletin*, Nos. 41 and 42, 169–85.

TILMANN, N. 1917. Die Fauna des unteren u. mittleren Lias in Nord – u. Mittel-Peru. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie*, Biel Bd, **41**, 628–712.