NEW PALAEONTOLOGICAL AND LITHOLOGICAL OBSERVATIONS ON THE LEGOUPIL FORMATION, NORTH-WEST ANTARCTIC PENINSULA

By M. R. A. Thomson

ABSTRACT. Fossil Bivalvia, including *Bakevelloides* aff. *hekiensis* (Kobayashi and Ichikawa) and *Neoschizodus halperni* sp. nov., indicate a Triassic age for the Legoupil Formation. This conflicts with the Cretaceous age previously proposed on radiometric grounds (Halpern, 1964, 1965). Attention is drawn to the presence of rhyolitic volcanic rocks in the Legoupil Formation. Although the formation shows structural and lithological similarities to the Trinity Peninsula Series, direct evidence for the age of the latter formation is so sparse that no positive conclusions can be reached concerning the stratigraphical relationships between the two.

Fossils were first discovered in the Legoupil Formation by M. Halpern (1964, 1965) on the Duroch Islands, 0·5 km. west of Cape Legoupil (Fig. 1). Several fossiliferous localities were mapped, notably on Kopaitic and Gandara Islands (Halpern, 1964, fig. 12). Plant remains from Kopaitic Island (Halpern, 1965, fig. 20) were indeterminate but, among some poorly preserved bivalves, there were two specimens which conformed in "hinge plate and dentition features to the genus *Platopis* sp. (?)" (Halpern, 1964, p. 336). The possible Cretaceous age suggested by these fossils was supported by two K-Ar dates which bracketed the age of the formation:

i. 116±4 m. yr. (Albian) for hornblende in a diorite pebble from a pebbly mudstone unit of the Legoupil Formation.

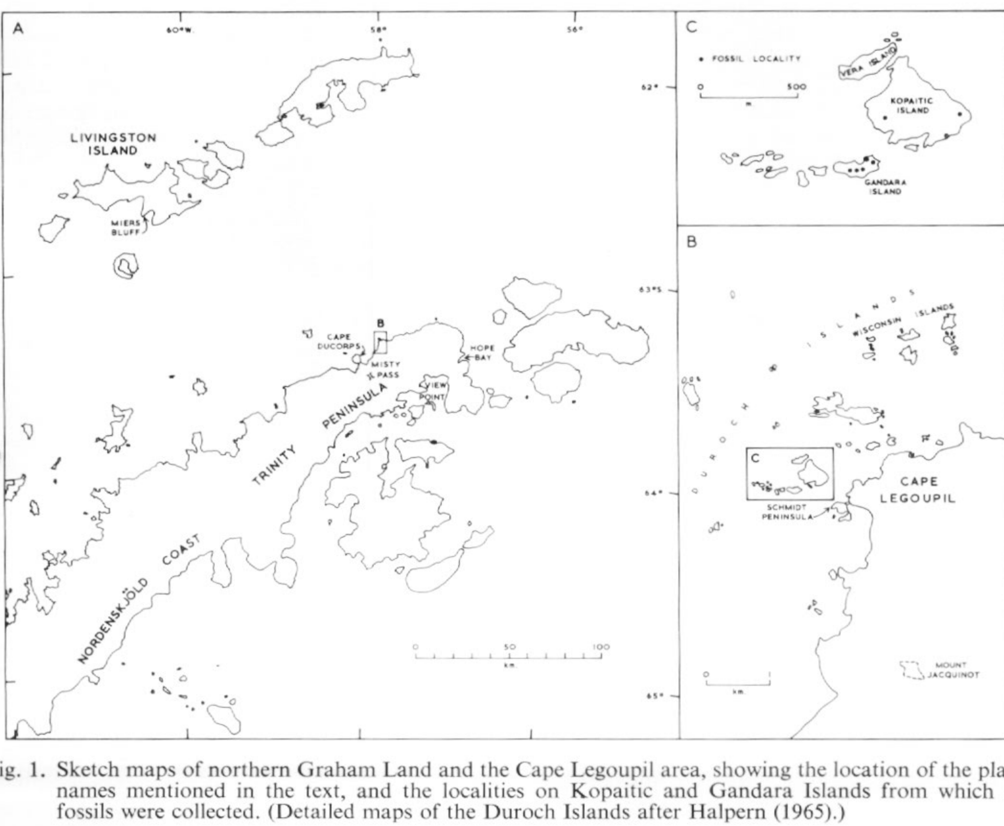

Fig. 1. Sketch maps of northern Graham Land and the Cape Legoupil area, showing the location of the place-names mentioned in the text, and the localities on Kopaitic and Gandara Islands from which the fossils were collected. (Detailed maps of the Duroch Islands after Halpern (1965).)

ii. 74±2·8 m. yr. (Campanian) for a pyroxene concentrate from an andesite dyke cutting the formation.

Furthermore, although the two are not seen in contact, the gently dipping porphyritic andesite flows of the Wisconsin Islands (Fig. 1B), dated at 86±7 m. yr. (Coniacian), were considered to overlie unconformably the more strongly folded and faulted Legoupil Formation. This would further restrict the period of deposition of the formation to some time during 30 m. yr. spanning the end of the Lower Cretaceous and the beginning of the Upper Cretaceous.

The age thus suggested proved to be controversial. Other workers argued that lithologically and structurally the Legoupil Formation was more akin to the (?) Upper Palaeozoic Trinity Peninsula Series of Graham Land, and the Miers Bluff Formation of Livingston Island (Elliot, 1965, p. 2, 1966, p. 41; Dalziel and Elliot, 1973). In addition, its fauna was quite unlike that of any Cretaceous sequence so far known in the Antarctic Peninsula area; *Platopis* had only previously been reported from the Lebanon and even its name was nomenclatorily unsound (p. 178; Vokes, 1952). An examination of some latex casts housed in the British Museum (Nat. Hist.), and prepared from some Legoupil Formation fossils sent to the late Dr. L. R. Cox for examination, showed that they had a distinctive dentition pattern comparable to that of some Permo-Triassic Myophoriidae.

In order to try and resolve the problem, British Antarctic Survey personnel made further collections of fossils on Kopaitic and Gandara Islands during a brief visit by R.R.S. *John Biscoe* on 26 February 1973. The Legoupil Formation is dominantly arenaceous and the greater part of it is apparently unfossiliferous. Most of the fossils collected came from a narrow (100 m. wide) belt which includes Gandara Island and the south-eastern part of Kopaitic Island (Fig. 1C). Plant remains are more common in the darker finer-grained sandstones with thin interbedded pyritiferous shales, whereas bivalves occur in pale grey to greenish grey, fine- to medium-grained sandstones. Usually the bivalves are concentrated in particular beds and they are locally present in sufficient numbers to form elongate lenses of coquina. Their state of preservation is palaeontologically unpromising. Most are preserved as more or less decalcified moulds, but careful cleaning, and the preparation of latex casts, has revealed a number of specimens with surprisingly well-preserved details of the hinge and dentition. Five species are recognized but more may be present among the less diagnostic material. All of these are notable for their smooth or feebly ornamented shells.

Other faunal remains are limited to a few rare finds. There is a possible fragment of an inarticulate brachiopod, some indeterminate trochiform gastropods, a single coiled serpulid attached to one of the bivalve shells, and a problematical trace fossil which may represent the tracks of a small arthropod. No micro-fossils were observed in any thin sections of the host rocks.

The sedimentology and depositional environment of the Legoupil Formation has been discussed by Halpern (1964, 1965). The fossiliferous sequence of Gandara Island was thought to have accumulated in a shallow-water littoral environment, whereas a quieter deeper-water situation was proposed for Kopaitic Island.

Systematic Descriptions

Brachiopoda (?)

In a thin section of a sandstone from Gandara Island (JB.501.10) there is a small (2·0 mm. by 0·1 mm.) piece of shell material with similar optical characteristics to those of some inarticulate brachiopods. The shell is finely laminated in layers which are alternately isotropic and of low birefringence (grey). Some isotropic layers have a microscopically granular texture and are pale brownish in ordinary light, although most are colourless. A closely similar kind of structure has been observed by the author in thin sections of the inarticulate brachiopod *Discinisca*, from the Lower Cretaceous of Alexander Island, and on an even finer scale in a modern *Lingula*. Presumably the alternate layers reflect a layering of the organic and phosphatic components of the shell.

Gastropoda

Two moulds on a specimen of a *Neoschizodus* shell bed (JB.502.18) represent poorly preserved trochiform gastropods. The species has a mean spire angle of about 50° and has high flat-sided whorls with stepped sutures. On the internal mould the base is seen to be low and deeply umbilicate. Neither specimen shows the aperture and both are too incomplete to attempt an identification. Other examples may be represented by two doubtful fragments on specimens JB.502.20 and 29.

Bivalvia

Family Myalinidae Frech 1891

Genus *Myalinella* Newell 1942
Myalinella (?) sp.

Fig. 2a

Material

About 20 poorly preserved and often fragmentary internal and external moulds in blocks of indurated sandstone from Kopaitic and Gandara Islands.

Description

The shell is sub-quadrate to mytiliform in outline and is anteriorly inflated (Fig. 2a). Most specimens are more or less equivalve but, when the material is good enough, the right valve appears to be marginally but consistently less inflated than the left. The postero-dorsal region of the shell is flattened into an almost wing-like area. The umbo is terminal and the angle between the dorsal and anterior margins ranges from 60° to 80°, although much of this variation may be caused by differences in preservation. Along its anterior margin, the shell is indented so that it meets the plane of commissure at about 90°. Over much of the shell the test was thin, but it was thickened in the region of the umbo, and some part internal/part external moulds suggest that the shell was considerably prolonged beyond the tip of the umbonal cavity. The anterior termination of the shell appears to have been sharply pointed and even rostrate in some specimens. Apart from feeble growth corrugations, the external surface of the shell is smooth.

Although there are several potentially suitable moulds on specimen JB.502.19, little detail of the internal characters is preserved, and the inference is that they were extremely simple. A cast from one internal mould (Fig. 2a) shows a narrow dorsal ligament area and an umbonal septum with a parallel-sided depression or gutter. The anterior extent of this depression is limited by a low steep wall formed by the anterior indentation of the shell. The ligament area shows faint longitudinal striations.

Remarks

The specimens included here all show general myalinid characteristics in their mytiliform, slightly inequivalve shells with simple internal characters. The projected or rostrate umbones are suggestive of *Septimyalina* (cf. illustrations by Newell (1942)), but none of the specimens has the very thick shell typical of that genus. The thin shell, and only slight tendency towards being inequivalve, accords better with the genus *Myalinella* Newell (1942, p. 60), of which a species with projected umbones has been described from the Middle Permian of Texas (Newell, 1942, p. 62, pl. 14, figs. 17–19).

Although they show overall resemblances to some mytilids, in which an umbonal septum is also present, the specimens described above apparently lack the rudimentary dentition and deeply set ligament of that group.

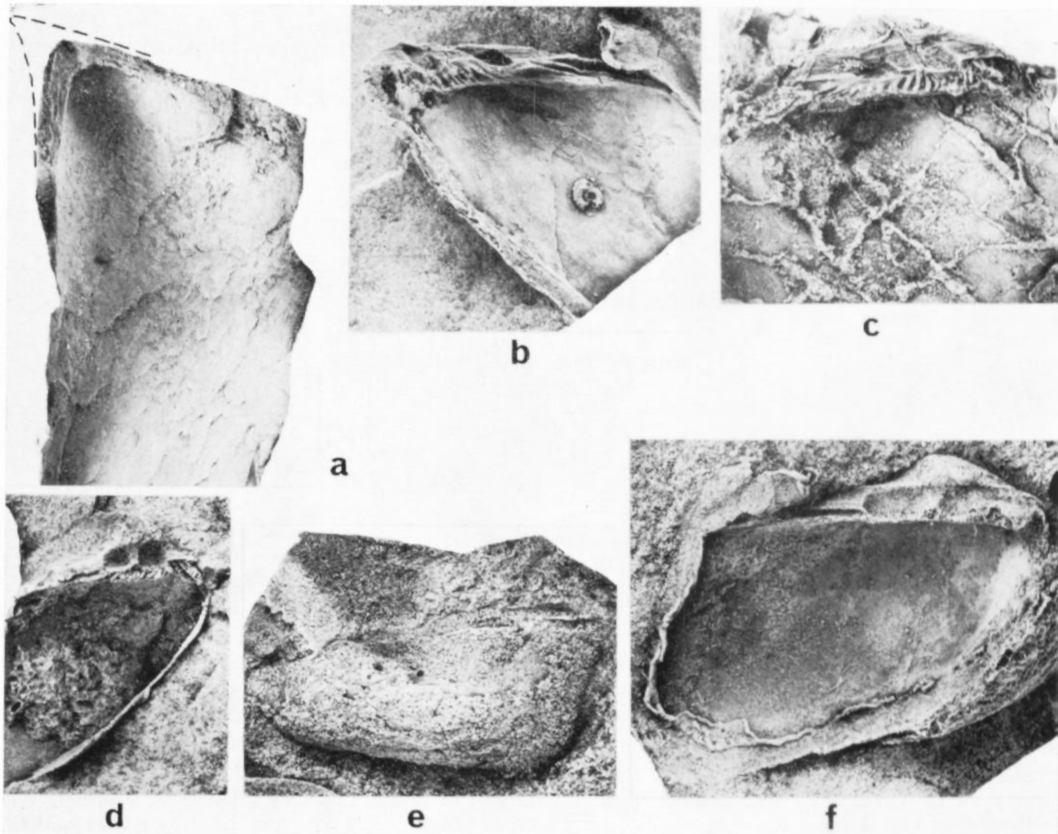

Fig. 2. a. *Myalinella* (?) sp.; latex cast from a natural internal mould. The dashed line indicates the probable form of the umbo as suggested by external moulds; ×2, coated (JB.502.19b).
b. *Bakevellia* (*Bakevelloides*) aff. *hekiensis* (Kobayashi and Ichikawa); latex cast from the natural internal mould of a right valve. A small coiled serpulid is adhering to the inside of the valve; ×2, coated (JB.502.15).
c. *Bakevelloides* aff. *hekiensis*; latex cast from the internal mould of a distorted left valve; ×2, coated (JB.502.10).
d. *Bakevelloides* aff. *hekiensis*; latex cast from a corroded internal mould of a left valve showing the prominent cardinal tooth; ×2, coated (JB.501.8).
e. *Hoernesia* (?) sp.; latex cast from a corroded external mould of a left valve; ×2, coated (JB.501.8).
f. *Hoernesia* (?) sp.; latex cast from a large internal mould; ×2, coated (JB.501.8).

Family Bakevelliidae King 1850

Genus *Bakevellia* King 1848
Subgenus *Bakevelloides* Tokuyama 1959
Bakevellia (*Bakevelloides*) aff. *hekiensis* (Kobayashi and Ichikawa 1952)

Figs. 2b–d and 3a–b

Material

Two specimens from Kopaitic Island (JB.502.10 and 15) and a less well-preserved example from Gandara Island (JB.501.11).

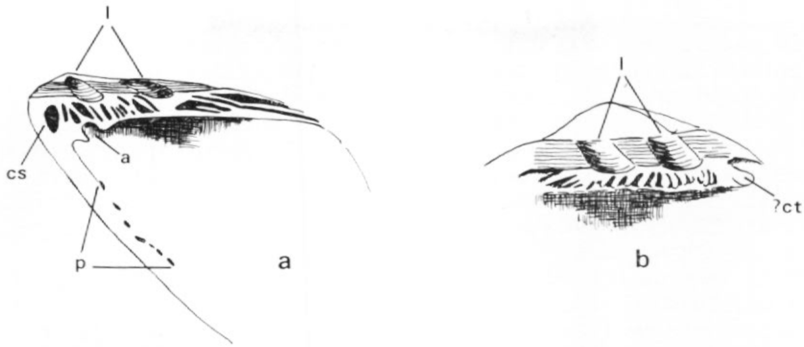

Fig. 3. *Bakevellia* (*Bakevelloides*) aff. *hekiensis* (Kobayashi and Ichikawa); diagrammatic sketches to show details of the cardinal area.
a. Right valve; ×2 (JB.502.15); cf. Fig. 2b.
b. Left valve; ×2 (JB.502.10); cf. Fig. 2c.
Black spots represent pits or tooth sockets; *a* anterior adductor muscle scar, *cs* cardinal socket, *ct* cardinal tooth, *l* ligament pits, *p* pits along palial line.

Description

The external form of this bivalve is imperfectly known and it is possible that there are many fragments of it in the collection which have gone unrecognized. In a bed of this species (JB.502.10) the shape of individuals varies considerably, presumably according to the orientation of each in relation to the deformational stresses which the rock has undergone. It appears that the shell was obliquely inflated, narrowed anteriorly, and had the umbo placed close to the anterior end. There was a flattened postero-dorsal wing-like area but no obvious anterior ear. The obliquity varies but it seems that the shell was pteriform as in *Bakevellia*, rather than ensiform as in *Gervillia*. Individual valves suggest that the shell was inequivalve, the left valve having a more prominent umbo than the right, and perhaps being a little more inflated. External ornament is limited to impressed growth lines or rugae.

Details of the ligament area and hinge plate of the right valve are well shown on specimen JB.502.15 (Figs. 2b and 3a). The ligament area is obtusely triangular, longitudinally striated, and is crossed by two prosocline ligament pits which cut down into the top of the hinge plate; the anterior pit is located immediately below the umbo. At the anterior end of the hinge plate there is a deep cardinal socket, and behind this there are 11 orthocline to gently prosocline denticles and a few elongate lateral teeth. The denticles are distributed as follows: three in front of the anterior ligament pit, three beneath it, and five behind it and beneath the posterior ligament pit. The posterior denticles are more prosocline than the others and the penultimate one is Y-shaped (Fig. 2b). The area beneath the posterior ligament pit is apparently smooth. Behind this, the hinge plate gradually narrows and carries two prominent lateral teeth, the more ventral of which bears a low secondary tooth or ridge.

A left valve of a slightly larger individual (JB.502.10; Figs. 2c and 3b) is badly crushed, although part of the hinge plate is more or less intact. The umbo projects above the ligament area, is prosogyrous and sharply carinate. Two ligament pits are present on the longitudinally striated area, and are apparently opisthocline, although this may be partly due to crushing. At the anterior end of the hinge plate there is a single prominent cardinal tooth, behind which is a series of ten denticles; these are orthocline at first but become increasingly prosocline below and behind the second ligament pit until they pass into the lateral teeth. Similar dentition is present on a second specimen from Gandara Island (JB.501.11; Fig. 2d) but on this specimen the ligament pits are orthocline.

The palial line and muscle scars are incompletely known. On both valves there are pits immediately below the anterior extremity of the hinge plate, which may correspond to the anterior adductor muscle scars. That of the left valve appears to be partly supported by a ventral extension of the cardinal tooth. On specimen JB.502.15 (Fig. 3a) the anterior part of the palial line is marked by a line of minute shallow pits (cf. Tokuyama, 1959, p. 148).

Remarks

In the past, the recognition of numerous sub-divisions within the Bakevelliidae led to considerable confusion and, in many papers describing these bivalves, the authors first included a review of the group setting out their own interpretations. Cox's revision of the family in the *Treatise on invertebrate paleontology* (Moore, 1969) has reduced the Bakevelliidae to a more manageable number of genera, and the identification of the present species is largely limited to a choice between two genera, *Bakevellia* King and *Gervillia* Defrance. Both of these have differentiated dentition, with pseudotaxodont teeth on the anterior part of the hinge plate and elongate lateral teeth behind, but the probable pteriform shell of the Antarctic species precludes an identification with *Gervillia*.

Although the two are not identical, the dentition of the present species shows a close resemblance to that of "*Gervillia*" *hekiensis* Kobayashi and Ichikawa (1952), type species of the subgenus *Bakevelloides* Tokuyama (1959), from the Upper Triassic of Japan. The dentition of *B. hekiensis* is very variable. Tokuyama (1959, p. 150, text-fig.) described a sequence of ontogenetic stages in *B. hekiensis* where the middle part of an initial series of denticles along the hinge plate became obsolete in the "two-pit stage",* such that the dentition was separated into anterior and posterior sections. However, in other examples (cf. Nakazawa, 1954, pl. V, figs. 3b and 4b, pl. VI, fig. 1) even in the "three-pit stage" the teeth form an almost continuous series between the cardinal tooth and the laterals. This is only interrupted or reduced by the incision of the two anterior ligament pits into the hinge plate. The three present examples have two ligament pits and a continuous row of pseudotaxodont denticles. The isolated valves described here suggest that the shell was more inequivalve than is normal for *Bakevelloides*, and the umbo of the left valve projects higher above the hinge line than in hitherto described examples of *Bakevelloides*.

The late Triassic–early Jurassic *Maizuria* Nakazawa (1959), suppressed by Cox (*in* Moore, 1969, p. *N*306) under *Bakevellia s.s.*, has a dentition pattern (Nakazawa, 1959, pl. 4, figs. 13b, 15c and 19–21) which is not unlike that of some variants of *Bakevelloides*. According to Nakazawa (1959, p. 159), the dentition of these two forms developed in different ways:

i. In *Maizuria* "through the differentiation of the cardinal teeth and 'pseudocardinals' posterior to the cardinals".
ii. In *Bakevelloides* "through crenulation along the lower margin of the ligament area or insertion of denticles between the anterior and posterior teeth".

It therefore seems that to distinguish between these two types of dentition an ontogenetic series of specimens is required, and that is not available for the present material. However, the lack of crenulations on the teeth as described from *Maizuria* (Nakazawa, 1959, p. 201) suggests that the present examples are better placed in the subgenus *Bakevelloides*.

Among European bakevelliids, similar dentition may be present in the Middle Triassic "*Gervillia*" *polydonta* Credner (Frech, 1909, pl. I, fig. 3) but this is an equivalve species in which the ligament area is apparently very narrow.

Genus *Hoernesia* Laube 1866
Hoernesia (?) sp.

Fig. 2e and f

Material

Three specimens of a medium-grained grey sandstone with greenish weathering from Gandara Island (JB.501.8, 11 and 17) and containing a number of moulds. A specimen from Kopaitic Island (JB.502.23) may also belong to this species.

Description

Small external moulds of this species (Fig. 2e) are narrowly elongate and trapeziform, with the umbo situated inside the anterior third of the shell. The hinge line is straight and meets the

* Terminology used by Tokuyama to describe the growth stage of bakevelliids by referring to the number of pits which are present in the ligament area. These pits appear one by one in the early growth stages, to a maximum of about three in *Bakevelloides*.

anterior margin at an angle of a little less than 90°. The anterior margin curves smoothly into the ventral margin and the height of the shell increases slightly towards the rounded postero-ventral corner. A prominent carina extends from the umbo to the postero-ventral corner, marking off a large postero-dorsal wing-like area. With the exception of a few faint growth lines, the shell is devoid of ornament.

One external mould on specimen JB.501.11 suggests that this species had a distinctly inequivalve shell with the left valve larger than the right. The umbo of the left valve projects above the hinge line, whereas that of the right apparently does not.

Specimen JB.501.8 is part of a shell bed and contains a moderately well-preserved internal mould of a left valve (Fig. 2f). This is larger than the external moulds described above and is relatively higher in proportion to their length than they apparently are. The visceral cavity extends behind the hinge plate and has two dorsal projections, one up towards the prosogyrous umbo, and the other towards the anterior end of the hinge plate. The ligament area bears two pits, the posterior one of which is so elongate as to suggest that it was enlarged by corrosion of the test before fossilization. The hinge plate is narrow and interrupted by the ligament pits; at its anterior extremity there is a stout triangular tooth, and posteriorly there is a long groove or socket which presumably received a corresponding tooth from the right valve.

Remarks

External moulds of left valves of this species (Fig. 2e) were first mistaken for *Parallelodon*. However, the recognition of ligament pits on supposedly related internal moulds, and the suggestion that the shell is distinctly inequivalve, indicates that it is more likely to be a species of *Hoernesia*. The sandstone matrix in which most of the specimens occur is too coarse for the preservation of fine detail and the dentition is imperfectly known. The description of the genus in the *Treatise on invertebrate paleontology* (Cox *in* Moore, 1969, p. *N*310) allows for great variation in the dentition pattern and the present material is not well enough preserved for comparison with known species.

Small dorsal extensions of the visceral cavity have also been described from some slightly inequivalve bakevelliids from Queensland, *Bakevellia capricorni* (Fleming, 1966, p. 24), and they were thought to be pedal muscle and visceral supporting muscle scars. Muscle scars in a similar position on the internal mould of *Bakevelloides hekiensis* (Nakazawa, 1954, pl. VI, fig. 1) were annotated as adductor and pedal retractor muscle scars. Like many bakevelliids, *B. capricorni* appears to be a very variable species (Fleming, 1966, pl. 7, figs. 7–12, pl. 8, figs. 1–7) but it differs from the present one in being less markedly inequivalve, in its pseudo-taxodont dentition and its more oblique antero-ventral margin.

FAMILY MYOPHORIIDAE BRONN 1849

Genus *Neoschizodus* Giebel 1855
Neoschizodus halperni sp. nov.

Figs. 4a–i and 5a–f

Material

Numerous examples in decalcified coquinas from Kopaitic and Gandara Islands. The best internal mould of a left valve on specimen JB.502.6 from Kopaitic Island is selected as the holotype.

Diagnosis

Shell small, sub-trigonal, moderately inflated, smooth except for a sharp umbonal carina and a postero-dorsal riblet; umbo prosogyrous. Dentition myophoriid; tooth 2 stout, transversely ridged in front, 4a and 4b poorly developed, 3a stout, 3b elongate. Myophorous buttress well developed.

The species is named after Dr. M. Halpern, who first discovered fossils in the Legoupil Formation.

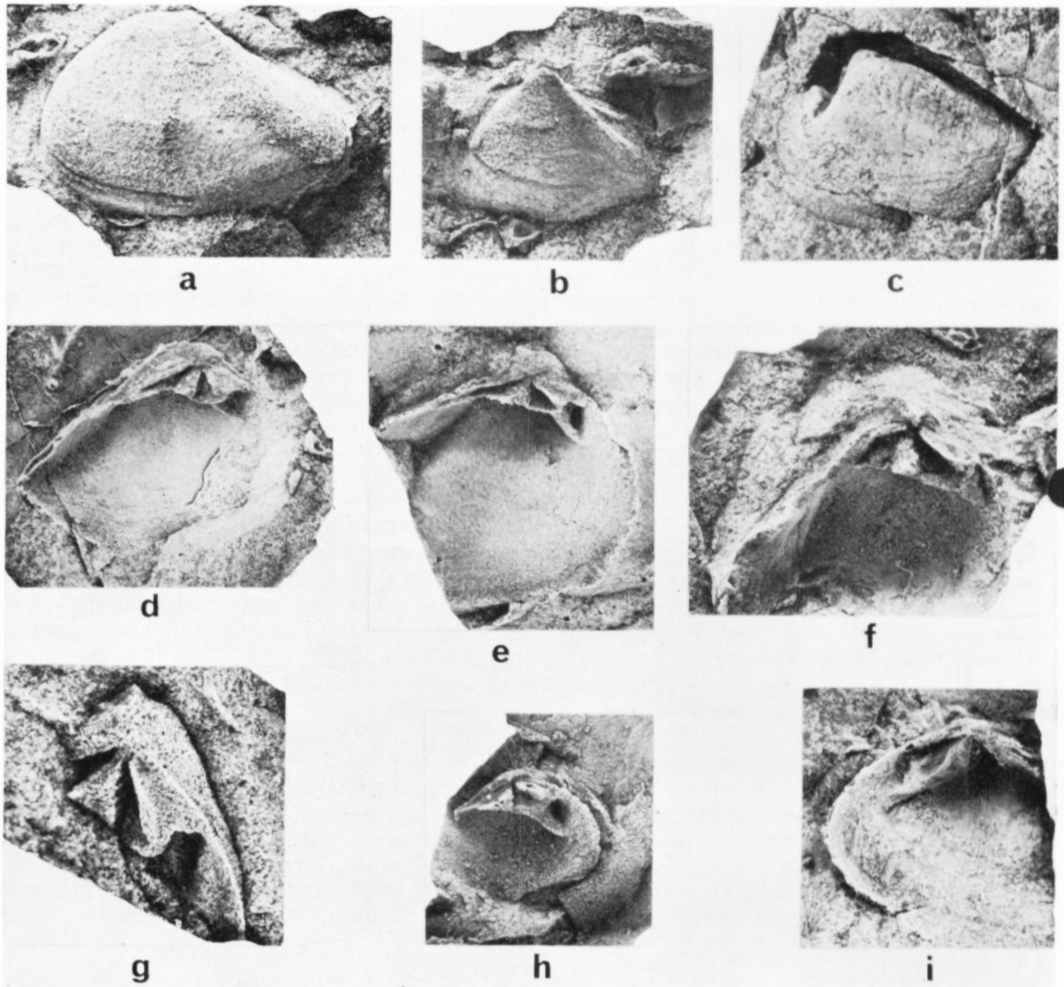

Fig. 4. a. *Neoschizodus halperni* sp. nov.; latex cast from the natural external mould of a large left valve; ×2, coated (JB.502.12).
b. *Neoschizodus halperni*; latex cast from the external mould of a small left valve showing the umbonal carina and the riblet on the postero-dorsal area; ×2, coated (JB.502.18b).
c. *Neoschizodus halperni*; holotype, an internal mould of a left valve showing the characteristic slot in front of the umbonal cavity infilling, denoting the position of the myophorous buttress; ×2, coated (JB.502.6).
d. *Neoschizodus halperni*; latex cast from the holotype; ×2, coated (JB.502.6).
e. *Neoschizodus halperni*; latex cast from an internal mould of a left valve. Tooth 2 is badly cast but the myophorous buttress is well shown; ×2, coated (JB.502.7).
f. *Neoschizodus halperni*; latex cast from a fragmentary internal mould of a large individual. The dentition is well displayed but the region of the anterior adductor muscle scar is damaged; ×2, coated (JB.502.17).
g. *Neoschizodus halperni*; latex cast from an internal mould fragment showing transverse ridges on the front of tooth 2; ×4, coated (JB.502.2).
h. *Neoschizodus halperni*; latex cast from a juvenile specimen showing transverse ridges on the front of tooth 2 and a strongly developed tooth 4a. The myophorous buttress is also well shown; ×2·5, coated (JB.502.12).
i. *Neoschizodus halperni*; latex cast from the internal mould of a right valve on the same slab as the holotype; ×2, coated (JB.502.6).

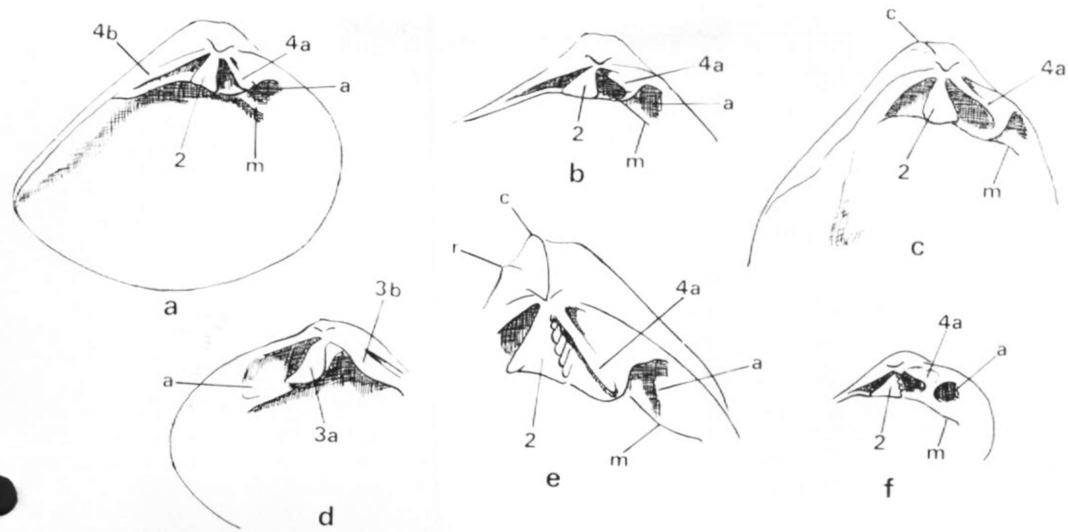

Fig. 5. *Neoschizodus halperni* sp. nov.; diagrammatic sketches to show details of the dentition.
a. Holotype; ×2·5 (JB.502.6); cf. Fig. 4d.
b. Left valve; ×2 (JB.502.7); cf. Fig. 4e.
c. Large left valve; ×2 (JB.502.17); cf. Fig. 4f.
d. Right valve; ×2 (JB.502.6); cf. Fig. 4i.
e. Well-preserved left valve showing transverse ridges on the front of tooth 2; ×4 (JB.502.2); cf. Fig. 4g.
f. Small left valve; ×2·5 (JB.502.12); cf. Fig. 4h.
The notation of the dentition is based on Douvillé's interpretation (Cox *in* Moore, 1969, p. *N*472, fig. D61, A and B). *a* anterior adductor muscle scar, *c* umbonal carina, *m* myophorous buttress, *r* postero-dorsal riblet.

Description

The external form of the shell is known from two external moulds of left valves (Fig. 4a and b). It is sub-trigonal in outline, rounded in front and angular behind, and it is smooth except for a sharp umbonal carina and a postero-dorsal riblet. The carina extends from the beak to the angular postero-ventral corner of the shell; internally it is visible as an angular inflation of the visceral cavity (Fig. 4e). The postero-dorsal riblet is less prominent and is barely visible on the larger specimen; it begins at the beak and extends along the postero-dorsal area marked off by the umbonal carina.

The dentition of the left valve is better known than that of the right (Figs. 4d–h and 5a–c and e–f). A stout median triangular tooth (2) beneath the beak is flanked by two deep sockets which receive teeth 3a and 3b of the right valve. The anterior socket is triangular and deeply excavated, even spoon-like, and it is bounded anteriorly by a poorly developed ridge-like tooth (4a). On most specimens this is difficult to see because only slight corrosion is necessary to remove all traces of it, and it is best preserved on one of the smaller internal moulds (JB.502.12; Figs. 4h and 5f). On at least three examples (JB.502.2, 6 and 12; Figs. 4g and 5e) the anterior face of tooth 2 bears prominent transverse ridges. The posterior socket is narrowly triangular and trends sub-parallel to the dorsal margin of the valve; it is bounded posteriorly by a long, somewhat obscure marginal tooth (4b). In its entirety, the hinge plate is triangular with a sinuous ventral margin that is gently concave beneath the posterior socket, convex below tooth 2 and the anterior socket, and is recurved at the anterior end, where it exposes the anterior adductor scar. This scar is limited posteriorly by a prominent myophorous buttress (Fig. 4d–h).

In the right valve (Figs. 4i and 5d), the hinge plate appears to have been cleaved between teeth 3a and 3b, so that tooth 2 would have fitted into a space rather than a socket. Tooth 3a is triangular and is about as stout as tooth 2 in the left valve. Tooth 3b is prominent, elongate and sub-parallel to the postero-dorsal margin. It is bounded posteriorly by a narrow marginal groove which probably represents the socket for tooth 4b. The large triangular socket in front of tooth 3a appears to be out of all proportion to the size of tooth 4a, and some of the space was probably occupied by the anterior adductor muscle. The myophorous buttress is not as ridge-like as in the left valve but forms a platform continuous with tooth 3a.

Measurements

Specimen number	*Length* (mm.)	*Height* (mm.)
JB.502.6 (holotype)	17·5	14·0
JB.502.7	19·0 (estimated)	15·0
JB.502.12	19·0	14·0
JB.502.18	14·0	11·0

Remarks

Neoschizodus halperni sp. nov. belongs to a widely distributed group of myophoriids usually described under the name of *N. laevigatus* (Ziethen), and characterized by small smooth sub-trigonal shells with myophoriid dentition and a posterior carina. Elongate forms have been referred to the variety, *elongata*, but some Japanese examples may owe their shape to deformation (Nakazawa, 1960, p. 57). The Antarctic species differs from the typical *N. laevigatus* in its sharper and more prominent umbonal carina, in the possession of a radial riblet on the postero-dorsal area rather than a radial furrow, and perhaps by the presence of striated teeth. A very prominent carina is present in *N.* cf. *laevigatus* from the Lower Triassic of Japan (Nakazawa, 1960, pl. VI, figs. 21–32), and the external moulds figured here (Fig. 4a and b) compare closely in outline with two of the Japanese specimens (Nakazawa, 1960, pl. VI, figs. 27a and 31). However, the Japanese forms have the posterior furrow typical of the true *N. laevigatus*. Some examples from the Middle Triassic of Afghanistan (Farsan, 1972, p. 178, pl. 45, figs. 1–3), assigned to *N. laevigatus*, possess a weak median ridge on the posterior area but they are more than twice the size of the Antarctic and Japanese forms discussed above.

In all probability, *N. halperni* is the same as *Platopis* (*?*) sp. first recorded from Kopaitic Island (Halpern, 1964, 1965). It is the commonest species in the present collection, and the dentition of the specimens described above is identical to that on casts in the British Museum (Nat. Hist.) prepared from some of Halpern's original material (p. 170). Only a natural internal mould has hitherto been illustrated (Halpern, 1964, fig. 4, 1965, fig. 19) and that has a broken umbo revealing triangular pits (teeth) and ridges (sockets) in the hinge region.

The name *Platopis* is nomenclatorily unsound (Vokes, 1952) and species once included in that genus are now included in *Nemetia* Casey (1955) and *Veniella* Stoliczka (Keen and Casey, *in* Moore, 1969, p. *N*650). The first of these is known only from the Aptian of Syria and the second is a coarsely ornamented Upper Cretaceous form with a wide geographical distribution. Since Halpern (1964, 1965) noted that, according to N. F. Sohl, the genus was restricted to the Lower Cretaceous, it may be assumed that "*Platopis*" was interpreted in the sense as used by Vokes (1946) and which is now synonymous with *Nemetia*. While the external form of *Nemetia* (Vokes, 1946, pl. 8, figs. 24 and 25) is not unlike that of *Neoschizodus*, internally it lacks the myophorous buttress and its dentition (Vokes, 1946, pl. 8, fig. 26; Casey, 1955) is more complex than that of the latter genus. In particular, *Nemetia* possesses long lateral teeth which are not present in *Neoschizodus* and nor apparently in "*Platopis* (*?*)" from Kopaitic Island (Halpern, 1964, 1965).

Indeterminate bivalve

Fig. 6a

An internal mould on specimen JB.502.23 from Kopaitic Island probably represents a fifth species of bivalve, although it is too poorly preserved to be properly identified. The shell is feebly inflated, roughly circular in outline and has a large median triangular pit on the hinge plate (Fig. 6a). Whether this pit represents a tooth socket or a resilifer pit is not certain.

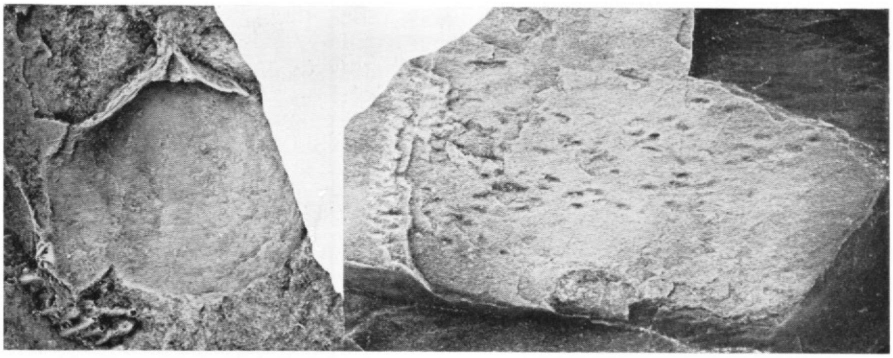

Fig. 6. a. Latex cast from an internal mould of a distinctive but indeterminate bivalve; ×2, coated (JB.502.23).
b. Possible arthropod tracks in a mudstone from Kopaitic Island; ×2, coated (JB.502.21).

Annelida

The annelids are represented by a single external mould of a small (2 mm. diameter) serpulid adhering to the inner surface of a right valve of *Bakevelloides* aff. *hekiensis* (Fig. 2b). Its shell is a simple planar coil of apparently smooth-sided whorls with a circular cross-section. Successive whorls increase rapidly in size and are barely in contact with one another.

Trace Fossils

One bedding surface on a small piece of cleaved mudstone (JB.502.21) bears a 6–7 mm. wide band of tiny elongate pits (Fig. 6b). These have no regular arrangement other than that they appear to be concentrated along the lateral margins of the structure, and that they are elongated parallel to it. Although only a short length (25 mm.) of the structure is preserved, its narrow confines suggest that it is some form of track rather than a diagenetic or metamorphic feature of the rock. In particular, it shows a general resemblance to a number of track types which have been ascribed to arthropods (cf. Lessertisseur, 1955, fig. 16B and D (top), pl. V, fig. 4).

Lithological and Structural Observations

Lithological and structural similarities between the Legoupil Formation and the Trinity Peninsula Series are well shown by the differences of opinion which exist over the mapping of some sedimentary rocks on the north-western shores of Trinity Peninsula. Halpern (1965, map in back pocket), working from the Duroch Islands, included rocks on the mainland at Cape Legoupil, Mount Jacquinot and Cape Ducorps (Fig. 1) in the Legoupil Formation, whereas Elliot (1965, fig. 2A), working from the interior of Trinity Peninsula, mapped the *same* outcrops as Trinity Peninsula Series. If the Legoupil Formation is Cretaceous in age (Halpern, 1964, 1965), the above observation could further imply that, either the Trinity Peninsula Series is Cretaceous in part, or that some of the rocks which have been mapped as Trinity Peninsula Series (? Upper Palaeozoic) in fact belong to a depositional cycle of much later age.

The rocks of the Legoupil Formation were first described by Halpern (1964, 1965) as including argillite, quartz wacke, quartz-feldspathic wacke, quartz-feldspathic arenite, arkosic arenite, granule to pebble conglomerate and pebbly mudstone. A sedimentary breccia of uncertain stratigraphical relationships but entirely composed of Legoupil Formation rock types was mapped at Halpern Point. Similar rock types have been reported from Trinity Peninsula Series rocks of northern Graham Land (Elliot, 1965, 1966; Aitkenhead, 1975) and the Miers Bluff Formation of Livingston Island (Hobbs, 1968).

Volcanic rocks

Hurriedly collected samples from Kopaitic and Vera Islands, obtained during a brief visit by British Antarctic Survey personnel in 1966, suggest that the Legoupil Formation also contains at least a small percentage of volcanic strata. Near the centre of Kopaitic Island, black mudstones alternate with thin beds of hard, pale greenish aphanitic rock. In a hand specimen (BS.4.7), one such bed contains four sharply defined layers within the space of about 5 cm.; these vary in colour from off-white to greenish grey. In thin section, the groundmass of this rock is cryptocrystalline, of low birefringence, and is strongly sericitized in places. Scattered through this are small (approx. 1 mm.) clots of epidote, chlorite and sphene, arranged more or less parallel to the bedding. In several cases the clots have tabular outlines and appear to be replacing feldspar crystals; in some areas of the rock relatively unaltered crystals of sodic plagioclase, up to 6 mm. long, are distinguishable.

A pale buff-grey aphanitic rock with scattered feldspar phenocrysts, at the western end of Vera Island, is similar to the above example from Kopaitic Island except that it is much fresher. In thin section the rock is very fine-grained and porphyritic. The groundmass consists of microcrystalline plagioclase laths, (?) quartz, sericitic alteration products and interstitial glassy material. A poorly developed trachytic texture is visible, especially where there is tangential alignment of feldspar laths around some of the phenocrysts. The phenocrysts all appear to be albite and show a variety of twinning, including simple, polysynthetic and interpenetrant types. They range in size up to 0·8 mm. and are scattered sporadically through the rock, either singly or in glomeroporphyritic aggregates of up to ten crystals. All are turbid in ordinary light, and they are peppered with small sericite crystals; in a few instances they are partially replaced by epidote and sheaves of non-pleochroic chlorite.

The importance of these fine-grained indurated rocks was not appreciated in the field, although it is significant that they were regarded as a normal part of the bedded succession. It is therefore unlikely that they represent thin high-level intrusions. The fine-grained and partially glassy groundmass of both rocks indicates that they were both cooled extremely rapidly, and probably represent rhyolitic lavas erupted subaqueously.

Provenance

The provenance of the Legoupil Formation may be deduced from the composition of the coarser sandstones and the conglomerates. In the sandy fractions of the conglomerates, and in the sandstones and greywackes, quartz is always the dominant constituent, whereas feldspar and lithic fragments are subordinate. The remarks made by Elliot (1965, p. 4) in relation to the difficulties of classifying the detrital *quartz* in arenaceous rocks of the Trinity Peninsula Series are equally pertinent to the present discussion. Furthermore, it should be emphasized that, also in the present case, virtually all of the detrital quartz grains show undulose extinction caused by strain. In some instances it is clear that part of this strain was the result of pressure between adjacent grains, and may be related to the low-grade regional metamorphism of the sedimentary sequence. If allowance is made for a slight superimposed strain, and quartz-bearing lithic clasts (below) are taken into account, it seems most probable that the bulk of the detrital quartz came from a plutonic and/or gneissic granite source, with minor contributions from volcanic rocks and granophyres.

The commonest *feldspars* are plagioclase and orthoclase. Although alteration of the plagioclase is sometimes considerable, extinction angles of albite twins are usually measurable and an albitic composition is generally indicated. Sericitization of orthoclase may be virtually complete. Minor amounts of perthite are often present, and chequerboard albite and microcline occur in a few of the thin sections.

Accessory minerals include zircon, sphene, epidote, iron ores, muscovite and biotite, chlorite, garnet and rare allanite.

Lithic clasts in the conglomerates, and to a lesser extent the greywackes, offer the best indications of provenance. In conglomerates on Kopaitic and Gandara Islands, Halpern (1964) recorded volcanic, hypabyssal, plutonic, metamorphic and cherty rocks, in addition to clasts of sedimentary rock. In the pebbly mudstones he listed a variety of plutonic rocks including pink, white and graphic granite, quartz-diorite, porphyritic quartz-diorite and hornblende-diorite. With the exception of the diorites, most of these rock types have been identified by the author in new material from the Gandara Island conglomerate. Apart from re-worked sedimentary fragments, the dominant clast types are volcanic. These consist of fine-grained to microcrystalline tuffs with large (0·7 mm.) crystals of quartz and feldspar, devitrified spherulitic rhyolites (possibly Halpern's spherulitic chalcedony) and occasional fragments of dark trachytic andesite. The crystals in the tuffs are varied and include rounded and embayed quartz, euhedral grains of oligoclase, and ragged grains of perthite and highly sericitized feldspar (some with remnant albite twinning); fragments of earlier tuffs also occur. Being fine-grained and of low birefringence, the matrix of these tuffs could easily be confused with chert (below) and it seems most probable that there is very little true chert in the Gandara Island conglomerate. In practice, tuff fragments without phenocrysts could only be distinguished with difficulty by their slightly coarser grain-size and lower birefringence; if much sericitization has occurred, a petrological distinction may be virtually impossible.

Although many clasts of sedimentary rock can be matched with beds in the Legoupil Formation itself, others are readily distinguished by their relatively higher metamorphic grade and are clearly derived from rocks of an earlier sedimentary cycle. These are mainly recrystallized or sheared sandstones but also include phyllite and spotted hornfels. Chert is probably an uncommon constituent in most of the rocks examined, but two conglomerate specimens from Kopaitic Island (BS.4.21 from near the south-eastern corner, and BS.4.13 from about 280 m. to the east-south-east of the latter) have chert as by far the most abundant lithic constituent. The coarsest is specimen BS.4.21 in which tabular chert clasts range up to 35 mm. by 17 mm. and vary from off-white to pale greenish in colour. In thin section, it is cryptocrystalline and cut by a network of quartz veins and thinner calcite veinlets; some recrystallization of the chert may have taken place adjacent to some of the quartz veins. The greenish variety contains small spherical aggregates which might be the recrystallized remains of radiolarian tests.

Granitic rocks are present in minor amounts and are represented by coarse-grained igneous and (?) gneissose granite fragments, grains of coarsely graphic quartz and, most frequently, by clasts of granophyre. These granophyres are notable in thin section for the intricacy of their quartz-feldspar intergrowths, many of which have an almost feathery texture.

The source area of the Legoupil Formation was thus dominated by volcanic and sedimentary rocks with granitic intrusions, and was similar to that advocated for the Trinity Peninsula Series (Elliot, 1965; Aitkenhead, 1975). It must be stressed that similar lithology and provenance is not proof of similar age, but the proximity of the two formations and the difficulty of distinguishing between them in the field would favour a close correlation. Minor differences in petrology between the two formations do occur but these could be due to local differences in provenance and depositional environments. For example, although the clast content of the Gandara Island conglomerate is remarkably similar to that of one reported by Aitkenhead (1975) from rocks of the Trinity Peninsula Series at View Point, the latter apparently lacks granophyre clasts and its contained detrital garnet grains are chloritized. Chert is an uncommon constituent in the Trinity Peninsula Series but it has sometimes been found as detrital grains, and Aitkenhead (1975) described beds of a pale green variety in nunataks north of Church Point. It is uncommon in Legoupil Formation rocks, although in at least one conglomerate it is the dominant constituent. No bedded cherts have yet been reported from the Legoupil Formation.

Structure

Apart from instances where the bedding is disturbed by faulting, the sedimentary succession of the Duroch Islands generally dips steeply north-north-westward at angles typically between 60° and 80°. The overall east-north-east strike of the beds is consistent with that of the Trinity Peninsula Series, whose strike follows the general trend of the Antarctic Peninsula. Mapping by Adie (1957), Elliot (1965, 1966) and Aitkenhead (1975) suggests that there is a general increase in the regional metamorphism and deformation of the Trinity Peninsula Series eastward and southward across the peninsula, to a maximum on the Nordenskjöld Coast (Fig. 1) where greenschists are present. Thus the least deformed and metamorphosed parts of the sequence might be expected to occur on the north-western side of Trinity Peninsula. Even if the greenschists of the Nordenskjöld Coast are part of the pre-Palaeozoic basement, as was suggested by Grikurov (1971), this does not invalidate the above argument. There is an overall, if slight, increase in regional metamorphism in the remainder of the rocks assigned to the Trinity Peninsula Series.

The effects of regional metamorphism are not obvious in the Legoupil Formation. None of the zeolite minerals associated with the lowest grade of regional metamorphism have been observed in samples obtained from the Duroch Islands. In the more argillaceous beds a poorly developed cleavage is detectable in the hand specimen as well as in thin sections, whereas fracturing is indicated in some arenaceous rocks by distorted fossils, ramifying quartz veins and the textures of rocks in thin section. This is closely comparable to the metamorphic state of Trinity Peninsula Series rocks from north-west Trinity Peninsula (Elliot, 1965).

Phyllites at Schmidt Peninsula (Fig. 1) were interpreted by Halpern (1964, fig. 6, p. 338) as having been formed by predominantly dynamic metamorphism associated with the "O'Higgins fault", and a similar origin has been suggested for the apparently anomalous occurrence of phyllites at Misty Pass (Fig. 1A) in an area of virtually unmetamorphosed Trinity Peninsula Series rocks (Elliot, 1965, p. 13, 23). Whereas the postulated fault at Misty Pass could have a throw of about 1 km., the magnitude and extent of the faulting at Cape Legoupil is uncertain (cf. Halpern, 1964, fig. 5, 1965, map in back pocket). Polyphase folding has been detected in the phyllites of Schmidt Peninsula and rocks of the adjoining mainland (Miller, 1966), but no detailed structural information is available for the phyllites of Misty Pass. Miller (1966) ascribed the structures of the Schmidt Peninsula area to the "Alpide" orogeny but later he (Miller, 1968, p. 152) commented that they were anomalously complicated in relation to the gentle folds generally associated with Cenozoic orogenesis in western Antarctica. Whatever the relationships between the Trinity Peninsula Series and the Legoupil Formation (p. 170 and 179), and to whichever of these the rocks in the Schmidt Peninsula area belong, it is not necessary to relate these complicated structures to so recent an event as the "Alpide" orogeny. Although such an interpretation was required when accepting a Lower Cretaceous age for the Legoupil Formation, it is suggested here that the rocks of this formation are Triassic in age.

Discussion

Age of the Legoupil Formation

There is nothing in the present collections which might suggest a possible correlation with any other fossil fauna known to the author from the Antarctic Peninsula. Of the bivalves described here, *Bakevelloides* aff. *hekiensis* and *Neoschizodus halperni* offer the most precise indications of age. *N. halperni* belongs to a widely distributed group of myophoriids based on *N. laevigatus* and largely of Lower to Middle Triassic age. Although the genus *Neoschizodus* ranges down into the Permian, the earlier species tend to have more rounded outlines and less marked umbonal carinae than *N. laevigatus* and its allies. *Bakevelloides* aff. *hekiensis* is a somewhat aberrant bakevelliid, distinguished by the presence of more teeth than is normal for *Bakevellia s.s.* Were it not for its trapeziform shell, it might have better been placed with *Gervillia s.l.* As yet, such bakevelliids are not widely known (particularly examples with continuous dentition across the mid part of the hinge area) but various species have been described from the Upper Triassic of Japan and New Guinea under the generic names of *Bakevelloides* and *Maizuria* (Nakazawa, 1959; Tokuyama, 1959; Skwarko, 1967). Of the other bivalves, *Myalinella* (*?*) sp. and *Hoernesia* (*?*) sp. are consistent with a general Triassic age, although they lack enough diagnostic features to be of direct use in themselves.

Largely on the basis of radiometric evidence, Halpern (1964, 1965) suggested a Cretaceous age for the Legoupil Formation. A crucial date was that of 116 ± 4 m. yr., obtained from a hornblende concentrate from a diorite pebble in a pebbly mudstone, and which set a lower age limit (Albian) for the formation. However, in the author's opinion, its fossil faunas show no close relationship with any known Cretaceous fauna from Antarctica, nor with Cretaceous faunas in general. The fossils match most closely with Triassic species and there is no reason to suspect that they were derived. Although one would expect hornblende to be radiometrically more stable than other minerals commonly used for K-Ar dating, the present interpretation of the palaeontological evidence suggests that the 116 m. yr. date is anomalous and that further investigations are required.

Age of the Trinity Peninsula Series

Because it is sparsely fossiliferous, data on the age of the Trinity Peninsula Series are far from satisfactory. Poorly preserved plant material from the sequence at Hope Bay was thought by W. N. Croft to be "not earlier than Carboniferous" (Adie, 1957, p. 2) and, since the "series" there is unconformably overlain by plant-bearing strata of Jurassic age, Adie (1957) tentatively assigned it to the late Palaeozoic. Spores obtained from the Trinity Peninsula Series at Hope Bay, and a correlated sequence on Alexander Island, were identified with forms from the Lower and Middle Carboniferous of the Donetz and Moscow basins, Kazakhstan and elsewhere (Grikurov and Dibner, 1968). However, the validity of suggesting a Lower to Middle Carboniferous age for the Trinity Peninsula Series on the basis of such data has been criticized by Schopf (1973). He suggested that the age assessment would have been more convincing had some of the spore species corresponded with Carboniferous forms from Argentina. Rb-Sr dates obtained from a cleaved mudstone of the Miers Bluff Formation (a correlative of the Trinity Peninsula Series on Livingston Island), and a deformed shale in the Trinity Peninsula Series at Hope Bay, are 197 m. yr. (late Triassic) and 242 m. yr. (late Permian), respectively (Dalziel, 1971). Both dates were interpreted as indicating the time of diagenesis and/or deformation.

This meagre evidence from such a thick and widespread sedimentary sequence led Grikurov (1971, p. 164) to suggest that the whole of the Trinity Peninsula Series was Permo-Carboniferous in age, while Dalziel and Elliot (1973, p. 193) thought it possibly spanned the Lower Carboniferous to Lower Permian; both age ranges are in general agreement with that originally suggested by Adie (1957). A study of poorly preserved plant material from the Miers Bluff Formation led Schopf (1973, p. 26) to conclude that "The general facies, seed, and foliaceous characteristics favor an age later than Carboniferous, and a Mesozoic age is not excluded".

Conclusions

Although the fossils from the Legoupil Formation are poorly preserved, sufficient details (particularly of bivalve hinge structures) are preserved on a number of the specimens collected to identify the following species:

Inarticulate brachiopod (?)
Indeterminate gastropod
Myalinella (?) sp.
Bakevelloides aff. *hekiensis* (Kobayashi and Ichikawa)
Hoernesia (?) sp.
Neoschizodus halperni sp. nov.
Indeterminate bivalve
Serpulid
(?) Arthropod tracks.

The Bivalvia indicate a Triassic age for the Legoupil Formation, and thus suggest that the Albian (116 m. yr.) date obtained from a diorite pebble in a pebbly mudstone (Halpern, 1964, 1965) is worth re-investigating.

It is not the purpose of this paper to make a decisive statement on whether or not the Legoupil Formation can be equated with the Trinity Peninsula Series. There are strong lithological and structural implications that the two should be correlated, even while admitting that lithological similarity need only imply similar provenance. However, unless the Trinity Peninsula Series has a younger age limit than has hitherto been suggested, the ages for the two sequences appear to be mutually exclusive, especially since a late Permian date has been obtained for the diagenesis and/or deformation of the Trinity Peninsula Series at Hope Bay (Dalziel, 1971).*

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* Since this paper was written, it has been learnt that the late Permian date for the Trinity Peninsula Series at Hope Bay is based on a two-sample isochron (personal communication from I. W. D. Dalziel) and is therefore not as reliable as the late Triassic age on the Miers Bluff Formation which is from a four-sample isochron. Thus the evidence for the difference in age between the Legoupil Formation and the Trinity Peninsula Series is less conclusive than is apparent at first sight.

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