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FOSSIL BARNACLES (CIRRIPEDIA: THORACICA) FROM THE LOWER MIOCENE BATESFORD LIMESTONE, VICTORIA

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Abstract: A cirriped fauna of 11 species (2 new), from the lower Miocene (Batesfordian) Batesford Limestone at Dog Rocks, Victoria, is described; it is the first record of these species from shallow water calcarenites.

Stratigraphic distribution of the cirripeds is analysed and is shown to be consistent with a gradual and apparently continuous marine transgression in the region. The absence of both the Chthamaloidea and the Balaninae is appraised, and reasons for this are proposed, with consideration given to the knowledge that both taxa were extant in the Miocene.

During the early Miocene, sediments of the Batesford Limestone were deposited on the flanks of Dog Rocks, a granitic pluton about 8 km northwest of Geelong, Victoria. The material discussed in this paper comes from a vertical sequence through the type locality of the Batesford Limestone, on the eastern side of Dog Rocks, in the Australian Portland Cement Company Quarry. Descriptions of the Batesford Limestone have been published by Hall and Pritchard (1892), Chapman (1910), Bowler (1963) and Foster (1970). Ludbrook (1967) indicated an early Miocene age for the deposit.

During the early Miocene, the Dog Rocks pluton existed as a small island which was slowly submerged in a transgressive sea (Bowler 1963). The limestone facies deposited on and adjacent to the island reflect this gradual change, both in lithology (Bowler 1963) and faunal characters (Foster 1970, Chapman 1910). Eleven species of Cirripedia are recorded from several horizons in the Batesford Limestone (Table 1). The distribution is interpreted as being a function of the gradually deepening marine environment. All figured and type material is held by the Palaeontology Section, Bureau of Mineral Resources, Canberra, A.C.T., Australia. RG prefixed numbers refer to the general collections and CPC numbers to type or figured specimens.

SYSTEMATIC PALAEONTOLOGY

Full descriptions are only given for new taxa. Fuller treatment of other species has been provided by Buckeridge (1982, 1983). Unless otherwise stated, the material was collected by G. Chapronière from the Australian Portland Cement Company Quarry at Batesford, Victoria.

Suborder Lepadomorpha Pilsbry 1916

Family Scalpellidae Pilsbry 1907

Genus **Calantica** Gray 1825

Calantica sp. cf. **C. villosa** (Leach 1824)

(Fig. 4e, f)

cf. 1851 *Scalpellum villosum* Leach 1824; Darwin, 274.

cf. 1978 *Calantica villosa* (Leach 1824); Foster, 44-45, pl. 5E, fig. 26 (see for earlier citations).

Material: A left scutum, CPC 22589, from sample RG 77640096.

Distribution and Age: Early Miocene, Victoria; Recent, New Zealand.

Description: Scutum somewhat thickened, strongly reflexed carinally with umbo elevated from valve platform to enclose scutal angle of tergum; growth ridges weak; interior with large deep adductor muscle pit close to apex on occludent margin; basi-tergal angle close to 90°.

Remarks: This scutum has a more deeply depressed adductor muscle scar than is evident in Recent specimens (a feature that may indicate a more vigorous environment), but otherwise conforms to the New Zealand material (see Foster 1978: 44). *C. villosa* is generally found intertidally, but has been recorded to depths of 201 m off Stephens Is. (Foster 1978).

Genus **Smilium** Leach 1825

Smilium sp. cf. **S. tortachillense** Buckeridge 1983

cf. 1983 *Smilium tortachillense* Buckeridge, 39-40, fig. 28.

Material: An incomplete right scutum from sample RG 77640091.

Distribution and Age: For *S. tortachillense*, late Eocene (Aldingan); South Australia.

Description: Apex only slightly inflected carinally; basal margin broadly rounded; exterior without clear apico-basal ridge. Interior with deep, well-formed subcircular adductor muscle scar positioned slightly above centre.

Remarks: Poor preservation and lack of diagnostic features prevents a more accurate systematic location of this specimen.

Suborder Verrucomorpha Pilsbry 1916

Family Verrucidae Darwin 1854

Genus Verruca Schumacher 1817

Verruca (Verruca) tasmanica tasmanica Buckeridge 1983

1983 *Verruca* (*Verruca*) *tasmanica tasmanica* Buckeridge, 57-58, fig. 43.

Diagnosis: Fixed scutum with radioalar wing approximately equitriangular, movable tergum about one and a half times longer than broad.

Material: Numerous compartments from RG 77640088 and RG 77640089.

Distribution and Age: Late Cretaceous to early Miocene, Australasia.

Remarks: Although recent Australasian Verrucidae are known only from depths greater than 250 m (Foster 1978), *Verruca laevigata* is found in the South American littoral zone (Darwin 1854). *Verruca laevigata* is similar to *V. tasmanica*, and it has been proposed by Buckeridge (1983) that an eastward dispersal, from Western Australia, via New Zealand and the Chatham Islands, lead to the establishment of the shallow water South American species.

Suborder Balanomorpha Pilsbry 1916

Family Pachylasmatidae Utinomi 1968

Remarks: Five species of pachylasmatids are recorded from the Batesford Limestone. Of these, *Eolasma rugosa* sp. nov. belongs to an extinct genus, and then only as disarticulated compartments and opercula. With the exception of *Hexelasma* sp. cf. *H. nolearia* Foster, none of the other species have extant representatives. Furthermore, no taxa are known with more than one compartment or valve in intimate association, hence, holotypes have been nominated using compartments, with most likely opercula included within the paratypes.

Subfamily Eolasminae Buckeridge 1983

Genus **Eolasma** Buckeridge 1983

Diagnosis: Shell with eight solid calcareous compartments, comprising rostrum, carina and paired latera, carino-latera and rostro-latera; rostro-latera do not enter into sheath; external alar growth lines parallel inferior alar margin; tergum with prominent articular ridge, scutum with weakly elevated articular ridge; basis apparently membranous.

Distribution and Age: Late Palaeocene to early Eocene: New Zealand; early Miocene: Victoria, Australia.

Type Species: *Eolasma maxwelli* Buckeridge 1983 (Late Palaeocene to early Eocene, South and Chatham Islands, New Zealand).

Eolasma rugosa sp.nov.

Figs 1a-k, 2f-h, 3a-d.

Diagnosis: Exterior of compartments strongly rugose, interior with sheath moderate to weakly developed; latera with strongly reflexed alae; tergum with moderately prominent ?triangular articular ridge, latera depressor muscle crests weakly developed; scutum of low relief.

Holotype: CPC 20217, a left latus from RG 77640102, 24.1 m above the basal granitic gravels.

Measurements: Holotype, CPC 20217, apico-basal 4.7 mm.

Paratypes:

CPC 20218 rostro-latus
from RG 77640096, apico-basal 6.4 mm

CPC 20219 rostrum
from RG 77640097, apico-basal 8.1 mm

CPC 20220 right carino-latus
from RG 77640096, apico-basal 3.5 mm

CPC 20221 right scutum
from RG 77640097, occludent margin 7.0 mm

CPC 20222 right tergum
from RG 77640097, carinal margin 3.8 mm

CPC 20223 rostro-latus
from RG 77640097, apico-basal 6.1 mm

CPC 22590 carina
from RG 77640097, apico-basal 6.8 mm

CPC 22591 left tergum
from RG 77640099, carinal margin 3.7mm

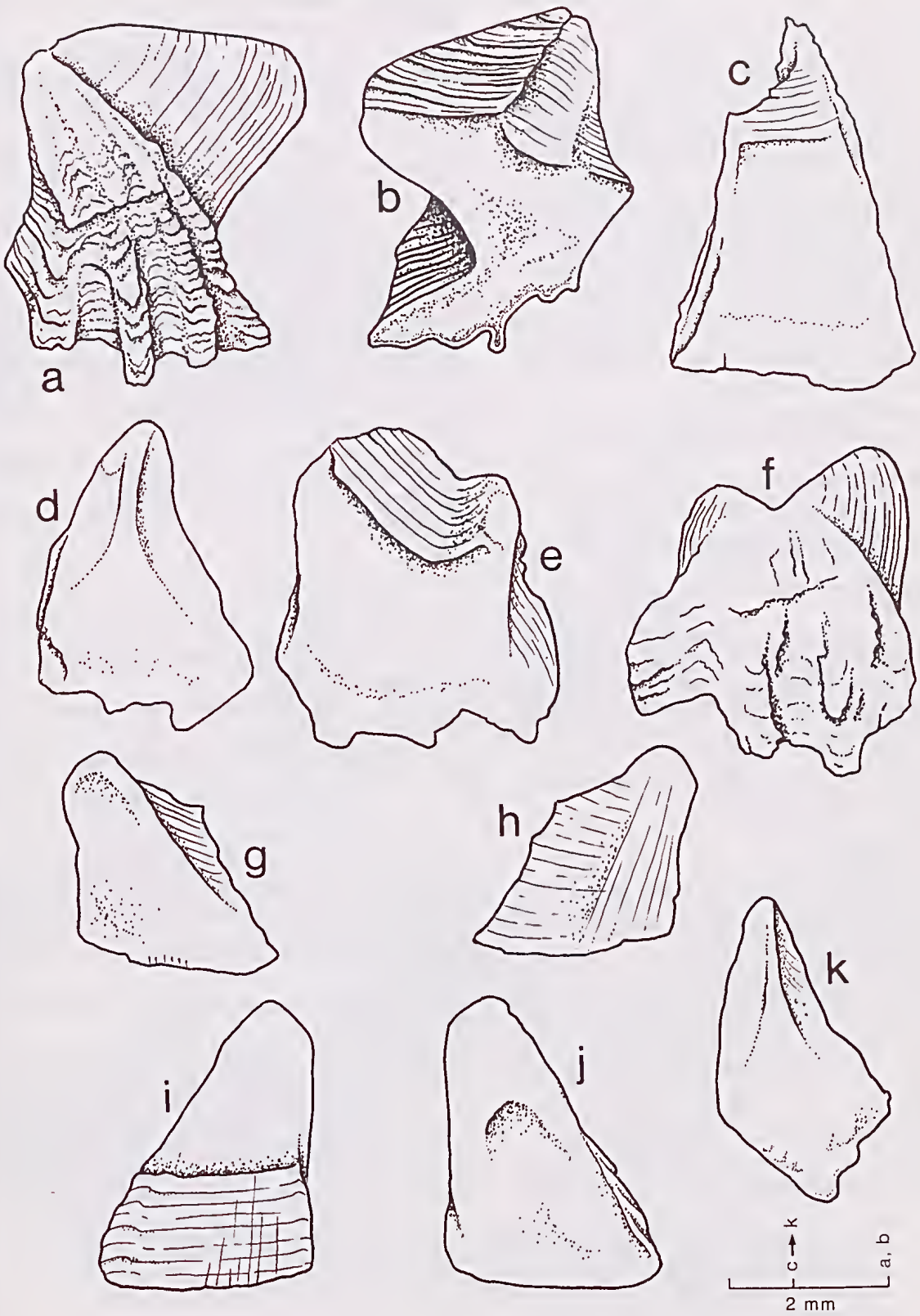
Material: Numerous disarticulated compartments and valves from the Batesford Limestone A.P.C. Company quarry, Batesford, and the Sherwood Marl, West Head, Flinders.

Distribution and Age: Early Miocene (Batesfordian), Victoria, Australia.

Description: Compartments solid, calcareous, with coarse, strongly developed longitudinal ribbing, which is cut by sharp growth ridges in some specimens to produce nodes; interior smooth except for fine growth lines on a weak to moderately developed sheath; alae without marginal extensions, growth lines parallel inferior margin, which is broadly rounded at the basal angle; alae often well developed, extending out by about the same width as the paries.

Scutum of low relief, adductor ridge low and broad; adductor muscle scar rounded, moderately deep,

Fig. 1—a-k, *Eolasma rugosa* sp. nov. a, b, left latus (Holotype), CPC20217, exterior, interior. c, rostrum, CPC20219, interior. d, rostro-latus, CPC20223, interior. e, f, carina, CPC22590, interior, exterior. g, h, right tergum, CPC20222, interior, exterior. i, j, right scutum, CPC20221, exterior, interior. k, rostro-latus, CPC20218, interior.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c, k
a, b
2 mm

situated slightly above centre; exterior with fine transverse growth ridges, slightly inflected close to occludent margin and cut by weak to moderately developed longitudinal striae. Tergum sub-triangular, articular ridge rounded ?triangular, moderately prominent; spur at basi-rostral angle; weak crests for lateral depressor muscles; exterior with weak, transverse growth lines cut by apico-basally radiating striae in the central region.

Remarks: This species is distinguished from *E. maxwelli* by its strong external ribbing and well developed alae. These features effect an articulated shell that is more resistant to erosion than *E. maxwelli*, such that *E. rugosa* may be interpreted as having occupied a more vigorous, and perhaps shallower, environment. This suggestion is further borne out by associated fauna, which includes intertidal barnacles like *Elminius* Leach 1825, and *Tetraclitella* Hiro 1939.

Etymology: Morphological, alluding to the rugose exterior of the shell (Latin *rugosa* = wrinkled).

Subfamily Pachylasmatinae Utinomi 1968

Genus **Pachylasma** Darwin 1854

Pachylasma veteranum Buckeridge 1983

Fig. 2 i,j

1983 *Pachylasma veteranum* Buckeridge, 67-68, fig. 51.

Diagnosis: Compartments considerably thickened, external ribbing either irregular or wanting; sheath weak or wanting; alae with external growth lines parallel to inferior alar margin, with no welting on inner or outer surface of superior alar margin; interior generally smooth, but some weak papillae may develop basally.

Material: Disarticulated compartments from between RG 77640090 and RG 77640101.

Distribution and Age: Palaeocene to early Miocene; Australia, Chatham Is.

Supplementary Description: A single right scutum (Fig. 2 i-j) from RG 77640099 does not conform to any of the other stratigraphically-associated cirripeds and may be attributed to *P. veteranum*. It is a typical pachylasmatine scutum with low internal relief and clearly formed apico-basal grooves on the exterior; adductor ridge low, rounded; central portion of interior slightly elevated as a weak adductor ridge; adductor muscle scar weak, elongate, close to occludent margin.

Subfamily Bathylasmatinae Newman & Ross 1971

Genus **Bathylasma** Newman & Ross 1971

Diagnosis: Shell wall of six solid compartments, rostrum not tripartite, rostro-latera absent; external superior alar margin with welting; terga and scuta generally with prominent articular ridges.

Distribution and Age: Palaeocene to Recent. Palaeocene, Chatham Is; Oligocene, New Zealand; Miocene to Recent, New Zealand, Victoria; Recent, deep seas.

Type Species: *Balanus corolliformis* Hoek 1883. Pleistocene to Recent. Circum-Antarctic.

Bathylasma costatum sp. nov.

Figs 2a-e, 3g, h, 4g-j

Diagnosis: Compartments moderately thick with strong, sharply defined longitudinal ribs separated by slightly more than their own width; alae with external growth lines diverging from inferior alar margin, superior alar margin with a moderate to weak welting; interior with very weak longitudinal ribbing; sheath poorly developed.

Holotype: CPC 22583, a rostrum from RG 77640106, 30.8 m above basal granitic gravels.

Measurements: Holotype, CPC 22583, apico-basal 4.6 mm.

Paratypes:

CPC 22584 left latus
from RG 77640106, apico-basal 3.6 mm

CPC 22585 rostrum
from RG 77640106, apico-basal 4.9 mm

CPC 22586 carina
from RG 77640106, apico-basal 4.4 mm

CPC 22587 right scutum
from RG 77640099, occludent margin 5.4 mm

CPC 22588 left tergum*
from RG 77640107, carinal margin 7.5 mm

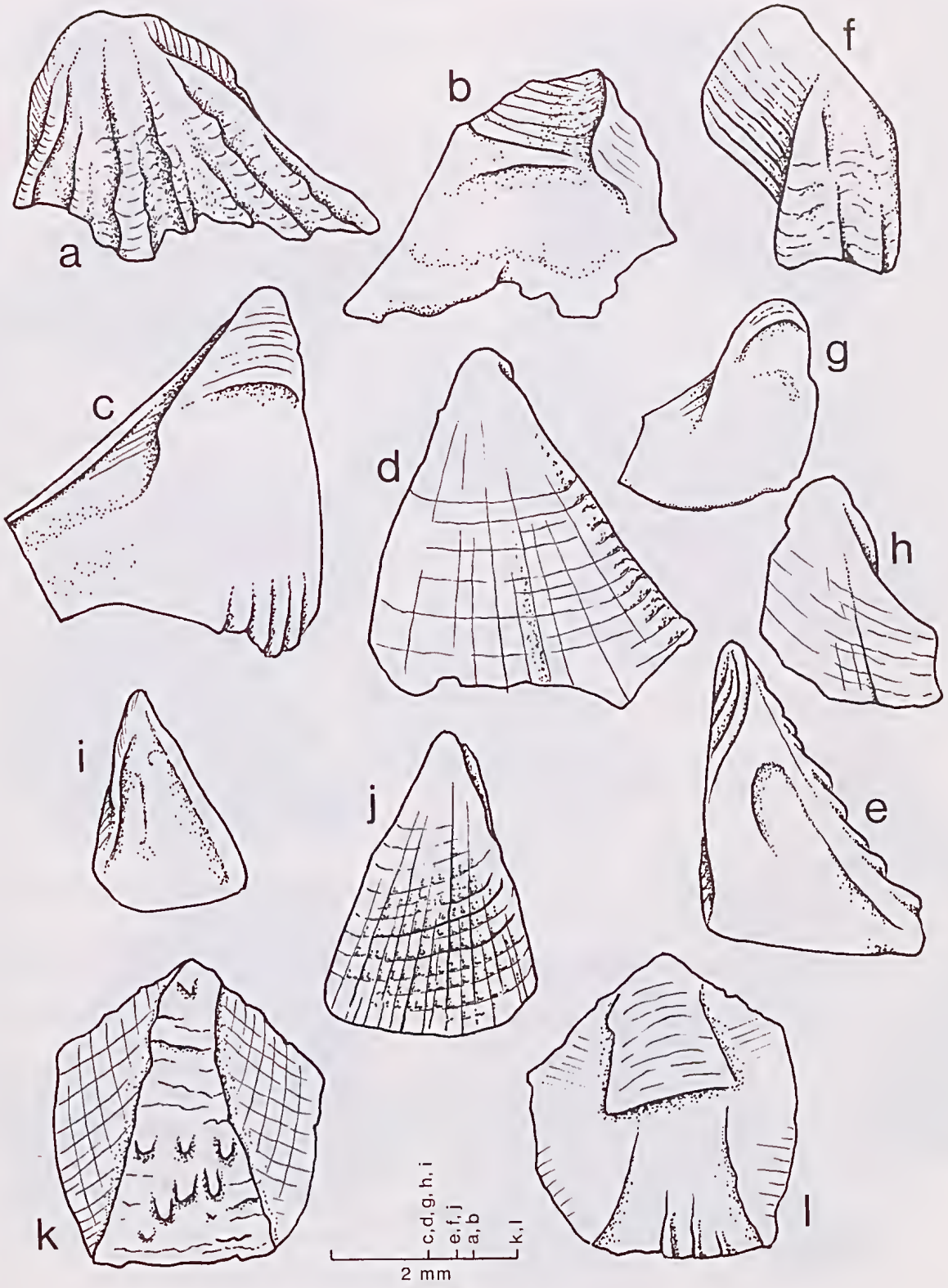
*denotes incomplete valve.

Material: Numerous disarticulated compartments, principally from horizons 25.6 m or more above the basal granitic gravels. Disarticulated compartments from the Sherwood Marl, RG 77640066 and RG 77640067 (cliff behind shore platform at West Head, Flinders).

Distribution and Age: Early Miocene (Batesfordian), Victoria, Australia.

Description: Shell moderately low, conical; compartments solid, moderately thick with strong, sharply defined, non-bifurcating longitudinal ribs, each separated by a little more than its own width; alae with external growth lines diverging from inferior alar margin, superior alar margin with a moderately developed welting; interior with very weak longitudinal ribbing or

Fig. 2—a-e, *Bathylasma costatum* sp. nov. a, b, left latus, CPC22585, exterior, interior. c, d, left tergum, CPC22588, interior, exterior. e, right scutum, CPC22587, interior. f-h, *Eolasma rugosa* sp. nov. f, right carino latus, CPC20220, exterior. g, h, left tergum CPC22591, interior, exterior. i, j, *Pachylasma veteranum* Buckeridge, right scutum (ex RG77640099), interior, exterior. k, l, *Acasta* sp. cf. *A. cyathus* Darwin, rostrum, CPC22582, exterior, interior.


a
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a,b
k,l
2 mm

weak basal papillae; sheath poorly developed, especially on carinae; basis wanting.

Remarks: The assignation of opercular valves to this species is tentative. Three other pachylasmatids are known to have co-existed with this species, and whilst opercula of *Eolasma* are distinctive, the differences between those of *Hexelasma* sp. cf. *H. nolearia*, *B. costatum* and *P. veteranum* are not clear. One mitigating circumstance is that although the known stratigraphic range of *Hexelasma* sp. cf. *H. nolearia* and *P. veteranum* is much greater than *B. costatum*, these opercula are found only in *B. costatum* horizons. However, difficulties clearly remain, particularly with respect to the relatively large size of the tergum (CPC 22588), which would have belonged to a much bigger shell than present reconstructions suggest. *Note*: Without these opercula, the small size and relatively thick compartments of *B. costatum* could be included within *Mesolasma*.

Tergum (CPC 22588) moderately elongate, articular ridge moderately high, triangular; lateral depressor muscle crests well developed; exterior with shallow, concave furrow; growth lines slightly inflected on occludent margin; faint apico-basal striae radiate from the apex to the basal margin in the carinal half. A further tergum, very incomplete and partially decorticated, from RG 77640106 differs from CPC 22588 in having no clear articular ridge. This difference may be ontogenetic, as other features conform. Scutum (CPC 22587) with articular ridge relatively low; adductor ridge weak, broadly rounded; adductor muscle scar moderately shallow, central; exterior with fine transverse growth lines.

Etymology: Morphological, alluding to the ribbed exterior of the compartments (Latin *costa* = a rib).

Genus Mesolasma Foster 1981

?Mesolasma newmani Buckeridge 1983

Fig. 3e, f

1983 ?Mesolasma newmani Buckeridge, 70-71, fig. 53.

Diagnosis: Compartments thickened, with weak longitudinal external ribbing; sheath well formed; interior with fine weak ribs basally; base of paries broad, flat, with numerous fine grooves and papillae.

Material: Disarticulated compartments from RG 77640090 to 77640094.

Distribution and Age: Oligocene to Miocene (Janjukian to Batesfordian), Victoria, Australia.

Remarks: Although very similar to that described by Buckeridge (1983) from the Point Addis Limestone, this material shows a higher degree of abrasion and decortication. Futher, the alar development is greater in some compartments, suggesting that this extension may have been developed in mitigation of a more energetic environment.

Subfamily Hexelasminae Newman & Ross 1976

Genus Hexelasma Hoek 1913

Hexelasma sp. cf. H. nolearia (Foster)

Figs 3i-l, 4c, d

1983 Hexelasma sp. cf. H. nolearia (Foster 1978); Buckeridge, 71, fig. 54.

Diagnosis: Compartments externally with distinct growth ridges; parietes divided into thicker outer and thinner inner shell laminae; internal ribbing low, terminating as papillae on the basal margin.

Material: Disarticulated compartments from RG 77640086-77640107, RG 77640123-77640126, Batesford Limestone, A.P.C. Company Quarry, Batesford. RG 77640066-77640068, Sherwood Marl (Batesfordian), Flinders. RG 77640184, Fishing Point Marl (Longfordian), Hordern Vale. Collected by G. Chapronière in 1977. RG 77640111, Fyansford Formation (Bairnsdalian), Torquay. Collected by S. Shafik in 1977.

Distribution and Age: Longfordian to Bairnsdalian (early to middle Miocene), Victoria, Australia.

Remarks: An isolated scutum (CPC 25611) from RG 77640087 is likely to belong to this species. It is somewhat apico-basally elongated and possesses an adductor ridge, much like that of *Hexelasma nolearia*; it has a moderately low articular margin, but unlike *H. nolearia* is relatively thick. This last feature may be an environmental adaptation, but without further material, no firm conclusions can be drawn.

Family Tetraclitidae Gruvel 1903

Subfamily Tetraclitellinae Newman & Ross 1976

Genus Tetraclitella Hiro 1939

?Tetraclitella sp. cf. T. purpurascens (Wood)

Fig. 4a, b.

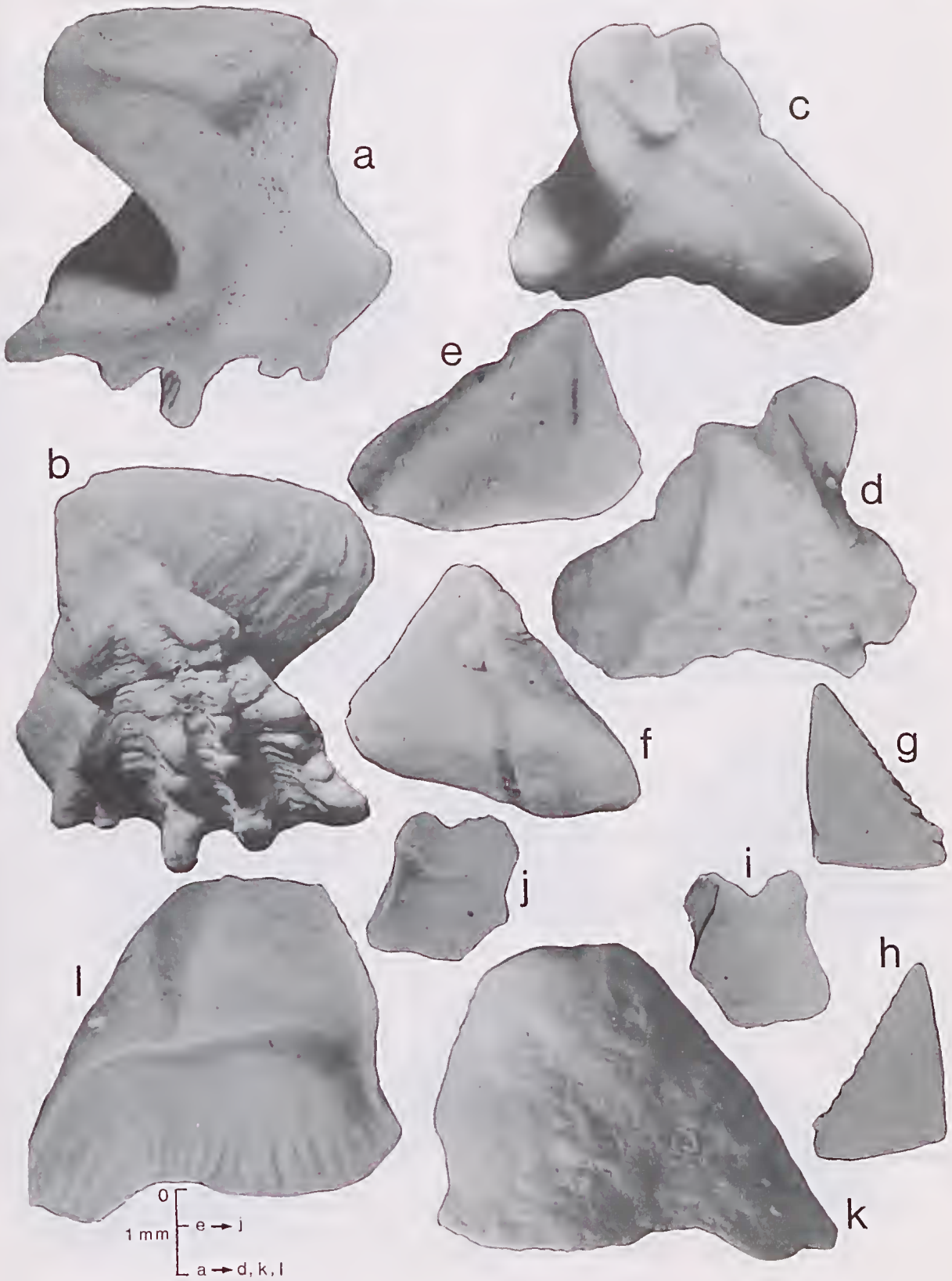
cf. 1983 Tetraclitella sp.cf. T. purpurascens (Wood 1815); Buckeridge, 77-78, pl. 5c, d.

Material: Two articulated compartments from RG 77640091 (Fig. 4a, b), isolated compartments from RG 77640090, RG 77640095, RG 77640099.

Distribution and Age: Early Miocene (Batesfordian), Victoria, Australia.

Description: Shell low, flat; parietes with a large number of small rounded hexagonal tubes; sheath weak, non-pendant; exterior with 30 or more fine, distinct, apico-basal ribs; radii smooth, sunken; internal nature of radii unknown, operculum unknown.

Fig. 3—a-d, *Eolasma rugosa* sp. nov. a, b, left latus (Holotype), CPC20217, interior, exterior. c, d, left latus (ex RG77640096), interior, exterior. e, f, *?Mesolasma newmani* Buckeridge, right carino-latus (ex RG77640097), interior, exterior. g, h, *Bathylasma costatum* sp. nov. right scutum, CPC22587, interior, exterior. i-l, *Hexelasma* sp. cf. *H. nolearia* Foster. i, j, carina (ex RG77640090), exterior, interior. k, l, latus (ex RG77640102), exterior, interior.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a → d, k, l

Remarks: This material is too poorly preserved to permit a more accurate taxonomic location. The best specimen is made up of two remarkably well-fused compartments, one of which was probably a latus. Unfortunately, the outer margins of both compartments are so corroded that the structure of the abutment areas of both parietes and radii is indeterminate. However, a radius is developed between the two compartments; this is sunken below the surface and is likely to have possessed a horizontal summit. The radius appears relatively smooth and very thin, the pores (if they are present at all) would probably be very small. The only clear way to determine the exact nature of the radii would be to break the specimen, but as the material is brittle, this course of action has not yet been pursued. The morphology of the compartments suggests a very low, flat shell, with perhaps 30 fine, distinct apico-basal ribs separated by their own width. Internally, the compartments can be seen to be comprised of a very large number of small tubes; the sheath is weakly formed and is not pendant. This material probably represents a new species, and can be distinguished from other Australasian *Tetraclitella* by the large number of external ribs. Further material with radii and hopefully, opercula, should clarify the status of these specimens.

Family Archaeobalanidae Newman & Ross 1976

Subfamily Archaeobalaninae Newman & Ross 1976

Genus **Acasta** Leach 1817

Acasta cyathus Darwin 1854

1854 *Acasta cyathus* Darwin, 312, pl. 9, figs 3a-3c.

Diagnosis: Carino-lateral parietes about quarter the width of lateral parietes; radii wider than parietes; basis nearly flat; tergum with spur truncated, half as wide as valve.

Distribution and Age: ?Miocene, Victoria; Recent, Morocco, Caribbean, East Africa, Indian Ocean.

Acasta sp. cf. **A. cyathus** Darwin 1854
Fig. 2k, l

Material: CPC 22582, a rostrum from RG 77640097, incomplete compartments from between RG 77640097 and RG 77640100.

Remarks: Although this material appears to belong to extant *A. cyathus*, a more definite taxonomic location cannot be made without articulated compartments and opercula. *A. cyatlus* is characteristic of moderately deepwater conditions, recent species being found between 15-180 m.

Subfamily Elminiinae Foster 1982

Genus **Elminius** Leach 1925

Elminius (Matellionius) chapronierei Buckeridge, 1982

1982 *Elminius (Matellionius) chapronierei* Buckeridge, 353-357, figs 1, 2, 3

Diagnosis: Compartments with a thickened, inflected, inner basal margin, scutum with articular ridge low, rounded, not dependent basally; tergum with spur confluent with basi-rostral angle.

Material: CPC 20213, holotype, complete shell with operculum; numerous compartments from RG 77640086-77640096.

Distribution and Age: Early Miocene (Batesfordian), Victoria.

Remarks: *Elminius chapronierei* is the oldest known species of *Elminius* from Australia. The thickening of the basal margin is a unique feature amongst the Elminiinae and is interpreted as an attempt at strengthening the shell to offset the effects of a vigorous environment. The species shows a similarity with *Palaeobalanus linsayi* Buckeridge 1983, from the Aldingan of South Australia, thus emphasising the link between the Archaeobalaninae and the Elminiinae (Buckeridge 1982).

Further archaeobalanid remains have been recovered from RG 77640184 (Longfordian Age; Fishing Point Marl, Lake Horden, Victoria; collected by G. Chapronière in 1977) and RG 77640111 (Bairnsdalian Age; Fyansford Marl, Batesford; Collected by S. Shafik in 1977). Unfortunately insufficent material is available for an accurate taxonomic location to be made. The material, unlike *E. chapronierei*, possesses broad radii, and, unlike *A. cyathus*, has wide parietes; growth form indicates that this material probably grew on a substrate similar to echinoderm spines.

CIRRIPED DISTRIBUTION IN THE BATESFORD LIMESTONE

Although the balanomorph barnacles are well represented in the Batesford Limestone (Table 1), a significant aspect is the absence from the fauna of the Chthamaloidea. Present Australian shores are inhabited by a diverse range of chthamaloids (e.g. *Catomerus* Pilsbry 1916, *Chamaesipho* Darwin 1854, *Chthamalus* Ranzani 1817, *Euraphia* Conrad 1837, *Octomeris* Sowerby 1825), and whilst these are characteristic of the upper littoral zone, those with thicker plates could be expected to contribute to the loose shell material collecting immediately offshore. Fossil chthamaloids are rare and, except for *Pachydiadema* from the Cretaceous, are known only from a few horizons (i.e. *Chthamalus* from the Miocene of Chile and Pliocene of Italy, *Chamaesipho* from the early Miocene of New Zealand). This poor fossil record reflects the high energy (highly corrasive) upper littoral environment occupied by chthamaloids, an environment that is rarely preserved intact except under conditions of rapid subsidence and burial. However, the

Fig. 4—a, b, *?Tetraclitella* sp. cf. *T. purpurascens* (Wood) ?rostrum and latus (ex RG77640091), exterior, interior. c, d, *Hexelasma* sp. cf. *H. nolearia* Foster rostrum (ex RG77640098), interior, exterior. e, f, *Calantica* sp. cf. *C. villosa* (Leach) left scutum, CPC22589, exterior, interior. g-j, *Bathylasma costatum* sp. nov. g, h, rostrum (Holotype), CPC22583, exterior, interior. i, j, left latus, CPC22584, interior, exterior.

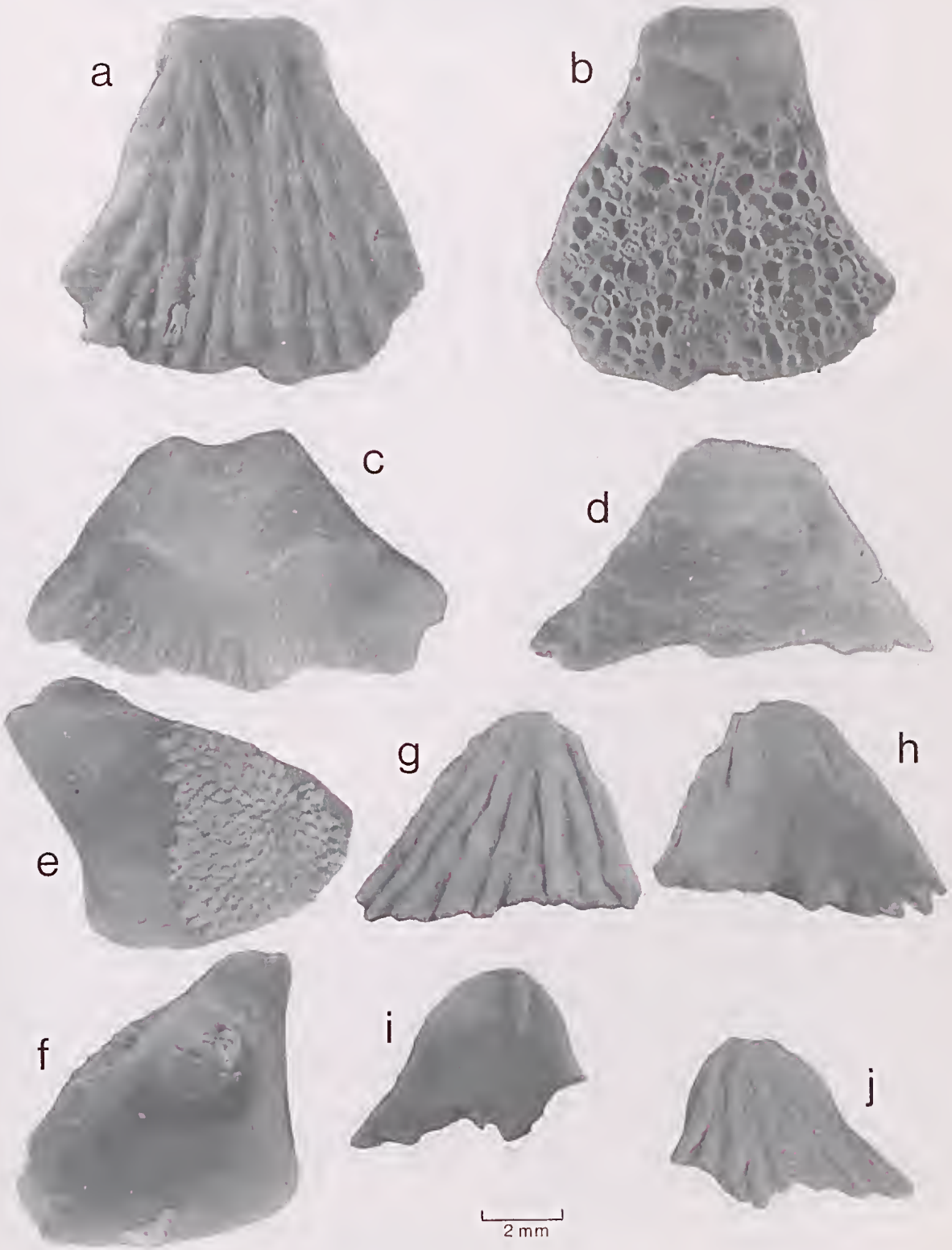
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TABLE 1
DISTRIBUTION OF BARNACLES IN A STRATIGRAPHIC SEQUENCE TAKEN FROM THE QUARRY FACE, 245 DEGREES NORTH FROM THE QUARRY OFFICE, AUSTRALIAN PORTLAND CEMENT COMPANY QUARRY, BATESFORD, IN 1977. † INDICATES OCCURRENCE; * INDICATES PROBABLE OCCURRENCE.

Collection Number	*Elminius chapronierei*	*Tetraclitella* sp. cf. *T. purpurascens*	*Smilium* sp. cf. *S. tortachillense*	*Acasta* sp. cf. *A. cyathus*	*Verruca tasmanica*	*?Mesolasma newmani*	*Pachylasma veteranum*	*Calantica* sp. cf. *C. villosa*	*Hexelasma* sp. cf. *H. nolearia*	*Eolasma rugosa*	*Bathylasma costata*	Height Above Quarry Floor (m)
RG 77640086	†								*			0
RG 77640087	†								†	?		3.0
RG 77640088	†				†							4.6
RG 77640089	†				†				†			6.7
RG 77640090		†				?			†	†		8.2
RG 77640091		†	†			†	†			†		9.8
RG 77640092										†		11.0
RG 77640093						†	†		†	†		12.5
RG 77640094						†			†	†		14.6
RG 77640095		*								†		15.9
RG 7764096	*						†	†	†	†	†	17.1
RG 77640097				†		†	†		†	†		18.3
RG 77640098				†	*		†		†	†		19.5
RG 77640099		*				†			†	†	†	21.0
RG 77640100				†					†	†		22.3
RG 77640101							†		†	†		23.5
RG 77640102									†	†		24.1
RG 77640103									†	†	†	25.6
RG 77640104									†	†	†	26.5
RG 77640105									†	†	†	29.6
RG 77640106							?		†	†	†	30.8
RG 77640107					†				†		†	32.6

TABLE 2
STRATIGRAPHIC DIVISIONS IN THE BATESFORD LIMESTONE, SHOWING TAXA CHARACTERISTIC OF EACH ZONE AND LIKELY SOURCE ENVIRONMENT.

Zone	Height Above Basal Gravels (m)	Sample Range	Significant Taxa	Likely Provenance
A	0-6.7	77640086-089	*Elminius* *Verruca*	littoral
B	0.2-22.3	77640090-100	*?Tetraclitella* *Acasta* *Calantica* *?Mesolasma*	upper sublittoral
C	23.5-32.6	77640101-107	*Bathylasma*	sublittoral (cooler?)

non-preservation of the chthamaloids in the Batesford Limestone is not altogether a satisfactory explanation for their absence, as other littoral taxa (*Elminius*, *?Tetraclitella*) are present. Rather, their absence could suggest that the environment was locally unsuitable for chthamaloids, or that no chthamaloids occurred in the region. The distribution of modern chthamaloids is governed by pressures such as competition and predation; but it appears that competition, at least from barnacles, would have been less during this period, as the highly successful balanines are not known from the Australasian lower Miocene.

It appears likely that both chthamaloids and balanines were introduced into the area from the Indo-Malayan region during the upper Miocene and Pliocene, but further collecting will be required to accurately pinpoint the source and arrival time of these taxa.

VERTICAL DISTRIBUTION

The gradual and apparently continuous increase in water depths at Dog Rocks has provided a valuable record of the relative water depths that were inhabited by barnacles. The collection numbers 77640086 to 77640107 comprise a stratigraphic sequence up the quarry face to a height of 32.6 m from the quarry floor. The lithological changes in the sequence, from calcareous 'basal' granitic sands and gravels through to a shallow water calcarenite (see Bowler 1963) are reflected in the vertical change in the composition of the barnacle population (Table 1). This sequence can be conveniently divided into three parts, each with a characteristic suite of barnacles indicative of a particular environment (Table 2).

Dr. G. Chapronière (pers. comm.) has indicated that as well as an increase in depth, foraminiferal evidence suggests a gradual cooling, a feature which may further emphasise the barnacle zonations.

COMPARISONS WITH RECENT DISTRIBUTION

The most significant difference lies in the shallow water occurrences of the verrucids and pachylasmoids, which in present day Australian conditions are deep water taxa. Barnacles are an opportunistic group, quickly adapting to fill available niches, and during the early Palaeogene (when balanines had not yet evolved), pachylasmoids occupied favourable shallow water conditions (Buckeridge 1983). This distribution was to change later in the Cenozoic as the evolving balanines, with a more efficient metabolism, smothered and outcompeted other shallow water barnacles. However, the influx of balanines at Dog Rocks seems to have occurred a little later than in other regions (e.g. New Zealand, Italy), enabling the pachylasmoids to survive in their shallow water habitats. Indeed, the Batesford Limestone contains the youngest known *Eolasma*, which in neighbouring New Zealand, survived only to the Eocene (Buckeridge 1983). The verrucids also are normally restricted to deeper waters but there are still a few species that have managed to survive in the highly competitive littoral zone (*Verruca laevigata* Darwin 1854, of Chile and *V. stroemia* Muller 1776, of Europe).

Of the taxa present, perhaps two have extant records (*Acasta*, *?Tetraclitella*). Amongst the others, only deductions can be made as to their preferred environments, but it seems probable that *Elminius* was littoral, especially as extant *Elminius* is littoral and the only other fossil *Elminius* is from an estuarine environment in the New Zealand Oligocene (Buckeridge 1984). Some interpretation may be placed on shell morphology, with those species that are characterised by thick, robust, often distorted compartments, being characteristic of high energy zones. This morphology is evident in *Eolasma rugosa* and *Pachylasma veteranum*, both of which are here interpreted as upper sublittoral. There are some discrepancies (e.g. *Hexelasma* sp. cf. *H. nolearia*, a relatively thin-walled and, externally, smooth-shelled species), but it is possible that these taxa could have occupied a less vigorous micro-environment in the sublittoral.

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