COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BULLETIN No 62

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Minister: SENATOR THE HON. W. H. SPOONER, M.M.
Secretary: H. G. RAGGATT, C.B.E.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS.

Director: J. M. RAYNER.

This Bulletin was prepared in the Geological Branch.
Chief Geologist: N. H. FISHER.

COMMONWEALTH OF AUSTRALIA

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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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CONTENTS

SUMMARY

Thirty-four species of planktonic foraminifera, referred to twelve genera, are recorded and illustrated from the Miocene-Pliocene beds of Papua and New Guinea; some species are recorded from this area for the first time.

The relationship between *Orbulina universa* and *Orbulina suturalis* is discussed, and it is suggested that *suturalis* can develop into *universa* during growth; the genus *Biorbulina* is placed in the synonymy of *Orbulina*. The structure now known as a bulla has been observed on several species and it is concluded that it has no taxonomic significance. Lineage within the *Globigerinoides quadrilobatus* group are discussed and a new subspecies, *G. quadrilobatus hystricosus*, is proposed.

This paper	European Stages		East Indies Stages
upper Miocene	Pontian	Sahelian	g
	Sarmatian		
middle Miocene	Tortonian	Vindobonian	f_3
	Helvetian		
lower Miocene	Burdigalian		$f_{1,2}$
	Aquitanian		e

TABLE 1

Relationship betwen European and East Indies stages and the terminology used in this paper.

INTRODUCTION

Planktonic foraminifera have been used for age determination and correlation in Papua and New Guinea for many years, but the results of this work appear as unpublished reports of companies engaged in the search for oil. The present paper records and illustrates most of the species known to the writer from this area. Two species of *Globorotalia* have been omitted so that further comparison may be made with described forms, and also one species of *Sphaeroidinellopsis* for which more material is required.

Specimens have been obtained from samples collected and supplied by geologists of the Bureau of Mineral Resources; by private companies engaged in oil exploration; and by field parties of the Division of Land Research and Regional Survey, Commonwealth Scientific and Industrial Research Organisation. Few samples have been collected in stratigraphical sequence, and it is difficult to obtain samples over a continuous measured section. For this reason little can be said here on the vertical ranges of the species recorded, and it is not known if any stratigraphical significance can be given to the variation observed within any one species. The oldest samples available from which free specimens may be obtained are of lower Miocene (Burdigalian) age; planktonic foraminifera are known to occur in a fine-grained limestone which is in part Aquitanian.

Throughout this paper the terms lower, middle and upper Miocene are used; it is not yet possible in Papua and New Guinea to delineate stages such as Helvetian and Tortonian in the middle Miocene or Sarmatian and Pontian in the upper Miocene. The relationship between these terms and the European and East Indies stages is shown in Table 1, which has been adapted from tables published by Glaessner (1945) and David (1950).

Acknowledgments are due to the following micropalaeontologists who have given valuable advice and assistance during the preparation of this paper: Dr W. H. Blow, of the British Petroleum Company Limited, who checked many of my identifications and discussed lineages within the *Globigerinoides quadrilobatus* group; Dr N. de B. Hornibrook of the New Zealand Geological Survey, who discussed the relationship between *Orbulina universa* and *O. suturalis* and the development of planktonic foraminifera in New Zealand, and forwarded outline drawings of specimens from the sequence at Clifden, New Zealand; Dr D. G. Jenkins of B.P.-Shell-Todd Petroleum Development Limited, New Zealand, who also discussed with me the relationship between *Orbulina universa* and *O. suturalis;* and Dr F. M. Kicinski of the Australasian Petroleum Company, Port Moresby, who discussed various aspects of the work.

The synonymy for each species is not complete and only selected references are given. For the original reference to many species reliance has been placed on the 'Catalogue of Foraminifera' (Ellis & Messina, 1940 et seq.).

All type specimens, figured specimens, and thin sections are deposited in the Commonwealth Palaeontological Collection, Canberra, Australia.

Genus ORBULINA d'Orbigny, 1839

ORBULINA UNIVERSA d'Orbigny, 1839

(Pl. 1, figs. 1-15)

1839 *Orbulina universa* d'Orbigny. D'ORBIGNY, *Foraminifères,* in de la Sagra, *Histoire physique et naturelle de l'Ile de Cuba,* Bertrand, Paris, p. 3; (plates, *Ibid.,* 8, pl. 1, fig. 1).

1846 *Globigerina bilobata* d'Orbigny. D'ORBIGNY, Foraminifères fossiles du bassin Tertiare de Vienne (Autriche). *Gide et Comp.,* Paris, p. 164, pl. 9, figs. 11-14.

1884 *Orbulina universa* d'Orbigny. BRADY, *Rep. Voyage Challenger, Zool.,* 9, p. 608, pl. 78; pl. 81, figs. 8-26; pl. 82, figs. 1-3.

1956 *Biorbulina bilobata* d'Orbigny. BLOW, *Micropaleontology,* 2(1), p. 69, text-fig. 29, fig. 16. (Synonymy).

1957 *Orbulina universa* d'Orbigny. BOLLI, LOEBLICH, & TAPPAN, *Bull. U.S. nat. Mus.,* 215, p.35, pl. 7, figs. 1-5.

1959 *Orbulina universa* d'Orbigny. BÉ, *Micropaleontology,* 5(1), p. 83, pl. 2, fig. 18.

1959 *Orbulina universa* Orbigny. GRAHAM & MILITANTE, *Stanford Univ. Publ. geol. Sci.,* 6(2), p. 113, pl. 19, fig. 3. (Synonymy).

1959 *Orbulina universa* d'Orbigny. BRADSHAW, *Contr. Cushman Fdn,* 10(2), p. 49, pl. 8, figs. 17-18.

1960 *Globigerina bilobata* d'Orbigny, 1846. BANNER & BLOW, *Contr. Cushman Fdn,* 11(1), p. 2, pl. 3, fig. 9. (Also given in explanation of plate as *Biorbulina bilobata* (d'Orbigny)).

O. universa as at present defined includes those specimens in which no trace of the initial chambers is visible externally. Observations on forms from Papua-New Guinea indicate that the initial chambers may be obscured in two ways: (a) by the final globular chamber completely enveloping the initial chambers; (b) by the addition of layers of shell material to specimens possibly to be included in *O. suturalis* Bronnimann, 1951, emended Blow, 1956.

Specimens described by Blow (1956) as *Biorbulina* are here regarded as only a further growth stage of single chambered forms, and this genus is considered to be a synonym of *Orbulina.*

The species *O. suturalis* is not given a separate identity here; all the forms figured are regarded as variants of a normal population. In other areas, such as Trinidad and New Zealand, *suturalis* is reported to appear before *universa* and a '*suturalis* zone' is recognised which is of stratigraphical value; this zone is not represented in available samples from Papua-New Guinea. Hornibrook (1958) shows *suturalis* appearing in the Clifdenian and *universa* in the Lillburnian and has also forwarded (pers. comm., 5th Sept. 1960) a series of outline drawings of planktonic foraminifera from the sequence at Clifden, New Zealand; *suturalis* develops from the *glomerosa* group in the middle Clifdenian and *universa* appears in the middle Lillburnian. Jenkins (pers. comm., 15th Sept. 1960) has suggested that the two species may be distinguished by defining *suturalis* as those forms which have pores confined to one hemisphere, while in *universa* the pores are scattered over the entire surface. He has also observed an intermediate condition in which no *Globigerina* chambers are visible and the pores are confined to one hemisphere; this investigation is in its initial phase and no definite conclusions can be made.

The evolution of *Orbulina* and *Biorbulina* as traced by Blow (1956) in material from Trinidad and Venezuela cannot be followed in Papua and New Guinea. In bioseries I as shown by Blow, stages 1 to 5 are not known from Papua, and in bioseries II, stage A and B are not known. Single-chambered and bilobate forms of *O. universa* occur in all samples examined, but the bilobate form is always the less common.

In any assemblage of *Orbulina* from Papua-New Guinea, several types may be distinguished on external appearance. These include:

1. Single-chambered, smooth forms with no trace of 'apertural pores'.
2. Single-chambered, smooth forms with 'apertural pores' developed.
3. Single-chambered forms with a reticulate ornament developed, but no, or very few, 'apertural pores'.
4. Single-chambered forms showing reticulate ornament and with 'apertural pores' well developed.
5. Bilobate forms.

The wall structure of representatives of each of these groups has been investigated in numerous thin sections. The shell wall in specimens from group 1 is very thin with no lamination evident. In specimens from group 2, the wall is still thin, but is formed of at least two layers of shell material. Specimens from groups 3 and 4 have thick walls, distinctly laminated, with several layers of shell material. This laminated wall was known to Brady (1884 p. 610, pl. 81, fig. 26). Bronnimann (1951) remarked that 'the walls of thick shelled specimens appear to be composed of two or more thin layers' and he also referred to the 'secondary growth of the wall'. Blow (1956) describing *suturalis* stated 'wall calcareous, composed of more than one layer'.

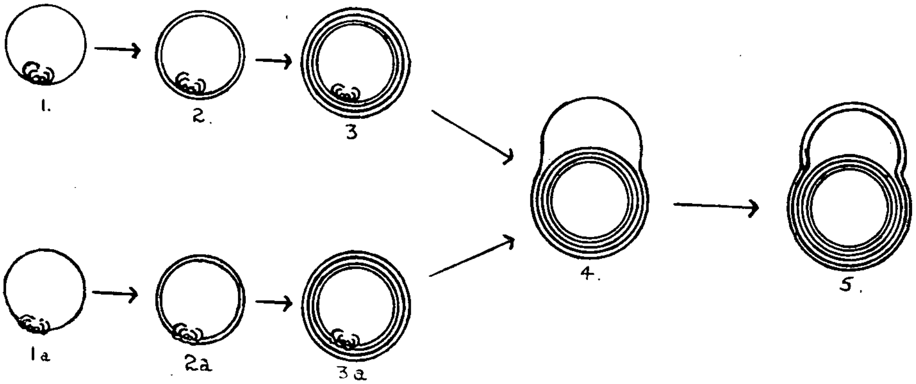

Figure 1. Development of bilobate specimen of O. universa from single-chambered forms.: 1-3: universa type. 1a-3a: suturalis type.

Among the bilobate forms are specimens which have a smooth last chamber, and others with the last chamber showing reticulate ornament and perhaps also 'apertural pores', usually developed around the base of the chamber. Sections show that the second chamber is formed by a lateral extension of the final lamina forming the wall of the test and as such is analogous to an added chamber of a lamellar foraminifer. It is again found that a smooth second chamber has thin walls, but if a reticulate ornament or 'apertural pores' are visible the wall is thicker, with indications of lamination. My observations indicate that bilobate forms develop only from thick-walled single-chambered specimens; none are known to have developed from specimens referable to groups 1 and 2. Brady (1884, plate 82, fig. 2) shows a bilobate form developed from a thick-walled single chamber; Bronnimann (1951) stated: 'It has been noted that the *suturalis* portion invariably develops a much thicker wall than the adjoining subglobular end chamber'. Bilobate forms originate from the *universa* stage as well as the *suturalis* stage; Banner & Blow (1960) state that the lectotype of *Globigerina bilobata* d'Orbigny (which is also the type specimen of the genus *Biorbulina* Blow) has no external trace of any chambers earlier than the penultimate.

Figures 1a to 3a in Text-figure 1 show the development of *O. universa* from the *suturalis* form by the addition of successive layers of shell material. It is clearly shown by thin sections that thick-walled specimens of *universa* would have been referred to *suturalis* after the formation of the initial globular chamber; others are of the *universa* type throughout. There are also forms in which the degree of overlap of the initial globular chamber was such that thickening of the wall did not obscure the earlier chambers, which may remain visible even in the bilobate stage. The obscuring of the early chambers by added layers of shell material has been observed before. Bronnimann (1951), among other remarks on *O. suturalis,* stated 'The *Globigerina* stage is somewhat concealed in thick shelled individuals because the additional thin layers also cover the initial portion of the test'. The lamination shown by tests of *O. universa* seems to me to indicate that the globular final chamber is not connected solely with reproduction, as is maintained by Hofker (1959). The formation of a second chamber in some thick-walled, single-chambered specimens may be connected with the need to achieve greater displacement in order to retain buoyancy.

Evolutionary sequences in planktonic foraminifera should be investigated in more detail, with examination of wall structure, pore distribution, and other features. Bilobate forms have possibly arisen along more than one lineage and detailed investigation may show that it is possible to distinguish between forms resulting from an evolutionary process and those which are clearly only growth stages of different species, and occur as aberrant specimens in all populations observed.

Drooger (1956) suggested that the Helvetian/Tortonian boundary is marked by the appearance of *Orbulina.* Eames & Clarke (1957) and Blow (1957, 1959) consider the first appearance of the genus to be in the uppermost Aquitanian. In

Papua, *Orbulina* is recorded from the Burdigalian, and also from limestones containing larger foraminifera indicating an Aquitanian age.

Dimensions:	*Max. Diameter*
CPC 4042	0.58 mm.
CPC 4043	0.46 mm.
CPC 4044	0.48 mm.
CPC 4045	0.35 mm.

Bilobate specimens	*Length*	*Max. Diameter*
CPC 4046	0.47 mm.	0.33 mm.
CPC 4047	0.54 mm.	0.40 mm.
CPC 4048	0.72 mm.	0.48 mm.

Occurrence: Figured specimens CPC 4042 to 4044 and 4047 to 4048 and thin sections CPC 4049 to 4055 from samples east of Karova Creek, Kerema-Karova Creek area, Papua (middle Miocene); figured specimen 4045 from a sample on upper Maipora Creek, west of Saw Mountains, Papua (middle Miocene); figured specimen CPC 4046 and thin section CPC 4056 from a sample on Hell's Gate Creek, about ½ mile from junction with the Tauri River, Papua (lower Miocene, Burdigalian).

Genus GLOBIGERINA d'Orbigny, 1826

GLOBIGERINA BULLOIDES d'Orbigny, 1826

(Pl. 1, figs. 16-20)

1826 *Globigerina bulloides* d'Orbigny. D'ORBIGNY, *Ann. Sci. nat.*, Paris, 1(7), p. 277.

1884 *Globigerina bulloides* d'Orbigny. BRADY, *Rep. Voy. Challenger, Zool.*, 9, p. 593, pl. 179, figs. 7a-c.

1951 *Globigerina bulloides* d'Orbigny. PHLEGER & PARKER, *Mem. geol. Soc. Amer.*, 46(2), p. 34, pl. 19, figs. 6-7.

1957 *Globigerina bulloides* d'Orbigny. TODD & BRONNIMANN, *Spec. Publ. Cushman Fdn*, 3, p. 40, pl. 12, fig. 1.

1957 *Globigerina bulloides* d'Orbigny, 1826. BOLLI, LOEBLICH, & TAPPAN, *Bull. U.S. nat. Mus.*, 215, p. 31, pl. 4, figs. 1a-c.

1958 *Globigerina bulloides* d'Orbigny. PARKER, *Reps. Swedish Deep-Sea Exped.*, 8(4), p. 276, pl. 5, figs. 1-4.

1959 *Globigerina bulloides* d'Orbigny. BE, *Micropaleonology*, 5(1), p. 83, pl. 1, figs. 15-17.

1959 *Globigerina bulloides* d'Orbigny. BLOW, *Bull. Amer. Paleont.*, 39(178), p. 175, pl. 9, figs. 38a-c.

1959 *Globigerina bulloides* d'Orbigny. GRAHAM & MILITANTE, *Stanford Univ. Publ. geol. Sci.*, 6(2), p. 110, pl. 18, fig. 9a-c. (Synonymy).

1959 *Globigerina bulloides* d'Orbigny. BRADSHAW, *Contr. Cushman Fdn*, 10(2), p. 33, pl. 6, figs. 1-4.

Specimens referred to *G. bulloides* occur in Papua-New Guinea from the lower Miocene (Burdigalian) to Pliocene. Blow (1959) considered *G. bulloides* to be not older than middle Miocene; further detailed taxonomic work may make it necessary to subdivide the present specimens.

Dimensions:

	Max. Diameter	*Height*
CPC 4057	0.42 mm.	0.30 mm.
CPC 4058	0.32 mm.	0.22 mm.

Occurrence: Figured specimens CPC 4057 and 4058 from a sample at Kisila village, east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene); thin section CPC 4059 from a sample east of Moie, Josefstaal Subdistrict, Bogia District, New Guinea (upper Miocene).

GLOBIGERINA SUBCRETACEA Lomnicki, 1901.

(Pl. 2, figs. 1-5)

1901 *Globigerina subcretacea* Lomnicki. LOMNICKI, *Abh. Naturf. Ver. Brunn, Verh.*, 39, p. 17.

1959 *Globigerina subcretacea* (Lomnicki). GRAHAM & MILITANTE, *Publ. Stanford Univ. geol. Sci.*, 7(2), p. 111, pl. 18, figs. 10a-c. (Synonymy).

G. subcretacea has been found in Papua-New Guinea in samples ranging from lower Miocene (Burdigalian) to Pliocene in age; it is more common in the younger beds.

Dimensions:

	Max. Diameter	*Height*
CPC 4060	0.59 mm.	0.41 mm.
CPC 4061	0.50 mm.	0.37 mm.

Occurrence: Figured specimens CPC 4060 and 4061 from sample at Kisila Village, east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene); thin section CPC 4062 from a sample 2 miles east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene).

GLOBIGERINA sp. cf. G. EAMESI Blow, 1959

(Pl. 2, figs. 6-9)

1959 *Globigerina eamesi* Blow. BLOW, *Bull. Amer. Paleont.*, 39(178), p. 176, pl. 9, figs. 39a-c.

Rare specimens closely resembling *G. eamesi* have been found in samples of upper Miocene age in New Guinea.

Dimensions:

	Max. Diameter	*Height*
CPC 4063	0.44 mm.	0.27 mm.
CPC 4064	0.47 mm.	0.37 mm.

Occurrence: Figured specimen CPC 4063 from sample at Kisila Village, east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene); figured specimen CPC 4064 from sample at Pagansop Village, north-north-east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene).

GLOBIGERINA GLUTINATA Egger, 1893

(Pl. 3, figs. 10-16; Text-fig. 2, 1-6)

1893 *Globigerina glutinata* Egger. EGGER, *Abh. K. bayer. Akad. Wiss., math.-phys. Kl.*, 18, (1895) (2), p. 371, pl. 13, figs. 19-21.

This species has been observed in upper Miocene beds in New Guinea, but not in available samples from Papua. A feature of numerous specimens is an umbilical cover-plate (bulla), which is variable (see Text-fig. 2). Several authors (Phleger, Parker, & Peirson, 1953; Parker, 1958; Bé, 1959; Bradshaw, 1959) have referred this species to the genus *Globigerinita* Bronnimann. Loeblich & Tappan (1957) emended the description of the genus *Globigerinita* and proposed the new genus *Tinophodella;* I prefer to place such specimens in *Globigerina*.

Dimensions:

	Max. Diameter	*Height*
CPC 4065	0.38 mm.	0.29 mm.
CPC 4066	0.34 mm.	0.27 mm.
CPC 4067	0.33 mm.	0.28 mm.
CPC 4068	0.30 mm.	0.28 mm.

Occurrence: Figured specimens CPC 4065 to 4068 from sample at Pagansop village, north-north-east of Josefstaal. Lower Ramu-Atitau area, New Guinea (upper Miocene).

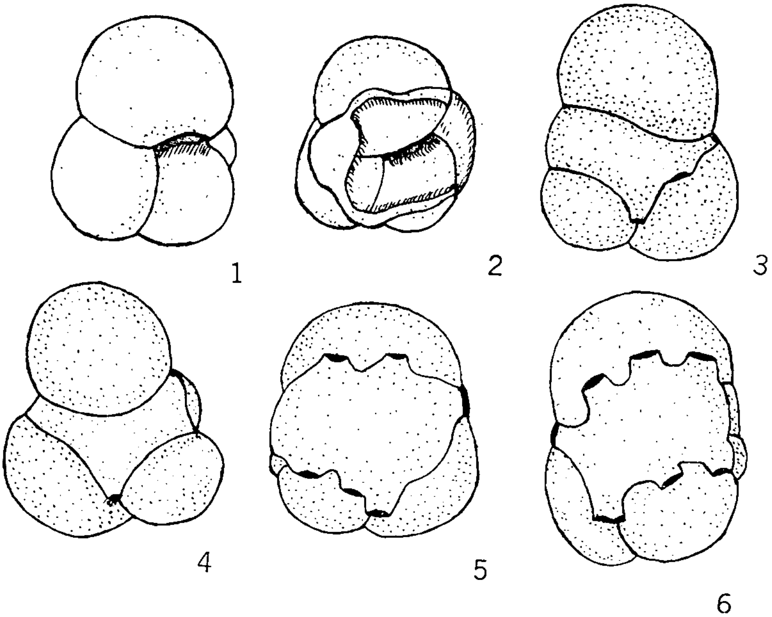

Figure 2. Globigerina glutinata Egger, C.P.C. 6069-6074. 1, specimen lacking a bulla; 2, specimen from which bulla has been broken; 3-6, specimens showing variation in shape and size of bulla, and position of accessory infralaminal apertures.

Remarks: Several generic names have now been proposed for Tertiary planktonic foraminifera, based on the nature of the bulla and the accessory infralaminal apertures; Bolli, Loeblich, & Tappan (1957) proposed the subfamily Catapsydracinae to include these genera. It is, however, apparent that the bulla is not a constant feature of any given population and that it varies on those specimens on which it does occur. Bé (1959) and Bradshaw (1959) figure *Globigerina glutinata* without a bulla; Phleger, Parker, & Peirson (1953) figure specimens both with and without a bulla, and also one with a supplementary aperture on the spiral side. This latter feature, which was also noted by Parker (1958), occurs on several New Guinea specimens. I have observed that such forms, which have developed a bulla over the primary aperture, also have a smaller bulla over the supplementary aperture. There is thus in these specimens a connexion with the genera *Globigerinoides* and *Globigerinita;* bullae are also sometimes formed in two series, as in the genus *Globigerinatella* Cushman & Stainforth 1945, with secondary bullae covering the infralaminal apertures of the primary bulla. Specimens of *Globigerinoides conglobatus* (Brady) with a bulla over the primary aperture, and some with smaller bullae over the supplementary apertures, have been observed. These are clearly bullae as defined by Bolli, Loeblich, & Tappan (1957) and not abortive end chambers (see Banner & Blow, 1959, p. 15). Parker (1958) noted the structure now known as a bulla on several species and suggested that it might have some connexion with the reproductive process. Hofker (1959) also considered that the supplementary processes are connected with reproduction, and concluded that many genera are based on forms which are the reproductive stages of other genera. I agree with Hofker that the bullae have no taxonomic significance and that genera defined on this basis have no value. Blow (pers. comm.) advises that he and Banner now reject the subfamily Catapsydracinae, which they had previously (1959) referred to as 'polyphyletic but taxonomically convenient' (Banner & Blow, in press).

Genus GLOBIGERINOIDES Cushman, 1927

GLOBIGERINOIDES QUADRILOBATUS QUADRILOBATUS (d'Orbigny), 1846.

(Pl. 2, figs. 17-21)

1846 *Globigerina quadrilobata* d'Orbigny. D'ORBIGNY, Foraminiferes fossiles du bassin Tertiare de Vienne (Autriche). *Gide et Comp.*, Paris, p. 164, pl. 9, figs. 7-10.

1960 *Globigerina quadrilobata* (d'Orbigny). BANNER & BLOW, *Contr. Cushman Fdn*, 11(1), p. 17, pl. 4, figs. 3a-b. (Also given in explanation of plate as *Globigerinoides quadrilobatus* (d'Orbigny)).

G. quadrilobatus quadrilobatus occurs abundantly in beds of upper Miocene age in New Guinea; specimens such as are figured here have not been recorded in any of the available material from Papua.

Dimensions:

	Length	*Breadth*
CPC 4075	0.69 mm.	0.50 mm.
CPC 4076	0.56 mm.	0.41 mm.

Occurrence: Figured specimens CPC 4075 and 4076 from a sample at Pagansop village, north-north-east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene).

GLOBIGERINOIDES QUADRILOBATUS (d'Orbigny) IMMATURUS Le Roy, 1939

(Pl. 2, figs. 22-24); Pl. 3, figs. 1-4)

1939 *Globigerinoides sacculiferus* (Brady) var. *immatura* Le Roy. LE ROY, *Naturk. Tijdschr. Nederl. Indie,* 99(6), p. 263, pl. 3, figs. 19-21.

1957 *Globigerinoides triloba immatura* Le Roy. BOLLI, *Bull. U.S. nat. Mus.*, 215, p. 113, pl. 25, figs. 3a-b, 4a-c.

1959 *Globigerinoides triloba immatura* Le Roy. BLOW, *Bull. Amer. Paleont.*, 39 (178), p. 188, pl. 11, figs. 62a-b.

G. quadrilobatus immaturus is abundant in all samples examined and is the commonest form of the *quadrilobatus* group in Papua-New Guinea, at least in the available material. There are also transitional forms between *immaturus* and *G. quadrilobatus trilobus.*

Dimensions:

	Length	*Breadth*
CPC 4077	0.50 mm.	0.38 mm.
CPC 4078	0.51 mm.	0.40 mm.
CPC 4079	0.58 mm.	0.43 mm.
CPC 4080	0.42 mm.	0.34 mm.

Occurrence: Figured specimens CPC 4077 to 4080 from a sample at Pagansop village, north-north-east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene).

GLOBIGERINOIDES QUADRILOBATUS (d'Orbigny) TRILOBUS (Reuss), 1850

(Pl. 3, figs. 5-8)

1850 *Globigerina triloba* Reuss. REUSS, *K. Akad. Wiss. Wien, math.-nat. Cl., Denkschr.*, 1, p. 374, pl. 47, figs. 11a-e.

1941 *Globigerinoides trilocularis* (d'Orbigny). CUSHMAN, *Contr. Cushman Lab.*, 17(2), p. 39, pl. 10, figs. 14-17; pl. 11, fig. 1.

1944 *Globigerinoides trilocularis* (d'Orbigny). LE ROY, *Quart. Colorado Sch. Mines,* 39(3), pt. 1, p. 40, pl. 3, figs. 38-39; pl. 6, figs. 41-42; pl. 7, figs. 43-45; pt. 3, p. 91, pl. 4, figs. 15-17.

1946 *Globigerinoides triloba* (Reuss). CUSHMAN, *Contr. Cushman Lab.*, 22(1), p. 20, pl. 3, figs. 8a-d; pl. 4, figs 16-18.

1957 *Globigerinoides triloba triloba* (Reuss). BOLLI, *Bull. U.S. nat. Mus.*, 215, p. 112, pl. 25, figs. 2a-c; text-fig. 21 (1a-b).

1959 *Globigerinoides triloba triloba* (Reuss). BLOW, *Bull. Amer. Paleont.*, 39 (178), p. 187, pl. 11, figs. 60a-b.

G. quadrilobatus trilobus is very rare in the present material; it has been recorded from samples of lower and middle Miocene age. Chang (1959) stated that *trilobus* is relatively rare in the Miocene of Western Taiwan.

The form described by d'Orbigny as *Globigerina triloculαris* was referred by Cushman (1941) to the genus *Globigerinoides,* but later (1946) he concluded that d'Orbigny's name was a *nomen nudum* and that *Globigerina triloba* Reuss was the correct name for this form. Bolli (1957) thought it probable that specimens which he recorded as *Globigerina* cf. *trilocularis* d'Orbigny could be regarded as ancestors of *Globigerinoides trilobus immaturus* and stated: 'Specimens of *Globigerina trilocularis* d'Orbigny and *Globigerinoides triloba immatura* Le Roy were found to be indistinguishable . . . ., except that the latter showed a supplementary sutural aperture in the last chamber'. Le Roy (1944) placed the species he had previously described as *Globigerinoides sacculiferus* var. *immatura* in the synonymy of *G. trilocularis* (d'Orbigny). Banner & Blow (1960) regarded *Globigerina trilocularis* d'Orbigny, 1862 as a *nomen nudum* and stated that the name must be credited to Deshayes, 1832.

Dimensions:

	Length	*Breadth*
CPC 4081	0.43 mm.	0.36 mm.
CPC 4082	0.37 mm.	0.34 mm.

Occurrence: Figured specimens CPC 4081 and 4082 from a sample east of Karova Creek, Kerema-Karova Creek area, Papua (middle Miocene).

GLOBIGERINOIDES QUADRILOBATUS (d'Orbigny) IRREGULARIS Le Roy, 1944.

(Pl. 3, figures 9-13)

1944 *Globigerinoides sacculiferus* (Brady) var. *irregularus* Le Roy. LE ROY, *Quart. Colorado Sch. Mines,* 39(3), p. 40, pl. 3, figs. 42-43.

I follow Banner & Blow (1960) in regarding *irregularis* as a subspecies of *G. quadrilobatus* d'Orbigny.

G. quadrilobatus irregularis occurs frequently in most samples examined. In all samples in which it is present there is a transitional series between *irregularis* and the lectotype form of *G. quadrilobatus sacculifer.*

Dimensions:

	Length	*Breadth*
CPC 4083	0.58 mm.	0.43 mm.
CPC 4084	0.53 mm.	0.42 mm.
CPC 4085	0.49 mm.	0.39 mm.

Occurrence: Figured specimens CPC 4083 to 4085 from a sample 2 miles east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene).

GLOBIGERINOIDES QUADRILOBATUS (d'Orbigny) SACCULIFER (Brady), 1877

(Pl. 3, figs. 14-16; pl. 4, figs. 1-6)

1877 *Globigerina sacculifera* Brady. BRADY, *Geol. Mag.*, n.s., dec. 2, 4(12), p. 535.

1884 *Globigerina sacculifera* Brady. BRADY, *Rep. Voy. Challenger, Zool.*, 9, p. 604, pl. 80, figs. 11-17; pl. 82, fig. 4.

1953 *Globigerinoides sacculifera* (H. B. Brady). PHLEGER, PARKER, & PEIRSON, *Reps. Swedish Deep-Sea Exped.*, 7(1), p. 16, pl. 2, figs. 5-6. (Synonymy).

1957 *Globigerinoides triloba sacculifera* (Brady). BOLLI, *Bull. U.S. nat. Mus.*, 215, p. 113, text-fig. 21, 4a-b; pl. 25, figs. 5a-c, 6.

1958 *Globigerinoides sacculifera* (Brady). PARKER, *Reps. Swedish Deep-Sea Exped.*, 8(4), p. 280, pl. 6, fig. 4.

1959 *Globigerinoides sacculifer* (H. B. Brady). BÉ, *Micropaleontology*, 5(1), p. 83, pl. 2, figs. 13-15.

1959 *Globigerinoides sacculifer* (Brady). GRAHAM & MILITANTE, *Stanford Univ. Publ. geol. Sci.*, 7(2), p. 112, pl. 19, figs. 1a-b, 2a-b. (Synonymy).

1959 *Globigerinoides sacculifera* (Brady). BRADSHAW, *Contr. Cushman Fdn.* 10(2), p. 42, pl. 17, figs. 14, 15, 18.

1960 *Globigerina sacculifera* Brady, 1877. BANNER & BLOW, *Contr. Cushman Fdn.* 11(1), p. 21, 4, figs. 1a-b, 2a-b. (Also given on plate as *Globigerinoides quadrilobatus sacculifer* (Brady)).

Only specimens showing an elongated or 'sac-like' final chamber are placed here; Parker (1958), Bé (1959), and Bradshaw (1959) also refer specimens lacking this chamber to the subspecies *sacculifer*.

Banner & Blow (1960) figured two specimens of *G. quadrilobatus sacculifer*, one designated as lectotype and one as ideotype; in their phylogeny these two forms are indicated as *G. quadrilobatus sacculifer* forma *typica* and *G. quadrilobatus sacculifer* (of Brady 1884) respectively. Forms similar to the lectotype were regarded as ranging probably from the middle or upper Aquitanian, and forms similar to the ideotype as not appearing before the Pliocene. The ideotypic form was considered to result from an evolutionary increase in size of both the primary and supplementary apertures. The similarity of apertural shape between *G. quadrilobatus altiaperturus* and the ideotypic form of *G. quadrilobatus sacculifer* was cited as an example of iterative development of a morphological character in closely related forms.

In correspondence with W. H. Blow, I proposed a lineage *Globigerinoides quadrilobatus immaturus*-*G. quadrilobatus sacculifer* (lectotype form)-*G. quadrilobatus hystricosus*, subsp. nov. However, I now agree with Blow that it is preferable to regard *G. quadrilobatus hystricosus* as directly derived from *immaturus*. The specimens figured on Plate 4, figures 1-4, are also considered by Blow to be the lectotype form of *sacculifer*, and to have arisen as outlined previously, namely by an evolutionary increase in size of the primary and supplementary apertures. Alternatively, it is suggested here that specimens of this type have developed directly from *Globigerinoides quadrilobatus quadrilobatus*. Again, the specimens shown on Plate 4, figures 5-6, are considered by Blow to indicate the beginning of fistulose development from the lectotype form of *sacculifer*; it is here suggested that this may be a fistulose development directly from *Globigerinoides quadrilobatus quadrilobatus*, leading to *G. quadrilobatus fistulosus*. Blow considers *fistulosus* to be a development from the lectotype form of *sacculifer*.

Whatever the origin of these forms may be they have considerable stratigraphical value. The lectotype form of *sacculifer* occurs in the oldest available samples (Burdigalian); the 'sac-like' final chamber is small and rounded and there are transitional forms between *sacculifer* and *G. quadrilobatus irregularis*. In younger samples the final chamber becomes radially elongate. The form thought here to be derived from *G. quadrilobatus quadrilobatus*, and characterized by larger primary and supplementary apertures, does not appear until the upper Miocene, and probably high in the upper Miocene. Specimens of this type have been found only in samples from New Guinea. Fistulose forms also do not appear before the uppermost Miocene and further work may show that the beds in which they first occur are Pliocene in age.

The naming and taxonomic subdivisions of the *quadrilobatus* stock, including the ideotype form of *sacculifer*, will be further considered by Banner & Blow in a publication now in preparation.

Dimensions:

	Length	*Breadth*L
CPC 4086	0.58 mm.	0.47 mm.
CPC 4087	0.69 mm.	0.54 mm.
CPC 4088	0.78 mm.	0.56 mm.
CPC 4089	0.97 mm.	0.69 mm.

Occurrence: Figured specimens CPC 4086 to 4089 from a sample 2 miles east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene).

GLOBIGERINOIDES QUADRILOBATUS (d'Orbigny) FISTULOSUS (Schubert), 1910.
(Pl. 4, figs. 7-10)

1910 *Globigerina fistulosa* Schubert. SCHUBERT, *Geol. Reichsanst., Verh.*, pp. 323, 324, fig. 2. (Also figured 1911, *Geol. Reichsanst. Abh.*, 20 (4), p. 101, figs. 13a-c).

1954 *Globigerinoides sacculifera* var. *fistulosa* (Schubert). CUSHMAN, TODD, & POST, *Prof. Pap. U.S. geol. Surv.*, 260-H, p. 369, pl. 91, fig. 13.

1959 *Globigerinoides sacculifera* (Brady) var. *fistulosa* (Schubert). HAMILTON & REX, *Ibid.*, 260-W, p. 792, pl. 254, fig. 14.

G. quadrilobatus fistulosus has been found abundantly in only one sample of either uppermost Miocene or Pliocene age from New Guinea; it is known to occur in Papua. The time of appearance of this species in Papua-New Guinea is not known, but was probably during the uppermost Miocene; the specimen figured by Hamilton & Rex (1959) was regarded as upper Miocene.

Blow considers *fistulosus* to result from evolutionary development of the lectotype form of *sacculifer;* I suggest that it was possibly derived directly from *G. quadrilobatus quadrilobatus* (see p. 16).

Dimensions (excluding spines):

	Length	*Breadth*
CPC 4090	0.57 mm.	0.48 mm.
CPC 4091	0.65 mm.	0.52 mm.

Occurrence: Figured specimens CPC 4090 and 4091 from a sample on the Nogam River, west of Periama village, Wewak subdistrict, Sepik District, New Guinea (uppermost Miocene or Pliocene).

GLOBIGERINOIDES QUADRILOBATUS (d'Orbigny) HYSTRICOSUS subsp. nov.

(Pl. 4, figs. 11-14)

This new subspecies is derived from *G. quadrilobatus immaturus* Le Roy by the development of distinct spines on the penultimate and last chambers. The last chamber is developed in the same way as that of *G. quadrilobatus sacculifer* and is usually radially elongate. Rare fistulose specimens which lack the terminal chamber have been found; these are also here included in *G. quadrilobatus hystricosus* subsp. nov. This new subspecies occurs in the same sample as *G. quadrilobatus fistulosus;* consideration was given to the possibility that these two forms represented different generations of the same species, but this could not be proved.

Dimensions (excluding spines):

	Length	*Breadth*
CPC 4092	0.40 mm.	0.30 mm.
CPC 4093	0.43 mm.	0.32 mm.

Occurrence: Holotype CPC 4092 and paratype CPC 4093 from a sample on the Nogam River, west of Periama village, Wewak Subdistrict, Sepik District, New Guinea (uppermost Miocene or Pliocene).

Remarks: The appearance of fistulose forms marks an evolutionary development which appeared at much the same time in different lines of the *quadrilobatus* group; two lineages resulted in *fistulosus* and *hystricosus* subsp. nov., and Blow (pers. comm.) mentions a third fistulose form developed from the ideotype form of *sacculifer* which is not represented in material from Papua-New Guinea. The development of fistulose forms seems to have begun in the upper Miocene.

GLOBIGERINOIDES CONGLOBATUS (Brady), 1879.

(Pl. 4, figs. 15-20; Text-figs. 3, 1-6).

1879 *Globigerina conglobata* Brady. BRADY, *Quart. J. micr. Soc.*, n.s., 19, p. 286.

1884 *Globigerina conglobata* Brady. BRADY, *Rep. Voy. Challenger, Zool.*, 9, p. 603, pl. 80, figs. 1-5; pl. 82, fig. 5.

1953 *Globigerinoides conglobata* (H. B. Brady). PHLEGER, PARKER, & PEIRSON, *Reps. Swedish Dep-Sea Exped.*, 7(1), p. 15, pl. 2, figs. 1-3. (Synonymy).

1958 *Globigerinoides conglobata* (Brady). PARKER, *Ibid.*, 8(4), p. 279, pl. 6, figs. ? 16-17.

1959 *Globigerinoides conglobatus* (H. B. Brady). BE, *Micropaleontology*, 5(1), p. 83, pl. 2, figs. 7-12.

1959 *Globigerinoides conglobata* (Brady). BRADSHAW, *Contr. Cushman Fdn*, 10(2), p. 40, pl. 7, figs. 5-6.

1960 *Globigerina conglobata* Brady, 1879. BANNER & BLOW, *Contr. Cushman Fdn*, 11(1), p. 6, pl. 4, figs. 4a-c. (Also given in explanation of plate as *Globigerinoides conglobatus* (Brady)).

Banner & Blow (1960) give the range of *G. conglobatus* as Pliocene to Recent, but it appears to occur as early as the upper Miocene in Papua-New Guinea. The specimens agree well with the description of the lectotype; the primary aperture may be slightly asymmetric and broadest posteriorly, but not all tests show this feature. All the forms observed have only two supplementary apertures and not three as on the lectotype. Two specimens figured by Brady (1884) in spiral view have three supplementary apertures, but in each case one aperture is not sutural in position. Several tests from Papua-New Guinea have a bulla over the primary aperture and sometimes also over the supplementary apertures.

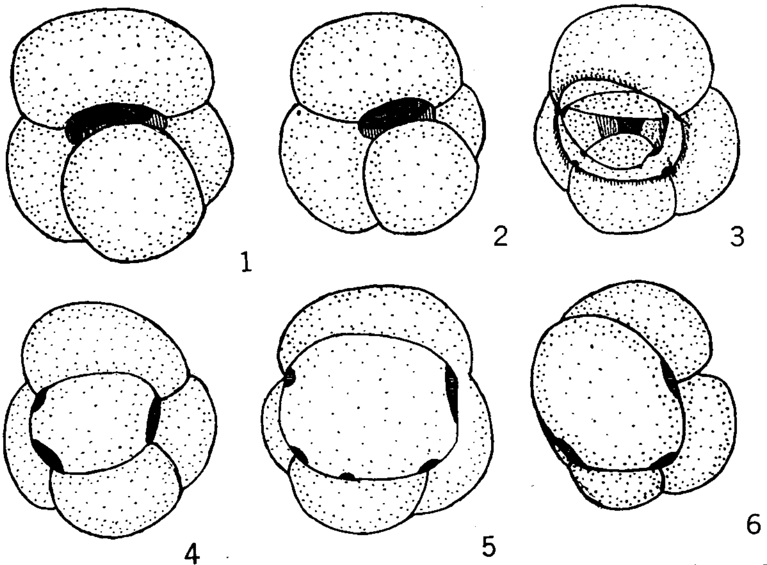

Figure 3. Globigerinoides conglobatus (Brady), C.P.C. 4097-4102. 1,2, specimens lacking a bulla; 3, specimen from which bulla has been broken; 4-6, specimens showing variation in shape and size of bulla, and position of accessory infralaminal apertures.

Dimensions:

	Max. Diameter	*Height*
CPC 4094	0.60 mm.	0.56 mm.
CPC 4095	0.73 mm.	0.67 mm.
CPC 4096	0.55 mm.	0.54 mm.

Occurrence: Figured specimens CPC 4094 to 4096 from a sample at Kisila village, east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene).

GLOBIGERINOIDES RUBER (d'Orbigny), 1834.

(Pl. 5, figs. 1-6)

1839 *Globigerina rubra* d'Orbigny. D'ORBIGNY, *Foraminiferes*, in de la Sagra. *Histoire physique et naturelle de l'Ile de Cuba*. Bertrand, Paris, p. 82. (Plates, *Ibid.*, 8, pl. 4, figs. 12-14).

1953 *Globigerinoides rubra* (d'Orbigny). PHLEGER, PARKER, & PEIRSON, *Reps. Swedish Deep-Sea Exped.*, 7(1), p. 15, pl. 2, figs. 4, 7.

1957 *Globigerinoides rubra* (d'Orbigny). BOLLI, *Bull. U.S. nat. Mus.*, 215, p. 113, pl. 25, figs. 12a-b (not figs. 13a-b).

1959 *Globigerinoides ruber* (d'Orbigny). BE, *Micropaleontology*, 5(1), p. 83, pl. 2, figs. 16-17.

1959 *Globigerinoides ruber* (d'Orbigny). GRAHAM & MILITANTE, *Stanford Univ. Publ. geol. Sci.*, 6(2), p. 111, pl. 18, figs. 12a-c.

1959 *Globigerinoides rubra* (d'Orbigny). BRADSHAW, *Contr. Cushman Fdn*, 10(2), p. 42, pl. 7, figs. 12-13.

1960 *Globigerina rubra* d'Orbigny. BANNER & BLOW, *Contr. Cushman Fdn*, 11(1), p. 19, pl. 3, figs. 8a-b (also given in explanation of plate as *Globigerinoides ruber* (d'Orbigny)).

G. ruber is common in most of the samples examined. High-spired specimens which occur in the upper Miocene and Pliocene are here included under *G. ruber.* They resemble those figured by Parker (1958) as '*Globigerinoides pyramidalis*' (Van den Broeck) and by Boltovskoy (1959) as *Globigerinoides rubra* (d'Orbigny) forma *pyramidalis* (Van den Broeck). However, the specimens from Papua-New Guinea do not have the numerous supplementary apertures of the type specimen of *G. pyramidalis* and the chambers are not so strongly inflated. Another similar species is *G. elongatus* (d'Orbigny), but the present tests are not as tightly coiled as the lectotype figured by Banner & Blow (1960, pl. 3, figs. 10a-c). Upper Miocene forms are small and have a somewhat flattened last chamber. Those from the Pliocene are very similar to the specimen figured by Bolli (1957, pl. 25, figs. 12a-b), which was also considered by Banner & Blow (1960) to be fully synonymous with true *G. ruber.*

Dimensions:

	Max. Diameter	*Height*
CPC 4103	0.60 mm.	0.62 mm.
CPC 4104	0.44 mm.	0.57 mm.
CPC 4105	0.37 mm.	0.49 mm.
CPC 4106	0.34 mm.	0.43 mm.

Occurrence: Figured specimens CPC 4103 and 4104 from a sample east of Atemble, Lower Ramu-Atitau area, New Guinea (Pliocene); figured specimen CPC 4105 from a sample at Pagansop village, north-north-east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene); figured specimen CPC 4106 from a sample east of Moie, Josefstaal Subdistrict, Bogia District, New Guinea (upper Miocene).

GLOBIGERINOIDES OBLIQUUS Bolli, 1957

(Pl. 5, figs. 11-14)

1957 *Globigerinoides obliqua* Bolli. BOLLI, *Bull. U.S. nat. Mus.*, 215, p. 113, pl. 25, figs. 9a-c, 10a-c; text-fig. 21 (5a-b).

1959 *Globigerinoides obliqua* Bolli. BLOW, *Bull. Amer. Paleont.*, 39(178), p. 191, pl. 11, figs. 68a-b.

Rare specimens of *G. obliquus* have been found in beds of midde Miocene age in Papua; none of the observed forms are as high-spired as the paratype figured by Bolli (1957).

Dimensions:

	Length	*Breadth*
CPC 4109	0.34 mm.	0.29 mm.
CPC 4110	0.29 mm.	0.23 mm.

Occurrence: Figured specimens CPC 4109 and 4110 from a sample east of Karova Creek, Kerema-Karova Creek area, Papua (middle Miocene).

GLOBIGERINOIDES BOLLII Blow, 1959

(Pl. 5, figs. 7-10)

1959 *Globigerinoides bollii* Blow. BLOW, *Bull. Amer. Paleont.*, 39(178), p. 189, pl. 10, figs. 65a-c.

G. bollii also occurs rarely in beds of middle Miocene age. It is distinguished from *G. obliquus* by its almost circular primary aperture and smaller supplementary aperture, and the last chambers do not show any lateral or oblique compression.

Dimensions:

	Length	*Breadth*
CPC 4107	0.34 mm.	0.27 mm.
CPC 4108	0.29 mm.	0.23 mm.

Occurrence: Figured specimens CPC 4107 and 4108 from a sample east of Karova Creek, Kerema-Karova area, Papua (middle Miocene).

Genus HASTIGERINA Thomson, 1876.

HASTIGERINA AEQUILATERALIS AEQUILATERALIS (Brady), 1879.

(Pl. 5, figs. 15-18)

1879 *Globigerina aequilateralis* Brady, BRADY, *Quart. J. micr. Soc., London*, n.s., 19, p. 285.

1884 *Globigerina aequilateralis* Brady. BRADY. *Rep. Voy. Challenger, Zool.*, 9, p. 605, pl. 80, figs. 18a-b, 19a-b, 20-21.

1953 *Globigerinella aequilateralis* (H. B. Brady). PHLEGER, PARKER, & PEIRSON, *Reps. Swedish Deep-Sea Exped.*, 7(1), p. 16, pl.2, figs. 9-11. (Synonymy).

1958 *Globigerinella aequilateralis* (Brady). PARKER, *Ibid.*, 8(4), p. 278, pl. 6, figs. 5-6.

1959 *Globigerinella aequilateralis* (H. B. Brady). BÉ, *Micropaleontology*, 5(1), p. 83, pl. 1, figs. 19-20, 27.

1959 *Hastigerina aequilateralis aequilateralis* (Brady). BLOW, *Bull. Amer. Paleont.*, 39(178), p. 171, pl. 8, figs. 31a-b.

1959 *Globigerinella aequilateralis* (Brady). GRAHAM & MILITANTE, *Stanford Univ. Publ. geol. Sci.*, 6(2), p. 111, pl. 18, figs. 11a-b. (Synonymy).

1959 *Globigerinella aequilateralis* (Brady). BRADSHAW, *Contr. Cushman Fdn*, 10(2), p. 38, pl. 7, figs. 1-2.

The opinion of Bolli, Loeblich, & Tappan (1957) and of Blow (1959), that *Globigerinella* is a synonym of *Hastigerina*, is accepted here.

H. aequilateralis aequilateralis is a common form in the younger Tertiary of Papua-New Guinea and has been found in samples ranging from lower Miocene (Burdigalian) to Pliocene in age. Observed specimens range from planispiral to trochospiral in the adult form, but in all cases the young stages are trochospiral. Bé (1959) investigated the morphological overlap of some Recent planktonic foraminifera and observed a morphological gradation between *H. aequilateralis aequilateralis* and *Globigerina bulloides* in mature tests.

Dimensions:

	Max. Diameter	*Breadth*
CPC 4111	0.57 mm.	0.41 mm.
CPC 4112	0.39 mm.	0.31 mm.

Occurrence: Figured specimen CPC 4111 from a sample east of Atemble, Lower Ramu-Atitau area, New Guinea (Pliocene); figured specimen CPC 4112 and thin section CPC 4113 from a sample at Kisila village, east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene).

Genus GLOBOQUADRINA Finlay, 1947

GLOBOQUADRINA ALTISPIRA ALTISPIRA (Cushman & Jarvis), 1936

(Pl. 5, figs. 19-24)

1936 *Globigerina altispira* Cushman & Jarvis. CUSHMAN & JARVIS, *Contr. Cushman Lab.*, 12(1), pl. a, figs. 13a-c, 14.

1957 *Globoquadrina altispira altispira* (Cushman & Jarvis). BOLLI, *Bull. U.S. nat. Mus.*, 215, p. 111, pl. 24, figs. 7a-c, 8a-b.

1959 *Globoquadrina altispira altispira* (Cushman & Jarvis). BLOW, *Bull. Amer. Paleont.*, 39(178), p. 183, pl. 8, figs. 51a-c.

Specimens referred to *G. altispira altispira* occur commonly in beds from lower Miocene (Burdigalian) to Pliocene age in Papua-New Guinea.

Dimensions:

	Max. Diameter	*Height*
CPC 4114	0.53 mm.	0.50 mm.
CPC 4115	0.53 mm.	0.52 mm.
CPC 4116	0.48 mm.	0.50 mm.

Occurrence: Figured specimens CPC 4114 to 4116 from a sample on the Nogam River, west of Periama village, Wewak Subdistrict, Sepik District, New Guinea (uppermost Miocene or Pliocene).

GLOBOQUADRINA VENEZUELANA (Hedberg), 1937

(Pl. 6, figs. 1-6)

1937 *Globigerina venezuelana* Hedberg. HEDBERG, *J. Paleont.*, 11(8), p. 681, pl. 92, figs. 7a-b.

1957 *Globigerina venezuelana* Hedberg. BOLLI, *Bull. U.S. nat. Mus.*, 215, pp. 110, 164, pl. 23, figs. 6a-c; 7a-b, 8a-b; pl. 35, figs. 16a-c, 17.

1959 *Globoquadrina venezuelana* (Hedberg). BLOW, *Bull. Amer. Paleont.*, 39(178), p. 186, pl. 11, figs. 58a-c, 59.

G. venezuelana occurs commonly in several samples of middle and upper Miocene age in Papua-New Guinea. The species is here referred to the genus *Globoquadrina*, as suggested by Finlay (1947). *G. venezuelana* is the only species of planktonic foraminifera in the present material in which I have been able to detect double septal walls (Bilamellidea of Reiss, 1957). Most observed specimens have the small rudimentary final chamber, but some have been found from which it is lacking.

Dimensions:

	Max. Diameter	*Height*
CPC 4117	6.05 mm.	0.58 mm.
CPC 4118	0.64 mm.	0.47 mm.

Occurrence: Figured specimens CPC 4117 and 4118 and thin section CPC 4119 from a sample at Pagansop village, north-north-east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene).

GLOBOQUADRINA sp.

(Pl. 6, figs. 7-11)

Specimens here referred to *Globoquadrina* sp. occur abundantly in a sample from the bank of the Masaweng River, north of Finschhafen, New Guinea. The later chambers are narrow, elongate, and laterally compressed; removal of the later chambers gives a form similar to the early stages of *G. venezuelana. G.* sp. also clearly shows double septal walls. Bolli (1957) discusses the variation observed in specimens of *G. venezuelana* from Trinidad. Without further information on the relationship between *G. venezuelana* and *G.* sp. in Papua-New Guinea it is not desirable to erect a new name for the latter form.

Dimensions:

	Max. Diameter	*Height*
CPC 4120	0.73 mm.	0.78 mm.
CPC 4121	0.60 mm.	0.48 mm.

Occurrence: Figured specimens CPC 4120 and 4121 and thin section CPC 4122 from a sample about 1 mile from the mouth of the Masaweng River, north of Finschhafen, New Guinea (upper Miocene).

Genus PULLENIATINA Cushman, 1927

PULLENIATINA OBLIQUILOCULATA (Parker & Jones), 1865

(Pl. 6, figs. 12-17)

1865 *Pullenia sphaeroides* (d'Orbigny) var. *obliquiloculata* Parker & Jones, PARKER & JONES, *Phil. Trans.*, 155, pp. 365, 368; pl.19, figs. 4a-b.

1941 *Pulleniatina obliquiloculata* (Parker & Jones). LE ROY, *Quart. Colorado Sch. Mines*, 36(1), pt. 1, p. 44, pl. 2, figs. 105-107.

1941 *Pulleniatina obliquiloculata* (Parker & Jones). LE ROY, *Ibid.*, 36(1), pt. 2, p. 87, pl. 4, figs. 16-18.

1941 *Pulleniatina obliquiloculata* (Parker & Jones). LE ROY, *Ibid.*, 36(1), pt. 3, p. 118, pl. 2, figs. 13-15.

1949 *Pulleniatina obliquiloculata* (Parker & Jones), BOOMGAART, *Geol. Inst. Univ. Utretcht*, p. 143, pl. 14, figs. 6a-b.

1959 *Pulleniatina obliquiloculata* (Parker & Jones). GRAHAM & MILITANTE, *Publ. Stanford Univ. geol. Sci.*, 6(2), p. 113, pl. 19, figs. 4a-c. (Synonymy).

P. obliquiloculata occurs commonly in many of the samples examined. Bolli, Loeblich, & Tappan (1957) give the range of the species as Pliocene to Recent, but it occurs in Papua-New Guinea in samples here referred to the upper Miocene. Le Roy (1941) recorded its occurrence in beds of possible uppermost Miocene age. Banner & Blow (1959) gave the range as middle Miocene? to upper Miocene to Recent, and subsequently stated (1960) that the typical form of this species appears to range only from Pliocene to Recent. They noted the occurrence in Fiji and Papua of primitive forms of possible uppermost Miocene age showing a relationship with *Globigerina inflata* of authors; no such forms have been found during the present study.

Dimensions:

	Max. Diameter	*Height*
CPC 4123	0.50 mm.	0.45 mm.
CPC 4124	0.36 mm.	0.36 mm.

Occurrence: Figured specimen CPC 4123 and thin sections CPC 4125 and 4126 from a sample at Pagansop village, north-north-east of Josefstaal, Lower Ramu-Atitau area, New Guinea (Pliocene).

Genus GLOBOROTALIA Cushman, 1927

GLOBOROTALIA CULTRATA (d'Orbigny), 1839.

(Pl. 6, figs. 18-22)

1826 *Rotalia (Rotalie) menardii* d'Orbigny. D'ORBIGNY, *Ann. Sci. nat. Paris,* 1(7), p. 273, mod. No. 10, lre. livraison.

1839 *Rotalina (Rotalina) cultrata* d'Orbigny. D'ORBIGNY, *Foraminifères,* in de la Sagra, *Histoire physique et naturelle de l'Ile de Cuba,* Bertrand, Paris, p. 76. (Plates *Ibid.,* 8, pl. 5, figs. 7-9).

1951 *Globortalia menardii* (d'Orbigny). PHLEGER & PARKER, *Mem. geol. Soc. Amer.,* 46, p. 36, pl. 20, figs. 1-2.

1953 *Globorotalia menardii* (d'Orbigny). PHLEGER, PARKER, & PEIRSON, *Reps. Swedish Deep-Sea Exped.,* 7(1), p. 19, pl. 3, figs. 1-4. (Synonymy).

1957 *Globorotalia menardii* d'Orbigny. BOLLI, *Bull, U.S. nat. Mus.,* 215, p. 120, pl. 29, figs. 6a-c, 7a-b, 8a-c, 9a-b, 10a-b. (Synonymy).

1959 *Globorotalia menardii menardii* (d'Orbigny). BLOW, *Bull. Amer. Paleont.,* 39(178), p. 115, pl. 18, figs. 119a-c, 120a-c.

1959 *Globorotalia menardii* (d'Orbigny). GRAHAM & MILITANTE, *Stanford Univ. Publ. geol. Sci.,* 6(2), p. 114, pl. 19, figs. 6a-c. (Synonymy).

1959 *Globorotalia menardii* (d'Orbigny). BRADSHAW, *Contr. Cushman Fdn,* 10(2), p. 44, pl. 8, figs. 3-4.

1960 *Rotalina cultrata* d'Orbigny. BANNER & BLOW, *Contr. Cushman Fdn,* 11(1), p. 34, pl. 6, figs. 1a-c. (Also given in explanation of plate as *Globorotalia cultrata* (d'Orbigny)).

Specimens referred to *G. cultrata* are among the most abundant and wide-spread forms in the Tertiary of Papua-New Guinea, and they occur in all samples examined. These forms have previously been recorded by authors as *G. menardii* (d'Orbigny). Banner & Blow (1960) have shown that the name *menardii* should properly be credited to Parker, Jones, & Brady; they regard *G. menardii* (Parker, Jones, & Brady) as conspecific with *G. cultrata* (d'Orbigny), but consider that there are grounds for subspecific differentiation between these two forms. The reader is referred the paper by Banner & Blow for a full discussion. No attempt is made here to establish or distinguish subspecies in the specimens examined.

Dimensions:

	Max. Diameter	*Height*
CPC 4127	0.89 mm.	0.36 mm.
CPC 4128	0.80 mm.	0.30 mm.

Occurrence: Figured specimens CPC 4127 and 4128 from a sample east of Atemble, Lower Ramu-Atitau area, New Guinea (Pliocene).

GLOBOROTALIA TUMIDA (Brady), 1877.

(Pl. 7, figs. 1-5)

1877 *Pulvinulina menardii* (d'Orbigny) var. *tumida* Brady. BRADY, *Geol. Mag.*, n.s., dec. 2, 4(12), p. 535.
1884 *Pulvinulina tumida* Brady. BRADY, *Rep. Voy. Challenger, Zool.*, 9, p. 692, pl. 103, figs. 4a-c, 5-6.
1941 *Globorotalia tumida* (Brady). LE ROY, *Quart. Colorado Sch. Mines*, 36(1), pt. 1, p. 45, pl. 3, figs. 103-103; pt. 2, p. 88, pl. 4, figs. 1-3.
1949 *Globorotalia menardii* (d'Orbigny) var. *tumida* Brady. BOOMGAART, *Min. geol. Inst. Rijks Univ. Utrecht*, p. 145, pl. 10, figs. 11a-c.
1951 *Globorotalia tumida* (H. B. Brady). PHLEGER & PARKER, *Mem. geol. Soc. Amer.*, 46(2), p. 36, pl. 20, figs. 14-15.
1953 *Globorotalia tumida* (H. B. Brady). PHLEGER, PARKER, & PEIRSON, *Reps. Swedish Deep-Sea Exped.*, 7(1), p. 22, pl. 3, figs. 3, 6, 7, 8, 10, 11. (Synonymy).
1957 *Globorotalia tumida* (Brady). BOLLI, LOEBLICH, & TAPPAN, *Bull. U.S. nat. Mus.*, 215, p. 41, pl. 10, figs. 2a-c.
1959 *Globorotalia menardii tumida* (H. B. Brady). LI-SHO CHANG, *Proc. geol. Soc. China*, 2, p. 69, pl. 5, figs. 12a-c, 13a-c.
1959 *Globorotalia tumida* (Brady). BRADSHAW, *Contr. Cushman Fdn*, 10(2), p. 47, pl. 8, figs. 9, 13.

G. tumida is common in many of the samples examined. The time of its appearance in Papua-New Guinea is not known exactly, but is within the limits given for the species by Banner & Blow (1960); that is, upper Tortonian and/or lower Sarmatian (top of middle Miocene or base of upper Miocene).

Specimens observed during the present work are strongly pustulose on the ventral surface of the early chambers of the last whorl.

Dimensions:

	Max. Diameter	*Height*
CPC 4129	0.83 mm.	0.48 mm.
CPC 4130	0.82 mm.	0.67 mm.

Occurrence: Figured specimens CPC 4129 and 4130 from a sample 1 mile south of Kumil River, Lower Ramu-Atitau area, New Guinea (upper Miocene).

Remarks: In some assemblages from the present material, transitional forms occur which are difficult to refer definitely to either *G. cultrata* or *G. tumida.* A random selection of specimens from a sample at Pagansop village, north-north-east of Josefstaal, Lower Ramu area, New Guinea, resulted in 118 specimens referred to *G. cultrata* and 104 referred to *G. tumida.* The 118 specimens referred to *G. cultrata* comprise 101 dextrally coiled specimens and 17 sinistrally coiled; of the 104 specimens referred to *G. tumida,* 6 are dextrally coiled and 98 sinistrally coiled. It was also noted that dextral specimens of *G. cultrata* mostly have 6 chambers in the last whorl, although specimens with 5 and 7 chambers were observed; sinistral specimens usually have 5 chambers. In the case of *G. tumida,* sinistral specimens usually have 5 chambers in the last whorl, although the number ranges from 4 to 6; of the 6 dextral specimens, 5 have six chambers and one has five chambers.

Random selections were also made from two other samples. The first, from west of Yangoru, Maprik sub-district, Sepik District, New Guinea, resulted in 46 specimens referred to *G. cultrata* (45 dextral and 1 sinistral), and 165 referred to *G. tumida* (75 dextral and 90 sinistral). The second sample, from the Nuru Valley, on a hill west of Diduella, New Guinea gave 75 specimens referred to *G. cultrata* (1 dextral and 74 sinistral) and 109 referred to *G. tumida* (2 dextral, and 107 sinistral).

When samples from measured sections become available, detailed investigation may show that stratigraphical use can be made of such variations within assemblages of *G. cultrata* and *G. tumida*. Features worthy of investigation are the relative frequency of occurrence of each species, preferred direction of coiling, and the ratio of dextral to sinistral forms.

GLOBOROTALIA TRUNCATULINOIDES (d'Orbigny), 1839.

(Pl. 7, figs. 6-9)

1839 *Rotalina truncatulinoides* d'Orbigny. D'ORBIGNY, *Foraminifères des Iles Canaries*, in: *Hist. Nat. des Iles Canaries*, by MM. P. Barker-Webb and Berthelot, 2(2), *Zool.*, p. 132, pl. 2, figs. 25-27.

1951 *Globorotalia truncatulinoides* (d'Orbigny). PHLEGER & PARKER, *Mem. geol. Soc. Amer.*, 46, (2), pl. 20, figs. 10-13.

1953 *Globorotalia truncatulinoides* (d'Orbigny). PHLEGER, PARKER, & PEIRSON, *Reps. Swedish Deep-Sea Exped.*, 7(1), p. 22, pl. 4, figs. 17-18.

1954 *Globorotalia truncatulinoides* (d'Orbigny). CUSHMAN, TODD, & POST, *Prof. Pap. U.S. geol. Surv.*, 260-H,p. 370, pl. 91, figs. 18a-b.

1959 *Globorotalia truncatulinoides* (d'Orbigny). BE, *Micropaleontology*, 5(1), p. 83, pl. 1, figs. 5-7.

1959 *Globorotalia truncatulinoides* d'Orbigny. BRADSHAW, *Contr. Cushman Fdn*, 10(2), p. 44, pl. 8, figs. 7-8.

Specimens referred to *G. truncatulinoides* have been found abundantly in several samples from upper Miocene and younger beds in both Papua and New Guinea. Banner & Blow (1960) were unable to find syntypic material for this species.

Dimensions:

	Max. Diameter	*Height*
CPC 4131	0.40 mm.	0.31 mm.
CPC 4132	0.41 mm.	0.32 mm.

Occurrence: Figured specimens CPC 4131 and 4132 from a sample at Kisila village, east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene).

GLOBOROTALIA SCITULA (Brady), 1884

(Pl. 7, figs. 10-15)

1884 *Pulvinulina scitula* Brady. BRADY, *Proc. Roy. Soc. Edinb.*, 11, p. 716.

1884 *Pulvinulina patagonica*, d'Orbigny, sp. BRADY, *Rep. Voy. Challenger, Zool.*, 9, p. 693, pl. 7, figs. 7a-c.

1951 *Globorotalia scitula* (H. B. Brady). PHLEGER & PARKER, *Mem. geol. Soc. Amer.*, 46(2), p. 36, pl. 20, figs. 8-9.

1953 *Globorotalia scitula* (H. B. Brady). PHLEGER, PARKER, & PEIRSON, *Reps. Swedish Deep-Sea Exped.*, 7(1), p. 21, pl. 4, figs. 13-14. (Synonymy).

1957 *Globorotalia scitula* (Brady). BOLLI, *Bull. U.S. nat. Mus.*, 215, p. 120, pl. 80, figs. 11a-c, 12a-c.

1959 *Globorotalia scitula* (Brady), BRADSHAW, *Contr. Cushman Fdn*, 10(2), p. 44, pl. 8, figs. 5-6.

1959 *Globorotalia scitula scitula* (Brady). BLOW, *Bull. Amer. Paleont.*, 39(178), p. 219, figs. 126a-c.

G. scitula occurs commonly throughout the younger Tertiary beds of Papua and New Guinea and has been found at all stratigraphic levels. No attempt is made here to distinguish the subspecies established by Blow (1959).

Dimensions:

	Max. Diameter	*Height*
CPC 4133	0.50 mm.	0.25 mm.
CPC 4134	0.41 mm.	0.24 mm.

Occurrence: Figured specimens CPC 4133 and 4134 from a sample at Kisila village, east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene).

GLOBOROTALIA HIRSUTA (d'Orbigny), 1839

(Pl. 7, figs. 16-21)

1839 *Rotalina hirsuta* d'Orbigny. D'ORBIGNY, *Foraminifères des Iles Canaries*, in: *Hist. Nat. des Iles Canaries*, MM. P. Barker-Webb and Sabin Berthelot, 2(2), *Zool.*, 131, pl. 1, figs. 37-39.

1884 *Pulvinulina canariensis*, d'Orbigny, sp. BRADY, *Rep. Voy. Challenger, Zool.*, 9, p. 692, pl. 103, figs. 9a-c, 9a-c, 10a-b.

1953 *Globorotalia hirsuta* (d'Orbigny). PHLEGER, PARKER, & PEIRSON, *Reps. Swedish Deep-Sea Exped.*, 7(1), p. 19, pl. 4, figs. 1-4. (Synonymy).

1959 *Globorotalia hirsuta* (d'Orbigny). BE, *Micropaleontology*, 5(1), p. 83, pl. a, figs. 4, 8.

G. hirsuta has been found in only one sample, in which it is abundant, from the upper Miocene of Papua. The Papuan specimens are not as strongly carinate as those figured by Brady (1884), but are of the type figured by Phleger, Parker, & Peirson (1953) and Bé (1959).

This is another species for which Banner & Blow (1960) were unable to find syntypic material.

Dimensions:

	Max. Diameter	*Height*
CPC 4135	0.37 mm.	0.25 mm.
CPC 4136	0.43 mm.	0.28 mm.

Occurrence: Figured specimens CPC 4135 and 4135 from a sample of the Tubu siltstone, Tubu area, Papua (upper Miocene).

GLOBOROTALIA FOHSI Cushman & Ellisor BARISANENSIS Le Roy, 1939

(Pl. 8, figs. 1-6)

1939 *Globorotalia barisanensis* Le Roy, LE ROY, *Natuur. Tijdschr., Nederl. Indie,* 99(6), p. 265, pl. 1, figs. 8-10.

1944 *Globorotalia barissanensis* Le Roy (sic). LE ROY, *Quart. Colorado Sch. Mines,* 39(3), pt. 1, p. 41, pl. 2, figs. 43-45, pl. 6, figs. 34-36.

1950 *Globorotalia fohsi barisanensis* Le Roy. BOLLI, *Contr. Cushman Fdn,* 1(3, 4), p. 88, pl. 15, figs. 5, 6a-c.

1957 *Globorotalia fohsi barisanensis* Le Roy. BOLLI, *Bull. U.S. nat. Mus.,* 215, p. 119, pl. 28, figs. 8a-c.

1959 *Globorotalia fohsi barisanensis* (Le Roy). BLOW, *Bull. Amer. Paleont.,* 39(178), p. 212, pl. 17, figs. 110, 111a-c.

G. fohsi barisanensis has been found only in Papua, in beds of lower Miocene (Burdigalian) age. It is possible that this species has a greater vertical range in Papua than is recorded in Trinidad (Bolli, 1957; Blow, 1959). Further taxonomic work and additional stratigraphic information are necessary to determine this.

Dimensions:

	Max. Diameter	*Height*
CPC 4137	0.34 mm.	0.19 mm.
CPC 4138	0.30 mm.	0.18 mm.
CPC 4139	0.33 mm.	0.19 mm.

Occurrence: Figured specimen CPC 4137 from a sample on Upper Maipora Creek, west of Saw Mountains, Papua (middle Miocene); figured specimens CPC 4138 and 4139 from a sample west of wharf at the Roman Catholic Mission, Yule Island, Papua (lower Miocene).

GLOBOROTALIA FOHSI FOHSI Cushman & Ellisor, 1939

(Pl. 8, figs. 7-11)

1939 *Globorotalia fohsi* Cushman & Ellisor. CUSHMAN & ELLISOR, *Contr. Cushman Lab.,* 15(1), p. 12, pl. 2, figs. 6z-c.

1950 *Globorotalia fohsi fohsi* Cushman & Ellisor. BOLLI, *Contr. Cushman Fdn,* 1(3. 4), p. 88, pl. 15, figs. 4a-c.

1957 *Globorotalia fohsi fohsi* Cushman & Ellisor. BOLLI, *Bull. U.S. nat. Mus.,* 215, p. 119, pl. 28, figs. 9a-b, 10a-c.

1959 *Globorotalia fohsi fohsi* Cushman & Ellisor. BLOW, *Bull. Amer. Paleont.,* 39(178), p. 212, pl. 17, figs. 112a-c.

G. fohsi fohsi is one of the less common species, and has been found in only one sample, of lower Miocene (Burdigalian) age, in Papua.

Dimensions:

	Max. Diameter	*Height*
CPC 4140	0.37 mm.	0.20 mm.
CPC 4141	0.35 mm.	0.20 mm.

Occurrence: Figured specimens CPC 4140 and 4141 from a sample on Hell's Gate Creek, about ½ mile from the junction with the Tauri River, Papua (lower Miocene).

Genus GLOBOROTALOIDES Bolli, 1957

GLOBOROTALOIDES VARIABILIS Bolli, 1957

(Pl. 8, figs. 12-16)

1957 *Globorotaloides variabilis* Bolli. BOLLI, *Bull. U.S. nat. Mus.*, 215, p. 117, pl. 27, figs. 15a-b, 16a-b, 17a-b, 18a-b, 19a-c, 20a-c.

1959 *Globorotaloides variabilis* Bolli. BLOW, *Bull. Amer. Paleont.*, 39(178), p. 208, pl. 16, figs. 103a-c, 104, 105.

G. variabilis has been found commonly in beds of middle Miocene age and rarely in upper Miocene beds. No specimens noted have developed beyond the *Globigerina* stage; some consist of the *Globorotalia* stage with a small bulla-like final chamber.

Dimensions:

	Max. Diameter	*Height*
CPC 4142	0.37 mm.	0.24 mm.
CPC 4143	0.34 mm.	0.19 mm.
CPC 4144	0.37 mm.	0.19 mm.

Occurrence: Figured specimens CPC 4142 to 4144 from a sample on Upper Maipora Creek, west of Saw Mountains, Papua (middle Miocene).

Genus CANDEINA d'Orbigny, 1839

CANDEINA NITIDA d'Orbigny, 1839

(Pl. 8, figs. 17-18)

1839 *Candeina nitida* d'Orbigny. D'ORBIGNY, *Foraminifères*, in de la Sagra, *Histoire physique et naturelle de l'Ile de Cuba*, Bertrand, Paris, p. 108. (Plates, *Ibid.*, 8, pl. 2, figs. 27-28,).

1884 *Candeina nitida* d'Orbigny. BRADY, *Rep. Voy. Challenger, Zool.*, 9, p. 622, pl. 82, figs. 13-20.

1956 *Candeina nitida* d'Orbigny. HOFKER, *Skrift. Univ. zool. Mus., Copenhagen*, 15, p. 99, pl. 12, figs. 10-17,

1959 *Candeina nitida* d'Orbigny. BE, *Micropaleontology*, 5(1), p. 83, pl. 2, figs. 19-20.

C. nitida occurs rarely in the present material, in samples of upper Miocene age.

Dimensions:

	Max. Diameter	*Height*
CPC 4145	0.41 mm.	0.42 mm.
CPC 4146	0.41 mm.	0.54 mm.

Occurrence: Figured specimen CPC 4145 from a sample at Pagansop village, north-north-east of Josefstaal, lower Ramu-Atitau area, New Guinea (upper Miocene). Figured specimen CPC 4146 from a sample on the Nogam River, west of Periama village, Wewak Subdistrict, Sepik District, New Guinea (uppermost Miocene or Pliocene).

Genus SPHAEROIDINELLA Cushman, 1927

SPHAEROIDINELLA DEHISCENS DEHISCENS (Parker & Jones), 1865

(Pl. 8, figs. 19-21)

1865 *Sphaeroidina bulloides* d'Orbigny var. *dehiscens* Parker & Jones. PARKER & JONES, *Phil. Trans.*, 155, p. 369, pl. 19, figs. 5a-c.

1953 *Sphaeroidinella dehiscens* (Parker & Jones). PHLEGER, PARKER, & PEIRSON, *Reps. Swedish Deep-Sea Exped.*, 7(1), p. 18, pl. 2, fig. 19. (Synonymy).

1957 *Sphaeroidinella dehiscens* (Parker & Jones). BOLLI, LOEBLICH, & TAPPAN, *Bull. Amer. Mus. nat. Hist.*, 215, p. 32, pl. 6, figs. 1, 2a-b, 3a-b, 4a-b, 5.

S. dehiscens has been found commonly in upper Miocene and younger beds. Structures of the type figured by Bolli, Loeblich, & Tappan (1957), regarded by them as bullae and by Banner & Blow (1960) as abnormally placed abortive chambers, have not been observed in the present material. Blow (1959) gives the range of this species as Pliocene to Recent, but typical specimens occur in the upper Miocene of Papua and New Guinea.

Dimensions:

	Length	*Max. Width*
CPC 4147	0.66 mm.	0.52 mm.
CPC 4148	0.59 mm.	0.46 mm.

Occurrence: Figured specimens CPC 4147 and 4148 from a sample at Kisila village, east of Josefstaal, Lower Ramu-Atitau area, New Guinea (upper Miocene).

Genus SPHAEROIDINELLOPSIS Banner & Blow, 1960

SPHAEROIDINELLOPSIS SUBDEHISCENS (Blow), 1959

(Pl. 8, figs. 26-28)

1959 *Sphaeroidinella dehiscens subdehiscens* Blow. BLOW, *Bull. Amer. Paleont.*, 39(178), p. 195, figs. 71a-b, 72.

1960 *Sphaeroidinellopsis subdehiscens* (Blow). BANNER & BLOW, *Palaeontology*, 2(1), p. 15, text-figs. 4f, 5a-c.

Rare specimens referred to *S. subdehiscens* have been found in samples of middle Miocene age in Papua. The final chamber is about equal in size to the combined previous chambers, and a narrow aperture extends along the suture between the last and earlier chambers.

Dimensions:

	Length	*Max. Width*
CPC 4152	0.41 mm.	0.31 mm.
CPC 4153	0.31 mm.	0.25 mm.

Occurrence: Figured specimen CPC 4152 from a sample on upper Maipora Creek, west of Saw Mountains, Papua (middle Miocene); figured specimen CPC 4153 from a sample east of Karova Creek, Papua (middle Miocene).

SPHAEROIDINELLOPSIS SEMINULINA SEMINULINA (Schwager), 1866

(Pl. 8, figs. 22-25)

1866 *Globigerina seminulina* Schwager, SCHWAGER, *Geol. Theil*, 2(2), p. 256, pl. 7, fig. 112.

1941 *Globigerina seminulina* Schwager. LE ROY, *Quart. Colorado Sch. Mines*, 36(1), pt. 1, p. 44, pl. 3, fig. 108.

1959 *Sphaeroidinella seminulina seminulina* (Schwager). BLOW, *Bull. Amer. Paleont.*, 39(178), p. 197, pl. 12, figs. 74, 75, 76, 77a-c.

S. seminulina seminulina has been observed in samples from lower Miocene (Burdigalian) to upper Miocene age. The species lacks a supplementary aperture and is referred by Banner & Blow (1960) to *Sphaeroidinellopsis*.

Dimensions:

	Length	*Max. Width*
CPC 4149	0.45 mm.	0.37 mm.
CPC 4150	0.54 mm.	0.45 mm.
CPC 4151	0.47 mm.	0.34 mm.

Occurrence: Figured specimens CPC 4149 and 4150 from samples east of Karova Creek, Papua (middle Miocene); figured specimen CPC 4151 from a sample on Upper Maipora Creek, west of Saw Mountains (middle Miocene).

Genus CHILOGUEMBELINA Loeblich & Tappan, 1956

CHILOGUEMBELINA sp.

(Pl. 8, figs. 29-30)

Rare, very small specimens referred to *Chiloguembelina* have been found in beds from middle to upper Miocene age; no specific determination can be made. The specimens are biserial throughout and the apertures are usually slightly asymmetrical, with a small raised margin which may be the remannt of a neck-like extension.

Dimensions:

	Length	*Max. Width*
CPC 4154	0.24 mm.	0.14 mm.
CPC 4155	0.17 mm.	0.11 mm.

Occurrence: Figured specimens CPC 4154 and 4155 from a sample about 1 mile from the mouth of the Masaweng River, north of Finschhafen, New Guinea (upper Miocene).

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LIST OF LOCALITIES

Sample locality maps are available for all samples in this list, except those from the Lakekamu River and Popo areas, Papua.

PAPUA

1. Tubu area, Papua.
   Samples from the Tubu Siltstone, forwarded by the Papuan Apinaipi Petroleum Company Limited; sample numbers 676, 677, 678, 687, 774, 776, 779, 884 (all upper Miocene).
2. Yule Island and Delena-Pokama areas; forwarded by Mines Administration Pty Ltd.
   Sample 1830, sea-cliff below L.M.S. Mission, Delena ((lower Miocene). Sample 1836, sea-cliff 250 yards north of L.M.S. Mission, Delena (lower Miocene). Sample 1902, west of wharf at Roman Catholic Mission, Yule Island (lower Miocene).
3. Lakekamu River and Popo areas; forwarded by Mines Administration Pty Ltd.
   Sample 1002, 2½ miles north-north-west of Olipai-Lakekamu junction (upper Miocene). Sample 1031, near culmination of Popo Anticline, 3½ miles south-south-east of Popo village (upper Miocene).
4. Kerema-Karova Creek area; forwarded by Mines Administration Pty Ltd.
   Samples 1413 and 1551, east of Karova Creek (middle Miocene).
   Sample 1330, Aipa Hills area (east of Ekiere fault (middle Miocene)).
5. Malalaua-Saw mountains area, forwarded by Mines Administration Pty Ltd.
   Samples 733, 1632 and 1650, Upper Maipora Creek, west of Saw Mountains (middle Miocene).
   Sample F.4, Hell's Gate Creek about ½ mile from junction with Tauri River (lower Miocene).
   Sample F.23, Poison Creek ½ mile west of Kapu River (middle Miocene).
   Samples F.26, F.29, F.31, F.34, F.35, F.36, section through Murua Mudstone, Yamuiti Creek area (upper Miocene).

NEW GUINEA

1. Samples collected by D. B. Dow, Bureau of Mineral Resources, north of Finschhafen.
   Samples MR.5, MR.6, MR.7, MR.8, MR.10, MR.12, MR14, MR.15, MR.22, MR.23, MR31 (all referred to the upper Miocene).

2. Samples collected by Dr E. Reiner, Division of Land Research and Regional Survey, Commonwealth Scientific and Industrial Research Organisation.
   Sample R.7, road cutting at new residence, north of aerodrome, Madang (Pliocene).
   Sample R.30, from top of ridge south of Kamambu (Old Kamambu) (upper Miocene).
   Sample R.44, in river below Banap II (upper Miocene).
   Sample R.167, Nuru Valley, between Diduella and Old Bauri, on hill with garden plot (upper Miocene).
   Sample R.527, Kolailo Creek, west of Tintingenei, Josefstaal Subdistrict, Bogia District (upper Miocene).
   Sample R.535, east of Moie, Josefstaal Subdistrict, Bogia District (upper Miocene).
   Sample R.550, road cutting south of Moab, Bogia District (upper Miocene).
   Sample R.612, below cliff at Maprik, Screw River, Sepik District (upper Miocene).
   Sample R.636, Numoiken road, south of Wewak, Sepik District (upper Miocene).
   Sample R.647, Nogam River, west of Periama village, Wewak Subdistrict, Sepik District (uppermost Miocene or Pliocene).
   Sample R.657, creek north of Ibab village, Wewak Subdistrict, Sepik District (Pliocene).
   Sample R.668, in valley west of Montsi village, Wewak Subdistrict, Sepik District (upper Miocene).
   Sample R.672, east of Yekimbolje village, Maprik Subdistrict, Sepik District (upper Miocene).
   Sample R.674, west of Yangoru, Maprik Subdistrict, Sepik District (upper Miocene).
   Sample R.676, creek near Wibiti I village, Maprik Subdistrict, Sepik District (Pliocene).
   Sample R.677, Tjidiletebe village, Maprik Subdistrict, Sepik District (upper Miocene).
   Sample R.685, creek west of Winge, Maprik Subdistrict, Sepik District (upper Miocene).
   Sample R.686, north road near Kabeubis village, Maprik Subdistrict, Sepik District (upper Miocene).
   Sample R.715, Forsayth Plantation, Mushu Island, Sepik District (Pliocene).

3. Samples collected by Dr D. W. P. Corbett, Bureau of Mineral Resources.
   Sample A.9, east of Atemble, Lower Ramu-Atitau area (Pliocene).
   Sample B.1, 2 miles east of Josefstaal, Lower Ramu-Atitau area (upper Miocene).
   Sample B.2, Kisila village, east of Josefstaal, Lower Ramu-Atitau area (upper Miocene).
   Sample B.15, Pagansop village, north-north-east of Josefstaal, Lower Ramu-Atitau area (upper Miocene).
   Sample C.37, Tributary of Kaukomba Creek, Lower Ramu-Atitau area (upper Miocene).
   Sample C.60, 1 mile south of Kumil River, Lower Ramu-Atitau area (upper Miocene).
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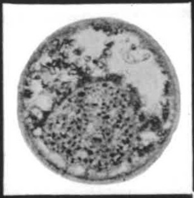

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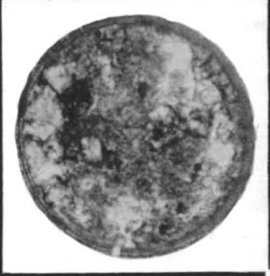

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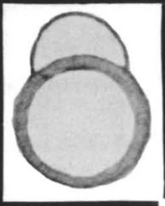

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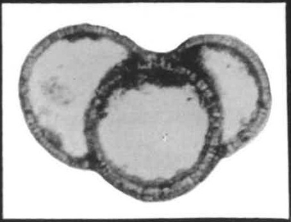

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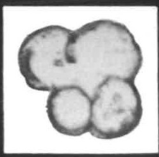

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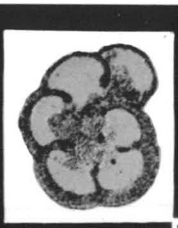
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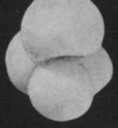
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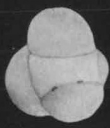
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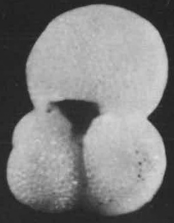
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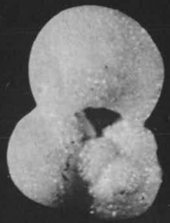
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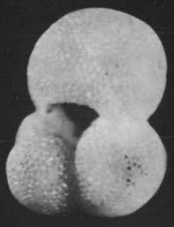
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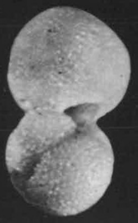
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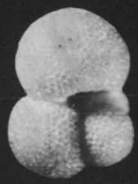
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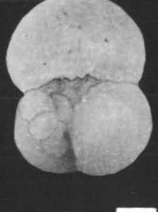
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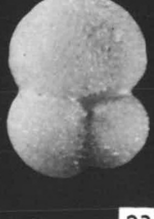
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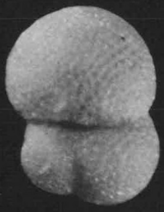
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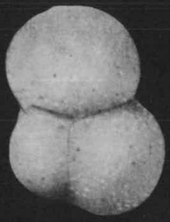
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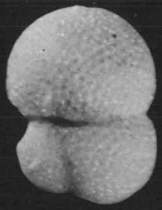
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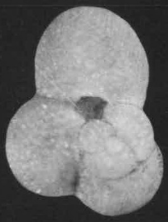
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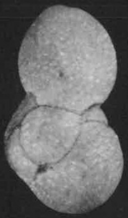
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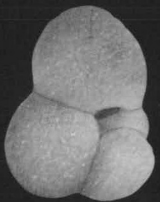
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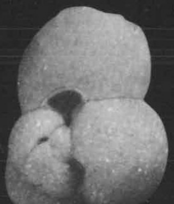
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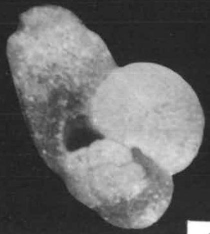
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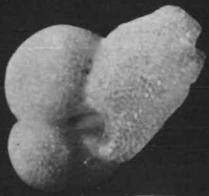
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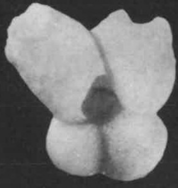
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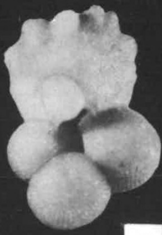
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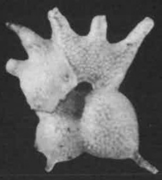
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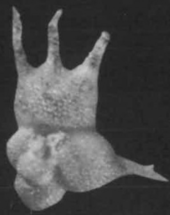
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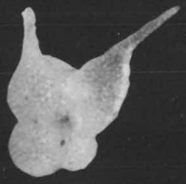
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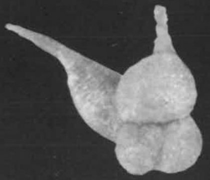
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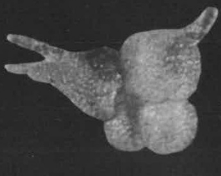
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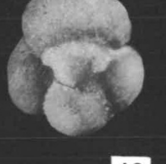
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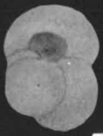
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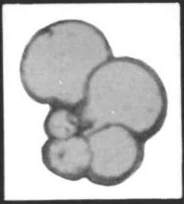
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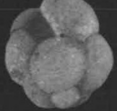
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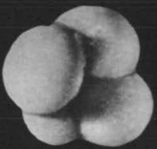
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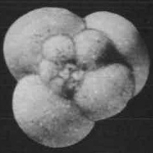
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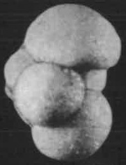
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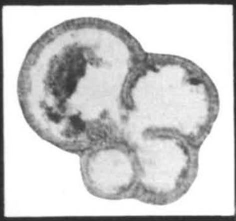
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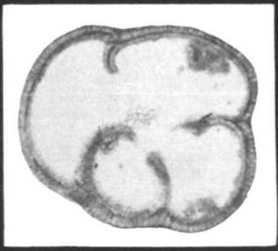
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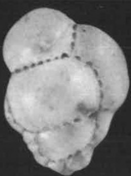
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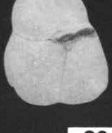
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COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BULLETIN No 62—2

Rhizocorallium in the Lower Cretaceous Rocks of Australia

By J. J. VEEVERS

Issued under the Authority of Senator the Hon. W. H. Spooner,
Minister for National Development
1962

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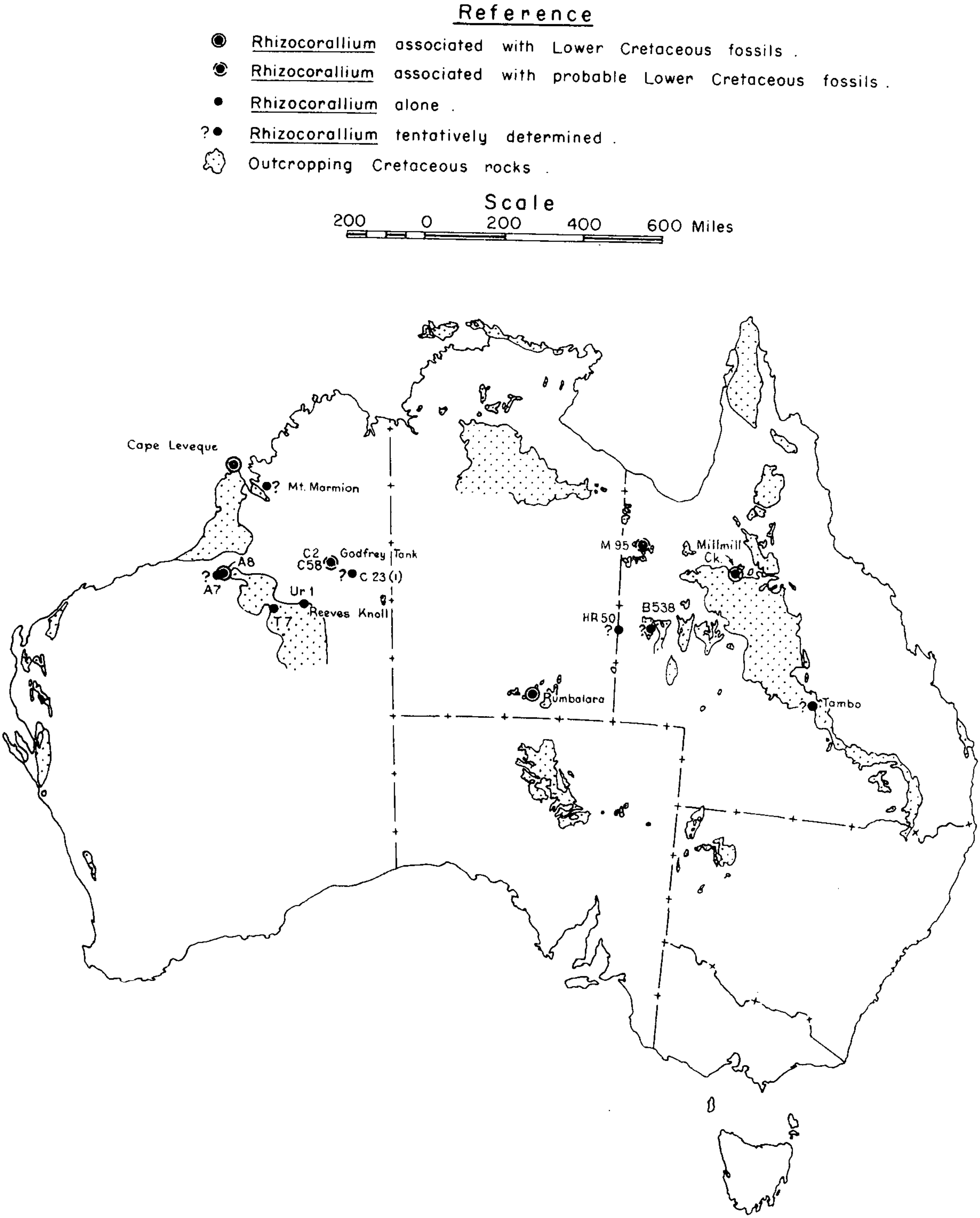
SUMMARY

The animal burrow *Rhizocorallium* is widely distributed throughout the marine rocks of northern Australia. Of the fifteen recorded localities of *Rhizocorallium*, fourteen are in Lower Cretaceous rocks, and one, whose locality and determination are both doubtful, in Permian rocks. The occurrence of *Rhizocorallium*-type fossils in the Permian rocks of the Carnarvon Basin is noted by Teichert, but not documented. *Rhizocorallium* in Australia may therefore be tentatively accepted as a Lower Cretaceous index. Descriptions and illustrations of Australian *Rhizocorallium* are given in the hope that they will help the recognition of this useful fossil, which otherwise might pass unnoticed. *Rhizocorallium* is probably the burrow of a worm-shaped animal that 'ate' the loose sediment or used the burrow as a nest.


Reference
◉ Rhizocorallium associated with Lower Cretaceous fossils.
◉ Rhizocorallium associated with probable Lower Cretaceous fossils.
● Rhizocorallium alone.
?● Rhizocorallium tentatively determined.
Outcropping Cretaceous rocks.
Scale
200 0 200 400 600 Miles
Cape Leveque
Mt. Marmion
C2
C58
Godfrey Tank
C 23 (1)
A8
A7
Ur 1
T7
Reeves Knoll
M 95
Millmill Ck.
B538
HR 50
Rumbalara
Tambo

Distribution of *Rhizocorallium* in Australia

Determination	Field No.	Number of specimens in BMR collections	4-mile map area	Map reference	Co-ordinates	Formation	Lithology of Specimen	Associated fossils	Remarks
?*Rhizocorallium*	A7	1	Anketell (F51/2) W.A.	Traves et al. (1956, geol. map) Anketell 4-mile geol. map.	20°23′S 122°16′E	Anketell Formation	Fine-grained micaceous quartz sandstone & siltstone	——	Not mentioned in Traves et al. (1956)
Rhizocorallium	A8	0	Anketell (F51/2) W.A.	Traves et al. (1956, geol. map) Anketell 4-mile geol. map.	20°23′S 122°20′E	Anketell Formation	Micaceous quartz sandstone & siliceous claystone.	Arenaceous Foraminifera (*see* App. C by I. Crespin in Traves et al., 1956)	Note corrections to Traves et al. (1956): p. 54—for Run 5/5026 read Run 6/5030; for A9, read A8
Rhizocorallium	—	1	Pender (E51/2), W.A.	Brunnschweiler (1957, geol. map)	16°24′S 122°56′E	Leveque Sandstone	Well-bedded quartz sandstone	*Inoceramus* spp. *Ptilophyllum* *Elatocladus* (*Taxites*)	
Rhizocorallium	T7	3	Tabletop (F5/11), W.A.	Traves et al. (1956, geol. map) Tabletop 4-mile geol. map.	22°07′S 124°02′E	Kidson Beds	Quartz sandstone		Illustrated by fig. 18 of Traves et al. (1956)
cf. *Rhizocorallium*	CL58	1	Derby (E51/7) W.A.	Derby 4-mile geol. map.	17°23′S 124°21′E	?Liveringa Formation	Friable cross-bedded quartz sandstone		Exact locality unknown
Rhizocorallium	Ur 1	1	Ural (F51/12) W.A.	—	22°02′S 125°40′E	Kidson Beds	Quartz sandstone	——	
Rhizocorallium	C58	4	Cornish (F52/1), W.A.	Cornish 4-mile geol. map.	20°12′S 126°32′E	Godfrey Beds	Medium-grained quartz sandstone, some siltstone	——	
Rhizocorallium	C2	5	Cornish (F52/1), W.A.	Cornish 4-mile geol. map.	20°15′S 126°35′E	Godfrey Beds	Medium-grained quartz sandstone, some siltstone	Pelecypods, determined by J. M. Dickins as *Etea* (?) sp.	
?*Rhizocorallium*	C23(2)	1	Cornish (F52/1), W.A.	Cornish 4-mile geol. map.	20°32′S 127°23′E	Godfrey Beds	Medium-grained quartz sandstone, some siltstone	——	——
Rhizocorallium	—	5	Charlotte Waters (G53/6) N.T.	Sullivan & Öpik. (1951, pl. 1)	25°14′S 134°45′E	Rumbalara Shale (Bed D)	White kaolinitic rock with hard bands of porcellanite; thin interbed of soft white sandstone contains *Rhizocorallium*	Radiolaria Sponges Pelecypods Crinoid stem-joints Indeterminate gastropods Silicified wood	Illustrated by pl. 6, fig. 1 of Sullivan and Öpik (1951).
?*Rhizocorallium*	near HR50	—	Tobermory (F53/12) N.T.	—	22°44′S 137°58′E	Unnamed	Sandstone	Wood (indeterminate)	Locality: Toko Range, 8 miles SSW of Mithaka Waterhole
Rhizocorallium	M95	1	Camooweal (E54/13), Q'land	—	19°15′S 138°51′E	Unnamed	Quartz sandstone, some beds silty; some silicified siltstone.	Overlain with an erosional contact by beds containing pelecypods (*Unio*) and plants of Cretaceous aspect; underlain by plants.	Locality: 2 miles NW of Seymour River crossing of Thornton-Riversleigh road.
?*Rhizocorallium*	B538	—	Glenormiston (F54/9) Queensland	—	22°35′S 139°28′E	Unnamed	Sandstone, some interbedded siltstone	——	Locality: 34 miles NW of Boulia
Rhizocorallium	—	—	Gilberton (E54/16) Queensland	—	20°00′S 142°50′E	——	——	Roma Stage fossils	Locality: Millmill Creek, 22 miles east of west edge of Gilberton 4-mile Sheet area.
?*Rhizocorallium*	—	—	Tambo (G55/2) Queensland	—	25°00′S 146°00′E	Tambo Formation	Shale	——	——

DISTRIBUTION

Rhizocorallium was first recorded in Australia by A. A. Öpik (in Sullivan & Öpik, 1951). In the Rumbalara area of the Northern Territory (fig. 1), 140 feet of cross-bedded sandstone (De Souza Sandstone) are disconformably overlain by the Rumbalara Shale, 130 feet of kaolinitic rock which includes two thin beds of sandstone. The sequence is capped by 10 feet of grey billy. An ochre deposit occurs at the base of the Rumbalara Shale. *Rhizocorallium* occurs in the lower sandstone bed ('Bed D') of the Rumbalara Shale, and is associated with the sponge *Purisiphonia.* The overlying and underlying kaolinitic beds contain an abundant fauna of pelecypods, indeterminate gastropods, and crinoid stem-joints. The pelecypods are similar to those described by Etheridge (1892) and Whitehouse (1925) from the Rolling Downs of Queensland (Roma Stage), and indicate Lower Cretaceous. Öpik's determinations (Sullivan & Öpik, 1951, p. 24) are:

Lower Cretaceous
Bed D (Sponge horizon)
    Purisiphonia clarkei Bowerbank
    Purisiphonia n. sp.
    Rhizocorallium n. sp.
Bed E (Upper kaolinic rock)
    Cyrene sp.
    Fissilunula cf. *clarkei* (Moore)
    Maccoyella reflecta (Moore)
    Panope cf. *rugosa* (Moore)
    Pecten (*Camptonectes*) sp.
    Pseudavicula anomala (Moore)
    Tatella maranoana Etheridge
    Tatella cf. *maranoana* Etheridge
    Large indeterminate lamellibranchs
    Indeterminate gastropods
    Pentacrinite stem-joints
Horizon unknown
    Silicified wood

In Appendix 1 of the same bulletin, Crespin recorded from Bed E the Radiolaria *Cenosphaera* and *Dictyomitra.*

Rhizocorallium is recorded by Traves, Casey, & Wells (1956) from the Anketell Sandstone* in the south-western part of the Canning Basin. At the type section of the Anketell Sandstone (T7), *Rhizocorallium* (op. cit., fig. 18) occurs in a two-foot-thick sandstone bed in the middle part of the 40-foot section. 170 miles

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* The Anketell Sandstone is amended in Veevers & Wells (1961) to Anketell Formation, and the section at T7, which, though nominated by Traves et al. as type section, is not at the type locality, is placed by Veevers & Wells in the Kidson Beds. A8, however, remains in the Anketell Formation.

north-west, at A8, *Rhizocorallium* is associated with Lower Cretaceous arenaceous foraminifera (determined by Crespin *in* Traves et al., Appendix C., p. 54-55) in a 30-foot-thick section of fine white micaceous sandstone capped by siliceous mottled claystone.

Crespin's determinations are as follows:

'*Ammobaculites fisheri* Crespin(r)
Ammobaculites minuta Crespin(f)
Ammobaculites romaensis Crespin(f)
Reophax sp. (f)
Spiroplectammina cushmani Crespin(c)
Spiroplectammina edgelli Crespin(c)
Trochammina cf. *minuta* Crespin(f)
cf. *Trochammina*'

A doubtful specimen of *Rhizocorallium* has been subsequently found in the collection of rocks from the Anketell Formation at A7, 5 miles west of A8.

In 1955, J. N. Casey, R. M. Elliott, and A. T. Wells (pers. comm.) collected *Rhizocorallium* and pelecypods from the Godfrey Beds, in the north-eastern part of the Canning Basin. J. M. Dickins (pers. comm.) has determined the pelecypods as *Etea(?)* sp. *Etea* occurs in the Lower Cretaceous rocks of North America.

In 1957 I collected a specimen of *Rhizocorallium* from the Kidson Beds 20 miles south of Lake Tobin, and 100 miles east of T7.

Rhizocorallium was collected from the Camooweal area of north-western Queensland by A. A. Öpik, J. N. Casey, and M. A. Randal (pers. comm.) in 1953. The 100-foot section at M95 consists of a plant-bearing sandstone succeeded by a *Rhizocorallium*-bearing sandstone and siltstone, disconformably overlain by sandstone containing the pelecypod '*Unio*', and plants of Jurassic-Cretaceous aspect. The marine *Rhizocorallium*-bearing sandstone, sandwiched between the two plant-bearing sandstones, is probably equivalent to the widespread unnamed Lower Cretaceous shale of the Camooweal region.

250 miles farther south, in the Georgina River area, ?*Rhizocorallium* has been identified in the field by J. N. Casey at two localities in a sandstone formation which is probably Cretaceous.

Recently J. J. Veevers and A. T. Wells found two unrecorded specimens of *Rhizocorallium* from the Canning Basin in the museum of the Bureau of Mineral Resources. The first of these comes from the Leveque Sandstone (Brunnschweiler, 1957) of Dampier Land, Western Australia. It was slightly damaged in the Bureau fire of 1953, but is nevertheless determinable. The Leveque Sandstone is known only from the type locality. Brunnschweiler (1957, p. 9) lists two indeterminate species of *Inoceramus*, and the plants *Ptilophyllum* and *Elatocladus*

(*Taxites*), but does not mention *Rhizocorallium.* The Leveque Sandstone is part of the Dampier Group, which is Lower Cretaceous. *Rhizocorallium* (under the name *Myelophycus*) is also associated with *Inoceramus* in the Jurassic Yakutat Formation of Alaska (Ulrich, 1910, pl. 13).

According to its label, the second specimen comes from '?Liveringa (Formation), Mt Marmion', 24 miles east of Derby; it was collected by D. J. Guppy and A. W. Lindner in 1948. The Permian Noonkanbah and Liveringa Formations are exposed at Mount Marmion, and, if the label has not been mixed (the specimen itself is not marked), the specimen is Permian. It differs from the known specimens of Cretaceous *Rhizocorallium*, and is identified as cf. *Rhizocorallium.* If this specimen does indeed occur in the Permian rocks of the Canning Basin, it must be extremely rare, for these rocks have been examined far more closely than the Cretaceous rocks of the basin, which are known to contain *Rhizocorallium* at seven localities.

Dr C. Teichert (in a letter dated 9.6.59) advises me that U-shaped burrows lying horizontally in the bedding-plane occur in the Permian rocks of the Carnarvon Basin, Western Australia (*See* also Teichert, 1946, p. 75; 1951, p. 79).

M. A. Reynolds (in a letter dated 17.6.59) recently reported the possible occurrence of *Rhizocorallium* from the Albian Tambo Formation 'at a tank, 4 miles from Jynoomah Station homestead by road towards the main Tambo-Minnie Downs road' (Queensland). More recently (17.9.59) Reynolds reported the occurrence of *Rhizocorallium* with Roma Stage fossils at Millmill Creek, Queensland.

AGE OF *RHIZOCORALLIUM* IN AUSTRALIA

In Australia, *Rhizocorallium* has been determined from nine localities, and tentatively from six others. In the Rumbalara area, in the Anketell area (A8), and, according to Reynolds, in the Millmill Creek area, *Rhizocorallium* is associated with Lower Cretaceous fossils; in the Godfrey Tank area (C2) it is associated with a probable Lower Cretaceous pelecypod; in the Camooweal area (M95), it occurs in a bed between Jurassic-Cretaceous plant-bearing sandstones, which are probably equivalent to an unnamed Lower Cretaceous formation in this area; and at Cape Leveque, *Rhizocorallium* occurs within the Lower Cretaceous Dampier Group. At the other localities *Rhizocorallium* occurs alone and no direct evidence of age is available; but stratigraphical mapping of the rocks at these localities, except Mount Marmion, indicates that they are Lower Cretaceous. cf. *Rhizocorallium* probably occurs in Permian rocks at Mount Marmion.

The available evidence indicates that in Australia *Rhizocorallium* is widely and abundantly distributed in Lower Cretaceous rocks, and so may be used, though with caution, as a Lower Cretaceous index. Caution is necessary because *Rhizocorallium* has been recorded outside Australia from Cambrian to Tertiary rocks, and, within Australia, may occur also in Permian rocks.

NOMENCLATURE

This is not the place for a review of the literature on *Rhizocorallium*. Most of the literature appears in German periodicals, and few of these are available in Australia. The nomenclature advocated by Westergaard (1931, p. 8-9) is accepted:

> 'As regards the nomenclature a real confusion as yet prevails which at least in part is due to many of the forms in question being still unsatisfactorily known. Recently Professor Kraus (1930) proposed that all forms of U-shaped burrows of "U-in-U"-structure should be brought together under one "generic" name, viz. *Rhizocorallium* Zenker, 1836, which is clearly defined and is probably the oldest of these which may be considered. Certainly it is wise not to make a too close discrimination as regards these burrows, the true systematic position of whose inhabitants we shall never know, as recent burrows of the same appearance in some cases are made by quite different animals. However, so far as I can see, there are fairly essential differences between *Diplocraterion* and *Rhizocorallium* s.s. The latter is oblique or parallel to the bedding-plane, the median line is curved and the connecting arches between the limbs of the U regular and parallel, whereas *Diplocraterion* is normal to the bedding-plane, the median line straight and the connecting arches as a rule irregular. Therefore I think it justified to retain *Diplocraterion* for a group of Rhizocorallid burrows showing these distinctions.'

DESCRIPTION

All the specimens dealt with here except the Mount Marmion specimen belong to *Rhizocorallium* as defined by Westergaard: the track is a U-tube; it is oblique or parallel to the bedding-plane; the median line is curved; and the connecting arches between the sides of the U are regular and parallel.

Specimens from the Godfrey Tank area (Plate 1, figs. 1-8; Plate 2, figs. 3, 6)

These specimens, the best-preserved in the collection, occur in a friable quartz sandstone. Two tracks intersect on CPC 286[1] (Pl. 1, figs. 1-7). Track A, of which 10 cm. have been preserved, is straight, and inclined at 45° to the bedding-plane; the tube is 11 mm. across, and both limbs of the tube cast are covered with longitudinal scratch marks. Its left limb[2] passes through the left limb of track B. 14 cm of track B are preserved; it is gently curved along its length, is inclined at 20° to the bedding-plane, and the tube is 9 mm across. An interpretation of these intersecting tracks is given below. They are associated with 'normal' *Rhizocorallium* that lies on the bedding-plane, and, apart from their steep inclination, tracks A and B correspond with the others.

[1] Commonwealth Palaeontological Collection, kept by the Bureau of Mineral Resources, Canberra.

[2] As shown below, the track advances in the direction of the convex side of the U; looked down on from above in the direction of advance, the U may be divided into left and right limbs.

U-bends are shown in Plate 1, figure 8, and Plate 2, figure 6. The regular, parallel U-in-U structure is particularly well shown by the two complete tracks seen in Plate 1, figure 8. A feature of special importance in the interpretation of these tracks (*see* below) is the plug of undisturbed sediment occupying the space between the limbs of the U at the opposite end to the U-bend. Only two tube casts are preserved in the specimen collected 65 miles east-south-east of Godfrey Tank, but they are sufficient to indicate *Rhizocorallium*.

Specimens from other localities

Specimens from T7 were collected from a duricrust surface on coarse sandstone. In CPC 291 (Pl. 2, fig. 4), the tube cast stands out in relief, probably indicating that the sediment of the cast is more strongly bonded than that of the connecting arches and surrounding sediment. This condition is also found in specimens from the Godfrey Tank area, from which the tube casts are readily detached in the form of long pencil-like rods. The tube casts of the other specimens collected from T7 (Pl. 2, figs. 5 and 7) stand out in relief above the connecting arches and the surrounding sediment. CPC 292 (Pl. 2, fig. 5) is exceptional in that the limbs diverge in the direction of the animal's advance. The specimen illustrated in Traves et al. (1956, fig. 18) comes from T7; it is 48 cm. (18½ in.) long, and is sinuous.

In CPC 290 (Pl. 2, fig. 2), the tube cast has not been removed by erosion as a unit (as it has in CPC 288, Pl. 2, fig. 6), but has been irregularly eroded so that the connecting arches are surrounded by a wide groove in which parts of the tube cast are still preserved. This specimen is exceptional in that its tube cast is softer than the surrounding rock.

The specimens from the Rumbalara area (Pl. 3, fig. 3-6) are preserved in white argillaceous quartz sandstone. Öpik (Sullivan & Öpik, 1951, p. 13) reports specimens more than two feet (60 cm.) long, and 5 inches (13 cm.) wide. Only one of the collected specimens (Pl. 3, fig. 4) has a well-defined tube cast. Connecting arches are prominent, and closely spaced, and in CPC 299 (Pl. 3, fig. 6) the main track penetrates an earlier-formed one.

At first sight, CPC 299 (Pl. 3, fig. 6) and CPC 286 (Pl. 1, fig. 1-7) appear to be unrelated, but associated fossils from Rumbalara (Pl. 3, fig. 4) and the Godfrey Tank area (Pl. 2, fig. 3) indicate that all these specimens are the same form.

CPC 295 (Pl. 3, fig. 2), from the Camooweal area, is preserved in silicified sandstone; it has a narrow tube cast, and well-developed connecting arches.

The Cape Leveque specimen (Pl. 2, fig. 1) most closely resembles the Rumbalara specimens. Its connecting arches are narrow, and the limbs are poorly defined.

Two probably unrelated tracks are preserved in the Mount Marmion specimen (Pl. 3, fig. 1), which is a duricrusted cross-bedded sandstone. The large track, identified as cf. *Rhizocorallium*, lacks any trace of limbs, and the 'connecting arches', unlike those of Cretaceous *Rhizocorallium*, stand out in strong relief. The form of the 'connecting arches' is possibly related to weathering, but the lack of limbs distinguishes this form from known Australian Cretaceous *Rhizocorallium*, and probably all other *Rhizocorallium*. The small track (seen in the top left-hand part of Pl. 3, fig. 1) cuts across part of the cf. *Rhizocorallium*. It is gently curved, and consists of a double row of bead-like mounds separated by a groove. Its origin is unknown.

INTERPRETATIONS

None of the following ideas appears in the few related papers I have seen, but this does not rule out the possibility of prior statement.

The basic interpretation is that the animal advances through the sediment by making a succession of U-shaped tubes that overlap to form a compound U-in-U structure. The interpretation of the main U-tube as a simple tube is dismissed because it does not account for the connecting arches. Three interpretations are proposed for the method of development of the burrow.

The first interpretation (Text-fig. 2) is as follows: the burrowing animal makes a simple U-shaped tube in the soft sediment, and lines it with mucus; the length of the tube equals that of the animal. The animal next transfers sediment with its appendages (indicated by the scratch marks in CPC 286) from the outer to the inner side of the U-bend, thus destroying the lining on the outer part of the tube, and reinforcing the inner side. The upper surface of the preserved half of the connecting tube will be inclined towards the inner part of the U-tube, i.e., in the opposite direction from that of the advancing movement; this direction of dip is observed in all well-preserved specimens. The repetition of this process leads to the formation of a long U-tube with the limbs connected by arches, each of which represents the inner wall of successive U-bends. The space between the limbs of the first-formed U is filled with undisturbed sediment, seen in the two specimens in Plate 1, figure 8. According to this interpretation, the animal does not pass the excavated sediment through its alimentary canal, but simply makes space for its tube by compressing sediment into the connecting arches. The U-tube is consequently left open when the animal leaves the tube or dies, and the tube is later filled with normally deposited sediment. The animal is not a mud-eater; it builds the tube as a protective nest. Food could have been provided by plankton carried into the tube by currents generated by movement of the appendages. This interpretation fails to explain one important fact: the strongly bonded sediment in the tube cast. One would rather expect to find specimens in which the original U-tube is empty, or only partly filled with sediment.

This objection is overcome in the following interpretation, suggested by M. A. Conden: the animal starts by excavating a simple U-tube; it does this by eating the sediment, which it defecates after removing the food; after reaching position 1 (Text-fig. 2), it burrows to the surface, and, after a while, returns along the first-formed limb to position 2. It emerges again at the surface and repeats the process until after reaching position 3, it leaves the burrow. In this way, the

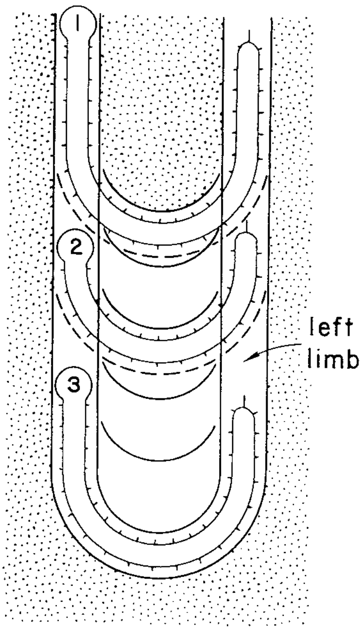

Figure 2
First and second interpretations

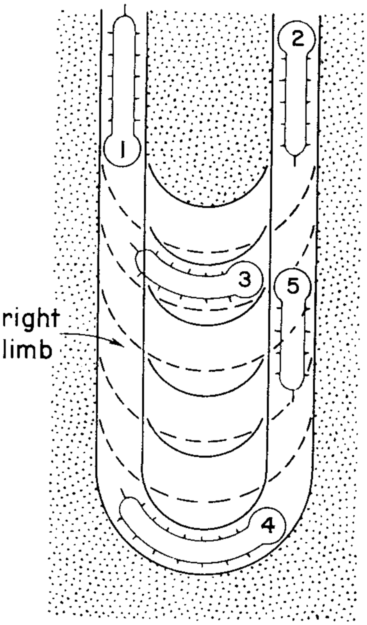

Figure 3
Third interpretation

Notes:

1. The shape of the animal is unknown. The head is indicated diagrammatically by part of a circle, the tail by a stroke. Appendages, indicated by scratch-marks on the tube casts, are indicated by short lines.
2. The numbers indicate progressive positions occupied by the animal.
3. The inner wall of the connecting-arch part of the tube is indicated by the connecting arch; the outer wall, which is destroyed to make way for the next tube, is indicated by broken lines.
4. For clarity, only a few connecting arches are shown.

'shavings' and defecated 'exhaust' are bonded together several times by mucus, and this bonded material forms a firm cast in the vacated tube. Moreover, the vacated tube, its cast, and the striations along the cast are continuous along their length, whereas according to the first interpretation, the tube would probably be constricted at many points, and the scratch-marks short. After each cycle, the animal burrows through the well-bonded cast in the tube. This could explain the shortness of most tubes because, after many cycles, the tube will be too firmly plugged to allow further entry. Against this interpretation stands the fact that the animal must push aside or eat all the tube cast formed in earlier cycles before it reaches fresh sediment. We can only speculate about the behaviour of the burrowing animal; but the well-bonded tube-casts composed of sediment identical in composition with that of the walls of the tube are observable, and this interpretation explains these observations.

A third interpretation (Text-fig. 3) fails to explain the continuous scratch-marks along the tube, but does not require the animal repeatedly to penetrate its own tube cast. The third interpretation is as follows: the animal starts by excavating a simple U-tube; it then reverses its motion to re-occupy position 1, and advances to position 3, destroying the outer lining of its first tube in the process. This is repeated until the last U-bend is made (position 4). By this time, the right limb is plugged with sediment that is bonded with mucus from its passage through the animal's alimentary canal. The tubes of the connecting arches will not be so tightly packed with sediment, except along the inner part of the U-tube where faecal sediment is compacted during the animal's reverse motion. At the top surface, the half tube will dip towards the open part of the U. One limb of the tube (in Fig. 3, the left one) will be empty except for 'shavings' left over from excavations in the connecting tubes, and some faecal sediment, which, however, would not be sufficient to fill the tube. The main bulk of the faecal sediment remains in the limb along which the animal enters (in Text-fig. 3, on the right side), and the other limb will be deficient in well-bonded sediment. No specimen shows one limb well cast with sediment and the other only partly filled; this, and the awkward forward-and-reverse motion required of the animal, are the shortcomings of this interpretation. The fact that the tube cast is composed of material identical with that of the enclosing sediment supports the idea that the cast is an 'exhaust', transported only a few centimetres, and not, as the first interpretation requires, a separately deposited sediment.

The scratch-marks on the right limb of Track A (Pl. 1, figs. 1, 3-7) are well preserved; they are long, and coil gently from left to right in the direction of advance. Marks on other tracks are poorly preserved and it is impossible to determine if this sense of coiling is general.

The animal possibly made grooved tracks on the sea-floor, but these would normally not be preserved; and the only tracks likely to be preserved are those formed at some depth beneath the floor, possibly when conditions on the floor were unsuitable. The animal drove inclined tubes, probably in one of the three ways outlined above, into the sediment until it reached a suitable bed, in which it made its main tube. According to the first interpretation, this would be when optimum conditions prevailed for generating a food-bearing current. According to the second and third interpretations, the animal burrowed downwards until it reached a bed rich in food, which it then exploited. Specimen CPC 286 shows a tube inclined at 45° that penetrated another track (Pl. 1, figs. 1-7). Track A penetrates B, and, from the convexity of the connecting arches, it is seen that both tracks were descending.

All but two tracks curve gently and uniformly to the right. The two exceptions are the specimen at T7 (Traves et al., 1956, fig. 18), which is sinuous, and CPC 286, Track B (Pl. 1, figs. 1-7). The photograph for the specimen at T7 is not sufficiently clear to show if there is an obvious cause for the change in curvature. The rock, however, is crowded with other tracks, and one of these might have caused the main track to curve to the left for a short distance.

The left limb of Track B of CPC 286 is penetrated by the left limb of Track A. Just above where it penetrates B, A has a prominent connecting arch, best seen in Plate 1, figure 4, indicating the position of a tube occupied by the animal for a longer time than usual. The abnormal left curvature of B was possibly caused by the animal trying to avoid crossing Track A. The recommencement of growth of A caused it to penetrate B, and to curve sharply to the right over the zone of penetration.

The reason for the normal curvature of the track to the right is not understood. According to the first interpretation, the head is always on one side of the tube, the tail on the other. In Text-figure 2, if the animal always burrowed the first tube from left to right, and if the posterior appendages burrowed slightly faster than the anterior ones, a right-curved tube would result. Alternatively, the same curvature would result from the right to left burrowing of the initial tube, and a faster anterior than posterior burrowing.

NOTE ON PALAEOECOLOGY

A glance at the Table shows that all the specimens (except the tentatively determined one from the shale of the Tambo Formation) are preserved in sandstone. Most of the localities contain beds of finer-grained rock, in particular a siliceous claystone, yet *Rhizocorallium* has not yet been found in these rocks. Future collectors of *Rhizocorallium* might be advised to search these rocks diligently with the aim of finding out if *Rhizocorallium* is indeed restricted to sandy beds, or if it occurs, though poorly preserved, in finer-grained rocks.

ACKNOWLEDGMENTS

I wish to thank Dr A. A. Öpik for unfailing help and advice in the preparation of the manuscript. I am grateful to Dr C. Teichert of Denver, U.S.A., for helpful correspondence. The photographs, except Plate 1, fig. 8, taken in the field by Mr A. T. Wells, are the work of Mr C. Zawartko.

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MAPS

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Derby 4-mile Geological Sheet, Western Australia. *Ibid.* 1958.
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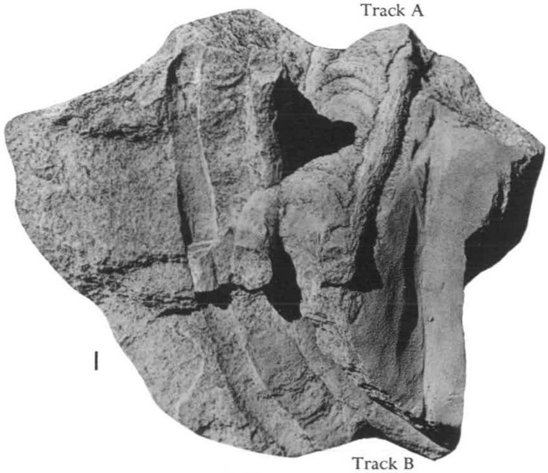
EXPLANATION OF PLATE 1

Figs. 1-7. *Rhizocorallium* Zenker, CPC 286, 1, view from above x 1/3; 2, 5, 7, lateral views x 1/3; 4, 6, lateral views x 2/3; 3, lateral view x ½. Note the scratch marks on track A, the even curvature to the left of track B, and the prominent connecting arch of track A at the point of intersection of the tracks. Godfrey Beds, Godfrey Tank area, Western Australia.

Fig. 8 Field photograph from above (x 1/3) of outcropping Godfrey Beds, Godfrey Tank area. Note undisturbed plug of sediment separating limbs of first third of track.



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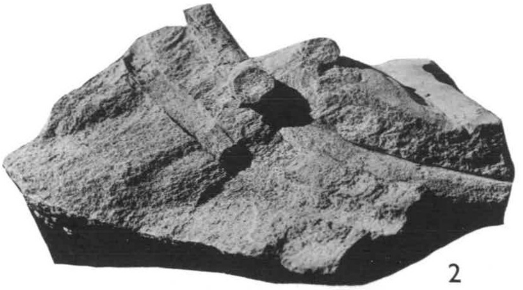

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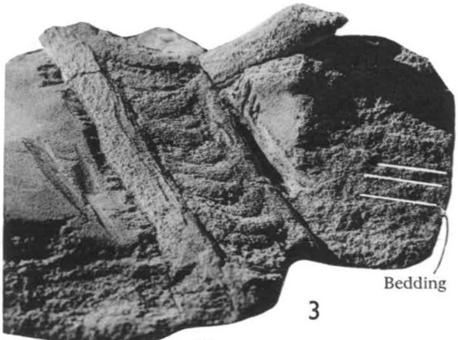

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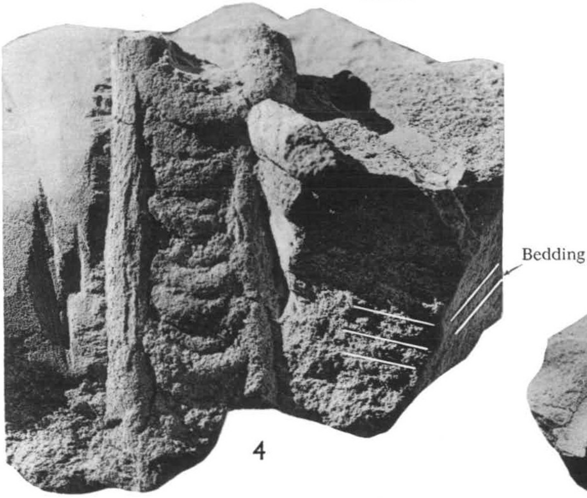

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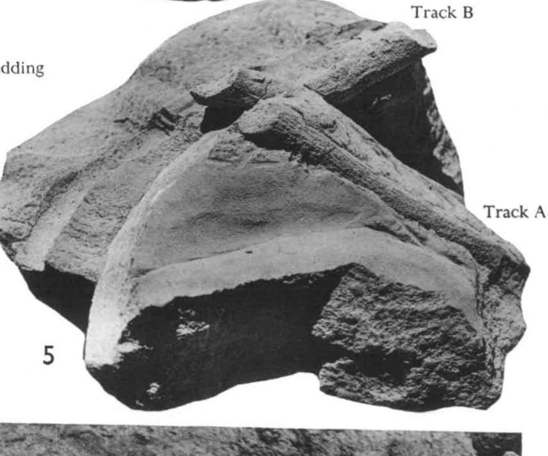

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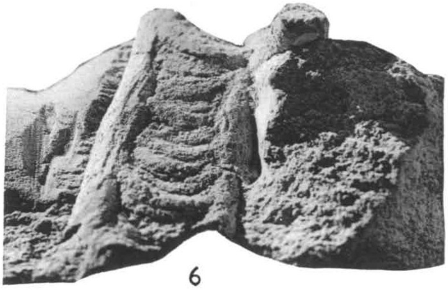

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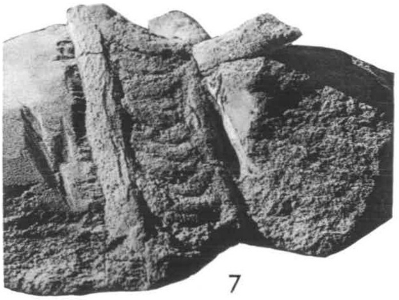

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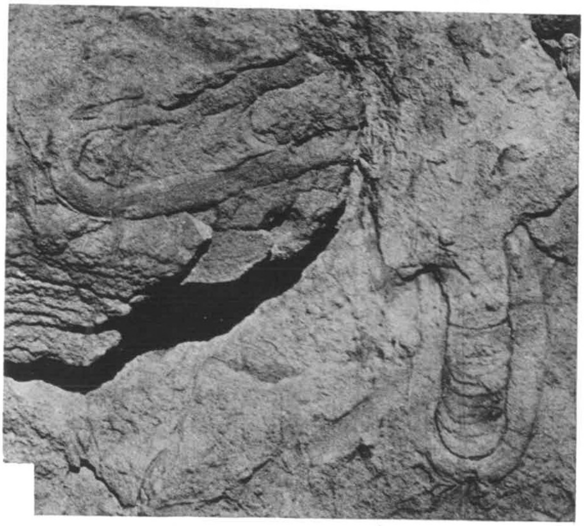

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EXPLANATION OF PLATE 2

Fig. 1. CPC 289 (x 2/5) from Cape Leveque, Western Australia. Note narrow connecting arches, and poorly defined limbs.

Fig. 2. CPC 290 (x 2/5) from Reeves Knoll, Western Australia. Note partly excavated tube cast.

Fig. 3. CPC 287 (x ½) from Godfrey Tank area, Western Australia. Note right-curvature, and partly excavated tube cast.

Fig. 4. CPC 291 (x ½) from the Kidson Beds, Tabletop area, Western Australia. The tube cast stands out in relief above the surrounding sediment.

Fig. 5. CPC 292 (x ½) from the Kidson Beds, Tabletop area, Western Australia. The limbs diverge in the direction of the animal's advance.

Fig. 6. CPC 288 (x ½) from Godfrey Tank area, an impression of a U-bend cast.

Fig. 7. CPC 293 (x 2/3) from the Kidson Beds, Tabletop area, Western Australia. The tube cast stands out in relief.

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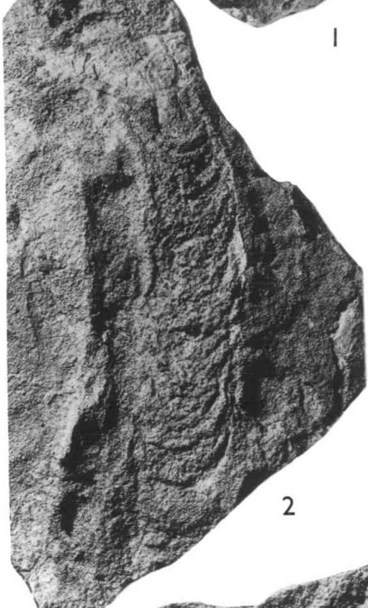

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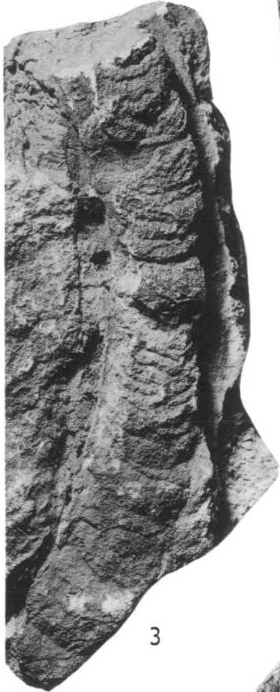

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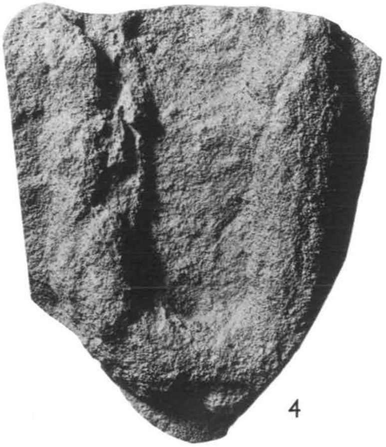

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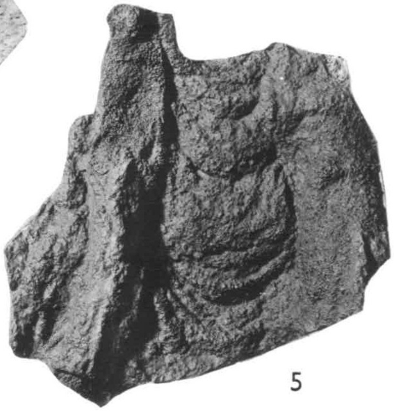

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EXPLANATION OF PLATE 3

Fig. 1. cf. *Rhizocorallium*. CPC 294 (x ½) from the Permian of Mount Marmion, Western Australia. A second track of unknown origin crosses part of the main track in the top left-hand part of the photograph. Note high connecting arches, and lack of limbs.

Fig. 2. CPC 295 (x ½) from the Camooweal area, Queensland. Note the right-curvature.

Fig. 3. CPC 296 (x ½), from the Rumbalara area, Northern Territory. Note wide track, narrow connecting arches, and poorly defined limbs.

Fig. 4. CPC 297 (x 1/3) from the Rumbalara area, Northern Territory. Note the right-curvature.

Fig. 5. CPC 298 (x 1/3) from the Rumbalara area, Northern Territory. Note narrow connecting arches, and poorly defined limbs.

Fig. 6. CPC 299 (x 1/3) from the Rumbalara area, Northern Territory. Note part of second *Rhizocorallium* track on left-hand side of photograph.

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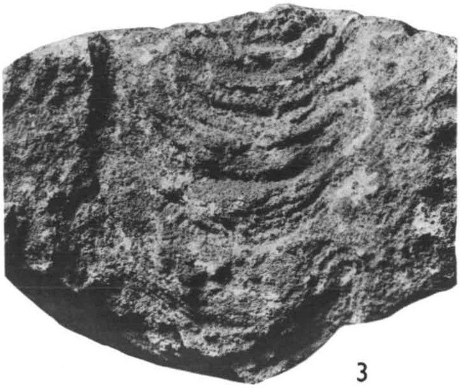

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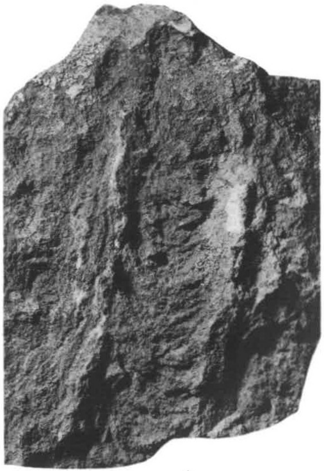

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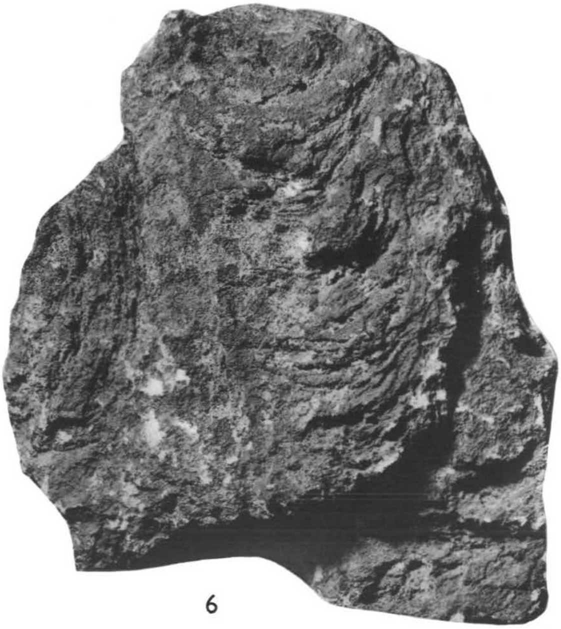

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COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BULLETIN No. 62—3

The Ostracod Genus Cryptophyllus in the Upper Devonian and Carboniferous of Western Australia

By P. J. JONES

Issued under the Authority of Senator the Hon. W. H. Spooner,
Minister for National Development
1962

CONTENTS*

FIGURES

* Manuscript submitted 28th February, 1961.

SUMMARY

Cryptophyllus has a wide geographical distribution throughout the Upper Devonian and Carboniferous rocks of Western Australia, and occurs in the Carnarvon, the Canning, and the Bonaparte Gulf Basins. Two new species, *C. diatropus* and *C. platyogmus,* are described, together with two species, *C.* sp. *a* and *C.* sp. *b,* both probably new, but left with open nomenclature, until more specimens are available for adequate descriptions. Specimens tentatively referred to *C. diatropus* are also described.

The upper limit of the time range of the genus is defined by *Cryptophyllus* sp. *b*. from the Upper Carboniferous (Westphalian) of the Canning Basin.

A detailed investigation of the morphology of the carapace has revealed for the first time the presence of a sub-central adductor muscle-scar, a very finely denticulate hinge-line, and two shell-layers.

The retention of instars within the single individual demonstrates the change in outline throughout its ontogeny, which assists in the orientation. *Cryptophyllus* is shown to have characteristics common to both the Leperditiidae and the Leperditellidae. It is suggested that the genus may be intermediate between the two families.

INTRODUCTION

The genus *Cryptophyllus* was proposed by Levinson (1951, p. 558), who selected as type-species *Eridoconcha oboloides* Ulrich & Bassler 1923, and interpreted the multiple shell layers of both *Cryptophyllus* and *Eridoconcha* 'as being due to incomplete shedding of molts accompanied by later cementation' (p. 555). As an excellent historical review of previous work on *Cryptophyllus* and the related genus *Eridoconcha* has recently been provided by Rome & Goreux (1960, p. 186-8)[1], the stratigraphical distribution of the North American and European species will be discussed only briefly here.

During the past five years, four species of *Cryptophyllus* have been found in numerous surface and subsurface samples of the Upper Devonian and Carboniferous rocks of Western Australia, by West Australian Petroleum Proprietary Limited, Westralian Oil Limited, Associated Freney Oil Fields N.L., and geologists of the Bureau of Mineral Resources.

The Lower Carboniferous specimens are well preserved, occurring in silty beds in great abundance; they consist mainly of dissociated calcareous valves, which can easily be picked from washings. On the other hand most of the Upper Carboniferous specimens so far found are exfoliated, preserved in a black argillaceous limestone; and the Upper Devonian specimens are either poorly preserved in an impure silty limestone, or well preserved in a hard limestone: in both cases the specimens are difficult to extract from the matrix. Rome & Goreux (1960, p. 186) reported difficulties in extracting specimens of *Cryptophyllus* from hard limestones in the Zone d'Etroeungt of the Belgium Lower Carboniferous.

I gratefully acknowledge: the kindness of Dr. S. A. Levinson of the Humble Oil and Refining Company, Houston, Texas, for his confirmation of the generic assignment of *Cryptophyllus diatropus* sp. nov.; the generous advice of Dr. D. R. Rome of the University of Louvain, on his methods of separating species of the genus; and the co-operation of Dr. J. A. Peterson of the Shell Oil Company, Farmington, New Mexico, who kindly confirmed my doubts concerning the authenticity of the age of *Eridoconcha monopleura*.

All type specimens, figured specimens, and thin sections are deposited in the Commonwealth Palaeontological Collection, Canberra, Australia, and are designated by the prefix CPC.

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[1] While this paper was in press, Adamczak (1961) published the results of his detailed study of multiple-layered ostracod carapaces (se addendum to this paper, p. 36).

TIME-RANGE OF *CRYPTOPHYLLUS*

North America

In North America, *Cryptophyllus* is well represented in the Ordovician. Harris (1931) described *Eridoconcha magnus* and *E. simpsoni* (included by Levinson, 1951, in the genus *Cryptophyllus*) from the Middle Ordovician Simpson Group (Chazyan to Blackriveran) of Oklahoma; he later (1957) described two more species, *C. gibbosum* and *C. nuculopsis,* from the Simpson Group. The type species, *C. oboloides* (Ulrich & Bassler), occurs in the late Middle Ordovician Decorah Shale of Minnesota, and *C. sulcatus* Levinson 1951 occurs in the late Upper Ordovician (upper Richmondian age) of Indiana and Ohio.

Only one species represents the genus *Cryptophyllus* in the Silurian, *C. concentricus* (Coryell & Williamson) of the middle Niagaran of Indiana.

Devonian representatives of *Cryptophyllus* in North America include *C. arsinius* Stover 1956, and possibly *Rhabdostichus pulex* (Clarke) 1882, both from the Middle Devonian Hamilton Group of Western New York. Raymond (1946, p. 276, pl. 5, fig. 4), in his study on fossil Conchostraca, erected the genus *Rhabdostichus* and chose as type species *Estheria pulex* Clarke 1882, but added 'one cannot be sure that it is really a conchostracan branchiopod'. His figure and descriptions were based on those of Hall & Clarke (1888, p. 206, pl. 35, fig. 10, 11); Rome & Goreux (1960, p. 191) suggest that they are those of a *Cryptophyllus* and not a conchostracan. Similar forms from the Upper Devonian of the Williston Basin have been described by Wilson (1956, p. 960, text-fig. 3) as *Rhabdostichus* cf. *R. pulex* (Clarke), while Levinson (1957, p. 372) had suggested that they are 'probably ostracodes of the genus *Cryptophyllus*'. Though the view of Rome & Goreux is probably correct, the type specimen of *Rhabdostichus pulex* still needs to be re-described, together with additional collections of topotype material, before it can be definitely placed into the genus *Cryptophyllus.* Furthermore, *Rhabdostichus pulex* should be compared with *Cryptophyllus arsinius* Stover, 1956.

Rome & Goreux (1960, p. 186) tentatively suggested that *Eridoconcha monopleura* Swain & Peterson 1951, from the Upper Jurassic Redwater shale of South Dakota, belongs to the genus *Cryptophyllus.* Whether or not this species represents the youngest record of the genus depends not only on the validity of the generic assignment, but also on the authenticity of the age of the specimens. It is possible that the Redwater shale specimens referred to *Eridoconcha monopleura* and *Paraparchites* ? by Swain[1] and Peterson (1951) may have been reworked from older beds. Dr. J. A. Peterson has written to me (letter, 10 February 1961):

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[1] Professor F. M. Swain of the University of Minnesota, kindly informed me (letter, 27 July 1961) that these specimens may have been reworked from nearby Palaeozoic rocks, though there is no definite evidence of this. Furthermore, he writes, ' - - - to my knowledge, Late Paleozoic ostracoda are almost unknown in that area (South Dakota) because of unfavorable facies. If they are reworked, it is just as likely that they could have come from the Triassic beds which occur in an evaporite and shale facies in this area.

'These assignments were made on the basis of only a few poorly preserved specimens which in my opinion could well have been reworked from older beds. The shell surfaces were heavily pitted and encrusted by what appeared to be solution and precipitation effects. The valve edges and ornamentation also appeared to be more rounded than would normally be expected, possibly explainable by abrasion. Furthermore, the only known occurrence of these forms is in a single bed near the base of the Redwater shale at the type locality. During the course of my work on the Jurassic, I made thorough study of at least 20 other surface localities (as well as several well sections) in Wyoming, Montana, and South Dakota and did not find a single additional occurrence of either of the above forms in all these sections (including the Redwater and its equivalents and also the "lower Sundance" or Rierdon and Stockdale Beaver shale). - - - the above specimens from the Redwater shale could well have been derived from nearby Paleozoic rocks, inasmuch as the area is not far from the Redwater shoreline.'

Europe

Until recently, *C. materni* (Bassler & Kellett) 1934, from the Upper Devonian (middle Frasnian) of Belgium, defined the upper limit of the time-range of the genus in Europe. Rome & Goreux (1960) have described even younger forms of *Cryptophyllus*, collected from the basal Lower Carboniferous (Zone d'Etroeungt) of Belgium. In the U.S.S.R., Egorov (1954) has shown that the minute bivalves previously referred to *Astarte socialis* Eichwald, found in the Upper Devonian of the Russian Platform, should be assigned to *Eridoconcha*. From his figures, it seems that these forms may belong to the genus *Cryptophyllus*. The oldest known European occurrence of *Cryptophyllus* has been reported by Rome & Goreux (1960, p. 188) from the Middle Devonian (Givetian) of Belgium.

Australia

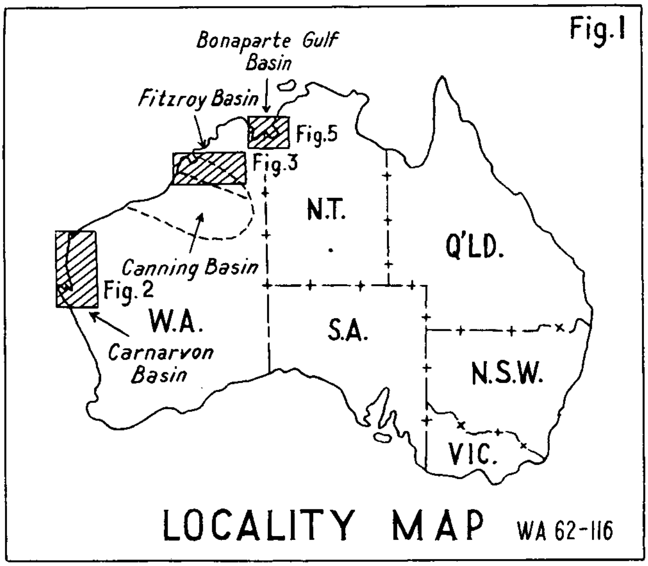
At present, the occurrence of *Cryptophyllus* in the Upper Devonian (middle Frasnian) rocks of the Carnarvon Basin represents the earliest record of this genus in Australia. *Cryptophyllus* also occurs in late Famennian and Tournaisian rocks of the Canning and Bonaparte Gulf Basins, and in Viséan rocks of the latter area. The occurrence of *Cryptophyllus* in the Upper Carboniferous (Westphalian) of the Canning Basin is at present the youngest authentic record of the genus.

As yet, *Cryptophyllus* has not been found in the Permian and Triassic rocks of Western Australia, and further work is necessary to determine the upper limit of its time-range.

Chapman & Parr (1937, p. 178) described a minute bivalve form as *Carbonicola minutissima* sp. nov., from beds now included in the Lower Triassic Blina Shale (McWhae et al., 1958). This formation was originally described by Brunnschweiler (1954), who maintained that the *'Carbonicola'* of Chapman & Parr belonged to the conchostracan genus *Isaura*. An examination of the type specimens of *'Carbonicola minutissima'*, indicates that they are distinct from *Cryptophyllus*, and that they have been properly assigned by Brunnschweiler to *Isaura*.

DISTRIBUTION OF *CRYPTOPHYLLUS* IN WESTERN AUSTRALIA

Cryptophyllus is widespread in Western Australia; it occurs in the Carnarvon, the Canning, and the Bonaparte Gulf Basins (Fig. 1).



Four species can be distinguished: *Cryptophyllus diatropus* sp. nov., *C. platyogmus* sp. nov., and two species, *C.* sp. *a,* and *C.* sp. *b.*, which are probably new, but are left unnamed as they are represented by only a few specimens. The known stratigraphical range of *Cryptophyllus* in Western Australia is from the Upper Devonian (Frasnian) to the Upper Carboniferous (Westphalian), and the species are distributed as shown in Table 1.

TABLE 1

DISTRIBUTION OF *CRYPTOPHYLLUS* IN WESTERN AUSTRALIA

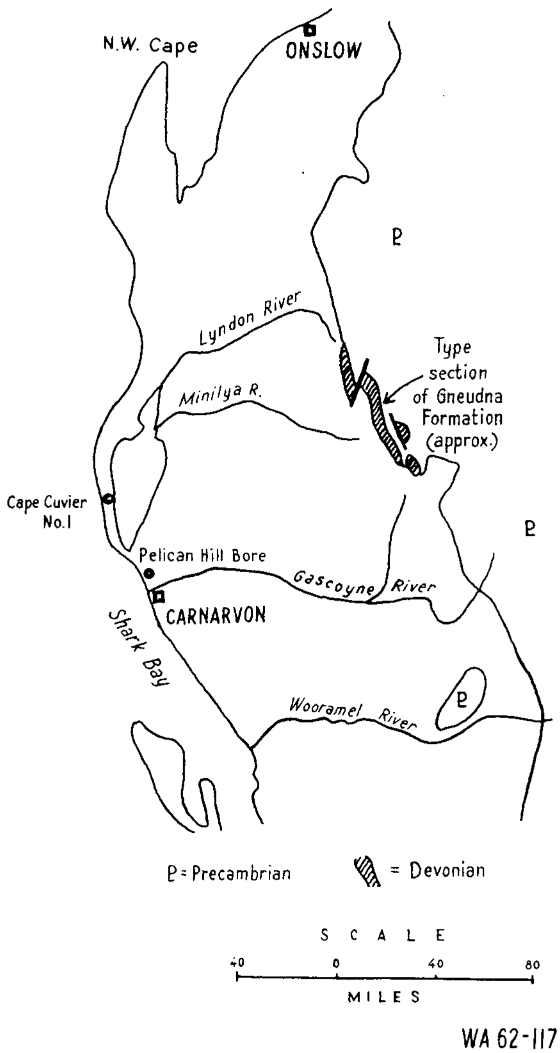
European equivalent	Carnarvon Basin	Canning Basin	Bonaparte Gulf Basin
Westphalian	....	sp. *b*	....
Namurian	....	....	....
Viséan	....	....	*platyogmus*
Tournaisian	....	*diatropus*	*diatropus?*
Famennian	....	sp. *a*?	*diatropus?*
Frasnian	sp. *a*	....	....

Carnarvon Basin

Gneudna Formation (*Upper Devonian*): *Cryptophyllus* sp. *a* occurs in a surface sample (Reg. No. F 17,271) collected from 380-400 feet above the base of the type section of the Gneudna Formation (locality TP162). This formation crops out on the eastern margin of the northern part of the Carnarvon Basin, in

Fig. 2

NORTHERN PART
of the
CARNARVON BASIN



the Williambury area, where it varies in thickness between 1,200 and 1,750 feet (Teichert, 1949; Thomas & Prichard, 1953; Condon, 1954). Hill (1954) described four species of corals from the Gneudna Formation, and concluded that 'the genera to which they belong are those dominant and characteristic in the Pillara Limestone of the West Kimberleys, and in upper Givetian and early Frasnian faunas elsewhere, so that the Gneudna Formation is probably of this age'. Glenister (1956) described four new species of *Cyrtospirifer* from this formation, which he regards as late Frasnian. Veevers (1959b) described five other brachiopod species from the Gneudna Formation, and determined the age of the formation as Frasnian, 'the lower half probably middle Frasnian, the upper probably upper Frasnian'.

Pelican Hill Bore (*Upper Devonian, in part*): An undetermined species of *Cryptophyllus* has been found in cores taken from the Pelican Hill bore, 9 miles north of Carnarvon, between 1,596 feet and 1,646 feet, at 2,000 feet, and between 2,293 feet and 2,307 feet. The presence of a species of *Cyrtospirifer* (closely related to the Gneudna species) in two pieces of core taken between 1,446 and 1,496 feet in this bore proved the presence of Upper Devonian rocks. Thomas & Dickins (1954) suggested that the interbedded limestone, siltstone, and sandstone in the bore between 1,406 feet and 2,206 feet may correspond to the Gneudna Formation. The core taken from 2,293-2,307 feet contains a species of the pelecypod family Parallelodontidae, which is known in the Upper Devonian and Lower Carboniferous rocks of the Carnarvon Basin. Taking all the evidence into account Dickins & Jones (in McWhae et al. 1958) consider that the whole section between 1,406 and 2,307 feet is of Upper Devonian age.

Cape Cuvier Bore No. 1 (*Upper Devonian, in part*): This bore was drilled in 1955 about 45 miles north-north-west of Carnarvon by West Australian Petroleum Pty Ltd. *Cryptophyllus* sp. *a* occurs in core 12 (1,411-1,416 feet), core 15 (at 1,492½ feet), and core 16 (1,494-1,500 fet), which have probably been taken from Upper Devonian rocks, and bear close lithological similarity to the Upper Devonian sequence of the Pelican Hill bore (McWhae et al., 1958).

Canning Basin

Laurel Formation (*Lower Carboniferous*): *Cryptophyllus* is common in many localities of the Laurel Formation, both in the main outcrop, south-east of Oscar Range, and in the restricted outcrop at Station Creek, north of the Lennard River. The Laurel Formation has been described by Thomas (1957, 1959a), who considered that its brachiopod fauna probably indicates a late Tournaisian age. The discovery of the ammonoid *Imitoceras rotatorium* (de Koninck) by Glenister (1959) also indicates a late Tournaisian age. Numerous well-preserved specimens of *Cryptophyllus diatropus* sp. nov. have been obtained from locality IV of Thomas (1959a), about 7 miles north of BMR 2, Laurel Downs.

BMR 2 *Bore, Laurel Downs* (*Lower Carboniferous, in part*): Well-preserved specimens of *Cryptophyllus diatropus* sp. nov. occur in abundance, high in the

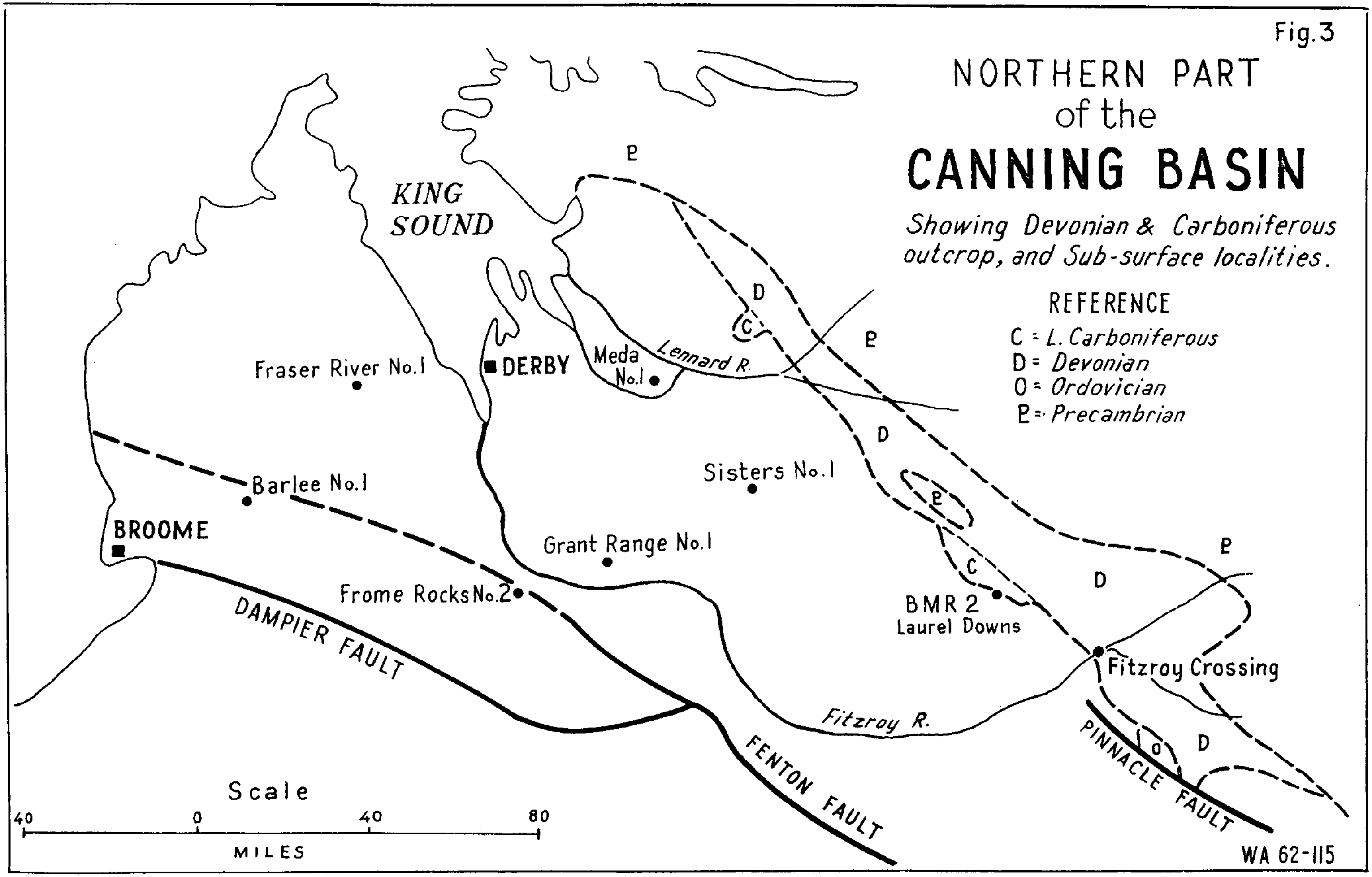


Fig.3

NORTHERN PART of the **CANNING BASIN**

Showing Devonian & Carboniferous outcrop, and Sub-surface localities.

REFERENCE

C = *L. Carboniferous*
D = *Devonian*
O = *Ordovician*
P = *Precambrian*

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section of the Laurel Formation penetrated by bore BMR 2, Laurel Downs, between 200 and 360 feet. *C. diatropus* sp. nov. is associated with the same rich ostracod fauna as occurs in surface samples of the Laurel Formation (Jones, 1959). Veevers (1959b) recorded the new brachiopod species *Camarotoechia eganensis* at 250 to 260 feet, and 350 to 360 feet, and from many surface localities of the Laurel Formation.

The Sisters No. 1 *Bore* (*Lower Carboniferous-Upper Devonian*): *Cryptophyllus diatropus* sp. nov. occurs in cuttings between 6,435 feet and 7,650 feet in The Sisters No. 1 Bore, drilled in 1957 by Associated Freney Oil Fields N.L., about 60 miles east-south-east of Derby. The exact position of the junction between the Lower Carboniferous and Upper Devonian in this bore is not known; the first definite Upper Devonian may be at 7,140 feet (Jones, 1961a), but the boundary may occur slightly higher, as the lowest definite Lower Carboniferous is at 6,093 feet.

Meda Nos. 1 *and* 2 *Bores* (*Lower Carboniferous, in part*): These bores were drilled in 1958 by West Australian Petroleum Pty Ltd, about 40 miles east of Derby. *Cryptophyllus diatropus* sp. nov. occurs in the upper part of the Lower Carboniferous sequence of both bores; between 5,000 feet and 5.430 feet in Meda No. 1, and 5,280 feet and 5,445 feet in Meda No. 2. The associated ostracod fauna in these bores closely resembles that of the Laurel Formation, both in outcrop and in BMR 2, Laurel Downs.

Grant Range No. 1 *Bore* (*Upper Carboniferous*): In 1955, West Australian Petroleum Pty Ltd drilled Grant Range No. 1 Bore, about 55 miles south-south-east of Derby, and discovered the Upper Carboniferous Anderson Formation between 7,900 feet and 12,915 feet, the bottom of the bore (McWhae et al., 1958). *Cryptophyllus* sp. *b* is found between 7,907 feet and 9,799 feet. Öpik (in McWhae et al., 1958) determined the Pennsylvanian conchostracan *Leaia* (*Hemicycloleaia*) Raymond between 7,907 feet and 8,536 feet, and he regarded the uppermost samples as upper Westphalian or lower Stephanian. Pelecypods identified by Dickins (in McWhae et al., 1958) as *Naiadites* sp. cf. *N. modiolaris* and *Anthracosia?* sp., from a core taken between 9,796 feet and 9,799 feet, suggest a Westphalian B age for this depth.

Barlee No. 1 *Bore* (*Upper Carboniferous?*): Barlee No. 1 Bore was drilled in 1960 by West Australian Petroleum Pty Ltd about 40 miles south-west of Fraser River No. 1 Bore (Fig. 3), and penetrated about 6,500 feet of Anderson Formation. Numerous poorly-preserved specimens of *Cryptophyllus* occur high in the Anderson Formation in core 2 (2,307-2,325 feet), together with a species of the brachiopod *Orbiculoidea* comparable with *O. missouriensis* and *O. tornacensis;* an association which indicates a general Carboniferous age (Jones, 1961b).

Frome Rocks No. 2 *Bore* (*Upper Devonian, in part*): Frome Rocks No. 2 Bore was drilled in 1959 by West Australian Petroleum Pty Ltd, about 22 miles west-south-west of Grant Range No. 1 Bore, and penetrated Upper Devonian rocks between 3,557 feet and 7,504 feet, the bottom of the bore. Damaged specimens of *Cryptophyllus,* which appear to belong to *C.* sp. *a,* are present in core 16 (4,852-4,861 feet) and core 17 (5,220-5,227 feet). Jones (1961a) referred the rich ostracod fauna found between 3,640 feet and 5,227 feet to the *Avonia proteus* zone of Veevers (1959a), of upper Famennian age. Glenister (in Veevers & Wells, 1961) determined *Platyclymenia* sp. in core 23 (6,986-6,993 feet), a genus restricted to the *Platyclymenia* zone of the German succession — approximately equal to the *Sporadoceras* zone of the Upper Devonian in Western Australia.

Bonaparte Gulf Basin

Specimens of *Cryptophyllus* occur in samples from outcrops of Burt Range Limestone, Septimus Limestone, and Point Spring Sandstone, and from subsurface Lower Carboniferous shales (Fig. 5). These samples were made available to the Bureau of Mineral Resources by Mr E. P. Utting, Chief Geologist of Westralian Oil Limited.

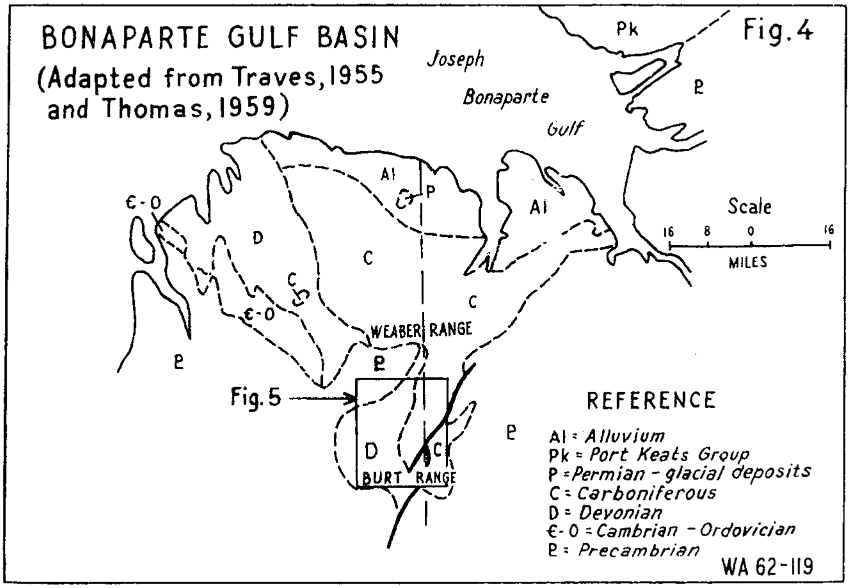

Fig.4

Burt Range Limestone (*Upper Devonian—Lower Carboniferous*): Poorly-preserved specimens of *Cryptophyllus,* doubtfully referred to *C. diatropus* sp. nov. occur in samples (MG 8, MG 10) collected from the middle part of the Burt Range Limestone, about 4 miles west of Milligans Hills, along the track which leads through Martins Gap. Teichert (*in* Matheson & Teichert, 1948) correlated the lower fossiliferous beds of the Burt Range Limestone with his '*Productella* limestone' (now referred to the Fairfields Beds, by Guppy et al., 1958) of the northern part of the Canning Basin, and with Stage IV of the German Upper Devonian sequence. He believed that the remaining beds (which would include localities MG 8 and MG 10) correspond to Stages V and VI of the German section. As no clymenids have been found in these beds, the possibility of a basal Lower Carboniferous age must not be excluded (Jones, 1961a).

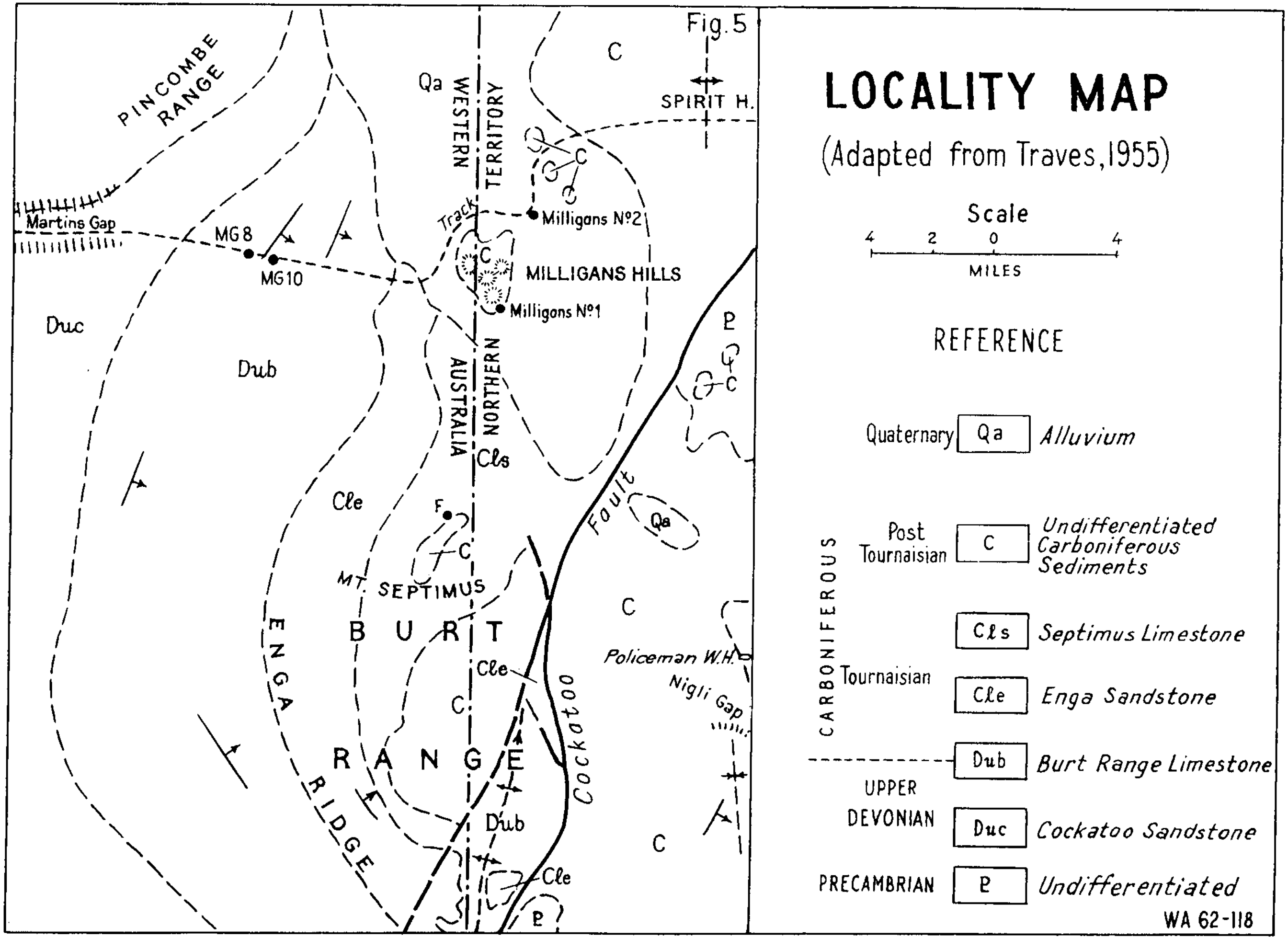

Fig. 5

LOCALITY MAP

(Adapted from Traves, 1955)

Septimus Limestone (Lower Carboniferous): Other poorly-preserved specimens which can possibly be assigned to *C. diatropus* sp. nov. also occur at locality F (Utting, 1957 unpubl.), 350 to 450 feet above the base of the type section of the Septimus Limestone, on the north-west flank of Mount Septimus. Öpik (Noakes, Öpik & Crespin, 1952) listed a rich brachiopod fauna from the fossil collection made at Mount Septimus. He concluded that the presence of *Leptaena analoga* indicates a definite Lower Carboniferous (Mississippian) age for the Mount Septimus Limestone. The presence of *Productus (Marginirugus)* is perhaps even more significant. Sutton (1938, p. 576) stated that *Marginirugus* is confined to the Keokuk and Warsaw formations of the Mississippian of the Mississippi Valley. Veevers (1959b) described a new species of *Camarotoechia (C. septima)* from the Septimus Limestone, which he compared with Tournaisian species from England, Belgium, and Russia. Thomas (1961) described the Septimus brachiopod fauna, and determined the age of the Septimus Limestone as upper Tournaisian.

Point Spring Sandstone (Lower Carboniferous): The Point Spring Sandstone was defined by Noakes et al. (1952) for the marine beds which crop out 6 miles east of Point Spring in the Weaber Range. Later mapping by Utting (1957, unpubl.), and the brachiopod studies of Thomas (1959b, 1961), have shown that outcrops of Point Spring Sandstone occur to the south, at Spirit Hill and Milligans Hills. Some of the poorly-preserved specimens of *Cryptophyllus* found in the Point Spring Sandstone, in the Milligans Hills (locality C1 of Utting), are comparable with *C. platyogmus* sp. nov.

Öpik (in Noakes et al., 1952, and Traves, 1955) tentatively suggested that the Point Spring Sandstone was Permian, whereas Thomas (in Traves, 1955) favoured a Carboniferous age. The recent brachiopod studies of Thomas (1959b, 1961), based on larger collections from the Point Spring Sandstone, have proved that the formation is Lower Carboniferous (Viséan to possible Namurian).

Subsurface Lower Carboniferous shales: Abundant well-preserved specimens of *Cryptophyllus platyogmus* sp. nov. occur in shales penetrated by the shallow bores Milligans No. 1 (185-472 feet), and Milligans No. 2 (111-186 feet), in the Milligans Hills area, about 5 miles north of Mount Septimus. There can be very little age difference between the subsurface shales and the overlying Point Spring Sandstone at Milligans Hills (locality C1), as they both contain the same ostracod fauna (Jones, in Thomas, 1959b).

MORPHOLOGY

The morphological terms followed in this paper are mainly those defined by Kesling (1951); the additional terms *umbo*[1] and *umbonate*[2] are particu-

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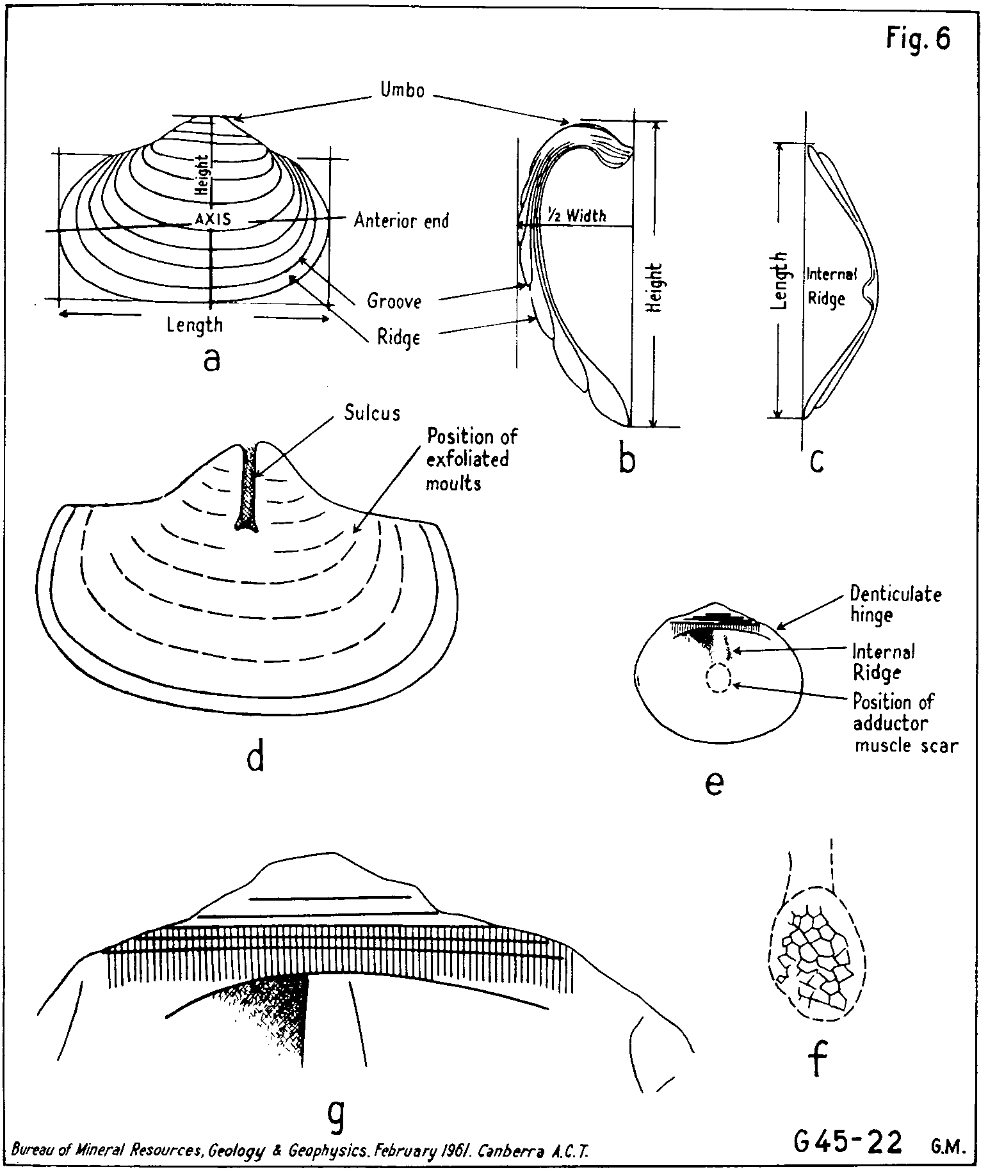
(1) Harris (1931) was the first worker to apply the term *umbo*, in his descriptions of the species *Eridoconcha simpsoni* and *E. magna* (both now placed in the genus *Cryptophyllus*.)

(2) Levinson (1951) appears to have been the first worker to use the adjective *umbonate*, in the generic description of *Cryptophyllus*.

larly useful to describe the dorsal border of *Cryptophyllus*, as they draw attention to its similarity to the umbo of pelecypods.



Bureau of Mineral Resources, Geology & Geophysics. February 1961. Canberra A.C.T.

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Figure 6.—Morphology of carapace.

Cryptophyllus diatropus sp. nov.; a: lateral view of right valve (holotype), CPC 4209, x 30; b: vertical section, CPC 4214, x 55; c: horizontal section, CPC 4215, x 34.
Cryptophyllus sp. b; d: lateral view, CPC 4228, x 33.
Cryptophyllus platyogmus sp. nov., CPC 4224; e: internal view, x 27; f: adductor muscle scar, x about 140; g: very finely denticulate hinge, x about 130.

No Western Australian species of *Cryptophyllus* has been observed to exceed a length of 2 mm. X-ray powder analysis of many broken specimens of *C. diatropus* sp. nov. showed that calcite — the only form of calcium carbonate present—is the major mineral constituent (W. B. Dallwitz, pers. comm.).

Externally, valves of *Cryptophyllus* consist of a succession of flat ridges, separated by grooves (Fig. 6a, 6b). Measurements taken normal to each ridge show that the succeeding ridges gradually increase in height; the most ventral ridge of adult forms appears to be narrower than the penultimate ridge. The earliest ridges usually form a distinct umbo, which may project well above the hinge-line. Harris (1957, p. 182-3) described a small umbonal spine in the Ordovician species *C. simpsoni, C. magnus,* and *C. nuculopsis,* but there is no evidence of this feature in the Western Australian species.

Thin sections of the carapace (Fig. 6b) show a multiple-layered structure, each layer growing from the umbo, underneath the earlier layers. Levinson (1951, p. 555) interpreted the multiple layers of both *Cryptophyllus* and *Eridoconcha* as retained moults. The thickened free-edge of each moult forms a ridge, which helps to strengthen the carapace. Thin sections show that the ridges of each moult consist of a thick inner layer of calcite, and a thin outer calcitic layer[1]. The structure of the inner layer is very difficult to interpret: no obviously prismatic pattern has been observed[2]. A maximum of thirteen ridges can be counted in the Western Australian species; the ridges are separated by either shallow V-shaped grooves, as in *C. diatropus,* or a minute gap, as in *C. platyogmus.*

The straight hinge-line coincides with the dorsal border of the last instar; thus the hinge-line of each previous instar appears under the umbo as a series of parallel striae (Fig. 6g). Hinge-details are difficult to recognise, even in the well-preserved Australian species. They lack a definite simple hinge (smooth ridge-and-groove type), a feature described by Levinson (1951, p. 558), and by Rome & Goreux (1960, p. 189), but some specimens show an extremely faint groove (e.g., CPC 4212, 4224). Numerous short extremely fine fibre-like crenulations occur along the total length of the hinge-line of the latest moult, and along those of earlier instars. This structure may be analogous to the finely and evenly denticulate hinge of certain leperditiids e.g., *Herrmannina waldschmidti* (Paeckelmann), *H. willsensis* (Ulrich & Bassler), *H. phaseolus* (Hisinger), *H. consobrina* (Jones), and *Leperditia scalaris* Jones, which developed in late Silurian and Devonian times (Swartz, 1949, p. 314). The crenulations along the hinge-line of *Cryptophyllus* are more delicate than the taxodont dentition of these leperditids; this may be not a significant difference, but a factor of total size.

Exfoliation of the initial instars forming the umbo reveals a sulcus; it is weakly developed at first, but as later instars are exfoliated, it rapidly increases in depth, and in *C.* sp. *b* it tends to bifurcate at its ventral end (Fig. 6d). The external sulcus corresponds to a well-developed internal ridge, extending from

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[1] Adamczak (1961) also recognized the presence of two layers in the shell-structure of Eridoconchinae Henningsmoen.

[2] Adamczak described the microstructure of the multilamellar astracod carapace as 'cryptocrystalline.'

the hinge-line to the ventro-central area, where an adductor muscle scar is seen (Fig. 6f). This is a pear-shaped to oval impression about 130 microns high and 100 microns wide, formed by at least 50 bosses, each one of the order of 13 microns in maximum width.

ONTOGENY

The retention of instars within the single individual provides excellent conditions for the study of the ontogeny of *Cryptophyllus.*

Rome & Goreux (1960, p. 189) point out that throughout the ontogeny of *Cryptophyllus,* growth is asymmetrical owing to a greater development at one end than at the other. The umbo appears first of all in the median position, and gradually shifts towards the less developed end; the hinge-line has the same tendency. These authors consider the more developed end as posterior, giving a 'leperditioid' aspect, or 'backward swing' in the sense of Ulrich & Bassler (1908, p. 280), produced by the more rapid growth of the posterior region of the animal. Therefore, the umbo, sulcus (when seen), and hinge-line are anterior. Henningsmoen (1953, p. 252) described similar effects of the faster growth of the posterior end of the holotype of *Conchoprimitia gammae* Öpik, 1935. The same type of 'leperditioid' growth occurs in *Eoleperditia fabulites,* as described by Scott (1951). Similar ontogenetic development, but to a lesser degree, is observed in the asymmetrical species of *Cryptophyllus* from Western Australia.

The orientation adopted in this paper is that proposed by Rome & Goreux (1960,' p. 189), which is opposite to that used by Levinson (1951, p. 556, 8) and by Harris (1957, p. 179).

CLASSIFICATION

Biological Position

The genus *Eridoconcha* was originally described as an ostracod by Ulrich & Bassler (1923, p. 297), and it has been accepted in the order Ostracoda by later workers (Marten, 1929; Harris, 1931, 1957; Bassler & Kellett, 1934; Coryell & Williamson, 1936; Kay, 1940; Levinson, 1951; Keenan, 1951; Egorov, 1954; and Rome & Goreux, 1960).

Schmidt (1941, p. 18) doubted the ostracod affinities of *Eridoconcha,* and believed that the similarity of its grooved carapace to that of the living conchostracan genus *Cyclestheria* merited its inclusion in the Phyllopod family Cyclestheridae. This view has been challenged by Rome & Goreux (1960, p. 191), who pointed out that unlike *Eridoconcha* and *Cryptophyllus,* ' . . . ces Conchostracés n'ont pas de vraie charnière, leurs valves se joignent comme le font celles des Cladocères; de plus elles ne sont pas calcifiées et sont minces. D'autre part ils possèdent entre les striés d'accroissement une ornamentation qui fait defaut chez les deux genres précitiés.'

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[1] Adamczak (1961) believed that the minute reticulation in his new species '*Eridoconcha*' *granulifera* resembles analagous structures in Conchostraca.

[2] Adamczak discovered calcified forms which he referred to Conchostraca, from the marine Silurian of Podolia.

Probably the most conclusive reasons for excluding these genera from the Conchostraca are (i) the lack of the delicate structures between the grooves e.g., punctae, granulae, polygons, dendritic striae, which mark the roots of epidermal cells in living conchostracans (Defretin, 1958, p. 249)[1], and (ii) the thick carapace at the umbo[2].

Rome & Goreux (1960, p. 191) in their discussion of the systematic position of *Eridoconcha* and *Cryptophyllus,* stated that there is no doubt that these genera belong to the order Ostracoda. The validity of this relationship largely depends upon (i) the mode of growth of the multiple-layered shell-structure of these two genera, in comparison with the growth of ostracod instars, and (ii) the conditions in which they are retained.

An ostracod affinity is favoured by the fact that the growth of each layer is initiated at the umbo, in contrast to typical molluscan growth by the addition of small increments of shell material at the margins. The prismatic shell-structure, which is characteristic of ostracods, cannot be seen in thin sections of *Cryptophyllus diatropus* sp. nov.; they do show, however, a thin outer layer. Levinson (1951, p. 554) has shown that the Leperditiidae have two shell-layers, and Scott (1951, p. 323) interpreted the thin layer on the external and internal surfaces of *Eoleperdita fabulites* as remnants of the original inner and outer chitin layers.

Moult retention occasionally occurs in ostracod species, as an accidental phenomenon, e.g., *Ectodemites plummeri,* as described by Cooper (1945), *Candona candida* (Muller) and *Cyridopsis obesa* Sars, as reported by Rome & Goreux (1960, p. 191). Henningsmoen (1953, p. 252) and Jaanusson (1957, p. 417) have both pointed out that the retention of an earlier moult stage in the genus *Conchoprimita* (in the sense of Öpik, 1937) is more or less an accidental feature, which cannot be used as either a generic or specific character. In contrast, the Upper Devonian and Carboniferous species of *Cryptophyllus* from Western Australia, like those from Belgium, demonstrate that the multiple-layered structure is a constant character, which suggests a normal pattern of growth.

Furthermore, the maximum of thirteen layers in the Australian species *Cryptophyllus diatropus* and *C. platyogmus* is unusually high, if they correspond to retained moults. No living ostracod species is known to exceed nine instars, and *Beyrichia jonesi* Boll with eleven stages is the only fossil species known to do so, which Spjeldnaes (1951) regards as a primitive condition. However, Kesling (1953, p. 103) using this species as an example, suggested that many ostracods of extinct families may have had more instars than existing forms.[1]

In the absence of evidence to demonstrate that *Cryptophyllus* and *Eridoconcha* belong to a different order, class, or phylum, I retain both genera in the order Ostracoda, but regard them as belonging to a specialized aberrant group.

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[1] Adamczak (1961) recorded a maximum of eleven lamellae in his definition of Eridoconchidae, whereas Rome and Goreux (1960, p. 198) recorded a maximum of twelve instars in their species *Cryptophyllus ellipticus.*

Generic Affinities

In his paper on thin sections of Palaeozoic Ostracoda, Levinson (1951, p. 554) revised the existing concept of *Eridoconcha,* and proposed the genus *Cryptophyllus,* selecting as type-species *E. oboloides* Ulrich & Bassler, 1923. He restricted the genus *Eridoconcha* to species similar to the genotype *E. rugosa* Ulrich & Bassler 1923, in which each layer bears a prominent external ridge, a short distance from its free-margin. In the genus *Cryptophyllus* however, 'the marginal portion of each layer is expanded to form a flat ridge which borders the free margins of the valve'; he also interpreted the multiple shell-layers of both genera 'as being due to incomplete shedding of moults accompanied by later cementation'. The retention of moults was independently noted by Keenan (1951, p. 564), who also recognised that the existing concept of *Eridoconcha* contained two distinct groups—ornamented, sulcate forms typified by *E. rugosa* on the one hand, and smooth, unornamented, non-sulcate forms typified by *E. oboloides, E. magna,* and *E. simpsoni* on the other. Both Levinson and Keenan excluded the latter group from the genus *Eridoconcha,* but Levinson proposed the genus *Cryptophyllus* for them, while Keenan considered that at least the forms from the Middle Ordovician Simpson Group (*E. magna* and *E. simpsoni*) are compound specimens of *Schmidtella* species. Keenan (1951, p. 566) also considered that the species *Placentula marginata* Ulrich 1890, later revised by Bassler & Kellett (1934, p. 349) to *Jonesites marginatus* (Ulrich), is synonymous with the species *Eridoconcha rugosa* Ulrich & Bassler 1923, replacing *E. rugosa* by *E. marginata* as genotype of *Eridoconcha.* He further suggested (p. 565) that the species *Milleratia cincinnatiensis* (Miller), genotype of *Milleratia* Swartz 1936, may belong to the genus *Eridoconcha.*

Harris (1957) assigned *Eridoconcha magna* and *E. simpsoni* to the genus *Cryptophyllus,* and made no comment on Keenan's suggestion that these species are compound specimens of *Schmidtella* species.

The Western Australian species of *Cryptophyllus* demonstrate that the multilayered carapace is a constant character of their growth, and not an accidental feature. Thus, *Cryptophyllus* has a valid generic status.

Rome & Goreux (1960, p. 192) pointed out that the identification of *Eridoconcha rugosa* with *Placentula marginata,* based only on the original type figures and description of Ulrich in 1890, seems very hazardous. *Placentula marginata* appears to belong to the genus *Eridoconcha,* but in the absence of a comparison of type-material, both species must be regarded as distinct.

To conclude, Levinson (1951) has shown that the generic concept of *Eridoconcha* Ulrich 1923 consists of two valid genera, *Cryptophyllus* and *Eridoconcha s.s.; Cryptophyllus* has affinities with *Schmidtella,* and *Eridoconcha s.s.* is closely related to *Milleratia.*

Henningsmoen (1953, p. 255) proposed the sub-family Eridoconchinae to include these four closely related genera, which he tentatively placed in the family Leperditellidae.

Familial Relationships

The systematic position of the Eridoconchinae is uncertain, and up to the present its genera have been assigned to the Aparchitidae, the Primitiidae, and the Leperditellidae. The Aparchitidae is not a well-known family, but it appears to include non-sulcate genera; and the type-species of *Aparchites* (*A. whiteavesi* Jones, 1889) possesses a distinct velate ridge. The Primitiidae also shows a velate structure, and a 'forward-swing' in lateral view (preplete outline of Jaanusson, 1957, p. 186). Thus, it seems unlikely that the Eridoconchinae belongs to either the Aparchitidae or the Primitiidae.

The Western Australian species of *Cryptophyllus*, however, show features which suggest a similarity to the Leperditiidae:

(i) Two shell-layers, seen in thin sections of *C. diatropus* sp. nov[1];

(ii) A finely crenulate hinge-structure, similar to the finely and evenly denticulate hinge of many leperditiids, e.g., *Herrmannina waldschmidti*, and *Leperditia scalaris;*

(iii) A submarginal ridge, which is present in the Isochilinid genera *Isochilina, Teichochilina* and *Dihogmochilina*, although Henningsmoen (1953, p. 256) pointed out that this feature is also found in the Bolliinae;

(iv) A tendency for the sulcus to bifurcate, as in the Isochilinid genus *Dihogmochilina;*

(v) A Leperditiid-like adductor muscle scar, on a greatly reduced scale.

On the other hand, there are important differences between *Cryptophyllus* and the Leperditiidae, which suggest a relationship to the Leperditellidae;

(i) Leperditiids range from about 5 to 20 mm. in length, or rarely to 30 mm. and more (Swartz, 1949, p. 311), whereas the genus *Cryptophyllus* is not known to exceed 2 mm. in length.

(ii) The 'backward-swing' (or 'postplete outline' of Jaanusson, 1957, p. 186) which is characteristic of the Leperditiidae, is very poorly developed in the Western Australian species of *Cryptophyllus*, though it is well developed in many of the Belgian Carboniferous species (Rome & Goreux, 1960), and the Ordovician species *C. nuculopsis* Harris, 1957.

(iii) An external tubercle—thought to have been the locus of the anterio-lateral eye of leperditiids—is not found in *Cryptophyllus*.

(iv) Muscle-scars other than that of the adductor muscle, e.g., subocular chevron-marks, are not found in *Cryptophyllus*.

The evidence presented above shows that *Cryptophyllus* appears to have characteristics common to both the Leperditiidae and the Leperditellidae, and therefore the genus may be intermediate between the two families. Also *Cryptophyllus* belongs to a specialized aberrant group of ostracods, the Eridoconchinae, which has developed from an unknown parent stock in the Middle Ordovician.

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[1] This feature can no longer be regarded as an affinity with the Leperditiidae, as Adamczak (1961) reported three shell-layers in this family.

Further investigation may show that the Eridoconchinae requires a higher taxonomic status, in order to work out its relationships.

SYSTEMATIC DESCRIPTIONS

Genus CRYPTOPHYLLUS Levinson 1951

Type Species: *Eridoconcha oboloides* Ulrich & Bassler, 1923, pp. 296-7, fig. 14, 6-8, by original designation of Levinson, 1951, p. 558.

CRYPTOPHYLLUS DIATROPUS sp. nov.

(Pl. 1, fig. 1-14; Pl. 2, fig. 1, 2)

Diagnosis: An elongate species of *Cryptophyllus* (height/length = 75%) of medium size; outline highly variable, nearly elliptical, oval or sub-quadrate; umbo large; greatest width in dorso-central region; maximum of thirteen instars, separated by narrow "V"-shaped grooves.

Description: Carapace medium size, equivalved; bilaterally asymmetrical in lateral view, elongate, height/length ratio 75% (mean), varies between 70.5% and 81%. Umbo well developed, projects well above the hinge-line, inclined towards the anterior end. Axis intersects height at angles between 85° and 90°; outline highly variable, nearly elliptical, oval, or sub-quadrate. Lens-shaped in dorsal view; compressed heart-shaped in end views, with the greatest width in the dorso-central region. Hinge-line straight, about one-half of the total length, deeply depressed between the umbones. Posterior cardinal angle greater than anterior cardinal angle; ventral border convex or parallel to hinge-line. Maximum of thirteen shell layers form flattened ridges, of variable width, separated by narrow V-shaped grooves, represented on inner dorsal border by a series of parallel striae. Each ridge consists of a thick inner layer and a thin outer layer of calcite, and rarely a faint groove. Extremely fine, fibre-like denticulations occur along hinge-line of each moult between parallel striae. Exfoliation of initial shell layers often reveals a deep sulcus corresponding to a distinct, broad internal ridge, pointing to the postero-ventral border. Adductor muscle scar located at ventral end of internal ridge.

Dimensions (in millimetres):

	Length (L)	Height (H)	Width	H/L %	Length of Hinge-line (l)	l/L %
Holotype	1.13	0.81	0.64	74	0.60	53
Paratype A	1.28	0.96	—	75	0.60	47
Paratype B	1.02	0.76	—	74	0.60	58.5
Paratype C	1.26	0.97	—	78	0.81	65
Paratype D	1.08	0.85	—	76.5	0.60	55.5

Figured specimens:						
CPC 4216	1.19	0.87	0.72	73	0.60	50.5
CPC 4217	1.22	0.93	0.72	76	0.60	49
CPC 4218	0.68	0.53	—	78.5	0.44	65
Mean values of 78 specimens	0.895	0.672	—	75	0.498	56

Occurrence: Holotype (CPC 4209), paratype A (CPC 4210), paratype B (CPC 4211), paratype C (CPC 4212), paratype D (CPC 4213), and figured specimens CPC 4214-4215 from Bore BMR 2 Laurel Downs, core 3, 253 feet, from the Lower Carboniferous Laurel Formation (Tournaisian). Figured specimens CPC 4216, locality IV of Thomas (1959a) in the upper beds of the Laurel Formation, about 7 miles north of BMR 2 Laurel Downs; CPC 4217, The Sisters No. 1 Bore in cuttings at 6,970-6,975 feet (basal Lower Carboniferous or top Upper Devonian); CPC 4218, Meda No. 2 Bore, core 2, 5,287-5,298 feet (Lower Carboniferous, Tournaisian).

Remarks: In lateral view the holotype of *C. diatropus* somewhat resembles the Belgian Strunian species *C. triangularis* (Rome & Goreux, 1960, fig. 9, p. 197), but it is more elongate and tumid. *C. diatropus* appears to be related to *C. platyogmus* but can be distinguished by its variable outline, prominent umbo, and the dorso-central position of its maximum width. The name of this species is derived from the Greek *diatropus* ('various'), and refers to the variability of the outline.

CRYPTOPHYLLUS DIATROPUS?

(Pl. 2, figs. 3-5)

Description: Carapace large, equivalved; bilaterally asymmetrical in lateral view, elongate, height/length ratio 69% (adult). Umbo prominent, acute, projecting well above the hinge-line, inclined towards the anterior end. Axis not quite normal to height; outline subquadrate. Lens-shaped in dorsal view; compressed heart-shaped in end views, greatest width in dorso-central region. Hinge-line straight, slightly exceeds one-half of total length. Cardinal angles rounded. Ventral border straight, slightly inclined to hinge-line. The large exfoliated specimen reveals a broad, deep sulcus, extending towards the ventral border, about two-fifths of the height, dividing the umbo into two unequal lobes, the anterior being the larger. Fine, fibre-like denticulations occur along the hinge-line. Adductor muscle scar impressions located at ventral end of sulcus.

Dimensions (in millimetres):

Figured Specimens	Length (L)	Height (H)	Width	H/L %	Length of Hinge-line (l)	l/L %
CPC 4219 (Adult)	1.30	0.91	0.66 (est.)	69	0.80	61
CPC 4220 (Immature)	0.95	0.72	0.52	76	0.53	56

Occurrence: Figured specimens from Westralian Oil Limited localities MG8 (CPC 4220), and MG10 (CPC 4219) about 4 miles west of Milligans Hills, from the middle part of the Burt Range Limestone of the Bonaparte Gulf Basin; Upper Devonian (upper Famennian) or basal Lower Carboniferous (Strunian).

Remarks: These specimens are only tentatively assigned to *C. diatropus*, as the adult form is considerably more elongate than the adult specimens of this species from the Canning Basin. Meda No. 1 and 2 Bores, however, have yielded exfoliated specimens of *C. diatropus* which possess the same type of sulcus and unequal lobes as seen in the Burt Range Limestone specimens. Further specimens are required to verify this identification.

CRYPTOPHYLLUS PLATYOGMUS sp. nov.

(Pl. 2, figs. 6-13)

Diagnosis: A slightly elongate species of *Cryptophyllus* (height/length = 79%) of medium size; outline obliquely sub-ovate; umbo small; greatest width in the centre; maximum of thirteen instars, separated by narrow flat grooves.

Description: Carapace medium size, equivalved; slightly bilaterally asymmetrical in lateral view, slightly elongate, height/length ratio 74-82% (mean 79%). Umbo small, either high and acute or low and broadly rounded, projecting above hinge-line, inclined towards anterior end. Axis at right angles to height; outline obliquely sub-ovate. Lens-shaped in dorsal view; compressed heart-shaped in end views, umbones slightly protruding above hinge-line, greatest width in centre. Hinge-line straight, about one-half of total length. Posterior cardinal angle slightly greater than anterior cardinal angle; convexity of carapace often merges these features in general outline. Ventral border convex, rarely straight. Maximum of thirteen shell layers form flattened ridges of variable width, separated by narrow shallow trough-shaped grooves, represented on inner dorsal border by a series of parallel striae. Extremely fine, fibre-like denticulations and rarely a faint groove occur along hinge-line of each moult between the parallel striae. Exfoliation of initial shell layers often reveals deep sulcus corresponding to distinct broad, internal ridge, pointing to postero-ventral border. Adductor muscle scar located at ventral end of internal ridge. Two forms can be distinguished, which may represent dimorphic differences. In Form A the umbo is high and acute, and the end view tumid; convexity of the carapace tends to merge the cardinal angles into the general outline. In Form B the umbo is low and broadly rounded, the end view compressed, and the cardinal angles just visible.

Dimensions (in millimetres):

	Length (L	Height (H)	Width W	H/L %	Length of Hinge-line (l)	l/L %
Holotype (Form B)	1.05	0.80	0.55	76	0.465	44
Paratype A (Form A)	1.05	0.84	—	80	0.53	51
Paratype B (Form B)	0.93	0.735	—	78.5	0.53	57
Figured specimen	0.81	0.66	—	82	0.51	62
Mean values of 100 specimens	0.866	0.687	—	79	0.463	54

Occurrence: Holotype (CPC 4221), paratype A (CPC 4222), paratype B (CPC 4223), and figured specimen (CPC 4224) from Milligans No. 1 Bore (185-472 feet), Lower Carboniferous shales (Viséan to possible Namurian) of the Bonaparte Gulf Basin.

Remarks: *C. platyogmus* (form A) has a similar general outline to the type species of the American Ordovician species *C. simpsoni* (Harris, 1931, pl. XI, figs. 1 a-d), but can be distinguished by its larger size, a greater number of ridges separated by narrow, flat grooves, and the lack of a small umbonal spine. The small umbo, the obliquely sub-ovate outline, the tumidity of the carapace, and the narrow, flat grooves distinguish *C. platyogmus* from *C. diatropus*. The name of this species is derived from the Greek *platys* ('flat') and *ogmos* ('furrow'), referring to the narrow, flat grooves between the ridges.

CRYPTOPHYLLUS sp. A

(Pl. 3, figs. 1-5)

Description: Carapace large, equivalved; ovate to slightly asymmetrical in lateral view, umbo low, poorly defined, projecting slightly above the hinge-line. Lens-shaped in dorsal view; compressed in end views with the greatest width in the dorso-central area. Hinge-line straight, cardinal angles indistinct; ventral border convex or parallel to hinge-line. At least eleven shell layers form wide flattened ridges.

Dimensions (in millimetres):

Figured specimens	Length (L)	Height (H)	Width (W)	H/L %	Length of Hinge-line (l)	l/L %
CPC 4225	1.46	1.16	0.69	79	0.87 (est)	59 (est)
CPC 4226	1.18	0.84	—	71	0.66 (est)	56 (est)
CPC 4227	1.28	0.92	—	72	0.73 (est)	57 (est)

Occurrence: Figured specimens (CPC 4225, 6, 7) from the Upper Devonian Gneudna Formation, about 9 miles south-south-east of Williambury homestead, Carnarvon Basin, about 400 feet above the base of the type section (middle Frasnian, *Ladjia saltica* zone of Veevers, 1959a).

Remarks: As the description is based on only three well-preserved specimens, and three immature moults, this species cannot be properly defined until more material becomes available. The oval outline, and poorly defined cardinal angles, distinguish *C.* sp. *a* from the Belgium Frasnian species *C. materni*. *C.* sp. *a* is distinguished from the Australian Carboniferous species of *Cryptophyllus* by its large ovate carapace, indistinct cardinal angles, and the low position of its poorly defined umbo.

CRYPTOPHYLLUS sp. B

(Pl. 3, figs. 6, 7)

Description: Carapace large equivalved; elongate, very slightly bilaterally asymmetrical in lateral view, umbo large, prominent, projecting well above hinge-line. Maximum height and width in dorso-central area. Hinge-line straight, long, deeply depressed between umbones, cardinal angles form distinct corners. Ventral border straight, parallel to hinge-line, curving abruptly towards the ends. At least eight faint grooves reveal the positions of former instars, now exfoliated. Sulcus deep, about one-third of the height, tends to bifurcate ventrally, corresponds to a distinct narrow internal ridge. Fine, fibre-like denticulations along hinge-line. Adductor muscle scar located at ventral end of internal ridge.

Dimensions (in millimetres):

Figured Specimens	Length (L)	Height (H)	H/L %	Length of Hinge (l)	l/L %	Length of Sulcus
CPC 4228	1.73	1.20	69	1.4 (est)	81 (est)	0.40
CPC 4229	—	1.20	—	—	—	0.40

Occurrence: Figured specimens CPC 4228, 9 from Grant Range Bore No. 1 9,796—9,799 feet, from the Upper Carboniferous Anderson Formation (possibly Westphalian B), northern part of the Canning Basin.

Remarks: The description of *Cryptophyllus* sp. *b* is provisional as it is based on damaged exfoliated specimens and shell fragments. *C.* sp. *b* can be distinguished from other Australian species of *Cryptophyllus*, however, by its elongate outline, prominent umbo, and long hinge-line.

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PLATE 1

Figures 1-8 and 11 were treated by a 10% solution of silver nitrate, and subsequently by a 10% solution of photographic developer, after the method described by Cummings (1956, p. 402). Figures 10 and 13 were whitened with ammonium chloride.

Unless otherwise stated, magnification about X30.

Cryptophyllus diatropus sp. nov. .... page 21

Figures 1-3, Holotype, CPC 4209, lateral, anterior and dorsal views.

Figure 4, Paratype A, CPC 4210, lateral view.

Figure 5, Paratype B, CPC 4211, lateral view.

Figure 6, Paratype C, CPC 4212, lateral view.

Figure 7, Paratype D, CPC 4213, lateral view.

Figure 8, Paratype C, CPC 4212, view of hinge-line, and retained moults below umbo, about X50.

Figure 9, CPC 4215, horizontal section, showing internal ridge, X34.

Figure 10, CPC 4216, lateral view, stereo-pair.

Figure 11, Paratype C, CPC 4212, internal ridge, and adductor muscle scar, X64.

Figure 12, CPC 4214, vertical section, showing retained moults, X55.

Figure 13, CPC 4217, lateral view.

Figure 14, CPC 4214, magnified portion of Figure 12, showing two shell-layers photographed through green filter, X about 135.


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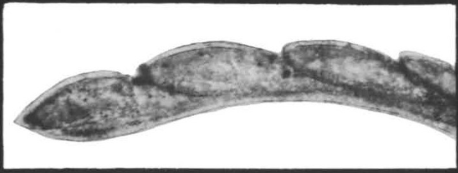
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PLATE 2

Specimens figured 1-5 and 13 were whitened with ammonium chloride, and specimens figured 6-12 were treated by the silver nitrate method, described by Cummings (1956, p. 402).

Unless otherwise stated, magnification about X30.

Cryptophyllus diatropus sp. nov. .... page 21

Figures 1, 2, CPC 4218, lateral view, stereo-pair; internal view showing hinge-line. X56.

Cryptophyllus diatropus ? .... page 22

Figures 3, 4, CPC 4219, lateral view; enlargement of sulcus showing adductor muscle-scar X 60.

Figure 5, CPC 4220, lateral view.

Cryptophyllus platyogmus sp. nov. .... page 23

Figures 6-8, Holotype, CPC 4221, lateral view, stereo-pair, dorsal and anterior views.

Figure 9, Paratype A, CPC 4222, lateral view.

Figure 10, Paratype B, CPC 4223, lateral view.

Figure 11, CPC 4224, internal view showing ridge, and hinge-line, X 27.

Figure 12, CPC 4224, denticulate hinge-line, X about 130, retouched.

Figure 13, CPC 4224, adductor muscle-scar, X about 140.


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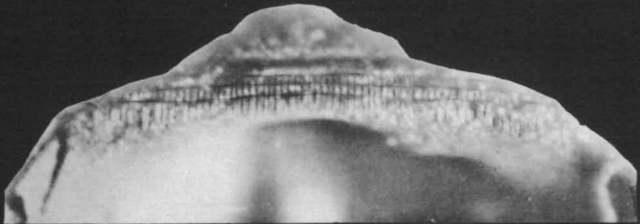
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PLATE 3

All specimens are whitened with ammonium chloride, and magnified about X30, unless otherwise stated.

Cryptophyllus sp. *a* .... page 24

Figures 1-3, CPC 4225, lateral, stereo-pair, and unwhitened end and dorsal views.

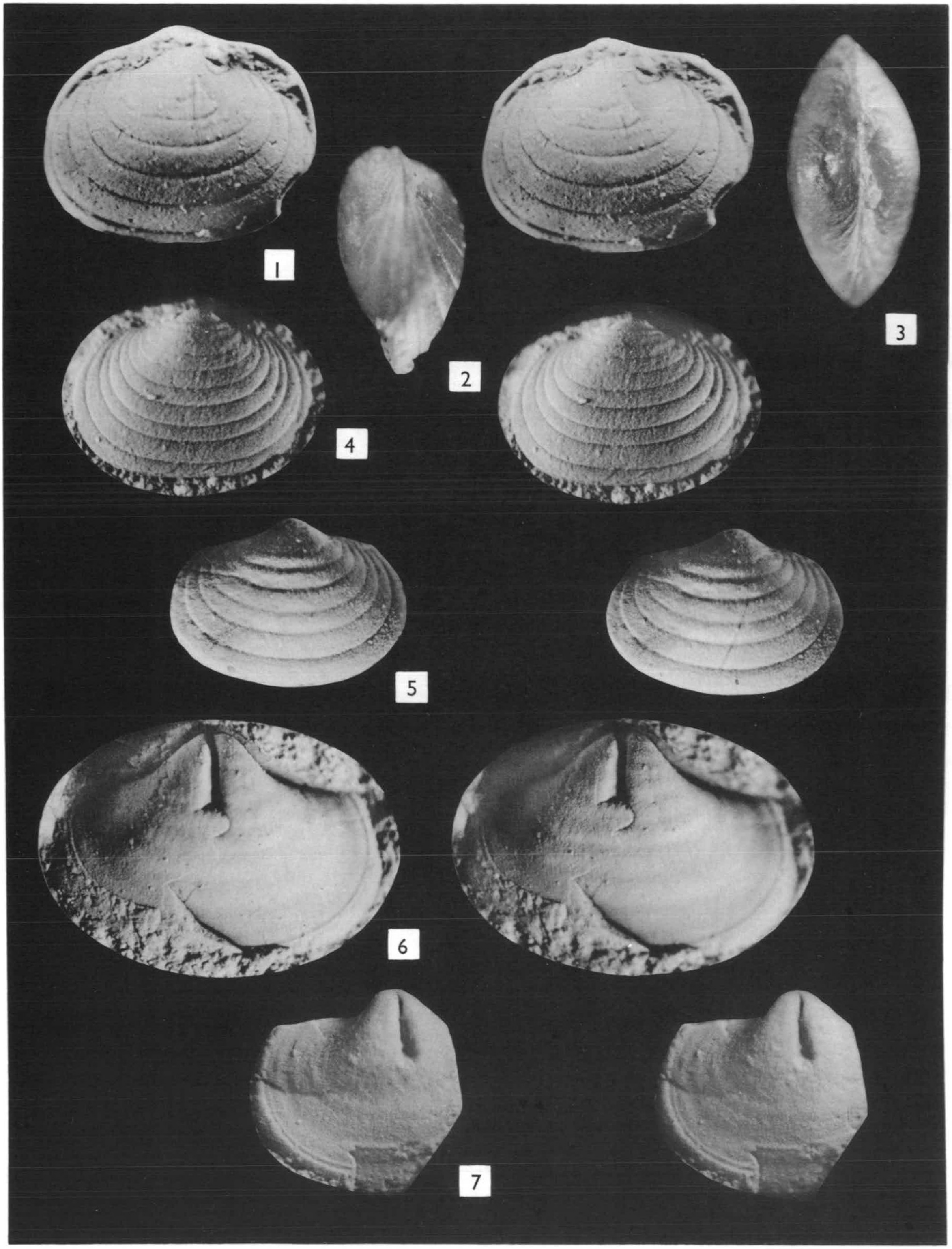
Figure 4, CPC 4226, lateral view, stereo-pair X 33.

Figure 5, CPC 4227, lateral view, stereo-pair.

Cryptophyllus sp. *b* .... page 25

Figure 6, CPC 4228, lateral view, stereo-pair, X33.

Figure 7, CPC 4229, lateral view, stereo-pair.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ADDENDUM

After this paper had gone to press, Adamczak (1961)[1] published the results of his detailed study of multiple-layered carapaces, which are briefly summarized below. He redefined the present generic concepts of *Eridoconcha* and *Cryptophyllus*, but I prefer to continue to follow Levinson's definitions of these genera, foı the reasons expressed herein.

Adamczak reported the presence of a two-layered 'cryptocrystalline' shell-structure in the Eridoconchinae Henningsmoen, and the palaeocope genera *Hollinella, Kozlowskiella,* and *Poloniella,* and a three-layered prismatic shell-structure in the Leperditiidae, and the genera *Bairdiocypris, Pachyodomella,* and *Bairdia.* He distinguished two types of carapace in the Eridoconchinae — the *aberroconchoidal* type, with internal chambers formed by uncalcified lamellae, on which he based the new genus *Aberroconcha,* and the *eridoconchoidal* type, found in the genus *Eridoconcha,* in which ' - - - lamellae have been completely calcified, and mutually adhere throughout the surface', and therefore lack internal chambers.

Adamczak believed that the minute reticulation in his new species '*Eridoconcha*' *granulifera* resembles analogous structures in Conchostraca, and that the minute pores at the boundary of the growth bands (= ridges, in this paper) of partly decalcified valves, which he referred to '*E. rugosa*', resemble the pores which contain setae in the chitinous mantle of recent Conchostraca[2].

He regarded the Eridoconchinae as a new sub-order of Ostracoda — the Eridostraca, possibly derived from the Cambrian Lepidittidae Kobayashi, which he accepted as Conchostraca. Adamczak postulated a diphyletic origin of the ostracods, the Leperditiidae and the Podocopa having been derived from the Cambrian Bradoriidae, while the Eridostraca and the Palaeocopa (excluding leperditiids), developed from early conchostracans (i.e., the Lepidittidae). The biological position of the Lepidittidae, however, is uncertain, and according to Kobayashi (1954, p. 129)[3], 'more and better material is needed before the reference of this family to the Conchostraca can be made final'.

According to Levinson (1951), 'moult-retention' is a specialized adaptative feature restricted to a small group of multi-layered (= multilamellar, in Adamczak) ostracods, an interpretation which, as Adamczak pointed out, would suggest that they descended from ancestors with a unilamellar carapace. Adamczak, however, proposed a different interpretation, in which the shells with seven or more lamellae (e.g., *Aberroconcha,* 9-10) represent the original condition inherited from conchostracan ancestors, while the shells with less than seven lamellae 'realize a new structural type of carapace', illustrating not 'retention', but the 'initiation' of moulting. The genera *Eridoconcha* and *Cryptophyllus* were redefined on the basis of the

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[1] ADAMCZAK, F., 1961: Eridostraca — a new suborder of ostracods and its phylogenetic significance. *Acta palaeont. polon.* 6(1), 29-102.

[2] Possibly the rows of concentric punctae on the valve of the puzzling species *Eridoconcha rotunda* Ulrich & Bassler, 1923, may be due to partial decalcification of its shell.

[3] KOBAYASHI, T., 1954: Fossil Estherians and allied fossils. *J. Fac. Sci., Univ. Tokyo,* Sect. 2, 9(1), 1-192.

number of lamellae they possessed; species with seven to eleven lamellae were referred to *Eridoconcha,* for which Adamczak emended and raised the Eridoconchinae to familial rank, and species with one to six lamellae were referred to *Cryptophyllus,* for which a new family—the Cryptophyllidae—was proposed.

While Adamczak's hypothesis on the biological position of the Eridostraca explains many of the features that he observed, it cannot, in my opinion, be regarded as evidence on which to redefine the present generic concepts of *Eridoconcha* and *Cryptophyllus,* or to propose a new family. Although Kesling (1953, p. 101-2) pointed out that the number of instars in the ontogeny of an ostracod appeared to be constant for a genus, he also quoted many examples of living ostracod species, which have a different number of instars in different environments. Therefore, the number of lamellae appears to be an unstable character on which to define either a species or a genus of the extinct Eridostraca. According to Adamczak, *Eridoconcha* has a minimum of seven lamellae, but there appear to be only six lamellae in the type-figure of the genotype, *E. rugosa* (Ulrich & Bassler, 1926, p. 296). It is admitted that this illustration is not very clear, and this problem can only be resolved when the type-specimen of *E. rugosa* is refigured, redescribed, and confirmed by topotype material.

Levinson based his definitions of *Eridoconcha* and *Cryptophyllus* on the non-dimorphic extensions of the valve. A short distance from the free-margin of each lamella of *Eridoconcha* an adventral structure is developed; the flat area ventral to this structure appears to be analogous to the subvelar field (of Jaanusson, 1957), which forms a typical U-shaped groove. In *Cryptophyllus,* however, the ridge is flat and occurs at the free-margin (= marginal structure ? of Jaanusson, 1957); as no 'subvelar field' is developed, the grooves are typically V-shaped.

Adamczak does not regard the shape of the grooves as systematically significant, as he claimed that both V and U-shaped grooves may occur in the ontogeny of *'Eridoconcha' granulifera,* and a species which he referred to *Aberroconcha magna* (Harris). His text-figures (figs. 9A, 17) of *Aberroconcha magna* show a special type of U-shaped groove which develops throughout its ontogeny. This species has no relevance to Levinson's definitions of *Eridoconcha* and *Cryptophyllus,* as it clearly belongs to a different genus. The only transverse section of *'Eridoconcha' granulifera* figured by Adamczak (fig. 10A), is of a single lamella, and, therefore, his description of 'more or less U-shaped' grooves in the later growth stages is unconfirmed. The section is of a specimen apparently of adult size, with a thickened submarginal ridge, and the absence of a 'subvelar field' suggests that the grooves are V-shaped throughout the ontogeny of the species.

Although Adamczak regarded the shape of the grooves of no systematic significance to distinguish *Cryptophyllus* from *Eridoconcha,* he anomalously used this feature (p. 71) to separate his new family Cryptophyllidae into two un-named groups.